Enabling the Structuring, Enhancement and Creation of Urban ICT through the Extension of a Standardized Smart City Reference Model

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***Abstract* — With the emergence of Smart Cities, a large number of technologies have been developed and deployed world-wide. However, as Smart City technology is continuously growing, the question emerges of how to reasonably structure the ICT landscape in an urban environment, such that an eco-system of ICT components, involving vendors, network/service providers, small-mid-size enterprises, large-scale industry, and open source initiatives can emerge. Hence, a reference model serving as a blueprint for ICT architectures for future cities is required – similarly as TCP/IP and ISO/OSI facilitated the growth and world-wide development of the Internet and telecommunication services. The current paper proposes a methodology for structuring the ICT landscape in a city according to emerging standards for Smart Cities on European and German level, towards the facilitation of extensible and evolvable eco-system of ICT components and stakeholders for Smart Cities. After introducing the standards and the methodology, two case studies from recent research projects are presented in order to validate our approach.**

***Index Terms*— Smart City, Reference Architecture, Open Urban Platform, Open Data, Next Generation Networks**

I. Introduction

Smart Cities are emerging as a major platform for ICT innovation, in parallel improving the quality of life of a large number of citizens across the world. Hence, many complicated ICT landscapes are emerging that need to be handled and structured based on well-defined blueprint principles. Thus, it is expected that the concept of a *reference model/architecture* can support in these circumstances, similarly to the way reference models and architectures were applied in the Internet and telecommunications domain – with ISO/OSI [1], TCP/IP [2] and TMN [3] being some of the most prominent ones.

The topic of an ICT reference architecture was the focus of a number of European research projects in the past years with H2020 Triangulum [4] and H2020 Espresso [5] being some of the notable examples for research activities in this area. In general, such ICT reference architectures for Smart Cities are depicted as a set of layers aiming at capturing the IT and telecommunication infrastructure in an urban environment. These layers normally start with the data sources (e.g. sensors) on the lowest layers and proceed with an interconnection layer that contains the communication infrastructure conveying data from the data sources to corresponding backend systems (e.g. servers in data centers). The data is stored in belonging data bases within the computational centers and prepared for utilization in services and applications running on top of the data. Furthermore, the services and applications (utilizing the data) are normally managed and offered over various market places, such as GooglePlay [6], App Store [7] and further, such that they can be utilized and installed on citizens' end user devices and contribute to better and optimized quality of life.

The rest of this paper is structured as follows: section II elaborates on Smart City reference architectures, followed by section III that introduces Open Urban Platforms as a standardized approach to implementing Smart City ICT based on reference models. The following section IV discusses on oupPLUS, which is our proposed extension to the reference model standard with the goal of detailing the specification of the open standardized interfaces among the reference architecture artefacts. Section V presents two case studies on applied reference architectures to Smart City solutions from our current research projects, whilst the final section VI concludes the presentation and outlines future research directions.

II. ICT Reference Architectures for Smart Cities

Reference architectures are an established means to creating eco-systems and enabling the integrative development of complex solutions with the potential to encompass the globe and provide sustainable solutions. The two most prominent examples for reference architectures originate from the domains of telecommunications and Internet, namely the ISO/OSI model and the TCP/IP model. These have enabled the scalable development and growth of systems for global voice and data communication that are built based on the interoperability between devices and services from various vendors, providers and operators. When enabling such complex global undertakings, reference architectures aim at structuring the potential technical eco-system and outlining the abstract open interfaces between the involved artefacts.

In the scope of a Smart City, an ICT reference architecture is expected to facilitate a number of vital aspects such as *to enable the creation of a unified view and understanding on the ICT development of a city*. In addition, it is imperative for an ICT reference architecture to not only provide the structure and blueprint for future developments, but to also accommodate established, already deployed systems.

Furthermore, an ICT reference architecture should provide design principles and guidelines for establishing and identifying the interfaces for communication between the involved components in an urban context. This would naturally enable the interoperability and subsequently the exchange of various components and software models along the standardized open interfaces. As a result, it can be expected that Smart City solutions can be exchanged between cities as well as decomposed and combined with other solutions and components on a large scale thereby enabling the rapid development and distribution of Smart City technology across the world.

