Facilitating eco-systems for Smart Cities through reference architectures

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A large number of activities have been conducted during the past years in the cross-domain area of Smart Cities. The research and development efforts started with various projects which aimed at opening the large amounts of data kept by the public administration – a goal which would ultimately enable various ICT based applications and services in urban environments.

However, Smart Cities necessitate not only data but also the technical infrastructure that permits its acquisition, its processing and its access by various stakeholders (e.g. citizens, companies, NGOs...). Indeed, the majority of pertinent urban data is not only of static nature, but also includes sensor measurements in line with the emerging concept of Internet of Things. Thus, an ICT infrastructure – for instance mobile access networks such as 4G/5G, telecommunications networks or cloud services – is required to enable the various processing and storing functionalities stemming from intrinsic requirements within the Smart City context. Such ICT infrastructures should emerge based on integration efforts involving different players in a global and local context, e.g. large vendors and operators, as well as local SMEs. The current paper provides an overview of various research and standardization efforts at defining a universal blueprint for ICT infrastructures in Smart Cities. In this line of thought, the concept of an ICT reference architecture is discussed which aims at enabling cities to design their ICT environment following established guidelines, thereby implementing an integrative pattern and establishing an eco-system of different vendors, operators, components and solutions for Smart Cities.

1. Introduction

A large number of activities have been conducted during the past years in the cross-domain area of Smart Cities. The research and development efforts started with various projects aiming at opening the large amounts of data kept by the public administration – a goal which would ultimately enable various ICT based applications and services in urban environments. In that scope, the authors gathered some vital experiences and insights into the initial developments in the area of ICT for Smart Cities. These developments were based on different concepts and software packages [1,2] that enabled the publishing of data and supported city administrations and related organizations to open up their data silos and facilitate first cross-domain scenarios in urban environments [7,8].

Going beyond the concept of Open Data[1], a city can be seen as an entity that dynamically consumes data from different sources as well as produces data to be utilized in various scenarios. Hence, aspects such as the existence of functional mobile networks (e.g. 3G/4G/5G, WIMAX or Wi-Fi) are of paramount importance for realizing Smart City solutions. In addition, different IoT technologies – e.g. 6LoWPAN, MQTT or ZigBee – play a significant role in obtaining data and making it available for smart services in urban environments. Furthermore, the security and operational management of the critical urban ICT infrastructure should be properly addressed to avoid jeopardizing cities and even endangering human life. There are only a few aspects of urban ICT which need to be handled and addressed in a unified way on national, European and even global scale. An abstract model is required that allows for capturing the emerging complexity and efficiently handling the integration, replication, management, development and operational challenges of various ICT infrastructures. Such abstract models are denoted as Reference Architectures/Models and have been widely used in the areas of telecommunications and Internet in the past decade, with ISO/OSI and TCP/IP being the two most prominent examples.

Extending the initial trend of *Data for Smart Cities*, the current paper presents reference architectures which are the result of key European projects and exemplifies their utilization in European cities towards the facilitation of ICT eco-systems and large scale integrative solutions. Furthermore, different collaboration and standardization activities are presented which outline the path towards standards and quality assurance within such dynamic ICT based eco-systems.

1 *In general, the concept of Open Data stands for the requirement to publish data under so-called open licenses, such that the data would be freely available to the community for usage and republishing without any sort of copyright limitations.*

The rest of this paper is organized as follows: Section 2 elaborates on Data for Smart Cities and presents a number of successful data driven projects for urban solutions. Section 3 introduces the ICT reference architecture from the H2020 Triangulum project [10] and showsits application in two European cities. The following Section 4 presents current international collaborations and standardization activities of relevance. Section 5 outlines research and development directions to be pursued within the coming years whilst the final section concludes and summarizes our paper.

