Prototyping Machine-to-Machine Applications for Emerging Smart Cities in Developing Countries

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Abstract – Urbanisation trends in both developed and developing countries continue to grow significantly. This presents an opportunity for developing countries to increase future economic growth if they invest in the development of Smart Cities. One aspect of the realisation of Smart Cities revolves around the concept of using information and communication technologies to enhance the quality of living for citizens. This has led to the subject of Smart Cities becoming an important ongoing research topic in both academia and industry. Even as Smart Cities present lucrative and exciting opportunities for the developing world, many challenges stand in the way before they can actually be realised.

This work tackles the first steps of moving towards this objective by identifying potential use cases for the Smart City context in developing countries such as South Africa. The focus is on a common problem faced by many such developing countries which is the lack of reliable and efficient management of power distribution. This paper introduces a framework that will allow for the development of Smart City energy management applications. The proposed architecture is based on a Smart City platform and an ETSI M2M/ oneM2M compliant Machine-to-Machine (M2M) communication framework.

Index Terms— Smart City; M2M; Smart Home; Testbed, Mobile Applications

I. INTRODUCTION

The developing world is experiencing an unprecedented migration pattern that has resulted in mass populations moving from rural areas into urban environments or cities. By the year 2050 it is estimated that more than two thirds of the global population will be inhabiting cities [1]; this is going to place a large strain on these cities to be able to offer services and infrastructure that can cope with these populations. The strain will be felt more so in developing countries as water, sanitation, electricity, waste, transportation, communications, housing and food security will need to be managed efficiently or "in a smart manner".

This brings forward the notion of smart cities. Smart cities can be defined as follows according to Cohen [2]: "Smart Cities use information and communication technologies (ICT) to be more intelligent and efficient in the use of resources, resulting in cost and energy savings, improved service delivery and quality of life, and reduced environmental footprint all supporting innovation and the low-carbon economy." Within the developing world context for example, Accra's definition of a smart city [3] (Ghana): "A Smarter City is one that accelerates its journey towards sustainable prosperity by making use of new smart solutions and management practices. As one of Africa's fastest urbanising cities, in one of the world's fastest growing economies, Accra, Ghana has unprecedented opportunity to use transformative technologies as the foundation for future growth and development. From transportation, through water, sanitation, healthcare, energy to city management and public safety – there are multiple urban systems which technology can help to address holistically."

Future economic growth will be predominantly centred on cities. It therefore becomes crucial to begin to prepare current cities towards the future direction of planning and developing for smart city realisation. The realisation of smart city implementations will involve the integration of various domains within a Smart City concept, for example communication infrastructure; data storage and management; and analytics, to be able to run an effective smart city management platform.

This work tackles the first steps of moving towards this objective by the implementation of use cases by means of application development within a smart city prototyping testbed. We identify the common problem faced in developing countries which is energy shortage and subsequent management and propose possible solutions that can be developed to be utilised in future smart cities of these developing nations.

The objective of this paper is to present the challenges faced by developing cities as they move towards being Smart Cities. Some scenarios are highlighted that demonstrate the potential positive impact of research and development in this area. We also highlight the ongoing research project involving both industry and academia stakeholders in both developed and developing countries towards the realisation of smart city application prototyping. The rest of this paper is organized as follows: in section II, we present the identified requirements and scenarios that show the potential benefits of Smart City application. In section III, we overview the concept of Smart City and related work in this area. In section IV we present the implementation environment for proposed architectures of

Smart Cities. Section IV showcases the development of example Smart City application for future energy management. Finally, conclusion and further work is provided in section V

II. Requirements and Scenarios

It is important to understand the requirements of the Smart Cities of developing countries, as these will differ somewhat from those of developed nations. We further describe some potential scenarios to highlight the benefits expected to obtain in future Smart Cities.

A. *Requirements*

The following are key requirements that all smart cities must aim to achieve.