A couple of European projects have developed such ICT reference architectures for Smart Cities with Triangulum [8][9], Espresso [10], and Streetlife [11] being some of the prominent examples in that area. Thereby, these activities extend the above understanding by either focusing on Open Data, Open Source or on the specifics of IoT and mobility use cases across the involved cities.

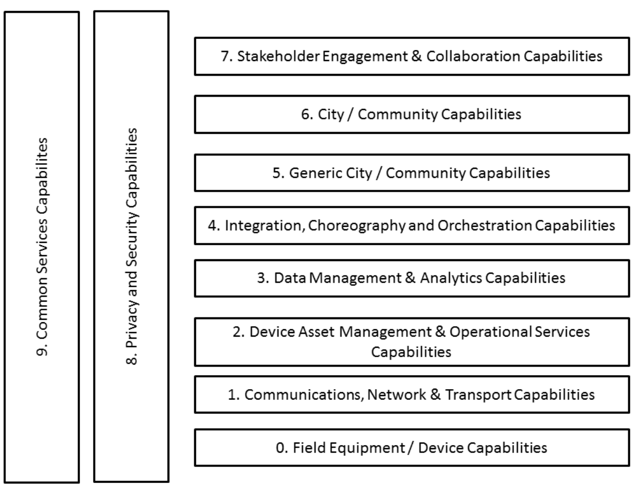

FIGURE 1: GENERAL STRUCTURE OF AN OPEN URBAN PLATFORM ACCORDING TO DIN SPEC OUP [15] AND EIP SCC [14]

III. OPEN URBAN PLATFORMS

Open Urban Platforms correspond to an initiative that was started by the European Innovation Partnership (EIP) [12][13][14] several years ago with the goal to provide an abstract ICT framework for the demand and supply side in an urban environment. Thereby, the demand side is given by the cities – their administrations and public institutions – as well as the citizens and other stakeholders consuming ICT services and applications in an urban environment. This resulted in a number of documents including a reference architecture document that reflects the needs of the demand side and provides the means for cities to create Open Urban Platforms based on an integrative approach of combining different solutions (components, modules, applications, services, devices, sensors, routers, multimedia gateway, cloud infrastructures …) across the corresponding layers as illustrated in Figure 1.

Following the activities on European level, the emerging reference architecture [14] was brought in as one of the inputs to German standardization at the DIN thereby constituting one of the main inputs for the DIN SPEC 91357 Open Urban Platforms [15]. The activities in this specification workshop continued for the duration of around an year and culminated in a DIN specification for Open Urban Platforms. This specification document [15] represents the German adaptation and understanding of the EIP collaboration activities and is currently reviewed on international level by ISO and is considered for international standardization.

The overall structure of an Open Urban Platform according to DIN SPEC 91357 [15] and the EIP SCC[1] collaboration activities and documents [12][13][14] is represented in Figure 1 and Figure 2. Figure 1 represents the rough structure of the layers and pillars, whilst Figure 2 lists the details of the capabilities belonging to each layer. The capabilities are meant to describe a layer or pillar in a semi-formal way thereby allowing the mapping of a component to a particular layer or pillar. Furthermore, the capabilities specify the features and properties of the corresponding artefact in the overall structure of the ICT reference architecture. An overall number of more than 100 capabilities are listed in Figure 2 and have been described in the corresponding standards [14] [15].

Coming back to the abstract representation in Figure 1, the lowest layer (*0. Field Equipment / Device Capabilities*) contains the devices and sensors, which are distributed across the city – this can be sensors of IoT networks, drones, smartphones collecting information, but also special types servers running software for acquiring data from various sources (e.g. social network analysis). The acquired data is communicated across the network elements and components contained in the layer above (*1. Communications, Network & Transport Capabilities*). The management and the operational services in the components on the first two layers is placed in the second layer (*2. Device Asset Management & Operational Services Capabilities*), which contain for example protocols for the management of IoT devices (e.g. COT – Cloud of Things [16]) and for the general steering of data acquisition activities in the layers underneath. The acquired data is further handled in layer *3. Data Management & Analytics Capabilities* where data is stored in data centers or in cloud infrastructures and compiled to represent informational objects, which can be further processed in the layer above (*4. Integration*, *Choreography and Orchestration Capabilities*). In this layer various services combine and process the data as to provide urban applications with the possibility to optimize processes in the city, to improve the life of citizens and facilitate the activities of various stakeholders, which is all reflected in the layers 5-7 that deal with *Generic City*, *City and Community Capabilities* and *Stakeholder Engagement*. Along this abstract infrastructure, various use cases and scenarios can be implemented based on components from different vendors and providers.

