Utilizing M2M technologies for Building Reliable Smart Cities

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***Abstract*— With a large majority of the world's population moving towards urban environments in the foreseeable future, the notion of Smart City is emerging globally as an important research topic. The population movement will affect the consumption rate of natural resources i.e. water, soil, and plants. Therefore, innovative management and monitoring systems are required to enhance citizen's quality of life. Additionally, the power grid complexity is increasing as more private or enterprise buildings become virtual power generation facilities by deploying clean energy generators based on renewable energy sources (e.g. Photo voltaic cells). By installing small smart and affordable devices in key points around the city, the information about environment status and resources consumption can be collected and transmitted (over different network technologies) to higher level control systems. This will support predictions, decision making, trigger prompt actions at device domain or notifying the consumers about possible actions adapt to the current power grid resources. When the predictions and control over demand behavior and reduction of unnecessary power generation are improving, there will be a positive impact on the costs and CO2 emissions, rendering the entire city smarter. This paper introduces an infrastructure for reliable Smart City, investigates a number of use cases scenario and propose possible solutions. The proposed architecture is based on a Smart City platform and an ETSI M2M/ oneM2M compliant Machine-to-Machine communication framework.**

Keywords: Smart City; M2M; Smart Power Grid; Air quality

I. INTRODUCTION

The concept of using Information and Communication Technologies (ICT) to enhance citizens' quality of living and building Smart Cities is becoming subject of ongoing discussions in both academia and industry. The main research direction in this area is toward building efficient communication platforms able to integrate various domain systems in an urban-scale system. This new paradigm of communication platform, known as Machine-to-Machine (M2M) platform, enables the reliable flow of information, gathered form connected objects (sensors and actuators), to decision making systems. Such platforms should be able to support new interaction models between connected objects, which are not under human control, produce small amount of data frequently, and have constrained-resources, i.e. they are limited in memory, energy, and computation power.

The need of prompt accurate information in Smart City systems, considering the characteristics of connected objects and produced traffic, evokes many new requirements and challenges to data exchange, information integration and services, as well as more complexity of the network architecture [1]. The main contribution of this paper is specifying a number of use cases and proposing proper solution based on M2M enabled Smart City platforms. The specified use cases consider the context and communication capabilities of the developing world. This paper presents an infrastructure for reliable Smart City, investigates a number of use cases scenario and propose possible solutions. The proposed architecture is based on a Smart City platform and an ETSI M2M/oneM2M compliant Machine-to-Machine communication framework. The rest of this paper is organized as follows: in section II, we overview the concept of Smart City and related work in this area. In section III, we present the proposed architecture for Smart City based on M2M platform. Section IV includes description of considered Smart City applications and operation scenarios. Finally, conclusion and further work is presented in section V.

II. OVERVIEW OF SMART CITIES

Smart City is widely considered as a hot topic in academia and industry; however, there is no clear definition of the Smart City concept among practitioners. Authors in [2] reviewed several working definitions and proposed a general Smart City framework based on eight factors: "management and organization, technology, governance, policy context, people and communities, economy, built infrastructure, and natural environment". The instrumentation of Smart Cities is considered as a key enabler, that will leverage the understanding of the City operations by "making the invisible visible" [3].

The main goal of M2M platforms is to connect the growing number of devices, and associate them to a set of services addressing use cases from different industrial domains such as energy, automotive, health, transportation etc. The need to exchange information between actors at different domains in a Smart City, motivate the need of an M2M middleware that mediate the communication between these systems. Developing a large-scale Smart environment, based on M2M communication, demands interoperability at

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all communication layers between devices, gateways, and services. However, most of existing M2M solutions are not interoperable and have been built in a decoupled vertical fashion, where data gathered by one platform can't be easily reused by other platforms. A middleware M2M platform is required in Smart City infrastructure to provide:

- Reliable transportation and session control.
- Secure access to privacy-sensitive information.
- Standard open interfaces toward service layer.
- Efficient data/event processing methodology.
- Ease of participation and application development.

