Design Aspects for a Reference M2M Communication Platform for Smart Cities

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Abstract— **For the last decades, we have witnessed new technological evolutions in the Internet, wireless networks, and sensors fields. Currently, we are able to build smart systems that improve quality of life and enhance environment management. However, most available smart systems are implemented based on proprietary hardware/software solutions, restricting interoperation, which is required for large-scale Smart City solutions. To enable the implementation of a general Smart City solution, a platform is needed to fulfill the communication requirements between heterogeneous access technologies. In this paper, we address the requirements and design aspects of a reference Machine-to-Machine (M2M) communication platform as an enabler for Smart Cities.**

Keywords: Internet of Things; Smart City; Machine-to-Machine, Future Internet;

I. INTRODUCTION

Smart City is becoming a commonly-used term to describe the concept of utilizing information and communication technologies (ICT) to enhance urban services and improve the quality of life for citizens and visitors. This objective shall be reached by the collaboration of various market sectors with government agencies, in order to increase the efficiency and efficacy of government services, and developing environment-friendly applications. According to the United Nations (UN), more than half of the World's population lives in urban areas, and it is suggested that thousands of new cities need to be built worldwide by 2050. Experts point out Smart Cities as an emerging market with enormous potential, which is expected to drive the digital economy forward in the coming years. The current consensus value of the IT market for Smart Cities globally is approximately $35bn [1].

Soon, most objects surrounding us will be connected to the Internet and able to send/receive different types of data and information to the outer world, constructing the Internet of Things (IoT). Most smart phones are currently embedded with powerful and programmable sensors such as GPS, camera, accelerometer etc. Connecting the physical and IT infrastructures, forms the new Machine-to-machine (M2M) communication trend, which is one of the most essential enabler technologies for Smart Cities. This trend coupled with the emergence of new features from network operators and IT infrastructure suppliers is driving the trend toward Smart Cities.

M2M communication platforms will take the role of controlling the communication between all connected objects and systems. The decline in costs of connectivity and device prices is driving the growth in M2M communications. A new ecosystem will be shaped combining services to add intelligence to these connected devices in an interoperable manner. In the Future Internet, service enablers should facilitate the harmonization of services into interoperable services forming an Internet of Services (IoS). A set of such services within the Future Internet infrastructure constitute the basis of what has come to be called as Smart Cities.

This paper defines the Smart City concept and discusses the requirements and research challenges from the communication point of view. The rest of this paper is organized as follows: Section II discusses the definition of Smart City and presents common research challenges in current implementations, Section III presents the architecture of Smart Cities. Section IV addresses the requirements and design aspects of a general M2M platform as an enabler for a Smart City. Finally, section V concludes the paper.

II. RESEARCH WORK IN SMART CITY

Smart City is widely considered as a hot topic; however, there is no clear definition of the Smart City concept among practitioners and academia. Authors in [2] represented the idea of a smart city as a "system of systems", where the integrated systems forms a closed loop and are characterized by functions: sensing, information management, analytics and modelling, and influencing outcomes. Each system produces its own information and consumes others' information in a well-defined urban planning.

A holistic definition of the term from [3] embraces six characteristics that need to act smartly to achieve a Smart City that is "well performing in a forward-looking way in economy, people, governance, mobility, environment, and living, built on the smart combination of endowments and activities of self-decisive, independent and aware citizens". Experts from various specialties provide more concrete definitions, which emphasize the role of their own approach and activities in the field. From the IT prospect, a Smart City can be defined as "a city connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city"

[4]. The main IT aspects of the Smart City are: Instrumented, Interconnected, Interoperated and Intelligent City.

As shown in Figure 1, Smart Cities include four main aspects: i) Smart Infrastructure to connect physical objects and sensors through heterogeneous communication networks, realizing the interconnections between human and machines (H2M) and between machines (M2M). ii) Smart Operations for improving the citizens' quality of live, by offering innovative services in every business sector and integrating application systems and information, to be the core elements supporting urban operation and management. iii) Smart Eco-System, where the analysis of the interconnected information should yield new insights for driving decisions and actions that improve process outcomes of systems, organizations, and industry value chains. Such outcomes must fundamentally change the end-user experience and ecosystem, i.e. they must demonstrate tangible value-add. iv) Smart Governance: Interconnection of urban components companied with integrated application systems need to be supported by urban-scale management with coordination of urban critical systems to make a city run best and smarter.