[1] SCC stands for Smart Cities and Communities

In addition, on the left side one can observe two pillars that reflect the need for cyber-security and common management activities relating to the technological solutions within the Open Urban Platform.

To summarize: the presented Open Urban Platform fulfills the requirements in the discussion on ICT reference architectures for Smart Cities and enables vital aspects such as the avoidance of vendor lock-in and the possibility to replicate solutions or part of ICT solutions across various cities. The following paragraph presents our specific extensions to this standardized model, which aim at providing means for quality assurance, interoperability and enforcing the utilization of standardized open interfaces based on so-called Service Access Points as known from the ISO/OSI reference model [1].

IV. OUPPLUS

oupPLUS constitutes a further development of the above elucidated standards with the aim to unify the view of different European stakeholders and provide a framework for establishing open interfaces with a Smart City, based on the DIN OUP und EIP SCC. The key contribution of oupPLUS is provided by the facilitation of interoperability between components, modules, layers and general artefacts of ICT systems for Smart Cities. In order to achieve this, the Fraunhofer FOKUS researchers are dealing with the identification and analysis of interfaces between the individual artefacts and lead corresponding discussions in the scope of standardization bodies involving established industrial players and market stakeholders. The ultimate goal of a high degree of interoperability would simplify the replication of ICT-based solutions between various urban environments.

A. General Architecture

The general architecture of oupPLUS is illustrated in Figure 3 and largely resembles the structure of the DIN 91357 Open Urban Platform standard. The extensions are provided by two aspects: 1) the various layers and pillars are tagged with explanations (e.g. *Data Sources*, *Security* …), which relate them to the understandings of various state-of-the-art projects, especially as elaborated in H2020 Triangulum [4] and H2020 Espresso [5], and 2) the concept of *Service Access Points (SAP)* which is introduced across the architectural layers and is meant to be a container for interface descriptions thereby denoting abstract Smart City interfaces and relating them to real world communication standards. The concept of SAP has been extensively used in the scope of ISO/OSI and is an established means for achieving large scale eco-systems, such as the existing telecom infrastructures and the Internet.

B. Achieving Open Interfaces

In order to identify suitable ICT standards, a method for performing gap analysis was conducted. With respect to the identification of abstract, open interfaces, oupPLUS has the goal to establish guidelines for well-defined interaction protocols between the various ICT components. This creates a variety of new options: Interoperability of different solutions in diverse areas and urban eco-systems, replication and reuse of urban ICT solutions across diverse cities, participation of SMEs in an urban ICT eco-system, and avoidance of vendor lock-in.

In the following, a list of key Service Access Points is provided along with a brief description of their function. It is

