Towards an Open Data based ICT Reference Architecture for Smart Cities

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***Abstract* — Given that ICT is at the heart of today's Smart City approach, it is of paramount importance to investigate concepts, which would enable the unification, the common understanding and the replication of ICT architectures/solutions/models across multiple cities. This unified and replicable approach can be best achieved by a very abstract model, aiming to capture the taxonomy and high-level structure of complex integrative ICT solutions for Smart Cities. The approach should be based on the idea of openness with respect to interfaces, software components and especially data, which is to be seen as the main ingredient of an ICT eco-system for Smart Cities. This paper presents an Open Data based ICT Reference Architecture for Smart Cities, which is developed within the EU project Triangulum [1].**

***Index Terms*—Smart Cities, Open Data, Big Data, Information and Communication Technologies, Reference Model, Reference Architecture, Future Internet, telecommunications**

I. Introduction

As Smart Cities emerge as a social, academic and industrial topic, it becomes increasingly clear that Information and Communication Technology (ICT) is at the heart of research and development efforts in that area. While every city is unique, cities in general function in a similar and comparable way. Thus, knowledge transfer among cities is of great interest. Many ICT solutions addressing specific city needs/problems could be widely used and replicated to further cities.

Given the importance of ICT, it is paramount to approach the ICT aspects of Smart Cities in a structured way that is able to accommodate the diverse needs and possible/available solutions on the market and/or the belonging ICT eco-system (e.g. developers, user communities, data stakeholders, etc.). Hence, there is a need for a reference model, which would be able to capture in an abstract manner the general structure of ICT solutions for a Smart City - especially such consisting of multiple independent interoperating components, e.g. from different vendors/developers. Thereby, the reference model could borrow some principles and ideas from other very successful reference models from the area of Internet and traditional telecommunications, such as the TCP/IP model or the ISO/OSI model. Furthermore, given the natural development of a Smart City around the data, which are gathered/acquired, published and processed in an urban environment, the ICT architecture should consider data and informational issues as a key aspect. This includes various concepts and trends of the last years, mainly referring to Open and Big Data related architectures and processes.

The objective of this paper is to specify such an abstract reference architecture for ICT in Smart Cities, thereby positioning Open Data at the center of it. This architecture will be used to structure the ICT aspects of the Smart City solutions, which will be developed and deployed within the project EU-H2020-Triangulum project [1]. In addition, the emerging ICT Reference Architecture could be used to enable the instantiation and replication of ICT based Smart City solutions to further cities. A special emphasis will be put on Open Data and its use within the reference architecture.

The rest of this paper is organized as follows: Section 2 reports on related work including open standardization activities for Smart Cities. Section 3 describes our proposed ICT Reference Architecture for Smart Cities presenting the structure of the ICT reference model and the different views on it, i.e. the *Technical*, *Informational* and *Organizational View*, as well as security and management aspects w.r.t the ICT Reference Architecture. The subsequent section describes an example instantiation of the ICT Reference Architecture for the scenario of electric mobility in an urban environment. The fifth and final section of this paper draws conclusions and outlines the next steps.

II. Related Work

In recent years, several attempts to define a formal architecture to guide the design of (ICT in) Smart Cities have been undertaken. Relevant information, such as level of detail, technical aspects, interfaces, data sources or use cases are considered for the characterization of each approach.

A. *Related Research Efforts*

In [2], Cretu proposes the Event-driven Smart Cities Architecture (EdSC), a high-level approach towards a reference model for Smart Cities. The key concepts of EdSC, including events, listeners and data, give rise to a rule based system, which enables the Internet of Things, the Internet of

Services, the Internet of People and the Internet of Data to connect and interoperate with each other. The proposed architecture is highly entangled with technical aspects like Linked Open Data, Ontologies and Cloud Based Systems. As mentioned above, EdSC serves as an initial reference model, thus, aspects like applications, use cases, or legacy systems integration are not addressed. Both interface- and API-description remain high level. No deployment based on EdSC has been carried out so far.

The Internet Connected Objects for Reconfigurable Ecosystem (iCORE) architecture [3] is a three-layer architecture aiming to speed up the creation, deployment and execution of IoT services and applications. Based on semantic web technologies, sensor networks and Open Data, the proposed architecture uses abstractions and virtualization to control and use platform functionalities and real world objects. The iCORE Service Level's task is enhancing the execution efficiency, the effectiveness and the situation awareness of services by leveraging of so-called Real World Knowledge. The iCORE Composite Virtual Object Level executes the services provided by the service layer in respect to potential system resource concerns. The goal of the iCORE Virtual Object Level is to unify the heterogeneity of connected equipment, e.g. sensors. In line with the iCORE architecture, use cases like "smart home living assistants", "smart urban security" or "Smart City transport" have been established, where the architecture has been deployed as a testbed.