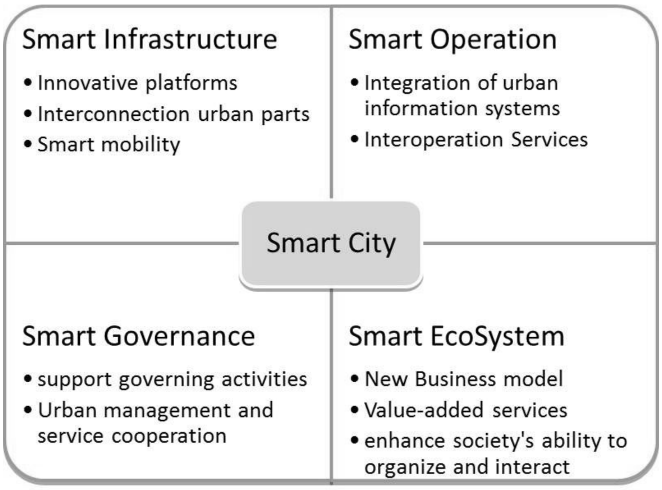

Figure 1. Main Smart City aspects.

Few initiatives address the creation of Smart Cities worldwide. Some examples are: Barcelona Smart City model [5] which aims to generate smart ideas in an open environment through raising clusters or developing proper living labs while directly involving citizens in the co-creation process of products or services. The main assets of the Barcelona Smart City model are: Smart Governance, Smart Economy, Smart Living, and Smart People.

Helsinki Smart City Region [6] forms a strong innovation oriented cluster around mobile technology, supported by local and regional government and driven by the Living Labs approach and mobile application cluster. Various Living Labs have been established in and around the Helsinki region. Their functions are diverse, but all are basing their activities on the principles of User-Driven Innovation (UDI). The aim of the Living Labs is to promote the Smart City concept and drive the development of the Future Internet, through bringing users with their knowledge, ideas, and experiences together with the developers of new services and products to increase the quality and usability of the services and products created. The city of Helsinki has stimulated the development of a Mobile Application Cluster through organizing competitions for innovative applications. The Smart City services that are developed in competitions benefit both the Mobile Application Cluster and the citizens. New firms show considerable potential to take full advantage of the new market channels and changing business environment of mobile applications, and create a new industry around Open Data.

Some big cities in China, Beijing, Shanghai, GuangZhou, and ChongQing have launched a Smart City strategy, in order to strengthen city management and improve their services dealing with traffic jams and overcrowding problems [7]. Shanghai is accelerating the development of its high-speed wireless broadband network as part of its bid to become a Smart City.

Generally, the common subset of research challenges faced by previously mentioned initiatives can be summarized as follows:

1) *Scalability:*
Considering the rapid increase in number of smart devices coupled with heterogeneity in sensor networks, scalability is a main technical challenge for enabling ubiquitous access including mobility and service continuity in large-scale deployment of smart environments. Existing technologies make the IoT concept feasible but do not fit well with the scalability and efficiency requirements at different levels, including: naming and addressing, communication and networking, data management, and service provisioning.

2) *Governance:*
Smart City services involve many different stakeholders, such as distinct application providers, devices vendors, and radio and core network providers. In order to be able to manage the overall system consistently, flexible horizontal solutions are needed for sharing skills, network infrastructures, and devices between stakeholders.

3) *Lack of Testbeds*:
To perform reliable large scale experimentation for the validation of research results, the need of a city scale testbed emerges. Many existing testbeds [8] [9] provide a good proof-of-concept, however they just offer experimentation and testing limited to specific environments or application specific deployments and do not allow conclusive experimentation. Additionaly, a Smart City deployment involves different non-technical stakeholders. Hence, many non-technical constraints must be considered such as users, public administrations, vendors, government, etc. Large-scale testbeds are required to provide the necessary critical mass of experimental businesses and end-users required for testing of IoT as well as other Future Internet technologies for market adoption.