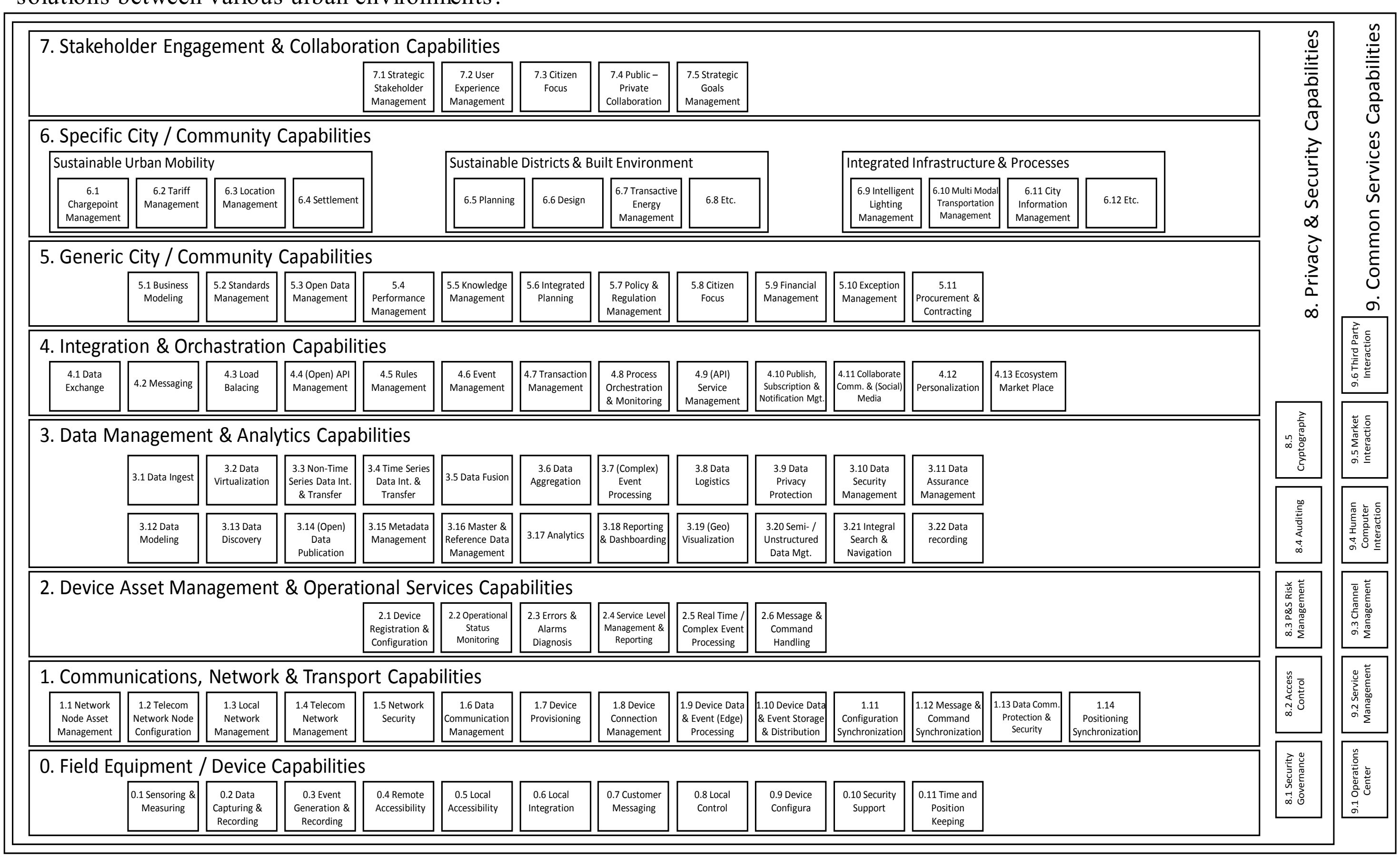

FIGURE 2: THE CAPABILITIES MAP OF THE OPEN URBAN PLATFORM [14] [15]

important to remark that an oupPLUS SAP can occur in a similar role between various artefacts of the reference model in Figure 3. Next, for each SAP we outline the different layers in the oupPLUS architecture (in Figure 3), between which the SAP takes responsibility of certain type of communication:

- **CTL-SAP** - *Control SAP* is utilized by end user devices from the *5. Generic City/Community Capabilities* in order to interface and steer the services in the layer underneath. Thereby, various functions of management, control and data acquisition can be established over this SAP. Furthermore, the SAP enables the *3. Data Management & Analytics Capabilities* layer to manage, steer and control the devices in the *0. Fields Equipment/Device Capabilities* layer on the bottom in Figure 3. In this scope, besides traditional networks/system management systems (NMS) and corresponding protocols, concepts and components from the areas of Software Defined Networking (SDN) and Network Functions Virtualization (NFV) can be installed in order to facilitate the dynamic control activities over this SAP.

- **DAD-SAP** – *Data Analytics Data SAP* which is used by entities in the top layers of oupPLUS to access the data from the analytics and data refinement and orchestration services in layer 4 (*4. Integration, Choreography and Orchestration Capabilities*). This SAP will normally be realized over REST (e.g. HTTP) and other type of (web-)service based communication.

