An OpenMTC platform-based interconnected European – South African M2M Testbed for Smart City Services

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***Abstract*— Recent advances in device, information and communication technologies have exhibited a strong potential to enhance the quality of life of inhabitants of Smart Cities. Interconnecting different Smart Cities' infrastructures can help in the exchange of information and experiences between developed and developing nations. However, more research work is needed to define the aspect of interworking smart services, and evaluate the benefits archiving this. In the developed and the developing world, there are common use cases where existing solutions can be reused or easily adapted. Nevertheless, there are also different use cases which may require different test environments simultaneously for efficient testing. Additionally, different environmental conditions can be used for experiment aspects. In this paper, we introduce an interconnected M2M platform testbed in the Smart City context based on the standardized M2M platform OpenMTC. Our approach aims to interconnect testbeds in Germany and South Africa, and enable resource sharing between systems. This approach is framed in the context of the TRESCIMO project. The integrated resources include sensors or devices used in the different test environments as well as applications. We present the planned experiments for the common and different use cases, which use devices located in either or both environments, with the aim of investigating possible problems arising due to delay and reliability. The experiments will consider different environmental settings to compare the considered scenarios in both developed and developing world.**

Keywords*— *M2M; IoT; Smart City; Testbed

I. INTRODUCTION

In a Smart City, various application domains need to work together as an integrated large-scale infrastructure to cover multiple operations that this complex system needs to perform. These integration points include the communication network, the Internet, sensors, devices, gateways, and the resources or services of the Smart City. Different technologies will be involved to enable the Smart City implementation, and the challenges towards the realization of smart services are numerous. Machine-to-Machine (M2M) communications, Wireless Sensor Networks (WSN) and other related technologies are the subject of many ongoing discussions in numerous academic disciplines and practical areas. Most studies highlight a limited set of factors from a variety of common components underlying a smart city [1][2]. One of the main challenges faced by different research directions is the lack of large-scale testbeds [3]. Most studies present a proof-of-concept using intended testbeds or systems, which might not be suitable for validating other concepts [4].

The heterogeneity of integrated devices adds another challenge when testing new services within the Internet of Things (IoT) support framework. More than nine billion devices around the world are currently connected to the Internet, and estimations show that by the end of 2020 there will be one trillion connected devices worldwide [5]. For service testing, the adjustment of many variables have to be taken into account which depends on the integrated devices or technologies.

The main contribution of this paper focuses on the design and implementation of a large-scale testbed for Smart City research. The testbed is based on a standardized M2M platform and open-source framework for managing and federating testbeds. Our experimentation framework will interconnect two M2M testbeds located in Berlin, Germany and Cape Town, South Africa, allowing the testing of multiple scenarios of Smart City services in both developed and developing countries. Additionally, the federation of both testbeds will allow the sharing of resources (i.e. sensors, actuators and data) between different services and users regardless of their location. The aim of the testbed is to support the investigation of M2M enabling technologies, architecture, devices and applications in different environmental conditions. This paper presents the components of the proposed testbed and our approach in experimenting Smart City services.

The rest of this paper is organized as follows: in section II, the related work in the context of this paper is presented. Section III overviews the some scenarios of Smart City services that will be considered in the planned experimentation. Section IV includes a description of the designed large-scale testbed and the used components. Finally, the conclusion and future work is provided in section V.

II. Related Work

A. *Emergence of Smart Cities*

Smart Cities are 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 [6] 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" [7]. The following are key requirements that all Smart Cities must aim to achieve:

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

A number of research projects focused on Smart Cities deployment and experiments, such as SmartSantander [8], LOG-A-TEC [9] and I3ASensorBed [10] to provide valuable insights of testbeds on a controlled environment. However, their work lack the interoperability with heterogeneous systems and platforms.

B. *TRESCIMO Architecture*

The Smart City project, entitled "Testbeds for Reliable Smart City Machine-to-Machine Communication" [11], 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 [12]:

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

The TRESCIMO architecture is realized by three-tiered layers, consisting of a sensors/things tier, an M2M gateways tier, and a service control tier. The sensor/thing tier provides the necessary mechanisms to digitize the physical data from the surrounding environment. Different types of devices and sensors can be connected to the system via suitable gateway interworking proxies. For power-constrained devices, a wakeup mechanism is developed as an energy-efficient solution for gathering data without real-time constraints [13].