III. SMART CITY COMMUNICATION ARCHITECTURE

The traditional Internet interconnects intelligent end-systems through a relatively simple network architecture. In contrast, a Smart City has an additional sensing layer, which enables the interconnection among non-intelligent or weakly-intelligent devices. Thus, it brings many new requirements and challenges to data exchange, information integration and services, as well as more complexity of the network architecture. Generally, the proposed architecture of a Smart City can be divided into four layers as shown in Fig 2, in order to address the requirement of an Instrumented, Interconnected, Interoperated and Intelligent Smart City:

A. Object sensing layer:

Here, the connection of sensing objects to short range communication networks is handled. The technical development in short-range, low-power, low-rate wireless technologies such as IEEE 802.15.4 and low-power WiFi has accelerated in the last few years. However, the main challenge with the evolution of wireless sensors networks (WSN) has been the large number of proprietary systems that lead to non-interoperable solutions.

B. Access and control layer:

This layer deals with the interchange and recombination of information between heterogonous WSNs and service delivery platforms (SDP). The majority of M2M and smart system applications have historically required low bandwidth. However, the evolution in connectivity technologies and smart device features will soon facilitate new applications that require high data rates, and hence consistent routing, Quality of Service (QoS), transport and network recovery techniques. The challenge of efficient interconnection among large-scale heterogeneous network elements is raised as a key scientific problem of the IoT trend. An additional platform is needed to suffice the requirement of the new communication paradigm that will be coming from the event-driven IoT communication scenarios. Previous network architectures (e.g. IP Multimedia Subsystem (IMS)) were built to be connection-oriented, suitable to primarily support Human-to-Human (H2H) communication. However, M2M presumes the independent communication between a large number of devices, sensors, and actuators – and service platforms, which in turn presumes the transmission of large amounts of data of heterogeneous types and sizes over the network. For instance, some M2M devices will have restricted processing, memory and transceiver resources. Also, it can be assumed that they will be placed in less accessible or critical locations.

C. Service Enablement layer:

The aim of this layer is to improve the cooperation between service providers and consumers, by providing