In "Smart Cities at the forefront of the Future Internet" [4] by José M. Hernández-Muñoz et al., a holistic approach for a unified urban ICT infrastructure is proposed, aiming at enabling sustainable economic growth and the management of complex interdependent urban systems. The key functionalities of the proposed ICT infrastructure are: a) the Urban Communications Abstraction - for decreasing inefficiency caused due to the heterogeneity of the existing or new communication infrastructures; b) the Unified Urban Information Model - for the interchange of data and information between different services and applications; and c) the Open Urban Services Development – to enable open and flexible interfaces on application and service level.

The ITU-T's Ubiquitous Sensor Network (USN) [5] addresses similar characteristics and serves as an example for a generic implementation. It uses Sensor Modeling language (SensorML) and Open Geospatial Consortium O&M language for data interchange. Potential data sources are sensors and governmental data. In line with the proposed architecture, use cases within the scope of the Smart Santander Project [6] are available.

The Smart City Framework (SCF) [7] defines a high-level framework for Smart City projects. Technical aspects cover Open Data, Data Portals, Sensor Networks as well as Linked Data. The data is supplied by sensors, governmental data and social networks. The SCF does not name any specific applications, use cases or domains and is yet to be deployed. The SCF structure is comprised of different views, such as the functional view, the interface and information view, as well as the security and privacy view.

In contrast to all other considered approaches, Komninos [8] does not focus on the architecture and the components of Smart Cities, but on the planning process itself. The authors of [8] introduce a holistic approach that allows a user-centric evolvement of Smart Cities. This approach consists of seven steps distributed over three stages and is designed to integrate the three major components of Smart Cities – urban space, innovation ecosystem and digital smart environment. It is considered to be rather a strategic roadmap than an architecture relating to structural and technical aspects. The proposed roadmap has been utilized in a district in the city of Thermi (Greece) addressing use cases like smart market places, air pollution and available parking.

B. Standards for Smart Cities

The complexity of the different areas, domains, infrastructures, organizations and activities within a city or community has turned out to be a huge challenge for standardization work groups. The IEC SEG 1 Systems Evaluation Group – Task Group "Reference Architecture Model" has the task to develop a holistic reference architecture for a city. The objective of this model is to describe all key elements, actors and stakeholders relating to aspects of the Smart City in a precise and understandable way. The group has already published a list with all necessary requirements for such a model [9]. Currently, there are many open standards activities for Smart Cities such as those conducted by the ISO TMB Task Force on Smart Cities, BSI British standards institution [29], DKE/DIN German standards institutes [10], ITU Focus Group on Smart Sustainable Cities, ISO/TC 268 - Sustainable development in communities, CEN/CENELEC, ETSI etc.

III. Proposed ICT Reference Architecture for Smart Cities

Based on the profound literature review and discussions within the Triangulum project, the following tangible list of main requirements for the emerging ICT reference model has been created:

Req. 1: Provide a unified view and understanding on the ICT strategies and deployments of existing city solutions.

Req. 2: Identify open interfaces between standard ICT components in a city, which implies the specifications/selection of suitable data formats (e.g. XML/JSON scheme, RDF and Ontology vocabularies), Application Programming Interfaces (APIs) and protocols (e.g. HTTP, REST, 6LowPan, ZigBee, COAP, Real-Time-Publish-Subscribe Protocol).

Req. 3: Put Open Data at the heart of the proposed ICT Reference Architecture.

Req. 4: Accommodation of legacy/existing systems within the concepts and artefacts of the ICT Reference Architecture.

Req. 5: Enable the exchange and interoperability of components and have them interoperate in Smart City scenarios, thereby utilizing the identified interfaces.

Req. 6: Highlight the advantages of and provide incentives for the use of Open Source components, in order to enable cities and communities to remain/become vendor independent.

Req. 7: Enable the replication of Smart City concepts/solutions between cities.