Building a Smart City requires the collaboration of various stockholders, to increase the efficiency of administrative services, and developing environment-friendly applications. Several works deal with Smart Cities frameworks and related issues. A good overview of Smart Cities initial examples and collaboration models is provided by [4]. The main technologies of interest in Smart City developments are: i) content fusion technologies to enable the collaboration between stockholders, ii) cloud service for federating all components, iii) scalable content management tools, iv) and intelligent high level solutions that use advanced sensors in an efficient manner.

III. PROPOSED SMART CITY ARCHITECTURE

The Smart City project, entitled "Testbeds for Reliable Smart City Machine-to-Machine Communication" [5], aims to address Smart and Green Cities challenges within underdeveloped countries. In this section, we describe the reference architecture. The overall architecture is presented in Fig. 1, which was defined to fulfil the following objectives:

- Deliver a specification of the overall architecture that involves an M2M communication platform [6] used as the basis for a Smart City platform.
- Interweave standard-based M2M platform with other sophisticated Smart City platform.
- Integrate resource-constrained devices over Delay Tolerant Networks (DTN).
- Perform the integration of the main building blocks (M2M, Smart City, Smart Energy) into a comprehensive platform using federation tools [7].
- Define specific enhancements for a Smart/Green City system, by implementing one pilot for Smart Energy consumption in the region Gauteng (South Africa) and one pilot for pollution monitoring in San Vicenç dels Horts (Spain) [8].

The OpenMTC platform will be used in the implementation and testbeds, which is a M2M platform compatible with ETSI M2M standards [8][9]. The platform is developed jointly by Fraunhofer FOKUS Institute and the Technical University Berlin (TUB), to act as a horizontal convergence layer supporting multiple vertical application domains such as logistics, automotive, eHealth, etc. It provides open-standard interfaces that facility interweaving with other Smart City platforms. OpenMTC is currently extended to be aligned with the new standards coming from oneM2M [11], bringing new concepts related to connectivity management and reachability for integration with the underlying network. For instance, The M2M gateways will be enhanced to integrate store and forward mechanism to support Delay Tolerant Networks (DTN), that are associated with intermittent connectivity, long or variable delay, asymmetric data rates, and high error rates.

This architecture will be validated by the implementation of the Smart Energy system in the region Gauteng (South Africa). The Smart City Application for energy providers will use the M2M platform to contact the M2M gateways in order to access and manage the smart energy meters and actuators. Additional, OpenMTC will be extended to support the Constrained Application Protocol (CoAP) [12] with DTLS for the end-to-end communication, so that both efficient transmission and security can be achieved.

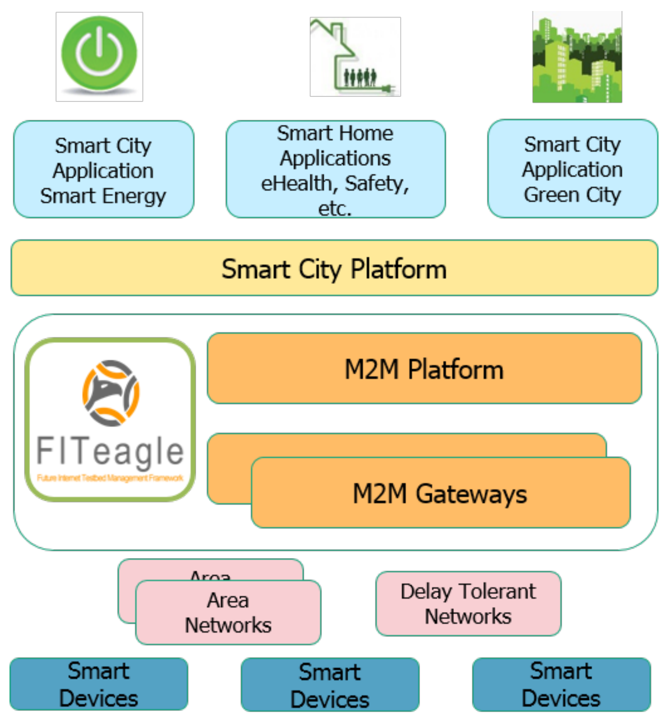

Figure 1. Smart City Reference Architecture.

