Testbeds for Reliable Smart City Machine-to-Machine Communication

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Abstract - With a large majority of the world's population moving towards living in urban environments in the foreseeable future, the notion of Smart Cities is emerging globally as an important research topic. A particular challenge is the unstable power supply of cities in underdeveloped countries, thus creating a need for smart energy management systems.

By installing small smart and affordable devices at the end-user's location, information about the state of the power grid can be collected and transmitted (over different network technologies) to a central controller. This can be the future technique for South Africa's grid overload management, which operates in a demand-response manner allowing for loads to be measured and limited as needed.

To investigate this issue we propose to interweave a Smart City platform and an ETSI/oneM2M compliant Machine-to-Machine communication framework. We emphasize secure identification and authentication of sensors and users as well as a policy-based store and forward functionality.

To validate our approach, we analyse the core developments by carrying out experimental research in federated testbeds in Berlin and Cape Town using a Slice Federation Architecture (SFA) compliant framework and conducting field studies (pilots) in Johannesburg and San Vicenç dels Horts.

Index Terms—Smart City, M2M, Federation, Testbeds

I. INTRODUCTION

In the near future, mechanisms for the development and management of smarter and greener cities will be needed to address economic, social, and environmental challenges. One particular challenge that arises in this context is the power supply of cities within underdeveloped countries such as South Africa, which has a large and growing demand on the national electricity grid.

For instance, the severe power outages of 2009 in Johannesburg and other areas damaged South Africa's economy severely, and demonstrated the need of a Smart energy management system. Furthermore, the residential sector represents 20% of South Africa's total electricity system load and is a significant contributor to both the morning and evening peak, resulting in an overall national load factor of 72%. In addition, the current capability is being negatively impacted as existing power generation substations have not been maintained as required, leading to common and significant breakdowns in the generation of energy. Not all power generation utilities are running at full capacity as the provision of fossil fuels is impacted by adverse weather conditions as well as damage to road infrastructure.

Another challenge in that regard involves smart sensors, deployed e.g. for energy consumption, waste bin levels, air pollution or traffic congestion with no permanent connectivity, due to insufficient network coverage or limited power supply.

In such scenarios, data is either sent by wired and wireless networks or collected in a delay tolerant fashion by mobile nodes equipped with a cellular interface. Those nodes can be installed on coaches or other vehicles which deliver the data once they collect it, or be mobile devices, such as phones, carried by employees or individuals (crowd-sourced). Such data is being stored locally, to be delivered when a suitable network connection is available.

In this context, another issue is to implement effective mechanisms to collect data from sensors with power constraints while maximizing their battery lifetime. To achieve this, wake-up mechanisms can be applied to wake up sensor nodes only for a short time when a mobile node is close to them and is able to collect the measured data. Consequently, there is a growing need for smarter technologies to be rolled out as a large-scale testbed utilizing delay tolerant networks, which can significantly reduce the peak loads as well as improve balancing of the load across the national grid.

Possible future approaches to address these issues involve the use of demand-response mechanisms. This includes the use of small devices that are installed at the customer edge, which can communicate over different network technologies to a central control point. This allows the load to be measured and limited on demand on the end-user level if necessary.

In this paper we discuss the effort to address these issues by the design and implementation of cross-industry horizontal Machine-to-Machine (M2M) experimental test environments with the specific focus on Smart Cities and Smart Energy. These environments leverage the use of real world sensors and Internet of Things (IoT) [1] [15] device deployments to collect information about the status of the grid to allow for efficient and effective management. The use of autonomic communication methods for end-to-end M2M communications will result in the achievement of Smart Cities focusing on Smart Energy management. Additionally, considerations will be made to ensure the communications of these devices to integrate delay tolerant methods. We emphasize secure identification and authentication of sensors and users as well as a policy-based store and forward functionality.

The contribution of this paper is to discuss the requirements, development and deployment of test environments for M2M enabled Smart City platforms.