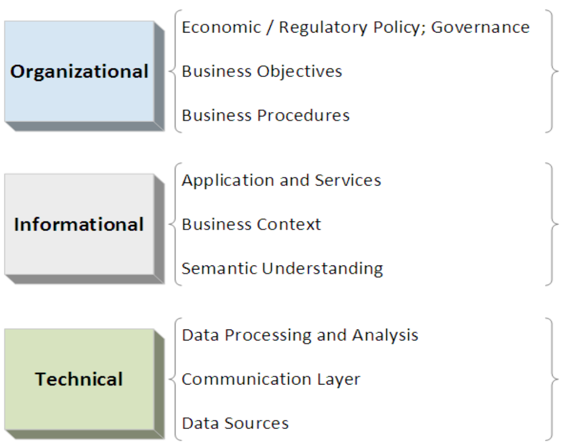

FIGURE 1: THE DIFFERENT VIEWS ON THE ICT REFERENCE MODEL FOR SMART CITIES BASED ON [11]

In accordance with the above considerations, different views on the emerging ICT reference model are taken into account, as illustrated in Figure 1: the *Organizational*, *Informational* and *Technical* view.

The *Technical view* is focused on the raw data sources and the communication and computational means to fuse data together and make it available for further processing and analysis. This data should be either commercially offered, or ideally made available over Open Data portals/platforms for reuse by and stirring of an eco-system of application/service developers and corresponding user communities. During *Data Processing and Analysis*, different aspects of the raw data are interconnected and enriched to become *Information*, thereby bringing it into the scope of the Informational view.

The *Informational view* foresees the refinement, structuring and further enrichment of the information, as to support semantic relations and a semantic understanding of the raw data and resulting information items. That means that different data/information pieces can be put in relation to each other leading to an enriched and deep understanding of the possible influences and implications in complex situations. This further processing can be seen as a service, which is commercially paid for, or in the case of Open Data as a community interaction, which is coordinated over the belonging Open Data platform (e.g. govdata.de).

Furthermore, the semantically enriched data/information is put into a Business Context that drives the development of advanced Applications and Services for Smart Cities, e.g. mobility or energy. These applications are one of the main business cases in Smart Cities, since the provisioning of Open Data would support start-ups and SMEs (small and medium-sized enterprises) to emerge and establish themselves on the market.

Finally, the above technical and informational aspects should be properly organized (in the scope of the *Organization view*) according to Business Models (including Business Procedures and Objectives) as well as various governance and regulations' aspects. For example, it is possible to implement various billing and charging models for data, in case of commercial (non-open) data providers, whilst at the same time regulating the use of Open Data based on free-licenses, governmental/political regulations and aspects, e.g. the PSI (Public Sector Information) directive of the European Union.

The above explanations refer to a broader interpretation of the model presented in [11]. For the current ICT Reference Architecture, we adopt these views but lay down a slightly different structure of layers within the views.

A. ICT Reference Architecture: Technical View

The overall picture of the emerging ICT Reference Architecture is given in Figure 2. In the following paragraphs, we focus on the different views and layers in turn.

As depicted in Figure 2, the Data Sources Layer encompasses the various sources of any data of relevance within a city, such as Sensor Networks, Social Media, Smart Meters collecting data related to energy consumption, as well as Governmental Data, which are currently the main source of Open Data across Europe. Furthermore, different commercial providers and certain mobile applications gathering crowdsourcing data, which is gathered through the usage of certain mobile applications and intended for commercial purpose (for example charging and billing for data etc.) can act as a source of data.

The *Communication Layer* includes all the facilities and infrastructure, which are required to obtain/gather the data from the *Data Sources Layer*, convey this to repositories and make them available for further processing. In general, we would like to consider data sources with their intrinsically belonging communication infrastructure as part of the Data Sources layer. In order to establish a clear separation, all the networks that belong to the Internet, plus storage servers, are regarded as components of the *Communication Layer*, whilst the specific "access networks" - e.g. the links amongst the sensors in a Sensor Network and links connecting towards the gateway/sink node or the wireless technology connecting a Smart Meter to a service provider network – are considered as belonging to the *Data Sources Layer*.