The Gateway tier links the sensor/thing layer to the upper service control layer over standard open interfaces. The integrated M2M gateway is ETSI/oneM2M compliant, and supports multiple transport protocols like HTTP (IETF RFC 2616) and CoAP (IETF RFC 7252). The service control layer is based on a Smart City enabler platform, which has a REST-based data model to describe resources that expose data from connected entities and allows for both device discovery and actuation. The device management mechanisms are developed according to the oneM2M standard [14].

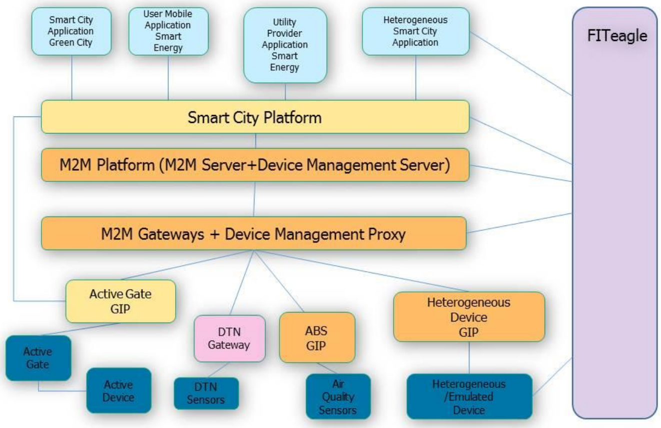

Fig. 1. TRESCIMO Reference Architecture

III. Scenarios and Experimentations

For the purpose of testing and experimentations, we consider some use cases that are commonly found in literature as key aspects of a Smart City. In this section, the addressed smart services and scenarios are described. Mainly, the goal of the experimentations is to perform the following tests:

1. Functionality testing: to validate the specified components of the system.
2. Configuration testing: to validate the performance of the implemented service under various environments, by conducting different measurements with configurable conditions.
3. Scalability testing: to demonstrate the ability of utilizing different hardware architecture or communication technologies in the designed solution.

A. *Energy*

The increasing demand of energy, depleting energy sources and the global warming problem caused due to the impact of energy usage are main issues that drive urban managers and operators to invest in studying technologies around the Smart City concept. Cities are looking to solve their problems with the development of new technologies to collect information and control energy in order to minimize urban energy consumption levels.

We define two scenarios for the Smart Energy use case; both involve an operator, customers and a utilities provider. In the first scenario, the customer is using a utility app that enables him to receive a daily report of his energy consumption. The analysis of aggregated information from the individual's energy consumption can help the operator in better understanding the customers' demands and usage pattern, and based on that offer suitable charging models. The customer shall benefit from such reports in learning about his/her usage pattern and for reduced consumption. The second scenario allows the operator to remotely control some devices that were assigned by their owners as "controllable". In case of energy supply drop due to some power station damage or maintenance, the power grid may become unstable and the operator would need to take action accordingly. First action shall be sending notification messages to customers located in the affected area to reduce their energy consumption. In the second step, the operator can send shutdown commands to some devices that were assigned by their owners as "controllable".

We are interested in investigating the performance of these scenarios using different communication technologies, and to experiment the efficiency of the control approach using lightweight device management protocols (such as OMA LWM2M) with the aim of maintaining the grid stability.

B. *eHealth*

Utilizing communication technologies in healthcare management aims to empower health specialists and improve the productivity of the service provided. However, in our test scenarios we will only consider informational services. The target is to help people be informed about any environment's status that may affect their health wherever they travel. For example, a person who has asthma will be concerned with the pollution levels in the air of the urban environment (air quality). Such a person would want to avoid the risk of an asthma attack. A simple application that retrieves this data from selected types of sensors (temperature, humidity, pollution, etc.) spread over the city, can be useful in order to highlight the areas of the city the individual should avoid when travelling around the city.

The data collected, by sensors measuring these environmental attributes, is usually small in size (few bytes) and generated at predictable frequencies. However, these sensors can be located in areas with poor communication coverage; there might be considerable delays in retrieving the information by the end-user. Our experimentations will consider various test environments to estimate the reliability of implementing similar (or more critical) eHealth services.

C. *Transport*

Intelligent Transportation Systems (ITS) are needed to support moving individuals (and goods) in an optimum time, and in a safe and cost effective manner. Many solutions have been proposed in this sector to manage routes and public transport. In our work, we will investigate the performance of sharing vehicles services.