- **DAM-SAP** – *Data Analytics Management SAP* is used by entities implementing data management activities and data management plans on top of the data stores and services in layer 3 (*3. Data Management & Analytics Capabilities*) and 4 (*4. Integration, Choreography and Orchestration Capabilities*). This includes activities like data archiving, data anonymization, general data handling and distribution according to pre-defined procedures and rules, as well as the preparation of data for machine learning and artificial intelligence algorithms. This SAP is used to steer, start and stop services implementing the above listed data management activities (among others).

- **MTD-SAP** - *Metadata SAP* accessed by entities in layer 4 (*4. Integration, Choreography and Orchestration Capabilities*) in order to interact with metadata hubs in *3. Data Management & Analytics Capabilities* layer for registering and retrieving metadata regarding data(-sets) existing or offered in the form of a stream and (web-)services.

- **ATH-SAP**- *Authentication SAP* utilized by layer 4 (*4. Integration, Choreography and Orchestration Capabilities*) and the layer underneath (*3. Data Management & Analytics Capabilities*) to regulate the secure access to data resources across the urban infrastructure.

- **DX-SAP** - *Data Exchange SAP* accessed and interfaced by entities from layer 4 (*4. Integration, Choreography and Orchestration Capabilities*) to obtain and exchange Big Data sets between repositories and to persist accumulated stream data to corresponding data stores.

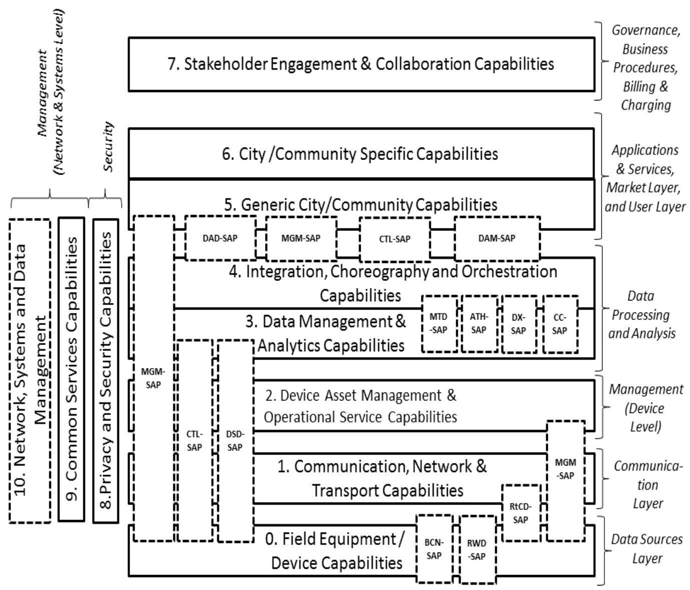

FIGURE 3: THE OUPPLUS ICT REFERENCE ARCHITECTURE FOR ENABLING SMART CITIES

- **CC-SAP** – *Cluster/Cloud Control SAP* which enables the dynamic steering of cloud infrastructures (by the layer *4. Integration, Choreography and Orchestration Capabilities*) in the course of dynamic service provisioning and orchestration between layer 4 and layer 3 (*3. Data Management & Analytics Capabilities*).

- **DSD-SAP** - *Data Sources Data SAP* utilized by layer 3 (*3. Data Management & Analytics Capabilities*) in order to obtain data from the devices in layer 0 on the bottom of oupPLUS. Usually the acquired data is accumulated to some extent and already minorly processed (e.g. through some operations on the edge/sink of a sensor network). The data is transferred to repositories or offered via data streams (described in metadata hubs) for further processing or direct display on end user devices.

- **RWD-SAP** - *Raw Data SAP* used by various components and software modules to process relevant data as close as possible to the source. The data sources can be of various types, e.g. charging stations for electric vehicles, smart meters, sensor networks, social media platforms and further. In general, raw non-accumulated data from sensors is conveyed to the sink, i.e. the gateway to a full-scale IP infrastructure. Hence, the communication in the segment before the gateway will be often realized by short range, low overhead wireless protocols in the case of traditional sensor network infrastructures. In the case of smart meters or social networks, one can utilize direct communication over IP and belonging security extensions where required (e.g. TLS for HTTP(s)).