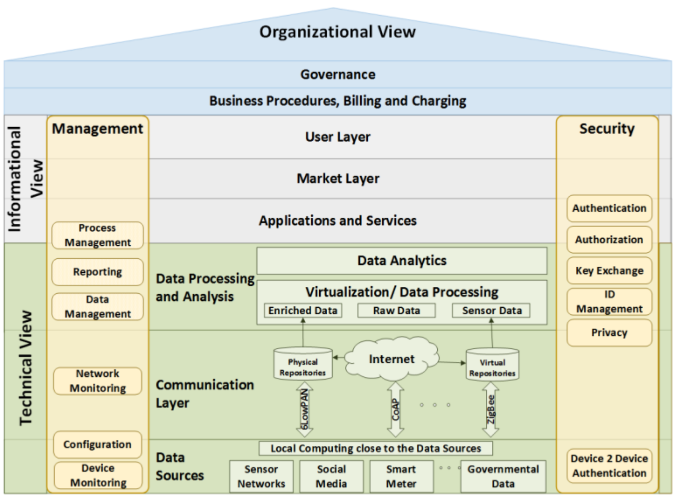

FIGURE 2: OVERVIEW ON THE EMERGING ICT REFERENCE ARCHITECTURE

The Internet and the belonging networks communicate over the Network Layer technology of the TCP/IP stack, which is the IP (Internet Protocol) in its two available versions – IPv4 and IPv6. The networks that build-up the Internet encompass different management aspects and have different service providers that operate them. Correspondingly, they are referred to as Autonomous Systems (AS) that interconnect in order to build up the Internet. The inter-domain traffic between Autonomous Systems is realized by so-called Exterior Gateway Protocols (EGP) [12] which take care of advertising routes to reachable end systems and user networks and steering the exchange of traffic on inter-domain level. A widely used EGP protocol is given by BGP [13], which stands for Border Gateway Protocol. The exchange of traffic between Autonomous Systems can be either established directly between two Autonomous Systems, or can be organized using so-called IXPs (Internet Exchange Points), which constitute a sort of market place between AS providers where traffic is exchanged and billing is done on the fly. Within an AS, so-called intra-domain routing protocols take care of establishing the routes and enabling the traffic forwarding within the intra-domain network. Typical examples for such protocols are given by OSPF, IS-IS, and RIP(-ng).

As data is moving over the infrastructure briefly described above, it arrives at data centers, which host large amounts of servers and where data repositories store the data and make it further available. These, can be for instance traditional physical data servers that run some large databases and are organized in Content Distribution Networks (CDNs). CDN are geo-graphically distributed data centers, which are designed as to quickly provide access to content thereby realizing aspects such as user load balancing between the servers and sub-data-centers. Given the modern trends in the domain of cloud computing, the data can also be hosted on virtual machines and correspondingly distributed over more complex structures on top of a virtualization layer, which is correspondingly represented by the virtual repositories in Figure 2.

On the *Data Processing and Analysis Layer*, data collected within the Data Sources Layer and accessed through the Communication Layer can be further processed, in order to extract desired information. On this layer, data from a variety of sources such as distributed public or proprietary sensor networks, governmental agencies, companies and even private citizens ideally converges to a single point of access and processing, e.g. on a Smart City Hub [14]. Such a Smart City Hub, depending on its financing and business model, should strive to contain a larger amount of freely usable Open Data sets, as to facilitate and prepare a belonging eco-system (including developers, data investigators/journalists and user communities in general)

After the initial optional enrichment of the data with information about context, different analyses are performed on its basis. The results thereof are not just limited to critical insights into the progress of goal realization (e.g. for Business Intelligence [15]) and to influence on decisions taken by the individual Smart City stakeholders, but also offer the possibility for the creation of dynamic self-regulating systems such as smart grids. As an example, cumulated data from past recording periods can serve as basis for a prediction model of future energy needs. Integration within/as real time feedback loop would allow for anticipation and alleviation of potential critical events such as consumption peaks [16]. Feedback of model predictions can then also be given on a per household basis to the inhabitants, in order to incentivize behavioral change, with the goal to reduce their energy consumption, while keeping the citizens' comfort constant or even raising it [17]. The realization of such a solution involves the integration of big amounts of data in near real-time and thus poses the need for scalable and fast stream processing engines. In addition, batch-processing engines are required for the creation of appropriate (data) models and information extraction for informed decision-making. The appropriate statistical analysis of (numeric) sensor data and video material collected throughout the city can be done by algorithms from fields such as machine learning [18] and computer vision [19] [20] respectively. Textual data collected from newsfeeds and social media platforms can be fed to natural language [21] and semantic processing algorithms, also making use of ontologies.

Especially in the course of Open Data, prior to release on publically accessible data portals, data which, if published, could violate individual privacy constraints, in addition to critical information regarding security, should be filtered out or processed in a way that the danger of rights violation or security breach is reduced (e.g. by smoothing sensor data over a predefined period of time). This is also to happen automatically. Afterwards, third party stakeholders can take over processing of the collected data. The concept of having third parties take over data processing and create working business models out of it is one of the core aspects of an Open Data eco-system and is pivotal in a Smart City, as governmental funding is limited and does not always lead to the optimal outcome. Data disclosure under open licenses and transparent analysis also helps to solidify citizens' trust [22] and spark engagement [23]. To assist the external creation of services, appropriate interfaces alongside example applications should and can be offered and data lineage should be kept transparent.

B. ICT Reference Architecture: Informational View

The Informational View on the ICT Reference Architecture is situated on top of the Technical View and consists of the *Application and Services Layer*, the *Market Layer* and finally the *User Layer*.