In some Smart City scenarios, the used sensors/devices have restricted processing, memory and transceiver resources. In addition, they can be placed in less accessible or critical locations. Therefore, the combination of delay tolerant communication technologies into Smart City platform is needed. The pollution monitoring pilot in San Vicenç dels Horts (Spain) will be an implementation of using DTN to support opportunistic information transmission in Smart Cities.

IV. SMART CITY OPERATIONS

The M2M platforms could be used in various Smart City domains. In the following subsections, we describe different operations where the reference architecture, presented in previous section, could be implemented to build a complete solution.

A. Smart Home applications

A number of application could be implemented to make homes Smarter. The M2M gateway from the presented architecture can be deployed in a household and communicate with the Smart City platform to receive information from different stockholders in the Smart City, as illustrated in Figure 2. This information would be translated by the M2M gateway into recommended actions, and the owner of the household can be notified about possible operations to decide upon it. An example is to receive weather statues warnings from related agency, and respond accordingly, such as in case of an incoming dust storm by actuating all the window shutters to close automatically.

The M2M gateway can collect other kind of information from internal sensors. For example, inside fire can be detected by monitoring smoke sensors. Fire from the neighboring buildings can be detected by applying advanced video recognition patterns from the outside video cameras. Motion sensors can enable earthquake detection. The M2M gateway can trigger corresponding actions like:

- playing a dedicated audio alarm
- alerting the emergency authorities and the inhabitants
- sending a notification to the not present inhabitants including the event type and the location using for example the OMA location protocol for M2M [13]
- acting upon pre-set actions like shutting down the gas and electric appliances, turning on electric light with accumulators
- follow recommendations from the owner or the emergency authorities

Another deployment option would be to install the M2M gateway outside the house so that these events do not affect its functionality. The M2M gateway may also have mobility policies so that it is able to perform handovers between the local WiFi access point (AP) and the public operator network in case the AP could be destroyed by the event and the operator network is considered more reliable.

With integrating proper sensors and actuators, some time consuming operations could be handled by the M2M gateway. For example, watering garden could be planned according to the analysis of information received from: the connected humidity sensors, weather forecast from Smart City Platform, and motion sensors installed in the garden.

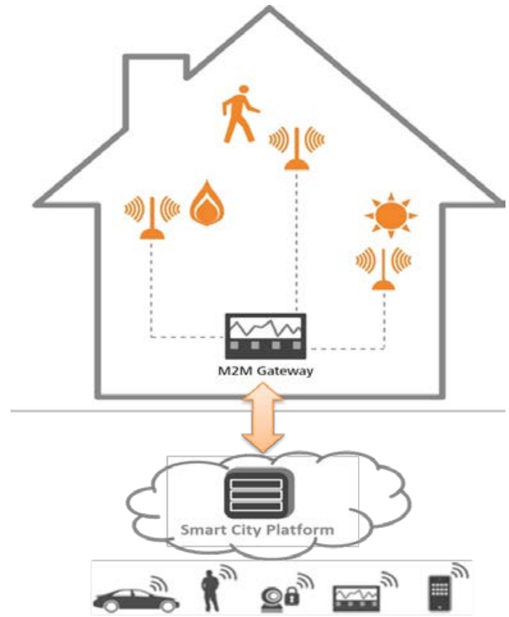

Figure 2. Smart Home model

B. Smart City Applications

M2M platforms could also be used to deploy many applications in the management and logistic sections, to respond to frequent problems like finding a specific type of parking place: being free of charge, underground located, the nearest one or provides special facilities such as an electric re-charger. For this scenario, data regarding the available resources from the local M2M gateways responsible for parking lots will be sent to the Smart City platform in a push or a pull mechanism. The inside car application will then query the Smart City Parking Application (SCPA) and according to the recommended option use the navigation system to reach it. In this way, the computation load can be shifted from the car device to the cloud application, supporting also the case when the device does not have the latest maps loaded, the car will be driven on the shortest past, resulting in many benefits including: optimization of traffic load, and reducing air pollution.