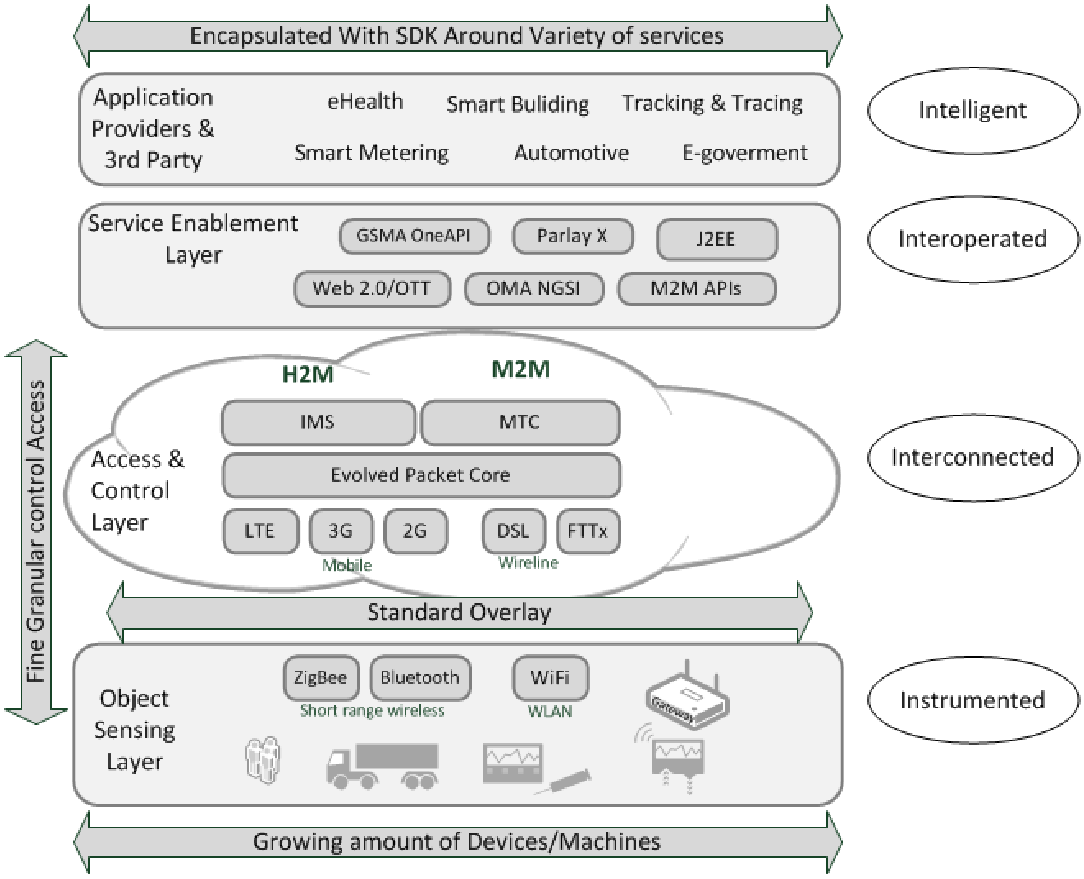

Figure 2. The Smart City four layer architecture.

service integration and orchestration between several application domains. In a dynamic smart system environment, services should be provided while being subject to uncertainties of interactive entity objects and randomness of interactions with the environment. Consequently, new software modelling theories, mechanisms, and methods need to be addressed, in order to take into account constraints of runtime platforms that meet the changing requirements in such environments. Using agnostic interaction technologies and protocols can significantly reduce service integration costs and time. Consequently, the principles of a Service Oriented Architecture (SOA) could be fully utilized in this layer.

D. Application layer:

This provides complex content services for various users. Open and flexible Web technologies facilitate developing innovative applications in the Internet where end users become producers and consumers of content and services. We assume that these technologies together with the possibilities provided by embedding sensor and actuators, cloud computing [10], and Big Data will pave the way to a whole new set of smarter applications.

IV. M2M Platform as Smart City Enabler

In the previous section we highlighted the need for a new platform in the access layer to support M2M communication, due to its distinct traffic characteristics. In this section we discuss the requirements of a M2M platform as an enabler for a Smart City implementation, and present our work in developing the OpenMTC platform [11] to support such implementation.

A. Requirements

The main goal of M2M platforms is to connect efficiently a great number of devices and associate them to a set of services. Consequently, the M2M platform should be characterized by the following properties:

1) Standard interfaces:

M2M platforms aim to interconnect the growing amount of devices and sensors [12] independently of their communication technology. Thus, standard interfaces appear as a must for M2M platforms. In addition, one main factor influencing the connection of the devices to services is related to the operational costs. It is assumed that M2M data traffic is different from the one of human-based communication due to the specialized functions involved: e.g. large data collection while having a sensor-level granularity and actuation of specific sensors in specific network locations. Consequently, it is important to optimize the usage of the M2M platform interfaces, in order to address interoperability and scalability issues and facilitating the harmonization of services into interoperable services forming the Internet of Services (IoS).

2) Efficient data/event processing methods

Efficient data and event processing is required to achieve real-time performance. M2M platforms share many of the key challenges similar to large scale data initiatives, in terms of handling the data streams aggregated from billions of devices, and make them usable by various applications. As huge amounts of data and information are provided to the system, methods must be involved in understanding, combination, and processing the content aggregated from different sources and in different formats, in order to address the Internet of Content (IoC) challenges. Through this horizontal middleware, proper governance can be realized avoiding the mishandling of data and unsuitable assigning of rights.

3) Security and Privacy

Currently, the applications gaining the highest momentum in the M2M area are the applications for which the safety and the robustness of the communication are critical such as eHealth or SmartGrid. Therefore, an M2M platform has to be secured directly from the design. The communication of the devices and the network core should be secured against a large variety of security threats. A major role in securing the communication between machines/devises is held by the network providers which are able to notify the M2M platforms on the availability of the device in the network, on its reachability parameters, as well as on the security credentials for safely exchanging data.

4) Ease of participation and application development

Integrating a new party in the business process of Smart City shall be enabled with as little effort as possible. This requires clear and easy addressing of a device, a capability. or a service through the backend. As different parties and citizens of Smart Cities typically bring their own device, mobile applications must be platform independent, in order to avoid effort for re-implementation, maintenance, and support for multiple platforms. Thus, browser-based thin-clients are to be preferred here.