On the *Applications and Services Layer*, the information extracted and gained within the layer underneath is incorporated into different Smart City applications and services. These applications can range from very complex and critical systems, e.g. involved in traffic light regulation and energy distribution, to simple information based applications about the current state of the city, e.g. providing information regarding traffic peak hours, own energy consumption in comparison to other households, and suggestions for optimizing the own behavior. As this layer is often closely interrelated with the *Data Processing and Analysis Layer*, it is not always possible to make a clear separation. Services require data analysis and processing in order to work, and data analysis is performed with the aim of future use in such applications and services. The gained information can be simply displayed – e.g., but necessarily based on the advanced visualization techniques/engines developed in the past years - or automatically trigger appropriate state changes of different Smart City entities.

The *Market Layer* is concerned with marketplaces for the publically available part of such applications and services. Those marketplaces are online platforms designed to help people and organizations to discover, purchase, and deploy integrated applications and services in different city domains. By taking an interoperable approach in Smart City solutions, applications and services can be developed independently by companies, specifically SMEs, but also by individuals or researchers, free lancers or Open Data enthusiast/developers.

Smart Cities require service marketplaces in which decisions can be supported by "votes"/reputation for particular service or application. City consumers will play key contributing roles in determining what applications and services are successful. In-store mechanisms like user ratings and recommendations, number of downloads and popularity indexes can help on shaping applications and services quality. In addition, security and trust concerns e.g., awareness of the potential for fraudulent and deceptive practices, protection techniques, and problems resolution can be addressed through city-defined controlling rules and policies. Thus, the envisioned marketplace is mixed, in the sense that both policy-driven and reputation based decision-making - for appropriate applications and services - should be offered and used [24].

The *User Layer* includes the download of apps to appropriate devices and their subsequent usage by the end users. The set of devices encompasses smartphones, tablets, traditional PCs or notebooks and possibly Smart Meters and further novel technical appliances. The users either might be using the apps on those devices or might be utilizing some services, which can be found through the corresponding marketplaces. That is, aside of downloading apps, users can also book or subscribe to specific services, which can, but are not necessarily, coupled with apps and Smart Appliances. The users can be citizens (e.g. using some mobility apps), companies utilizing services, created based on the Smart City Open Data, or data journalists that make use of the technical features of an ICT Smart City architecture (mainly the Open Data related aspects), in order to come up with qualitative and insightful articles. The User Layer complements the view on the ICT Reference Architecture with respect to how the (open) data, turned into information, is utilized within a Smart City.

C. ICT Reference Architecture: Organizational View

The Organizational View on the ICT Reference Architecture consists of the *Governance Layer* and *the Billing and Charging*.

Johnston and Hansen [25] [26] define governance as the *interaction of processes, information, rules, structures, and norms that guide behavior towards stated objectives that impact collections of people*, and governance infrastructure as the *collection of technologies, people, policies, practices, resources, social norms, and information that interact to support governing activities*. A Smart City needs a smart governance infrastructure, bringing together multiple stakeholders, worked-out processes (social and decision-making), rules and policies, as well as supporting tools in driving growth and adaptability of smart services within the city. Derived from [27] [28] [29], the main elements of a Smart City governance model include: smart city objectives and strategy, smart city principles, leadership, dedicated organization, policies and regulations, stakeholder collaboration, Smart City development and management processes and performance measurement. These elements can further serve as criteria for analyzing the maturity level of a Smart City governance model.

Moving on to the second part of the Organizational View: The aspects of *Billing and Charging* are of extreme importance for business models within a Smart Cities eco-system. In that line of thoughts, various business procedures stemming from the belonging business models need to be established on top of the ICT Reference Architecture. In general, it is possible to monetize the use of (mobile) apps, services, and data. The apps are paid through the app stores. Services can be paid for based on different models, which can be taken from the SaaS (Software as a Service) domain, such as payment on a per service call/invocation basis. For the data (this does not apply to Open Data), billing and charging models from the traditional telecommunications domain can employed. This includes flat rate type of payment models, pay per volume, pre-paid etc. To summarize: the usage of approaches for billing and charging as well as the presence of business activities and processes in and around the ICT Reference Architecture, will support the implementation of business models that will create the possibility for generating revenue for companies.

D. ICT Reference Architecture Verticals: Management and Security

Network/Infrastructure Management and Security are important aspects of the ICT Reference Architecture. Management has to be considered across multiple domains and thus, is correspondingly depicted across all layers in Figure 2. Management consists of many different aspects such as the monitoring of devices and networks, their configuration, data management and reporting.