2. Data for Smart Cities

Fraunhofer FOKUS – as one of the leading European institutions in applied science – has formed and supervised a number of projects which enabled the exchange and publication of data in urban environments. In this scope, these projects focused mainly on opening the large amount of data from public administrations and establishing Open Data platforms in German and European contexts.

The first project was given by Berlin Open Data, which started with a study and subsequent pilot in 2011. Thereby, Fraunhofer FOKUS worked out the technical concept and supervised the deployment of the CKAN backend component [1]. Furthermore, an initial definition for a metadata scheme suitable for Germany was specified, such that static datasets coming from the public administration can be described and made available/ searchable over a metadata portal *(http://daten.berlin.de)*. Thereby, the datasets still reside on the systems within the different institutions whilst being available over a REST interface and accessible over the Internet. Hence, the Open Data Platform is responsible for keeping track of all these datasets and making them available to the community within an urban environment. Finally, it should be noted that after one year of pilot operation, *daten.berlin.de* was transferred to a local SME which is taking care of the IT infrastructure and of enabling the expansion in terms of captured datasets.

Interestingly, after the success of the Berlin Open Data platform, an energy provider operating in the area of Berlin engaged with the research community (represented by Fraunhofer FOKUS), in order to provide key open data regarding their energy network and belonging consumption. This resulted in a pilot *(http://www.netzdaten-berlin.de)* operated since December 2012 which was designed by Fraunhofer FOKUS based on a similar technological stack as the Open Data Platform of Berlin. The initial amount of datasets available over this industrial Open Data Platform involved 93 datasets relating to various topics such as *electricity supply, balance sheets, connections with the grid, coverage area and electrical grid structure*. All of these datasets have been *anonymized* before provisioning and the underlying processes are further researched on in large scale projects such as WindNode [17]. The latter aims at further extending the functionalities of the portal, meanwhile also supported by a variety of players on the Berlin energy market. Finally, *netzdaten-berlin.de* can be seen as a strong initial push from the energy industry towards publishing Open Data even though the last years show that this topic is followed in a very pragmatic and minimalistic manner.

Another successful data sharing project is given by the German national governmental portal *(https://govdata.de)* that was initiated by the German Federal Ministry of Interior and conceptualized and prototyped by Fraunhofer FOKUS. The prototyping was preceded by a study [16] of (open) data potentials across Germany combined with initial technological designs as well as a legal, operational and financial analysis of the required processes towards the establishment of an Open Data portal for Germany. The first prototype was launched in February 2013 and was operated and improved until 2015 when it turned fully operational and is currently taken care of by a dedicated IT provider. GovData.DE provides different types of (open) data related artefacts including datasets, documents and applications, which are published under different licenses.

The big challenge in this context is the harvesting[2], i.e. the integration of different datasets from various institutions and cities – i.e. city (open) data portals – into a common meta-portal. This harvesting process had to be conducted in a way that guarantees high quality of the automated harvesting results, which led to a formal process involving several iterations and regular audio conferences with relevant data providers. More details on these processes and the obtained experiences are provided in previous publications such as [15].

Finally, one of the latest Open Data developments with a direct link to Smart Cities is constituted by the Pan-European Open Data Portal *(https://www.europeandataportal.eu/)*, which is currently operated as a pilot by a consortium including Fraunhofer FOKUS as a main technical partner. It harvests and aggregates data from all EU members as well as from a large number of EU associated countries, which means that 35 states automatically provide data. Thereby, datasets can pass different paths and are harvested on multiple levels until finally being represented on the Pan-European level. For example, a dataset published in Berlin is automatically harvested to the German national Open Data platform (presented in the preceding paragraph) and then in turn harvested to *www.europeandataportal.eu*. Hence, the Pan-European Open Data Portal serves among others as a unified view on urban data originating from cities and regions across Europe.