B. Proof-of-concept Implementation

As a proof of concept we have implemented an M2M platform enabling academia and industry to integrate various machine devices and application platforms into a single local testbed [11][13]. The OpenMTC platform implemented features are aligned with ETSI M2M Rel.1 specifications [14] [15] [16]. The aim of the OpenMTC platform is to provide a standard compliant middleware platform for M2M oriented applications and services enabling Smart City implementation, through supporting application domain driven scenarios such as eHealth and Smart metering services. As illustrated in Fig. 3 the first release of the OpenMTC platform covers all ETSI M2M architecture interfaces, and Gateway and Network Service Capabilities Layers (GSCL and NSCL). Interested readers are referred to [13] for full description of the platform capabilities. In the following, we discuss how the OpenMTC platform can address the requirements identified in the previous sub-section:

1) Applying ETSI M2M interfaces

ETSI specifications define three interfaces: mIa, dIa, and mId, as depicted in Fig. 3, which offer generic and extendable mechanism for interactions with the xSCL. The mIa interface mediates the interactions between applications in the application domain (NA) and the Network SCL (NSCL), the

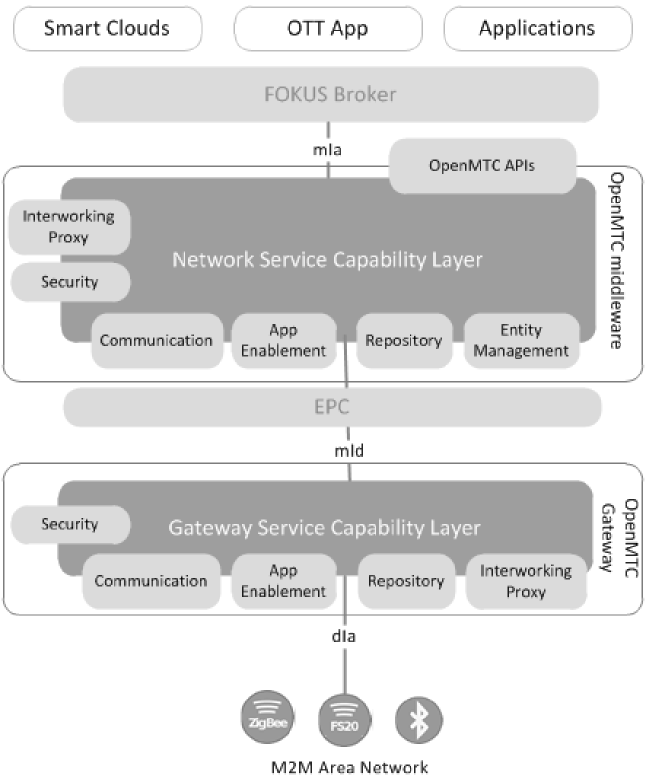

Figure 3. OpenMTC Architecture

dIa interface mediates the interactions between applications in the M2M network area - being Gateway applications (GA) or Device Applications (DA) – and the gateway SCL, and the mId interface mediates interactions between xSCL. OpenMTC supports a client/server based RESTful architecture, and communication over all interfaces is independent of the transport protocol. HTTP is commonly used as transport protocol with RESTful-based services, CRUD operations (i.e. Create, Retrieve, Update and Delete) are mapped to HTTP methods POST, GET, PUT, and DELETE. Currently. only HTTP is supported as a transport protocol in OpenMTC platform. However, M2M devices are generally resource-constrained devices, i.e. they are limited in memory, energy, and computation power. Therefore, HTTP is most likely difficult to implement in them, and many protocols have been standardized to incorporate such devices into the Internet. The Constrained Application Protocol (CoAP) is emerging to support essential features required for constrained M2M devices, such as low header overhead. Future work in OpenMTC will consider supporting CoAP.

2) Event-Based Architecture

OpenMTC supports a client/server based RESTful architecture with a hierarchical resource tree defined by ETSI. This style governs how M2M Applications (xA) and gateway and network capability layers (xSCL) are exchanging data with each other. Each entity in the M2M system (being an application, gateway, or device) is presented by a uniquely addressable resource in the hierarchical tree, which can be accessed and manipulated by CRUD verbs over different stateless transport protocols (e.g. HTTP). The OpenMTC Reachability, Addressing and Repository (RAR) capability manages a subscription and notification mechanism. Through this mechanism, applications, gateways and the OpenMTC platform are able to receive events notifications from each other, enabling management and control of devices which belong to the same service provider or using the same technology family. The MongoDB NoSQL database was used in the RAR implementation, due to its performance and scalability. Fig. 4 depicts a simple scenario of M2M interaction through OpenMTC, where an application could search and subscribe for device resources in the system based on specified criteria (i.e. functionality, time of registering, etc.). Whenever a new event occurs, data is sent to the connected gateway, leading to the notification of a subscribed application. According to the system configuration, also other actions might be triggered on other devices connected to the platform.