- **MGM-SAP** - *Machine Management SAP* used for configuration of machines, devices, gateways, network elements and network infrastructures and service infrastructures as a whole (e.g. router or firewall configurations). This SAP is utilized by layer 4 (*4. Integration, Choreography and Orchestration Capabilities*) as well as by layer 2 (*2. Device Asset Management & Operational Service Capabilities*). Thereby, traditional networks/system management systems (NMS), operations support system (OSS) and corresponding protocols are in place to enable the management activities over this SAP.

- **BCN-SAP** - *Beacon and Near Field SAP*, this is a temporary SAP for both NFC objects and readers on the data sources layer, i.e. layer 0 (*0. Fields Equipment/Device Capabilities*).

- **RtCD-SAP** - *Routing Coordination and Discovery SAP*, this SAP is responsible for the establishment of basic network functionality such as a functioning addressing and routing in the scope of IPv4/6. The SAP is an abstract place holder for various routing and network discovery protocols on various levels of the network infrastructure (e.g. in the sensor segment, in the access network or in the core telecom network).

The presented SAPs describe abstract interfaces that enable the exchange of data / information between components placed in the various artefacts (layers and pillars) of oupPLUS. They are also the main concept that enables Quality Assurance (modelling, testing of conformance, interoperability and security aspects) for ICT in Smart Cities along the layers of the oupPLUS reference architecture. Thereby, different data formats and protocols of relevance for urban ICT are mapped to the corresponding SAPs and represent a concrete instance of an SAP. The following standards are considered among others: (1) Network Routing and forwarding protocols (e. g. OSPF, RIP, BGP, IPv4/v6, ARP, 6LowPan, ICMP(v6)) , (2) Transport Layer Protocols (e. g. TCP, UDP, RTP), 3) Tunneling and secure data transmission (e.g. L2PT, IPSec, TLS), (3) Application / Service Layer Communication Standards (HTTP, CoAP, SOAP, SIP and others), (4) Relevant Formats for Data Representation (XML, JSON, CSV et cetera) as well as further established communication protocols and data representations. Indeed, based on such mapping of standards to SAPs, it is feasible to implement integrative urban ICT solutions. These solutions will be based on the exchange of data and interoperability between the components of different vendors complying with established communication standards.

V. CASE STUDIES

The following case studies illustrate the utilization of oupPLUS in order to structure solutions for urban environments in a way that they can be understood and described in terms of layers and interfaces (i.e. SAPs). The first case study originates from the EMYNOS [17] European project relating to Next Generation 112 emergency communication [19]. The second case study relates to the anonymization of energy urban data, which is required in platforms such as [24] of the city of Berlin.