- Utilisation of existing underlying communication infrastructure;
- Cost effective data storage and management;
- Systematic computational analysis of data or statistics;
- And interoperability of connected systems and services.

a) Interconnection of multiple technology domains

In a Smart City, many different subsystems need to work together such that the Smart City system performs as intended. These integration points include the communication network, the internet, sensors, devices, gateways, and the resources or services of the Smart City. These different technologies, or Machine to Machine enabling technologies, will work together to enable the Smart City.

b) Integration of existing city information systems

Within a city already many sources of information exists. A Smart City will provide data aggregation and analysis tools to use this information in creating novel new applications for the benefit of city inhabitants. Machine-to-Machine (M2M) enabling technologies will be used in every business field and integrate application systems, data and Internet to be the core elements supporting urban operation and management. City support systems such as “energy”, “transport”, “safety”, “health”, “education” and “water”, stand poised to benefit from the Smart City enabling framework. It is clear that, taking into account the similarities and differences of each management domain there is a value in developing a global, standardised framework for Smart Cities.

c) Overcome challenges inherent in the developing world context

In the developing world, many other obstacles are faced that are different from those in the developed world. Most important is the availability of affordable and reliable connectivity, as connectivity can be expensive and limited. In a Smart City, connectivity is an important requirement. This means that when developing applications for smart cities in the developing world this limitation needs to be built into operational requirements. Other challenges include inefficient transportation systems, prevalence of informal settlements, high rates of service delivery protests which would halt delivery of city services, and energy related challenges such as power shortages resulting in frequent power cuts or load shedding situations. Figure 1 depicts such a real world example of load shedding due to the national demand exceeding the national capacity of South Africa.

Figure 1: South African National Load shedding on 6 February 2014

B. *Potential Scenarios*

Scenarios for the development of applications in Smart Cities are presented here below focusing on energy management. Many others exist for various Smart City domains, but these are not mentioned in this specific paper.

a) Simplified energy management by utility providers

Utility providers in the energy sector aim to provide uninterrupted power supply to all of the electrified population. It is therefore essential to always insure that demand is met in order to “keep the lights on”. When resources are scarce, smart management systems should enable the utility providers to employ some emergency procedures that mitigate the need to go into blackouts or load shedding modes. Ultimately, factors such as atypical weather or time of the year place heavy demands on municipalities, industries and home-owners.

For example, if a utility provider has an unscheduled maintenance on one of its power generation substations; this will result in an unstable power grid due to decreases in generation capacity. If the utility provider is able to access an aggregated view of both industrial and residential areas, they could have the ability to identify areas and entities of high utilisation. Furthermore, the utility provider could be able to notify targeted individuals who may be drawing higher than normal energy resources through a demand management signal to reduce consumption, rather than declaring a general call to the entire population to reduce consumption. Additionally, for critical situations, utility providers can send a command to devices that previously have been nominated by their owners as “controllable”. This emergency intervention has the potential to achieve the desired outcome of the grid returning to a stable state.

b) Simplified energy management by individuals

Giving energy consumers the ability to get information of their households or business energy consumption can also be provided as a Smart City application. During the case when (as mentioned in the above scenario) a user is notified to reduce consumption because he/she has left, for example, the lights/hot water boiler/pool pump on, the user is then able to act accordingly. It may even be the case that the user is not on their respective premises, but still receives this notification, and is still able to act on it as the user has the ability to control devices remotely. The user is then able to assist the utility provider to mitigate a power outage situation from any location.

Additionally, from a safety point of view, users would be able to monitor and additionally be alerted if, for example, a heater has been left on whilst no one is at home. This Smart City energy scenario allows for many other applications at the disposal of the energy users in a Smart City.

c) Energy management toward "Green Living"

A further application of a robust energy monitoring and management scenario involves the drive towards achieving higher levels of energy usage efficiency. Smart Cities also aim to be Green; a main objective is considered to be the reduction of energy resource utilisations. Users of such a system may be environmentally conscious individuals who would like to use energy more efficiently. They would then have the ability to get a better understanding of their consumption patterns in order to make better and more informed decisions regarding their energy usage. The application is able to further process these usage statistics and formulate detailed analysis of consumption even to the benefit of being able to adapt the behaviour of users such that monthly utility bills would be reduced.

d) Additional smart management scenarios

Energy management for service disruptions: for situations where power outages are inevitable, utility providers can notify users that opt in to receive information about imminent unplanned power outages. This would enable users the ability to take action such as taking sensitive equipment offline to avoid damages.

Energy management towards Smart Home automation: for situations where users have the access to smart home control systems, these can be interfaced with the Smart City application such that the management and control of devices is automated without the necessity of human intervention. The smart home system can automatically make decisions and take actions based on notifications received from the utility provider, if users are for some reason not reachable or able to act.