The above paragraphs outline the initial trend in Smart Cities which was driven by the vision of opening the large amount of data treasures kept inside various institutions within in a city. However, a large amount of

2 *Harvesting stands for the process which obtains metadata about datasets from online systems, databases, webservices, other Open Data platforms and alike.*

use cases go beyond using only this data and require real-time data obtained from different sensors and more general data sources (e.g. social networks, crowd sourcing et cetera). This leads to a much more complex urban ICT environment, which is at the heart of the next section.

3. ICT reference architectures for Smart Cities

ICT reference architectures are a required concept for Smart Cities for various reasons, many of which were formulated as requirements within [9]. These include the need to provide an abstract picture and understanding of the ICT strategies and developments within a city, as well as to serve as a tool for describing the ICT artefacts within an urban environment. ICT reference architectures are meant to accommodate and explain existing ICT infrastructures on the one hand, and to enable extensions and the introduction of new components and solutions on the other hand. Furthermore, the identification of abstract interfaces among different layers and involved components, as well as the enforcement of appropriate design principles permits the creation of integrative solutions compiled and provided by different stakeholders in an urban ICT eco-system (e.g. large industry or local SMEs) [11]. This would support cities in avoiding vendor-lock-in and the continuous dependence from specific providers. In addition, the path would be set for using solutions based on Open Source and Open Data in combination with data exchange over interoperable and standardized interfaces [6,11].

As previously mentioned, examples of similar efforts are constituted by the extremely successful Internet/ Telekom Reference Models – TCP/IP and ISO/OSI layered models. Similarly, as in the case of these models, an urban ICT reference architecture is needed in order to facilitate the replication and reusability of components and solutions across multiple urban eco-systems and to finally speed up the development of ICT based Smart Cities in Europe and across the globe.

3.1. Triangulum ICT reference architecture

The Triangulum reference architecture – as defined in [9] and [11] – is illustrated in *Figure 1* with its different views thereby zooming into the *Technical View*. Further views on the reference architecture are constituted by the *Informational and Organizational View*, which relates to aspects such as market places, user applications and services, as well as business procedures, billing, charging and governance. The Technical View accommodates three layers including the *Data Sources* layer, the *Communication* layer and the *Data Processing and Analysis* layer. On top of the Data Processing and Analysis layer different applications and services can be developed which are managed and distributed over marketplaces from the Market Layer within the Informational View. These marketplaces provide the belonging services and applications to end users within the User Layer. In addition, two pillars related to Management and