The rest of the paper is organized as follows: Section II provides an overview of the related work and literature; Section III highlights the expected outcome while Section IV presents the overview of the testbed layout and architecture, it also discusses the requirements the testbed aims to fulfil; Section V touches on the evaluation aspect. Finally, Section VI concludes the paper and highlights the future work.

II. RELATED WORK

More devices are being added to the Internet every day. Estimations show that by the end of 2020 there will be 50 billion connected devices world-wide [1]. Almost any kind of device will be allowed to seamlessly integrate into a large-scale M2M environment [15]. In contrast to human-to-human and human-to-machine communication (which mainly involves multimedia sessions, web browsing, and remote control), M2M setups provide the opportunity of deploying a new category of services, however they have traffic patterns very different from those human-centric above.

In M2M, Smart devices are connected through the networks to novel service platforms in a self-controlled system; however, the current communication networks are designed to support human-centric communication, optimized for devices, which are under direct human control. In the following subsections we will summarize the on-going work in M2M standards and research projects respectively.

A. *M2M Standards*

As discussed in detail in [10], recognizing the need for reliable network infrastructures, various Standards Developing Organizations (SDO) have recently promoted several standardization activities in the M2M domain. In 2009, the European Telecommunications Standards Institute (ETSI) created a Technical Committee (TC) whose standardization work is mainly focusing on the service middleware layer. The ETSI M2M Release 1 standards were finalized in 2012, enabling integration of different M2M technology choices into one managed platform. Release 1 has been published in three parts: requirements [2], architecture [3], and interfaces [4].

The Open Mobile Alliance (OMA) develops mobile Service Enabler specifications, and has several standards that can be mapped into the ETSI M2M framework. A link has been established between the two standardisation bodies in order to map OMA Enablers into ETSI M2M Service Capabilities [5]. The OMA Device Management (DM) protocol is considered as a stable starting point to provide the desired associations between ETSI M2M standards and OMA supporting Enablers. OMA DM has been designed to provide remote device configuration-related functions such as: configuration management, performance management, and fault management.

The 3rd Generation Partnership Project (3GPP) started standardization activities on M2M in September 2008 under the title "Machine Type Communications" (MTC). 3GPP Rel. 10 specifications cover use cases, service requirements, and a functional architecture for MTC intended for application in mobile networks. In 3GPP Rel 11, different aspects of LTE devices are addressed aiming to make them competitive with GSM/GPRS devices [6] [7].

The newly formed oneM2M Partnership Project (www.onem2m.org) will be of particular importance. Among others, it addresses the high fragmentation of existing M2M solutions, the missing interoperability in this area and the slow development of the global M2M market. oneM2M endeavours to consolidate the standardization work of ETSI TC M2M and a large number of additional bodies, such as ATIS (Alliance for Telecommunications Industry Solutions) and TIA (Telecommunications Industry Association) in North America, as well as the respective bodies in China, Japan and Korea (e.g. China Communications Standards Association (CCSA); Korean Telecommunications Technology Association (TTA); Japanese Association of Radio Industries and Businesses (ARIB); and Japanese Telecommunication Technology Committee (TTC)). The aim of oneM2M is to "develop technical specifications which address the need for a common M2M Service Layer that can be readily embedded within various hardware and software, and relied upon to connect the myriad of devices in the field with M2M application servers worldwide" [8]. Figure 1 gives an overview of the different SDOs and their focus on the M2M area.