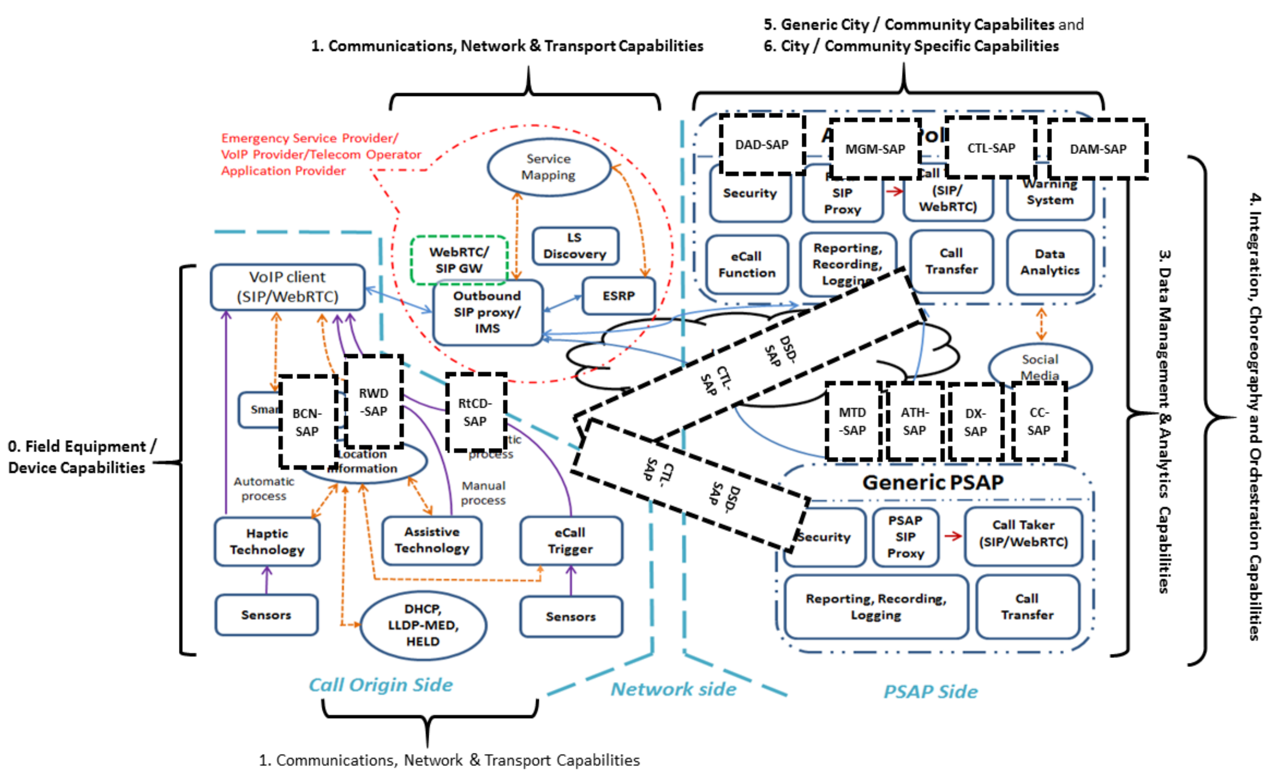

FIGURE 4: THE EMYNOS NEXT GENERATION EMERGENCY COMMUNICATION [18] WITH THE BELONGING PLACEMENT OF OUPPLUS ARTIFACTS

A. Next Generation Emergency Communications

The EMYNOS project [17][18][22] developed an IP based emergency communication framework according to the EENA NG112 Long Term Definition (LTD) document [21] and the ETSI specifications [23] in response to the European Commission mandate M493 for caller location determination. As its name reveals, the EENA NG112 LTD [20] [21] document provides a long term definition of an European emergency services architecture. The core concept of this architecture is the Emergency Services IP network (ESInet) [18] [22]. These IP based private networks can serve a set of Public Safety Answering Points (PSAPs), a region, or a set of states. The NG112 architecture describes a variety of functionalities needed for a successful emergency call (audio, video, text) including emergency call identification, caller location transmission, call routing, and security. The underlying protocols in this architecture are mainly standards developed in IETF such as SIP, DHCP extensions, LoST, and HELD. In the context of EMYNOS, we extended the NG112 architecture by considering scenarios where medical profiles, sensor data (based on SensorML), and symbol languages need to be shared with the PSAPs. These features are of special importance for persons with disabilities or for the Next Generation eCall. The EMYNOS project also provides the ability to analyze, in real time, data from social media (e.g, Twitter, Facebook) related to an occurring emergency event and offer the results to the PSAPs which helps them to build an overview of the situation.

The overall EMYNOS architecture and its structuring according to the design principles of oupPLUS are illustrated in Figure 4. One can observe the various tiers in the architecture starting with the *Call Origin Side*, *Network Side* and *PSAP Side*. The *Call Origin Side* involves the caller, the caller device and the place from where an emergency call is initiated, whilst the *Network Side* represents the necessary infrastructures (e.g. telecom operator) for handling VoIP emergency calls according to the standards discussed earlier. The PSAP side contains a variety of components and functionalities that are in particular in charge of terminating, answering, and reporting the emergency calls in conformance to European privacy rules.