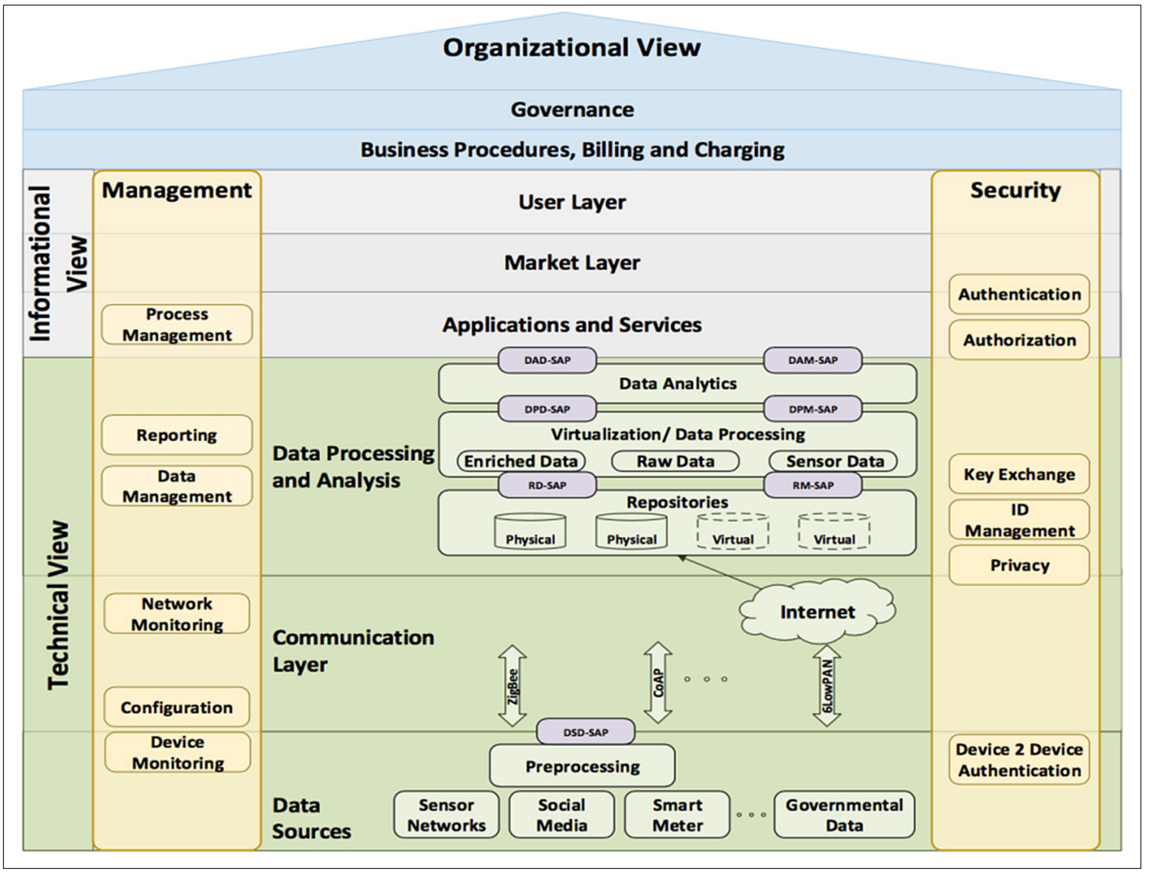
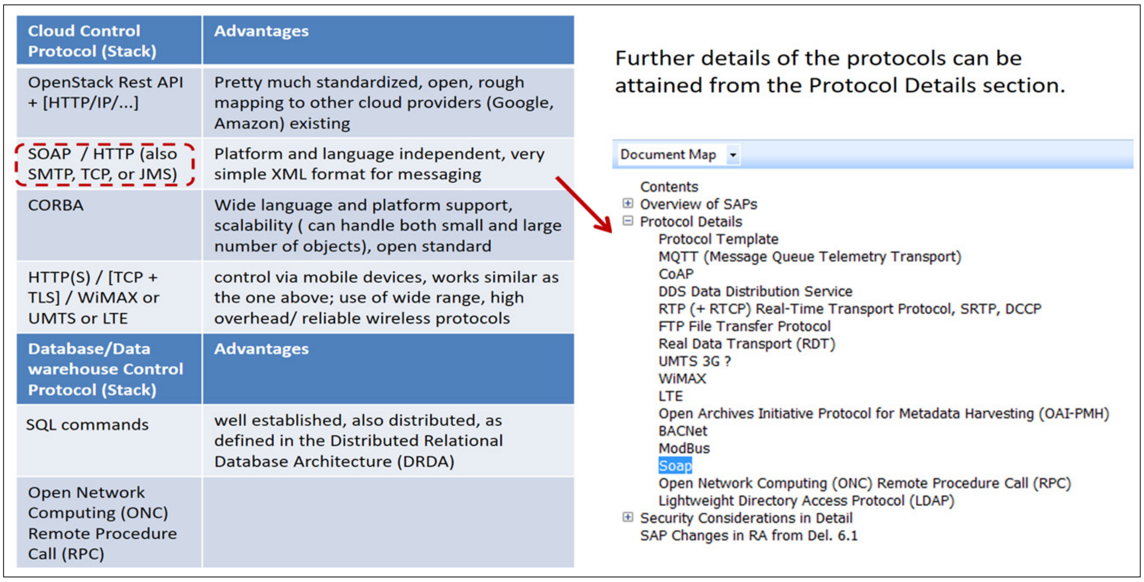