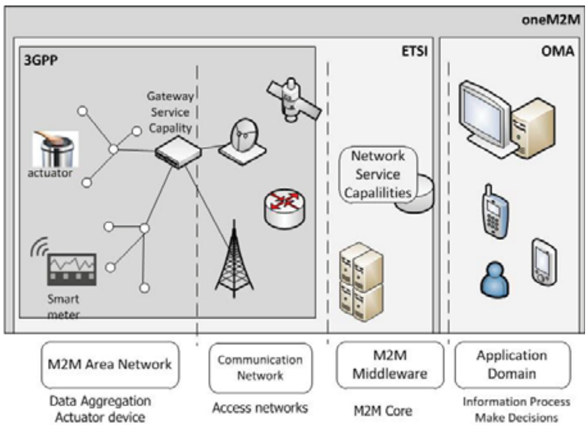

Figure 1: Overview of the M2M Areas of the SDOs [10]

B. *OpenMTC*

The OpenMTC platform is an implementation of an M2M middleware aiming to provide a standard compliant platform for Smart City and M2M services [9]. Developed jointly by Fraunhofer FOKUS Institute and the Technical University Berlin (TUB), the OpenMTC platform has been designed to act as a horizontal convergence layer supporting multiple vertical application domains such as transport and logistics, utilities, automotive, eHealth, etc. [9][10] which may be deployed independently or as part of a common platform. OpenMTC features [11] are aligned with ETSI M2M Rel. 1

specifications. The OpenMTC platform can be applied to any use case as an enabler to a Smart City system. In [11] [12] use cases are presented as implementations to demonstrate the OpenMTC capabilities in building smart environments.

To support the development of innovative M2M applications easily and quickly, the OpenMTC toolkit provides a Software Development Kit (SDK) to expose the core assets and service capabilities of the platform to 3rd party developers. The OpenMTC SDK consist of a set of high-level abstraction Application Programming Interfaces (APIs) which hide internal system details and allow the developer to focus on the implementation of the business logic [13].

C. Future Internet Testbeds

Within the context of Future Internet research activities, different approaches are in the process of being developed starting with incremental evolutionary attempts onwards to complete revolutionary ideas. In order to evaluate new protocols and architectures, testbeds with a wide range of heterogeneous resources and variability in terms of size and complexity are needed.

Although there are several existing wireless and wired testbeds on which to run experiments, they are – in terms of user management, experiment control, and connectivity – often independent of, or even incompatible to each other. Some approaches address these issues.

1) Slice Federation Architecture

To overcome testbed heterogeneity, the Slice Federation Architecture (SFA) was designed [16]. By all indications, it is assumed that this architecture is going to develop into an industry standard while more and more facilities are going to adapt the architecture.

2) FITeagle

Future Internet Testbed Experimentation and Management Framework (FITeagle) is an extensible open source experimentation and management framework for federated Future Internet testbeds developed by TUB and inherits its basic conception architecture from Panlab FIRE-Teagle (Future Internet Research and Experimentation) [14]. It already contains components to both provide resources and book resources using the interfaces defined in the SFA. FIRE-Teagle was successfully deployed and used in the PII project and is currently going to be extended within the FIRE projects OpenLab and Fed4FIRE. FITeagle is designed to support heterogeneous resources such as physical and virtual machines, devices, software, as well as abstract concepts and services, FITeagle offers several interfaces to create experiments comprising arbitrary resources from different facilities and combine them in a so called FIRE-Teagle “Virtual Customer Testbeds” (VCTs) or SFA Slices. Internally, FITeagle employs an Orchestration Engine to instantiate (“book”) these groups in a reproducible manner regarding their dependencies.

D. M2M Communication Framework Requirements

The overall architecture and implementation is presented with the following objectives:

- Deliver a specification of the overall architecture that involves an M2M communication platform used as the basis for a Smart City platform.
- Define specific enhancements for a Smart Energy System
- Apply needed modifications to the involved smart devices
- Perform the integration of the main building blocks (M2M, Smart City, Smart Energy) into a comprehensive platform

Using the OpenMTC toolkit and federation tools such as the SFA and FITeagle, this project aims to create a platform for the investigation of the Smart technologies needed for a large-scale testbed utilizing delay tolerant networks, which can significantly reduce the peak loads as well as improve balancing of the load across the national grid.