IV. LARGE-SCALE SMART CITY TESTBED

A. *OpenMTC: standard M2M Platform*

The OpenMTC platform is a prototype implementation of M2M middleware, developed by Fraunhofer FOKUS and Technical University of Berlin (TUB) [15]. It has been designed to act as a horizontal convergence layer supporting multiple vertical application domains, such as transport, utilities, automotive, eHealth, etc., which may be deployed independently or as part of a common platform. The first release of OpenMTC features are aligned with ETSI M2M Rel. 1 specifications [16][17], providing an implementation of ETSI specified Service Capability Layers (SCL) at the Frontend (Gateway GSCL) and Backend (Network NSCL) M2M architecture. Currently, release 3 is finalized to support ETSI M2M Rel.2 and now the oneM2M specifications are adapted on the design of the upcoming OpenMTC release 4.

OpenMTC supports a client/server based RESTful architecture with a hierarchical resource tree defined by ETSI, and communication over all interfaces is independent of the transport protocol. 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 notifications from each other, enabling management and control of devices, which belong to the same service provider or using the same technology family. As illustrated in Figure 2, the OpenMTC platform includes a Generic Transport (GT) layer that enables the interaction between the frontend and backend over unmanaged access, as well as managed access networks by integrating with the OpenEPC framework. The GT layer includes an Adaptable M2M Transport (AM2MT) module, which provides pluggable transport protocols such as Hypertext Transfer Protocol (HTTP) and Constrained Application Protocol (CoAP) [18].

OpenEPC provides enhanced communication management capacities for Quality of Service (QoS) enforcements, communication channel management and bootstrapping. The OpenMTC gateway supports a Store and Forward (SAF) feature for applications. This feature enables the handling of different traffic streams based on their priority. To support integration of heterogeneous sensors, the design of the platform enables the integration of various specific inter-working proxies. Each proxy is responsible for one technology (e.g., FS20, ZigBee, etc.) and acts as a controller for the external devices by mapping these devices for monitoring and controlling into the M2M resource tree. In order to support the development of M2M applications and make the core assets and service capabilities available to 3rd party developers, the OpenMTC application enablement consists of a set of high-level abstraction Application Programming Interfaces (APIs). These APIs hide the internal system complexity, and allow the developer to focus on the implementation of the application logic. The system supports either XML or JSON format for data representation.

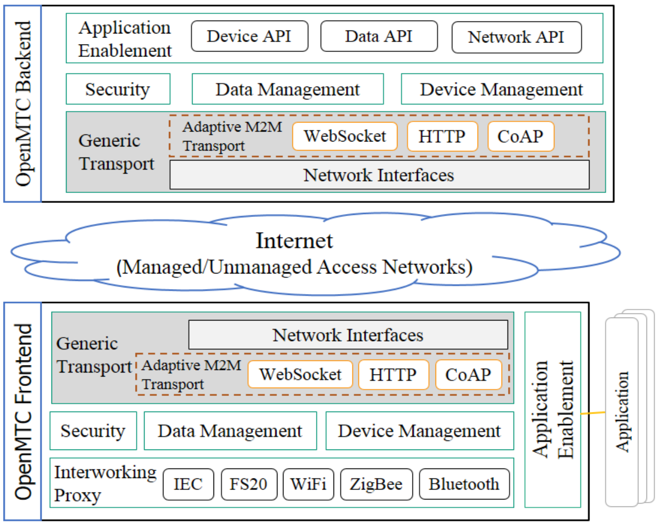

Fig. 2. OpenMTC Platform

B. FITeagle

FITeagle is a framework for managing and federating testbeds. It was developed at the TU Berlin. The intention is to use this framework for managing the interconnected testbeds at TUB and University of Cape Town (UCT). It will give the experimenter the possibility to access resources at the testbeds via the FIRE API [19].

C. Testbed deployment

The testbeds at TUB and UCT are connected via a Virtual Private Network (VPN) connection. Both shall be realized as a mix of virtual and physical components. The testbeds and their interconnection are set up in tasks of the TRESCIMO project. Both interconnected testbeds shall host several devices and gateways, for aggregating and exchanging data. The M2M Middleware core is using the OpenMTC platform and a Smart City Platform, which is developed by CSIR and is responsible for the Big Data analyses and provide APIs for experimenters, Smart City users and other Smart City Applications.