Energy management towards cost reductions: the inclusion of additional features such as real time billing and energy reports incorporated into the Smart City application, allowing the ability to provide contextual information comparing individual usage to average usage of the surrounding area, users can be incentivised to adapt behaviour even further to reduce on bills.

III. Existing Solutions

Even though Smart Cities are widely considered as a hot topic in academia and industry, there is no standardised definition of the Smart City concept among practitioners. Authors in [4] 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" [5].

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 motivates the need of an M2M middleware that mediates the communication between these systems. Developing a large-scale Smart environment, based on M2M communication, demands interoperability at all communication layers between devices, gateways, and services. However, most of existing M2M solutions are not interoperable and have been built in a highly vertical fashion, where data gathered by one platform can't be easily reused by others. 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 [6]. 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, and iv) intelligent high level solutions that use advanced sensors in an efficient manner.

Smart City principles in a developed world have been explored, and implementations are being realised (e.g. SmartSantander [7]). In a developing world, even though the potential of introducing the concepts are clearly evident, Smart City concepts have yet to make the required breakthrough.

IV. Implementation Environment

The Smart City project, entitled "Testbeds for Reliable Smart City Machine-to-Machine Communication" [8][9], 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. 2, which was defined to fulfil the following objectives:

- Deliver a specification of the overall architecture that involves an M2M communication platform [10] 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 [11].
- 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).

The OpenMTC platform is used in the implementation and testbeds, which is a M2M platform compatible with ETSI M2M standards [12][13]. 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, energy, eHealth, etc. It provides open-standard interfaces that facilitate interweaving with other Smart City platforms. This will be validated by the implementation of the Smart Energy system in the region Gauteng (South Africa). Results obtained from this trial will be discussed in future publications.

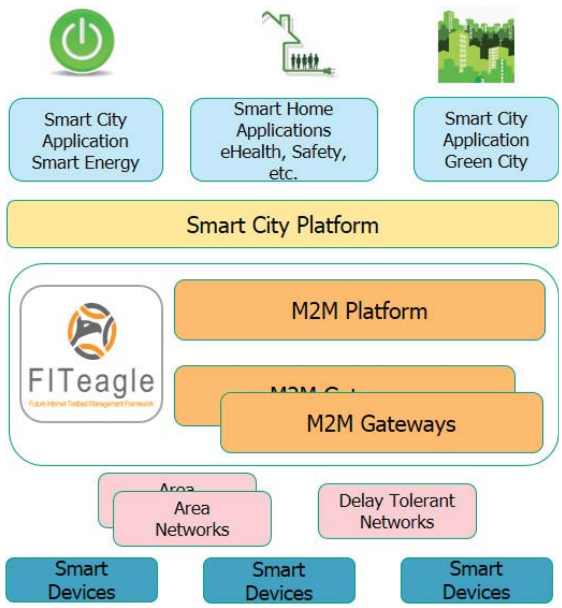

Figure 2: Smart City Reference Architecture

V. Realisation of Example Scenario

The realisation of the following smart home application will demonstrate the OpenMTC functionalities, which monitors the energy production and consumption in an arbitrary number of buildings at a certain area in the city. Each device in a building is connected through an OpenMTC home gateway component. In the system, the user can zoom in on a particular building and discover the energy consumption of individual appliances and possibly to control them.

Technical components of the M2M Smart City system include the OpenMTC M2M software which interconnects and coordinates with an FS20 wireless smart home control system. Some of the actual devices in the smart home system include:

- A radio switching socket plug with the capability of control through the FS20 radio communication protocol
- A remote control that is able to be programmed to control the individual sockets and by proxy the devices connected through these sockets
- USB wireless transceiver that is able to act as a Gateway Interworking Proxy (GIP) enabler that allows for communication between the smart home devices and the OpenMTC M2M middleware software.

The OpenMTC platform runs both a Network Service Capability Layer (NCSL) and a Gateway Service Capability Layer (GSCL). The platform is designed for interworking with actual sensors and actuators (e.g. using ZigBee, FS20 enabled smart devices). These functionalities are exposed using the mIa reference point (between the NSCL and the network applications to be implemented) and dIa reference point (between the GSCL and the device to which communications occurs).

These reference points' communication are implemented in REST request and responses using CRUD (Create, Retrieve, Update and Delete) commands. The libcurl libraries which is client-side URL transfer library supporting various protocols e.g. FTP, FTPS, HTTP, SCP etc. could be used to interact with the platform over stateless transport protocols, like HTTP and Constrained Application Protocol (CoAP). CoAP is proposed to support essential features required for resource-constrained M2M devices, such as low overhead. The gateway interworking proxy (or GIP) is used for device interworking in the OpenMTC. The GIPs implemented are the ZigBee GIP, the FS20 GIP and HTMLv5 sensor GIP.