III. EXPECTED OUTCOME

The main objective is to construct a robust and secure Smart City software stack by combining different communication technologies that will provide a convergent M2M layer to adapt to the situation of the devices and sensors. The outcomes of this project advance the state-of-the-art in the corresponding areas which include:

Improved context awareness: By balancing the supply and demand by utilising data from the different domains that are integrated into the Smart City platform.

Geo-spatial load forecasting with automated Settlement classification: High-resolution satellite imagery is used together with advanced algorithms to classify settlements into types (i.e. informal, formal, formal with back yard dwellings). This information can be used to improve electricity and water use through geo-spatial electricity and water load forecasting. Access to historic utilization information will be required to produce a load forecasting solution.

Multi-hazard disaster terminals: These systems make use of real-time monitoring to provide potential environmental disaster information to disaster management centres, e.g., field fires, extreme weather, seismic activity, flooding. This solution works in partnership with SA Weather Services, Council for Geo-Science.

Integration of Delay-Tolerant Networks into M2M platforms: The OpenMTC platform will be extended to integrate delay-tolerant networks into the M2M area network. This integration will pose some constraints on the M2M communication, which is not addressed by current systems.

Enhanced wake-up system for environments with energy restrictions: Most sensor nodes deployed in Smart Cities are expected to be small devices powered by batteries or using energy harvesting methods. Thus, energy consumption is a key issue to minimize. The project will investigate useful and necessary improvements to wake-up systems beyond the state of the art. First, methods to improve the range of the system with mobility are required in order to reach a larger number of devices. Another issue to resolve is the implementation of addressing mechanisms for wake-up receivers; so that it will be possible to support unicast and multicast addressing, and thus identify and wake-up only a specific group of sensor devices. The project will investigate radio wake-up approaches with identification using standard interfaces such as Wi-Fi.

IV. Architecture

The developments are implemented using experimental research in testbeds (Cape Town and Berlin) and field research in pilots (Johannesburg and San Vicenç dels Horts). Based on these test environments further research in the context of Smart City and M2M platforms can be conducted. The interaction is illustrated in Figure 2 and the components are described as follows:

National Pilots: By creating a national pilot that incorporates Future Internet technologies, opportunities are created to integrate future international technology advances into the pilot that can lead to enhanced performance and ensure the continued viability of the pilot in future. The national pilot will allow for experimentation in a context vastly different from that in Europe, thus creating opportunities to develop new insights valuable to both South Africa and Europe. Elements such as adverse weather conditions, theft, challenging connectivity and the need for low cost approaches (from an operational as well as infrastructural viewpoint) make the creation of a national pilot an interesting challenge. Through the creation of the pilot, important local intellectual property will be developed which will aid in other initiatives linked to bringing smarter technologies and better connectivity to previously underserved areas (e.g. rural schools).

National Testbeds: To the authors' best knowledge, currently no experimental ETSI/OneM2M compliant Machine-to-Machine testbed exists. Therefore, the creation of such testbeds in Europe and South Africa is envisioned. The FITeagle framework is being extended to offer M2M resources and to federate these with other FIRE facilities using the Slice-based Federation Architecture (SFA). Due to the extensible architecture of FITeagle, it is possible to write resource adaptors (RA) for any kind of heterogeneous resource. Therefore, RAs are being written to support the use cases for these experiments resulting in the provision of the first FITeagle-/SFA-enabled Smart City / M2M testbeds. In addition to managing and controlling the facility, an environment conducive to experimentation for all participants is being created. Through this, the possible learning and impact is significantly increased.

V. Evaluation

Evaluating a working platform capable of demonstrating the technological capabilities of the implemented solutions requires a feedback design and implementation process. This helps to reduce implementation risks. Hence, the evaluation has the following objectives:

- Describe suitable evaluation criteria of the developed architecture and components;
- Establish and improve open experimental testbeds to deploy, emulate, interconnect, and evaluate all elements of the developed architecture;
- Interconnect different experimental testbeds using existing federation frameworks in order to improve cooperation on Future Internet experimental research;
- Expand the experimental evaluation of the architecture by using an empirical approach (pilots);
- Provide feedback to adopt the architecture and implementation based on the evaluation results.