Figure 1. The Triangulum ICT reference architecture as specified in [9] and [11]



Cloud Control Protocol (Stack)	Advantages
OpenStack Rest API + [HTTP/IP/...]	Pretty much standardized, open, rough mapping to other cloud providers (Google, Amazon) existing
SOAP / HTTP (also SMTP, TCP, or JMS)	Platform and language independent, very simple XML format for messaging
CORBA	Wide language and platform support, scalability (can handle both small and large number of objects), open standard
HTTP(S) / [TCP + TLS] / WiMAX or UMTS or LTE	control via mobile devices, works similar as the one above; use of wide range, high overhead/ reliable wireless protocols
Database/Data warehouse Control Protocol (Stack)	**Advantages**
SQL commands	well established, also distributed, as defined in the Distributed Relational Database Architecture (DRDA)
Open Network Computing (ONC) Remote Procedure Call (RPC)	

Figure 2. Mapping communication standards and data models to Service Access Points

Security span over all layers of the Technical and Informational View. The Security column accommodates functions such as *Authentication* and *Authorization*, *Key Exchange* and *ID Management,* whilst the Management pillar deals with various flavors of data, processes and infrastructure management including monitoring, configuration, network management, data management and further.

The various artefacts of the ICT reference architecture (especially within the Technical View) communicate over abstract interfaces denoted as Service Access Points (SAPs). Examples of SAPs are given by the DSD-SAP (Data-Sources-Data-SAP) responsible for communication from the data sources (e.g. sensors, social networks, ...) over the *Communication Layer* to the *Data Processing and Analysis Layer*. Similarly, different data communication SAPs – those with "D" before "-SAP" in Figure 1 – and management SAPs – those with "M" before "-SAP" in Figure 1 – are in place in the upper layers towards enabling the exchange and interoperability among components in the layers of the *Technical* as well as the *Informational View*.

The question arises on how SAPs enable the communication between components in different layers of the Triangulum reference architecture. Firstly, [11] specifies a number of generic formats regarding messages flowing over SAPs. However, the more realistic approach is given by establishing a mapping between established protocol standards (e.g. IPv4/v6, DHCP, CoAP, HTTP, SOAP, ...) along with data models/formats (e.g. DCAT-AP, JSON, XML, RDF, ...) and SAPs. Hence, for implementing a particular SAP, a component should implement certain belonging protocols and thus enable the possibility of information exchange over the SAP.

Figure 2 provides a screenshot of our current navigational documents capturing protocols mapping on different SAPs of the Triangulum architecture. Based on the combination between the layers of the Triangulum reference model and the SAPs with belonging mappings, it is possible to explain and structure the ICT eco-system in a city, thereby enabling its extensibility and modular enhancement, as achieved within the Triangulum project.

3.2. Applying the reference architecture

Within the Triangulum H2020 the authors applied the above architecture, in order to structure various ICT systems in the involved European cities – i.e. Eindhoven, Manchester and Stavanger as lighthouse cities. Due to non-disclosure agreement aspects, we are not able to report on details regarding these deployed systems. However, two of the most interesting examples are given by the ICT system which is introduced as a set of components for **energy management including smart gateways** in the city of Manchester, and the **Big Data Analytics Engine and Data Hub** from the city of Stavanger. In both cases the systems were described through a mapping of their components to the layers of the ICT reference architecture, as well as through the mapping of their communication flows and interfaces to the belonging SAPs and communication protocols. This structuring is the basis for the replication of urban ICT solutions between lighthouse and follower cities as planned in the following two years of the Triangulum project.