On the lower layers (e.g. Data Sources Layer and Communication Layer in Figure 2), proper configuration of the various heterogeneous devices and networks has to be addressed. This includes characteristics such as hostnames, routing, quality of service etc. Furthermore, it should be possible to track changes in these configuration settings, such that in the case of a faulty or insecure configuration it is possible to switch back to a previous functioning one. Thereby, the availability of services and the overall system reliability can be increased. Fault detection and fault analysis are other important aspects that need to be taken into account. It should be possible to react to different faults in an appropriate way, including the change of the configuration of devices and/or networks. Common information about different entities (sensors, smart meters, applications, users etc.), including their current state, relations between devices, authorization and access rights should therefore be readily retrievable and if necessary updated at any time.

Similar to network/infrastructure management, security has to be considered across multiple domains and includes aspects such as authentication, authorization and identity management. This has to be done repeatedly for all the layers in Figure 2. Common relevant security technologies are: OpenID - a decentralized authentication system for web-based services [30]; the Security Assertion Markup Language (SAML) - an XML-based framework for authentication and authorization [31] [32]; OAuth - an open standard for authorization [33] and Kerberos - a ticket-based system allowing secure authentication over a non-secure network [34] [35].

Privacy is another key aspect of security in the ICT Reference Architecture. Topics like data anonymization and the addition of artificial noise to the data are key discussion points during the conception and implementation of Smart City solutions and hence should be further accommodated. These have already been shortly addressed in the section concerning the *Data Processing and Analysis Layer*.

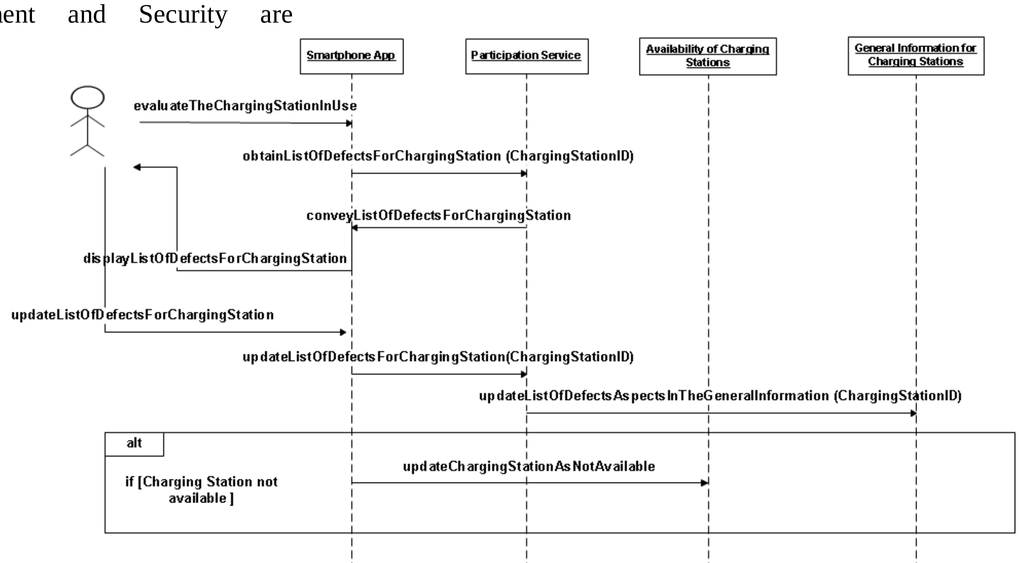

FIGURE 3: INTERACTION FLOW FOR REALIZING PARTICIPATION FOR ELECTRIC MOBILITY [36]

IV. DEMONSTRATION EXAMPLE / INSTANTIATION OF THE ICT REFERENCE ARCHITECTURE

This section describes a possible instantiation of the introduced ICT Reference Architecture concerning electric charging and electric mobility. The example is adopted from a technology paper [36], which provides components for electric mobility in Smart Cities. This paper transfers this typical scenario into the context of the Triangulum ICT Reference Architecture. General architectural aspects, including dynamic aspects and a user perspective scenario are described in the coming paragraphs.

As discussed earlier, the ICT Reference Architecture accommodates a large variety of data sources. In this particular scenario, relevant data may include Map Resources, Open Governmental Road Data, Vehicle Provider Data, et cetera. These various types of data are integrated and offered over servers residing in the *Data Processing and Analysis* sub-layer of the Reference Architecture, such that applications/services can be eventually developed on top of it (see Applications/Services in Figure 2, which resides on top of the Data Processing and Analysis layer).