1) Overview

The testbed shall have two parts, a virtual part and a real part. Figure 3 shows the deployment at TUB and UCT. The testbed will be realized via OpenStack. That means all virtual machines are hosted inside the OpenStack Hypervisor to represent different M2M entities (e.g., devices and gateways). OpenStack also virtualizes the used networks, and provides interfaces for FITeagle allowing for readily available computing processing power for potential high loads in stress testing. The combination of OpenStack and FITeagle will empower researchers to conduct distributed experiments and verifications. Additionally, a real network shall be added in order to enable the integration of real devices/sensors into the system.

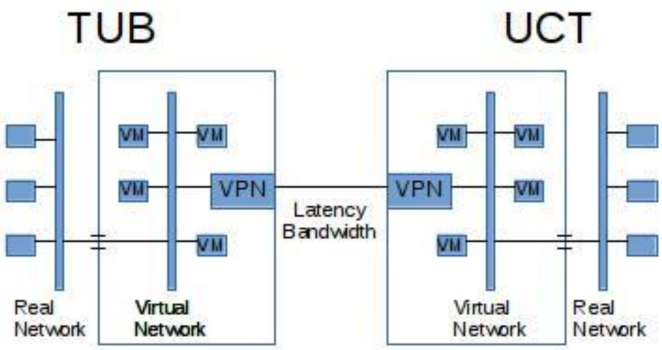

Fig. 3. large-scale M2M testbed

The connection between both testbeds shall be realized with a VPN connection, which is managed by OpenVPN, an open source program for handling of VPN connections. Because the testbeds are located at different continents, the connection will be subjected to different problems and limitations. The connection itself may be a problem due to the reliability of sea cables. Latency is certainly a problem because of the great distance and number of routers between the two testbeds and the limitation due to the speed of light. However, this will leverage the realistic behaviour of the obtained results.

2) Components

For setting up the testbed existing software was used. OpenStack was used to establish the virtual environment, the virtual machines and the virtual networks. For securely connecting both testbeds OpenVPN was used. With that, the two private networks of the testbeds are reachable from both sides.

For integrating the Smart City Platform and the M2M Middleware into the testbed, similar approaches are used for the virtual and the physical ones. On the physical nodes the components are installed as a service which can be started and stopped via operating system methods. For example “service start openmtc-nscl” on a GNU/Debian based distribution. Configuration is achieved by altering the configuration files. The physical nodes are always powered. These services are also deployed to virtual images, which are separately created per service and are used to start VMs with. Then these services are started when booting. Configuration is done by using a metadata service of OpenStack to change configuration on boot up.

Integrating the devices is possible in diverse manner. It depends on the devices itself. Devices that can be directly connected to the network are integrated with no effort. Integrating devices which are connected via different media like Bluetooth or ZigBee need a mediator in between. On the one hand, this mediator is needed to connect these devices with the M2M platform during the experiments. On the other hand, the mediator will provide mechanisms to control such devices for experiment management.

3) Status

The setup of the testbed started recently. At TUB, the virtual testbed was setup with OpenStack and the VPN server was set as a VM in the virtual testbed. At UCT, work has started to set up the real testbed. For this purpose, some physical nodes were connected to each other and to a physical VPN server. The VPN connection was already set up and the first tests were performed.

In the future, both testbeds shall be extended so that they have a virtual and physical part. On both sides, the devices shall be added to the system and integrated into the Smart City architecture.

V. CONCLUSIONS AND FUTURE WORK

The remarkable increase in worldwide populations moving from rural into urban areas will affect the economic growth and add more challenges of planning and managing cities. 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 utilization of past and future generations of Information, Communications and Technologies (ICT).

The need for large-scale testbeds for Smart Cities has been recognized by industry and academia, in order to develop a candidate model for the Smart City implementation. In our work, we build a large-scale testbed for the research and experimentation of enabling technologies, standardize platforms and applications for Smart City. Our work takes into consideration the different requirements and challenges of developing M2M services in both developed and developing world.

The future work will focus on conducting the designed experimentations using the implemented testbed. The first phase of the experimentation will perform functionality testing to validate the components and mechanisms of the system. Later on, services of various domains will be tested. The testbed is extensible to higher-level components, such as data analytic tools required within smart city platforms.

ACKNOWLEDGMENT

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 611745, as well as the South African Department of Science and Technology under financial assistance agreement DST/CON 0247/2013. Authors acknowledge the collaboration of the rest of the TRESCIMO consortium partners.

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