When developing a network or device application that allows for interworking with mobile devices, the HTMLv5 GIP exposes monitoring and control capabilities, this becomes handy if one wishes to develop mobile applications that can act on certain signals from the Smart City network applications alerts.

Figure 3 highlights the ETSI connected home example. This Smart Home system has the ability to offer a monitoring application for homes: i) monitoring the energy production and consumption of buildings in a certain area of the Smart City; ii) OpenMTC offers the integrated solution that allows home gateway devices to communicate with OpenMTC backend servers mediating the interactions between the network application and the home gateway; iii) allows for device access within the smart home using access technologies such as Zigbee or FS20. Figure 4 demonstrates how this is implemented within the OpenMTC M2M system.

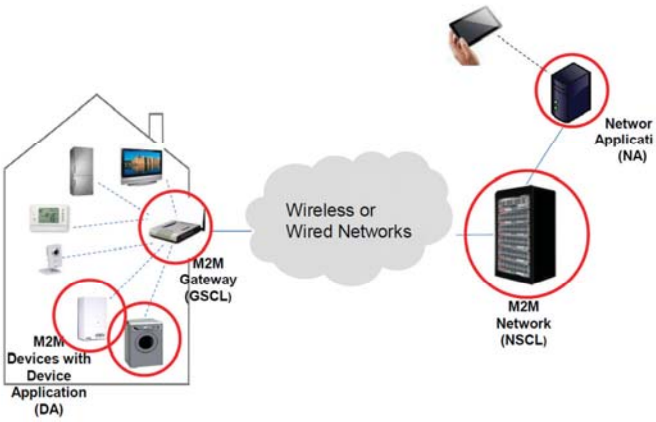

Figure 3: ETSI M2M connected home example

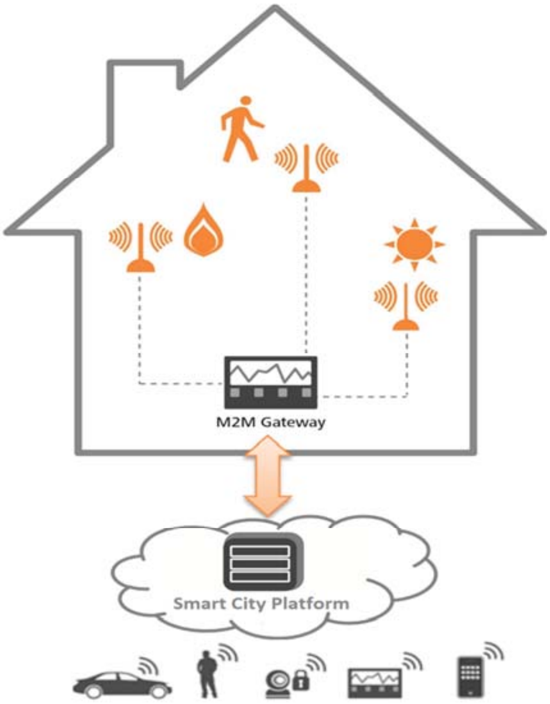

Figure 4: OpenMTC smart home model.

VI. Conclusions and Future Work

Cities and communities worldwide are facing various challenges, due to increased populations and prospective economic growth. Furthermore, the connected world is extending exponentially including physical objects, computers and smartphones in a global Internet of Things (IoT). For Smart Cities to be successful, they will need to leverage the utilisation of past and future generations of Information, Communications and Technologies (ICT). Additionally, great benefit will be observed if the integration of different M2M enabling technologies with the different service and resource sectors of a Smart City is well planned. The collection and analytics of certain data and information will also enhance the quality of living for Smart City inhabitants. All these factors will work to achieve the goals of high efficiency of Smart City management, timely and convenient service delivery, reliable urban operations, green economy and comfortable living.

As interoperability is a very important issue, we believe that the architecture described here are based on the ETSI and oneM2M standards is a starting point when developing or deploying a smart energy management system. 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 [14]. In this project two pilots targeting both air quality monitoring in urban areas for the developed smart city and smart grid integration with smart city applications in the developing work Smart City will be deployed.

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