Cities having local or surrounding bridges over rivers could benefit from installing sensors to read the water level and M2M gateways to monitor and send such data to the Smart City platform. Applications at control systems would use data related to the water level of the tributary rivers, statistics and meteorological forecasts to estimate the risk level and send commands to the M2M gateways responsible of setting the alarm and closing the bridge after all the cars have passed. Video cameras could also be activated to enable local authorities to monitor the course of the action.

C. Smart Energy Applications

One of the most important infrastructure of a city that can benefit from advanced M2M technologies is the energy distribution network (Figure 3). For this field the ICT connectivity is defined as the IT communication links between systems components in the smart power supply systems. Standards that have already been defined focus on the application level only, such as IEC 61850 and IEC CIM, and Device Language Message Specification/Companion Specification for Energy Metering (DLMS/COSEM), with the indication of not using proprietary authentication schemes at lower levels.

Large cities with numerous inhabitants can confront peaks of energy consumption at certain hours related to the working schedule of the majority. To accommodate these peaks and provide a reliable service in a most efficient manor, the energy service providers should apply a demand response strategy in which the current reported and the near future estimated demand can be accommodated by triggering specific actions. The estimation of the near future energy demands requires information about previous consumption models, such informations can be gather from the M2M gateways located at consumer's premises. The gateways are connected to the smart meters of households, buildings and industrial customers, and possibly aware about the future activities like pre-programmed appliances that will start function in the future, e.g. at the period of lower energy tariff. Another important source of information comes also from applying statistics analysis of the energy consumption from recent days and past seasons that could estimate the behavior of the citizens, e.g. on a free sunny day the population will retreat to outside activities and not use the television set or the electric light.

The energy produced as response to the estimated future load, can come from bulk generation sources ranging from power plants fired by fossil fuels i.e. coal, oil and gas, nuclear power plants or from green energy generation sources: on/offshore wind farms, offshore wave farms, along with hydroelectric, solar panel or biomass power plants. To accommodate the peaks, the nuclear power plants are requested to produce more energy or the provider can buy energy from the energy trading markets. The generated energy that is not used will be stored and used on demand. The storage and use of stored energy are not 100% in efficiency, as any electric process. This means that if the surplus of energy is lower, the energy generation and distribution will be more efficient.

In recent years, solar panels from the energy customers have been introduced in the Energy Grid as virtual power plants (VPP) and are able to supply the power grid with energy. Thus, a new term called "prosumer" was introduced to define a consumer with generation capability. By estimating their total possible input, the Energy Service provider can use the data reported regarding the current energy capacity, and estimate its value in the future based on the foreseen duration and intensity of the sun light. By these means the energy response coming from other sources can be balanced and optimized in terms of costs, CO2 footprint, and nuclear pollution. Thus, will lead to lower energy process for the households, industry customers and city authorities.