Figure 3 illustrates an example of an interaction flow that utilizes the Applications/Service layer of the ICT Reference Architecture for the purpose of end user participation for the evaluation of a charging station in the scope of electric mobility. The prerequisite that a customer has just charged the battery of an electric vehicle at a charging station (or at least attempted to do so) is not illustrated.

Figure 3 captures the flow of the customer-service interaction for the evaluation of the charging station and/or complaint registration given that the charging station has any functional problems. Three services are implicated in this evaluation procedure: *Participation Service*, *Availability of Charging Stations Service* and *General Information for Charging Service*. These services would reside in the Applications/Service Layer of the reference architecture (see Figure 2). Thereby, the customer uses a smartphone app that communicates (*obtainListOfDefectsForChargingStation*) over the mobile network (3G/4G) with the Participation Service [36]. The Participation Service returns the list of defects for the charging station in question (*conveyListOfDefectsForChargingStation*). These defects would be normally stored on a server residing in the Data Processing and Analysis layer of the ICT Reference Architecture. This list of defects is presented to the user, such that she/he can check it and update it if needed. The possibly renewed list of defects is communicated by the smartphone app back to the Participation Service (*updateListOfDefectsForChargingStation*). Thereupon, the Participation Service updates the general information for the charging station in question by linking the updated list to the general charging station data over the General Information Charging Stations service (*updateListOfDefectsAspects-InTheGeneralInformation*) [36]. Lastly, in case the charging station was marked as damaged and unusable by the customer, its availability is updated (*updateChargingStation-AsNotAvailable*) over the "Availability of Charging Stations Service".

The above-described sequence demonstrates only a minor part of the dynamic aspects in the application of the reference architecture for electric mobility in a Triangulum lighthouse city (such as for instance Eindhoven). The following paragraph elaborates a user-centered perspective on a complete electric mobility scenario. Thereby, it is shown how the reference architecture could be applied to such an electric mobility scenario and in what way the scenario could benefit from the ICT reference architecture. The subsequent figures describe the user perspective of the reference architecture utilization for the purpose of electric mobility in Smart Cities.

Figure 4 describes the required steps in the scope of the disposal and reservation of an electric vehicle over a smartphone. The descriptions above the arrow elaborate the process itself, whilst the explanations underneath the arrow clarify on aspects of this process [36]. The user experience starts with the search for an electric vehicle according to a number of criteria, such as geographical reachability, temporal availability, target reachability estimations and other user specific criteria. Thereby, the user (belonging to the User Layer) must have obtained a corresponding app (Market Layer). The app and the services (Application/Services layer from the architecture) behind consume data which has been processed and prepared within the Data Processing and Analysis layer underneath, and was obtained and centrally pooled over the Data Sources and the Communication Layer of the ICT Reference Architecture.

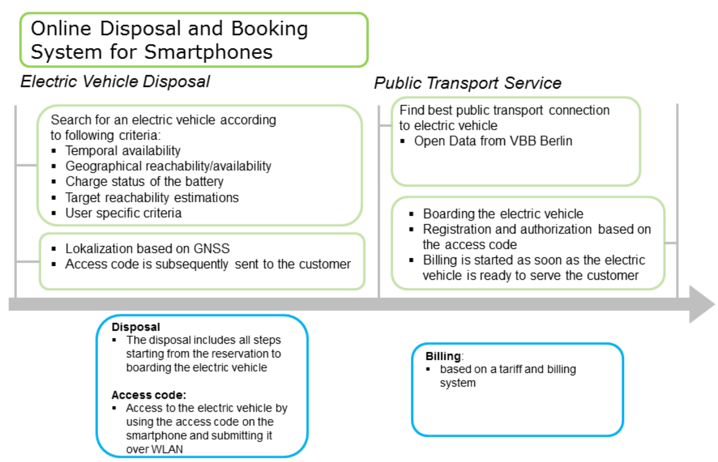

FIGURE 4: ACCESSING AND ELECTRIC VEHICLE OVER THE ICT REFERENCE ARCHITECTURE [36]

Once an appropriate electric vehicle has been found and reserved by the customer, an access code is generated by the corresponding service and sent back to the customer's smartphone. This access code is later used during the WLAN communication between smartphone and the electric vehicle in order to unlock it. Having reserved an electric vehicle, the customer/user has to reach it. This can be accomplished using a service for public transport information (once again, this would be a service in the Applications/Service layer in Figure 4). After reaching the electric vehicle, the customer boards it and can begin her/his journey.