4. Standardization activities and collaborations

An ICT reference architecture for Smart Cities is the perfect object for standardization having the potential outreach to involve multiple players in an urban eco-system. Hence, a large consensus among a large number of players, including cities, large industry, utilities, SMEs and end users is required in order to establish a viable ICT reference architecture. Indeed, standardization bodies such as ETSI, ISO and DIN, to mention a few, can play an important role in future Smart Cities through their standards and capabilities to create consensus among multiple parties. In this line of thought, the following two sections deal with relevant international collaborations and standardization activities in close relation to the presented reference architecture research.

4.1. MOU EIP SCC

In 2015, the European Commission initiated the Memorandum of Understanding (MoU) towards open and interoperable urban platforms within the European Innovation Partnership (EIP) on Smart Cities and Communities (SCC). A number of key players from industry, academia, SMEs and cities committed to work on a number of topics organized in three working streams – *WS1: Standards & Standardization, WS2: Reference Architecture & Design Principles* and *WS3: Scale (Market Perspectives, Business Models, Extend Reach, Collaboration, PMO, ...*). Thereby, the overall goal of the MoU consortium is constituted by the ambition to engage cities, infrastructures companies, service providers, telecommunication players, and utilities in order to establish a strong EU city market for urban platforms. This implies that in the future EU citizens will be using such urban platform(s) to conduct and handle their business with a city whilst the city and its administration can gain valuable insights and can optimize their processes based on urban platforms. Furthermore, urban platforms can drive local innovations by providing data but also by enabling different players (e.g. local SMEs) to be part of a complex innovative urban ICT eco-system.

The establishment of an urban ICT eco-system is especially dependent on *WS2: Reference Architecture & Design Principles* from MoU EIP SCC. WS2 produces a potential standard for an ICT reference architecture and design principles for Smart Cities [6], which is available for partners over the portal of the European Innovation Partnership [4]. The resulting specification constitutes a layered model encompassing all the layers from data sources up to user interfaces, business processes and management consoles. Each layer is characterized through a number of capabilities which are explicitly defined within the reference architecture document [6]. These capabilities together with the design principles of openness, open interfaces and the proposed increased utilization of standards, instead of proprietary protocols, lays the ground for further development and standardization activities (e.g. DIN SPEC OUP described in the coming paragraphs). In addition, the reference architecture of WS2 supports the cities in avoiding vendor-lock-in and establishing a sustainable local ICT infrastructure based on SMEs, open standards and Open Data.

4.2. DIN SPEC 91357 Open Urban Platform

In November 2016, DIN – the German Institute for Standardization famous for its DIN A4 standard – started a working group that gradually converged in their discussions towards a specification for an Open Urban Platform. The DIN SPEC 91357 is based on the European partnership and the reference architecture [6] that was worked out in the scope of MoU EIP SCC. A dozen of partners from cities, municipalities, industry, research, automotive, software, network providers, and energy suppliers were meeting regularly with the goal to discuss and adapt the European reference model [6] to the needs of the German market. The discussions included a review of various standards and global undertakings such as oneM2M [13] from telecommunications, FI-WARE [14] from the area of Future Internet, as well as relevant ITU-T and ETSI initiatives. Fraunhofer FOKUS was active in various topics around the emerging specification and supported the overall outcome of the consortium, which was published at the end of 2017.

The resulting document contains the abstract design of an open urban ICT Reference Architecture for the German market. This Open Urban Platform is based on open interfaces which enable the exchange and interoperability along multiple layers for communication and data processing. These layers incorporate the paradigms of security and privacy in various patterns and thus guarantee the trustful realization of different use cases and scenarios described in [3]. Hence, based on the considerations and consensus of the above standardization output, different projects have been initiated and influenced in Germany and across Europe [18,19].