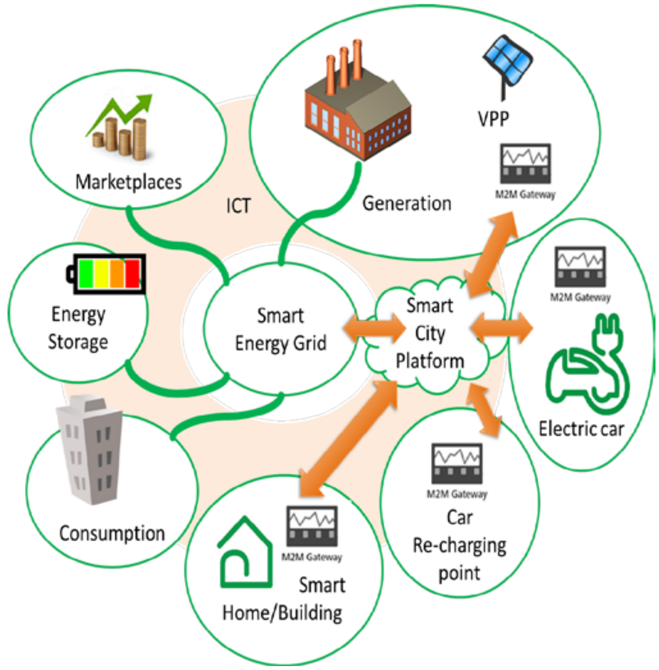

Figure 3. System model of the electricity grid using the Smart City platform to accommodate new services like searching for the nearest free electric car re-charge point

The energy Smart Grid can collect the total data about the current and foreseen consumption from the Smart Energy meters and control simultaneously the virtual power plants from consumers to start or stop production by interfacing with the Smart City application. The Smart City application will hide the unnecessary details of the partners, which have smart meters and/or smart actuators for VPPs and appliances. The task of the Smart Grid is to analyze the received data and send specific commands to control the VPPs. The control can also be extended to types of appliances, e.g. appliances from the households, which have the highest usage, in case the foreseen demand cannot be counterbalanced in time, in order to guarantee a stable distribution service. Also monthly charging for the supplied amount of electric energy can be transferred to the Smart City platform and relieve the Smart Energy Grid from fine granularity information processing.

The field of electric powered cars is becoming a reality as currently produced cars have more and more autonomy regarding the distance that they can cover with a full battery. The gas stations adapt and introduce electric supplies. In order to reach a destination the driver of an electric car will need a complex system to determine when to recharge and where based on: the current traffic conditions (unexpected traffic jams), duration of recharge of other cars, and location of the recharge stations.

Smart applications integrated to electric cars and connected to Smart City platforms, will be able to use the gathered information form M2M gateways to will help the car driver to create a query with the type of battery and the required power to get important information to plan his/her trip. The Smart City platform can evaluate the amount of time required to recharge it, and based on the data collected from the M2M gateways installed in the recharge stations the current load of a location can be evaluated, as well as the time one is expected to be free. By correlating the current and expected load and the time that the car needs to reach the recharge points, the Smart City application can recommend the more suitable station. The computation problem might be NP-complete but heuristics and expert systems can be developed to give an approximate solution.

V. CONCLUSION AND FURTHER WORK

Cities and communities worldwide are facing various challenges, due to the increased population and the economic growth. Furthermore, the connected world is extending exponentially including physical objects, computers and smartphones in a global Internet of Things (IoT). More than nine billion devices around the world are currently connected to the Internet, and the estimations show that by the end of 2020, there will be one trillion connected devices world-wide [14].

Interoperability is very important issue, as the M2M gateways, M2M platform and the Smart City platform might come from different vendors, or use heterogeneous technologies, and they all have to integrate in the global IoT. This is why we believe that the architecture described here based on the ETSI and oneM2M standards is a starting point for developing or deploying a Smart Grid system. Similar standards and recommendations have been defined for gas and oil infrastructure and the same architecture can be used to monitor the demand and adjust the exploitation accordingly. Other important aspects are the security and privacy [15] of all the actors linked to the smart devices, like the households, car owners, etc. All the gathered data should be anonymised and exchanged in a secure manner. One solution would be to have M2M gateways use HTTPS to transport data to the M2M platform. Using CoAP with DTLS can provide the same level of security with a lower overhead as the data coming from the M2M gateways might have a very small payload and HTTPS adds additional overhead to the transport network. All types of access network might be used: from WiFi to GPRS, UMTS or LTE (for ensuring a low delay in communication). In the case of smart energy grids specific QoS policies managed by the Smart City application by interacting with the local telecommunication operators would be required to guarantee the network resources for time sensitive data.

The presented architecture is part of the research collaboration between partners from EU countries and South Africa during the European Union's Seventh Framework Programme funded project TRESCIMO [5] . In this project, two pilots targeting both air quality monitoring in urban areas and Smart Grid integration with Smart City applications will be undergone.

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