3) Security and privacy

From a security perspective, ETSI M2M builds on top of existing proven technologies and protocols standardized by other organizations. The types of security considerations addressed by ETSI M2M include key management, authentication, and cryptography. OpenMTC renders privacy by allowing each entity in the system to assign different access policies (READ, WRITH, DELETE, UPDATE, DISCOVER) of its own resources to others. In future work secure bootstrapping and mutual authentications procedures of M2M devices and gateways will be implemented in OpenMTC.

4) Associated Software Development Kit (SDK)

The OpenMTC platform is associated with a Software Development Kit (SDK) to support the development of M2M applications and make the core assets and service capabilities available to 3rd party developers. The OpenMTC SDK consist of a set of high-level abstraction Application Programming Interfaces (APIs) which hide internal system complexity, and allow the developer to focus on the implementation of the application logic. In [17] we present and describe our work in designing a set of APIs for the OpenMTC platform. Adopting the RESTful style facilitates the development of M2M applications, due to its simplicity in comparison with most SOA technologies. The mIa interface of OpenMTC is exposed to the FOKUS Broker [18] allowing telecommunication and Internet services composition with M2M services. The FOKUS Broker is a policy-based service broker. It enables the definition of request- and service-specific policies between a service access gateway to applications enablers in an operator environment and cloud based applications in 3rd party domains.

V. CONCLUSION

Smart City development depends on the cooperation of innovative firms, governments, infrastructure providers, and users. All these different actors need a communication platform to support their cooperation through a set of

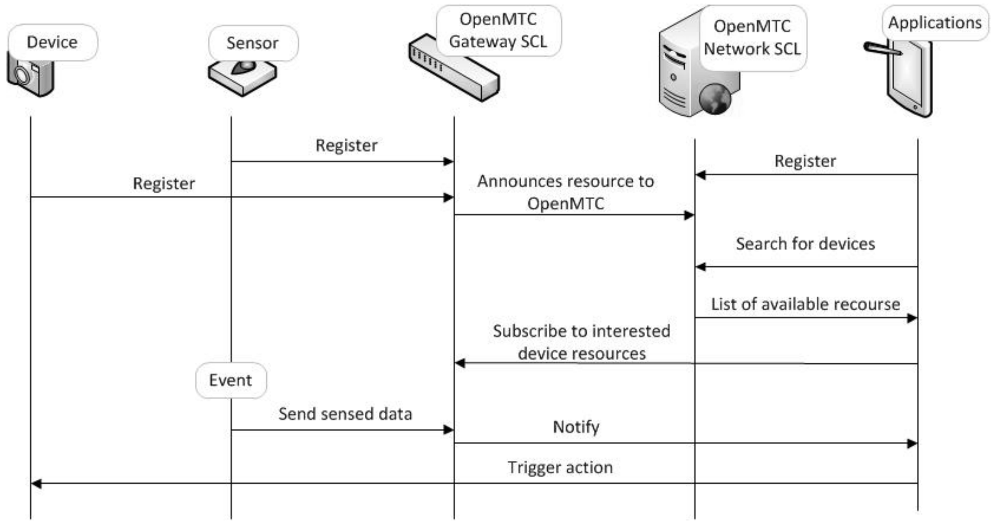

Figure 4. Messeage flow of a simple scenario.

capabilities, which overcome different technical barriers in the road of Smart City deployments. M2M technologies can be beneficially applied to a broad range of applications and services in Smart Cities, by creating a scalable IP-based environment where machines can communicate with each other without human intervention. Currently, service providers are building new eco-systems with partner vendors to offer new solutions for M2M and Smart Cities. Standards like the one provided by ETSI TC M2M can help in accelerating the development of globally accepted solutions for M2M. The OpenMTC platform provides a standard compliant middleware prototype for M2M oriented applications and services enabling Smart City implementation and evaluation.

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