Thus the evaluation process is subdivided into the following sections.

A. Experiment description

The goal of this task is to plan and to describe the

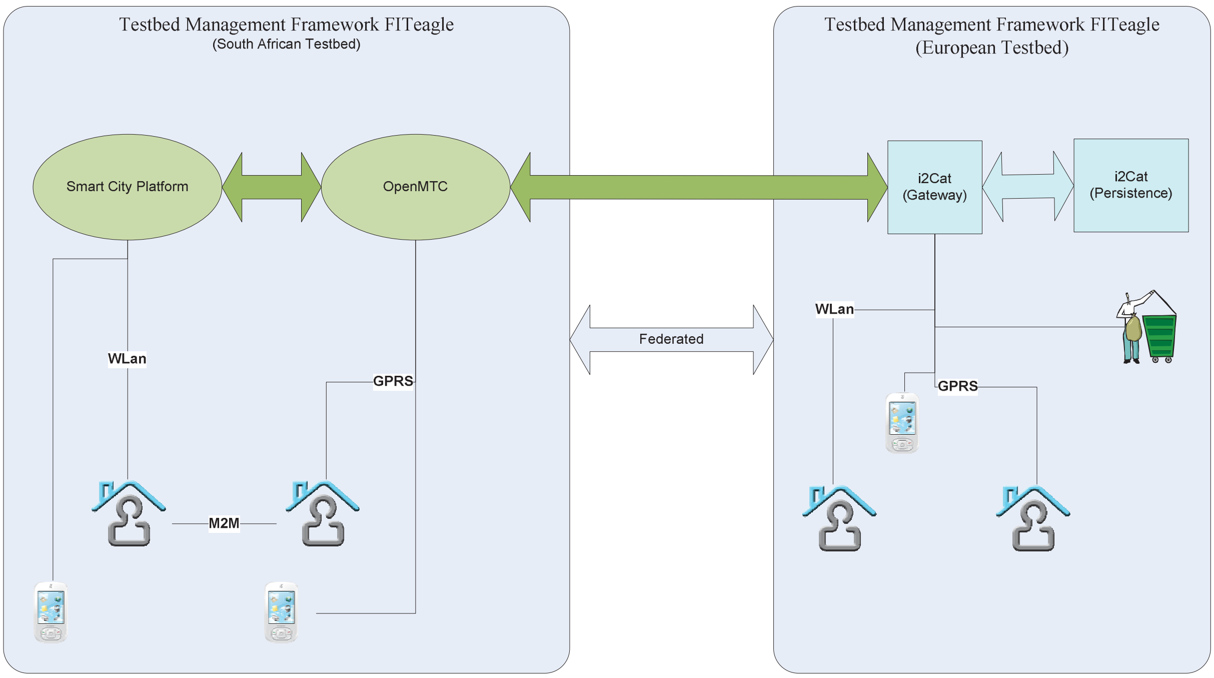

Figure 2: Overview and interconnection of testbed facilities

experiments that will evaluate the enhanced Future Internet communications platform implemented. The experiment is being designed to include the scenarios defined in initial requirements in order to evaluate the communication platforms in both real world environments and in scalable testing facilities.

B. Testbed and pilot setup

This task focuses on the deployment of two experimental testbeds and two pilots, which serve to test and evaluate the enhanced Future Internet communications platform implemented.