5. Future work – oupPLUS

oupPLUS [12] is a vision of Fraunhofer FOKUS which will materialize in the near future. Thereby, oupPLUS aims at combining various features from the above presented standardization and R&D activities – i.e. MoU SCC EIP [5], DIN SPEC 91357 OUP [3] and Triangulum reference architecture [9,11]. Indeed, oupPLUS intends to build on the layered structure and capabilities proposed by MoU SCC EIP [5] and DIN SPEC 91357 OUP [3]. In addition, some further layers/pillars are introduced, which allow for improved network and systems management and increased security of the critical urban infrastructure including aspects such as confidentiality, integrity, availability and data privacy. However, the most crucial aspect will be given by the introduction (and detail specification) of the Triangulum SAPs to the layered structure of MoU SCC EIP and DIN SPEC 91357 OUP. This allows for laying down the basic constraints and design principles for communication of Smart City components placed/belonging within the various layers/pillars of the oupPLUS reference model.

The SAPs will be a key artefact within the emerging oupPLUS reference model. Through a suitable mapping of communication protocols and data models to the SAPs, it would in turn be possible to apply model-driven approaches, testing and various quality assurance processes to an integrative urban eco-system based on oupPLUS. For example, it would be possible to define a generic meta-model for oupPLUS based components that generates skeletons, interfaces and WSDL, IDL/CORBA or ASN.1 descriptions for the communication flows between different urban components of an oupPLUS based eco-system. Furthermore, given the fixation of SAPs as communication gateways between components on different layers and with different capabilities within instances of oupPLUS, it is possible to introduce testing of components for Smart Cities based on the characteristics and established test suites for relevant protocols, e.g. IPv6, XML, CoAP, MQTT, DHCPv6, SOAP and Mobile IP to give just a few examples.

The SAP testing can have different goals:

1) Conformance testing of the component according to the standards accommodated within and SAP, i.e. it is checked whether an urban component complies to an SAP within the oupPLUS model,

2) Interoperability testing, i.e. it is checked whether an urban component can interact with other components attached at the other end of an SAP in question, and

3) Security testing, i.e. it is checked whether the SAP implementation of an oupPLUS urban component can guarantee a certain level of security and privacy. Hence, this testing approach enables different processes and undertakings, e.g. a certification process can be put in place that asserts the quality of Smart City components according to the oupPLUS design principles.

Furthermore, it is possible to introduce certification processes for conformance and security as well as to organize interoperability testing events allowing urban ICT vendors to test and protocol the interoperability of their solutions.

6. Conclusions

The current paper gives a comprehensive introduction to the topic of ICT reference architectures for Smart Cities and on the basic principles leading to the creation of eco-systems of ICT vendors and operators in an urban context, including SMEs, NGOs, Open Source initiatives and large industry.

ICT reference architectures can be seen as a logical next step in the development of Smart Cities following the initiatives to opening the data treasures in public administrations, which were illustrated on a couple of projects at the beginning of this paper. Given the dynamicity of the required data – e.g. sensor data, continuous data, maps, geolocations, video streaming, ... – it is apparent that an integrative approach is required that enables the interoperability of various ICT components from different stakeholders in an urban environment. Hence, the tool of an ICT reference model is introduced and related developments are presented thereby focusing on the Triangulum ICT reference architecture. In this scope, it is also briefly elucidated how such a reference architecture has already been applied within European cities to accommodate Big Data solutions and ICT components relating to energy optimization.

International collaboration and national standardization activities have moved beyond initially limited models created within single projects, such as the Triangulum ICT reference architecture. This was mainly achieved through the active engagement of various players such as cities, IT vendors, telecommunication vendors and operators, automotive industry and further stakeholders from the urban community. Indeed, MoU SCC EIP and DIN SPEC 91357 represent the two most prominent undertakings in this regard and were described in the current paper.

To conclude the paper, an outlook into the coming research and development activities of Fraunhofer FOKUS was given by drafting the ideas around oupPLUS which will focus strongly on quality assurance, modelling and model checking, as well as testing for ICT in Smart Cities. Thereby, oupPLUS constitutes a combination of various features from MoU SCC EIP, DIN SPEC 91357 OUP and Triangulum reference architectures for ICT in Smart Cities.

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