Referring to the layers of oupPLUS, those are annotated in black color on the different sides of Figure 4. Furthermore, one can observe the mapping of the corresponding SAPs within the architecture of EMYNOS. The devices on the caller side will need to implement protocols according to the BCN-SAP, the RWD-SAP and the RtCD-SAP as an interface to the *1. Communications, Network & Transport Capabilities* layer corresponding to the *Network side*. In addition, the DSD-SAP and the CTL-SAP provide the abstract framework for the *PSAP side* to communicate with the caller side over the telecom infrastructure. Due to the clarity of presentation, we omit the detailed description of all the services and SAPs in the PSAP core network. However, it is obvious that the SAPs and the abstract structuring constitute a paramount prerequisite for structuring the architecture of a Smart City solution and facilitating the exchangeability of components from different vendors and their corresponding interoperability.

B. Anonymization of Energy Data

The anonymization of energy data is of paramount importance for opening various amounts of energy data and enabling the community to follow transparently the market situation within a city. Furthermore, through the publishing of data it enables the implementation of various services and applications and the integration of energy data within cross-domain use cases enabling the citizens to handle and optimize their behavior with respect to energy aspects.

In order to achieve the above aspects, data anonymizers are required which should aggregate and present the relevant data in a suitable way for the involved stakeholders. Thereby, it shouldn't be possible to relate back and identify single persons or households (relating to their energy profile) based on the anonymized datasets. A typical portal publishing energy related Open Data is given by [24] and is being extended in the scope of the WindNODE project with features relating to data anonymization. Thereby, the off-the shelf data anonymizers reside in the layer 3 and/or layer 4 depending on their architecture and required flows and interfaces. Furthermore, the data anonymizers process the closed data which has been gathered from within the household sites, e.g. through the usage of smart meters – hence it has flown over layer 0, layer 1 up to layer 2 and the DSD-SAP (over a networking infrastructure established through RtCD-SAP) until arriving in a closed database within the *3. Data Management & Analytics Capabilities* layer. This closed data is gathered by the energy grid provider and normally kept within its secure internal databases. Hence, before publishing it is pushed through the DX-SAP of oupPLUS, such that the data can be anonymized according to data management plans which are setup over the DAM-SAP and finally published at the Open Data platform [24]. After arriving within the Open Data portal, it is made accessible for apps and services running on top over the DAD-SAP. The apps and services would be naturally residing in layer 5-6 on top of the *4. Integration, Choreography and Orchestration Capabilities* layer.

VI. Conclusions

The current paper presented our approach to structuring the ICT landscape of emerging Smart Cities in a unified way. Thereby, we propose to utilize the concept of a reference architecture towards creating a viable eco-system of ICT stakeholders and components for the dynamic and scalable development of smart urban ICT eco-systems. Reference architectures are an established approach from the domain of communication networks with ISO/OSI and TCP/IP being the two most prominent examples, which have enabled the rapid growth and interoperability of components towards the establishment of global telecom and Internet type of networks. After presenting the overall understanding of reference architectures (including aspects such as *vendor lock-in independence*, *open standardized interfaces* and further), the activities of various European projects and collaborations are elucidated, such as EIP SCC, H2020 Triangulum and H2020 Espresso. In addition to these activities, the German standardization efforts within the DIN standardization body are presented and their relation to the European activities elucidated.

The resulting DIN Open Urban Platform reference model is the base for further research activities within the Fraunhofer FOKUS institute leading to the definition of the oupPLUS model, which extends DIN OUP by introducing Service Access Points between the artefacts of the standardized model. These SAPs represent abstract artefacts for specifying and mapping the protocols and data representation formats that enable the interoperability and exchange among ICT components in an urban environment. Thereby, the SAPs are meant to represent open standardized interfaces based on established communication protocols and meta-models. The current paper discusses on the oupPLUS approach and gives examples for standards of relevance for the SAPs.

Having sketched the oupPLUS research activities, two case studies are presented that demonstrate the application of oupPLUS to typical Smart City solutions – the first one being a platform for VoIP emergency communication and the second one being an anonymization service of energy data. Thereby, it is shown, how the oupPLUS model can be used as a blueprint for explaining the complex relationships in these architectures through the prism of a unified reference architecture for the establishment of an urban ICT eco-system.

With respect to future work, a number of paramount activities are planned, including the provisioning of a reference implementation of oupPLUS. Furthermore, the establishment of a standardized approach can be planned, in the scope of which ICT components are validated against the SAPs and standards they implement according to SAPs.

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