The University of Cape Town (UCT) has been involved in the setup of an experimental M2M testbed with the use of the Fraunhofer FOKUS OpenMTC toolkit. The latter provides a standards compliant middleware platform for M2M oriented applications and services and is additionally linked to the CSIR Smart City Platform which provides for the integration of Internet connected devices via chat protocols such as XMPP. The testbed and associated pilot integrate the smarter nodes as developed. The Spanish DTN-based monitoring pilot for Smart Cities, developed by I2CAT (Internet i Innovacio Digital A Catalunya) in Barcelona, is devoted to the monitoring of different parameters and will serve as the second proof-of-concept and experimentation scenario. Concretely, this pilot exploits the following features of the platform:

- Application of the platform for the collection of open data, which might serve as an input for the future deployment of several useful services for citizens (e.g. air pollution monitoring and alerts, tracking of the filling of trash containers in order to optimize trash collection etc.);
- Collection of non-critical data from sensors in a cost-effective manner and without the need for an existing infrastructure based on Delay Tolerant Networks;
- Usage of wake-up systems to communicate to sensors with power constraints (energy-efficient solution)

C. Testbed interconnection

This task interconnects the involved experimental testbeds using existing federation frameworks in order to allow larger, interdependent experiments and to open the testbeds for the research community. The overarching goal is that each testbed offers an SFA interface and establishes a trust relationship with the interconnected partners. As a result, the evaluation experiments can be propagated in different interconnected testbeds and each facility will provide an open interface that allows further cooperation within the context of Future Internet experimental research.

D. Experimentation

This task serves to validate and optimize the platform that has been designed and deployed. The experimentation provides both, quantitative and qualitative results that will help to state the benefits, enhancements and innovations of the project in comparison to prior solutions. Furthermore, the experimentation serves as a feedback tool to rapidly detect and correct possible problems in the deployment of the testbeds and pilots. Finally, it is also being used as an input for further optimizations.

Concretely, some of the issues that are being taken into account in the evaluation are the following: efficiency of the pilots, amount of transmitted data and control messages, rate of successful load management actuations, end-to-end delay, and packet losses.

All participants of the project involved in this task perform the evaluation of their corresponding testbed or pilot. The partnership contributions are described below:

- The Technical University of Berlin works firstly, in conjunction with Fraunhofer FOKUS, on the deployment of the OpenMTC prototype and secondly on the FITeagle Future Internet Testbed Management framework towards interconnection;
- The South African Council for Scientific and Industrial Research (CSIR), based on its experience, knowledge and understanding of the South African conditions contributes to the experiment creation as well as the deployment of the testbeds and pilots. CSIR is actively involved in the evaluation of the South African pilot and in the identification and application of optimisations required. The CSIR's based Smart Platform forms a component in the testbed and the creation of the pilot applications;
- The University of Cape Town (UCT) hosts manages and controls the South African M2M testbed.
- Airbase Systems Ltd. from Israel takes part in the experiment in Barcelona by deploying its Smart City mini air pollution monitoring stations. The devices were enhanced to meet the DTN-based monitoring system for Smart Cities, and test and evaluate the systems in the field;
- Eskom Holding Ltd. contributes to the creation of the South African pilot through the incorporation of the smarter Utility Load Manager (ULM) edge nodes;
- I2CAT contributes with the deployment and performance evaluation of the 'DTN-based monitoring system for Smart Cities' pilot.

Following successful completion of experiments, an evaluation of the environment is being documented and the gathered results are collected and analysed. This provides a global view of the performance of the whole architecture and helps to identify possible enhancements and optimizations, which should be taken into account in future developments.

VI. Conclusion and Further Work

This paper highlights the efforts to investigate Machine-to-Machine research applications with emphasis on Smart energy management for cities in an emerging country such as South Africa. This is being achieved by the joint collaboration and interconnection of a Smart Cities testbed platform that allows for these applications being designed, tested and evaluated in Germany, Spain and South Africa.

This research allows for the ability to test new applications for M2M communications in the energy consumption management scenario. The communication can be over reliable IP networks or over delay tolerant modes where transmission is not instantaneous. Further challenges are the deployment of affordable smart sensors as well as gathering information from nodes with limited power resources and capabilities.

Since this project is in its early stages, future work includes the setting up of the experimental testbeds and performing some first tests, and then moving on the field studies (pilots) further into the project.

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