Depending on the battery charge condition, it may be required that the customer uses a charging station. In this case, the customer would need to go through the steps described in Figure 5. First, a charging station needs to be searched for over the app on the customer's smartphone. As in the case of the electric vehicle disposal, various constraints would need to be considered, such as geographical reachability, temporal availability, type of electricity (e.g. percentage of green energy). The search could be conducted over an *Availability of Charging Stations Service* in the Applications/Service layer of the ICT Reference Architecture (as described previously), and a list of charging stations matching the customer's criteria is displayed on the customer's smartphone. The belonging data would have been again prepared, offered and gathered over the various layers under the Applications/Service layer of the ICT Reference Architecture, i.e. Data Processing and Analysis layer, Communication layer, and Data Sources layer.

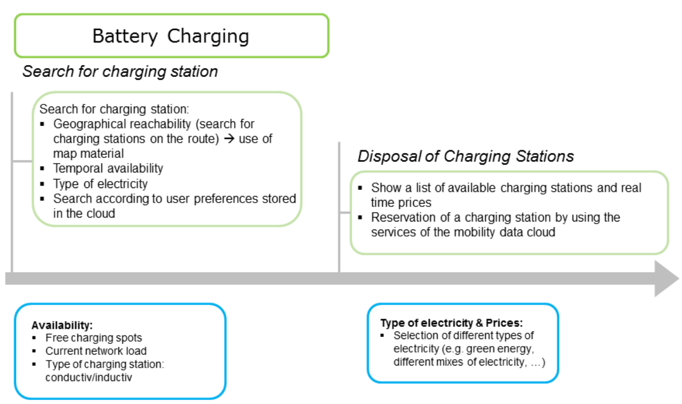

FIGURE 5: SUPPORT FOR BATTERY CHARGING OVER THE ICT REFERENCE ARCHITECTURE [36]

Based on the list of charging stations, a suitable one is reserved over a Charging Station Reservation Service, and the charging of the vehicle's battery can be triggered as soon as the customer arrives at this station.

The last step in the presented utilization is constituted by the disposal of the electric vehicle. This process is described in Figure 6, and consists of the customer leaving the electric vehicle and receiving the billing information for the time she/he has been using the vehicle. This information is displayed on the customer's smartphone and requires to be confirmed by the end user. Moreover, the disposal takes place in compliance to additional information/constraints, such as parking lots and various urban conditions (e.g. parking taxes etc.).

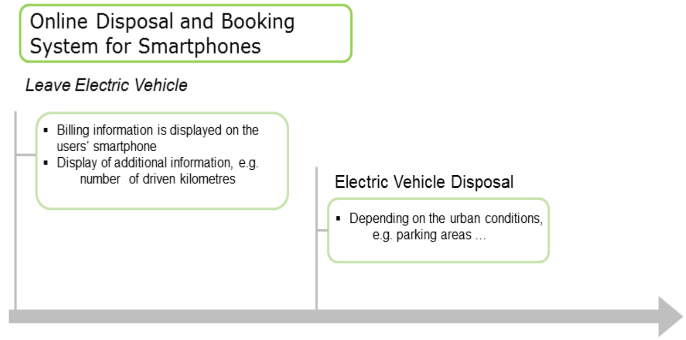

FIGURE 6: ELECTRIC VEHICLE DISPOSAL [36]

The scenario presented here, even though far from capturing all possible use cases and flows, exemplifies how a citizen would utilize the reference architecture in the scope of collaborative electric mobility.

V. CONCLUSIONS

The current paper presents our considerations regarding the topic of an (Open) data based ICT Reference architecture for Smart Cities, which were discussed and worked out in the initial phase of the Triangulum project. The goal of such an architecture is to provide an abstract model for complex, distributed and integrative ICT solutions, which should be at the heart of Smart Cities.

Data, especially Open Data, is at the heart of the proposed ICT Reference Architecture. For that reason, the reference architecture is motivated in a way as to define components along the paths on which data is processed processed – starting from sensor networks and reaching to data portals/platforms and mobile applications/services on top. Seeing data as the key enabler for Smart Cities allows specifying different abstract components and layers around it, thereby addressing the different needs. Therefore, the proposed architecture comes with different views at its core, which include the Technical, Information and Organizational perspectives. The current document deals with each of these perspectives and explains the relations among the various abstract layers, components and concepts. Finally, a case study is presented which shows the instantiation of the proposed ICT Reference Architecture for an integrated and distributed solution from the domain of mobility.

With respect to further steps: The architecture will be subsequently refined in a series of discussions with the relevant stakeholders in the lighthouse and follower cities of the Triangulum project. The goal is to meet all the ICT needs of the emerging solutions within Triangulum, whilst at the same time accommodating as many as possible of the existing solutions. In that line of thoughts, the ultimate goal is to have an abstract model that will enable the replication and interoperability of ICT solutions among the lighthouse and follower cities within Triangulum.

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