

Prototyping Smart City Applications over Large Scale M2M Testbed

Nyasha MUKUDU¹, Neco VENTURA¹, Joyce MWANGAMA¹,
Asma ELMANGOUSH², Ronald STEINKE³, Thomas MAGEDANZ²

¹Department of Electrical Engineering, University of Cape Town, Cape Town, 7701,
South Africa, Email: {nyasha, joycebm, neco}@crg.ee.uct.ac.za

²Technische Universität Berlin, Marchstraße 23, 10587 Berlin, Germany,
Email: asma.a.elmangoush@campus.tu-berlin.de, thomas.magedanz@av.tu-berlin.de

³Fraunhofer FOKUS, Competence Center Next Generation Network Infrastructures
(NGNI) Berlin, Germany, Email: ronald.steinke@fokus.fraunhofer.de

Abstract: Many cities around the globe are adopting the use of Information and Communication Technology (ICT) as part of a strategy to transform into Smart Cities. These will allow cities in the developing world to cope with the ever increasing demand for services such as an effective electricity supply, healthcare and water management. Machine-to-Machine (M2M) communication standards play a vital role in enabling the development of Smart Cities by supporting new innovative services. Although Smart City services offer an exciting future, many challenges still have to be addressed in order to allow for mainstream adoption. This work focuses on issues related to prototyping Smart City services that utilize standardised M2M middleware platforms. In addition, the use of an inter-continental testbed for Smart City applications as an enabler for innovative, automated and interactive services is presented. The services developed will use an architecture which is based on the Smart City framework developed as part of the Testbeds for Reliable Smart City Machine-to-Machine Communication (TRESCIMO) project. These services will also serve as means to validate the use of Smart services within an African City's context. In addition, the architecture is validated by taking into account various real world use cases for Smart City applications.

Keywords: Smart City; Machine-to-Machine; Smart Home; Testbed.

1. Introduction

Cities offer their populations greater opportunities for education, employment and prosperity. As a result, more than half of the world's people now live in cities and the number is expected to rise to about two-thirds by 2050 [1]. It is expected that nearly 90 percent of this increased urban population will be concentrated in Africa and Asia. Urbanisation puts increasing pressure on the city's available resources, infrastructure and service delivery systems. The effects of urbanisation are more severe in developing countries as they are ill-equipped to deal with this additional pressure. The emergence of technologies such as embedded and mobile devices, wireless sensor networks, and Information and Communication Technologies (ICT) have given rise to Smart Cities. According to Barrionuevo et al, "Being a smart city means using all available technology and resources in an intelligent and coordinated manner to develop urban centres that are at once integrated, habitable, and sustainable" [2]. Realising this vision requires the interconnection of various subsystems such as security, health care and energy grids, with the intention of providing better services for a city's residents. Future economic growth will be predominantly centred on cities. Experts point at Smart Cities as an emerging market

with enormous commercial potential, which is expected to drive the digital economy forward in the coming years. Globally, the current consensus values the IT market for Smart Cities at approximate \$35bn [1]. Companies will have to leverage existing services and resources to take advantage of opportunities provided by smart cities.

The realisation of Smart City implementations will involve the integration of various domains within a common framework, for example communication infrastructure; data storage and management; and analytics, to be able to run an effective Smart City management platform. Machine-to-Machine (M2M) communication technology aims to enable all physical objects to be connected and make data available in various formats through the use of the internet. Smart City services should have the capability to analyse data and provide instant real-time solutions for many challenges faced by cities. There are many domains and environments in which new services are likely to improve the quality of life such as Smart buildings, transportation, and Healthcare. Additionally, a Smart City deployment involves different technical and non-technical stakeholders. Hence, many non-technical stakeholders such as users, public administrations, vendors and governments must be considered. Consequently, large-scale testbeds are needed to provide the necessary critical mass of experimental data required by businesses and end-users for testing of M2M and other Internet of Things (IoT) technologies for market adoption.

The interest in Smart City applications has been enhanced by increased efforts in developing M2M standards and advances in embedded systems available at a lower cost [3]. Integrating data produced by different Smart City applications and devices into a common framework, which may be reusable by other applications, is an important issue in Smart City implementations. For example, Smart Home applications produce a lot of data, which if analysed would allow for the identification of useful resource consumption trends and patterns. These insights may then be used to improve resource utilisation within the smart home. For instance, identifying electricity consumption trends will enable users and energy providers to plan better and manage electricity usage. The common framework would have to be based on prominent M2M standards such as the OneM2M [4] or European Telecommunication Standards Institute (ETSI) M2M in order to avoid creating an isolated, vertical platform. Currently, most devices utilize technology that does not comply with a common standard middleware. This results in hardware developers requiring a platform that allows them to test and develop new devices or interworking proxies for existing devices in varying city conditions. Additionally, the end-to-end aspects of communication between connected devices and servers are critical to some applications [5]. Interconnected applications while having various advantages such as sharing of devices, also raise complex issues such as privacy and security. Users of Smart Homes generally worry about external parties having access to sensitive data and devices [6]. In the most frightening case, users worry that unauthorized third parties may be able to control remote appliances in their home and misuse data from the smart home application. Therefore, it is necessary to provide experimental tools to provide an effective option to evaluate the behaviour of integrated M2M software and hardware before implementing real deployments in real homes.

In this paper, we describe the use of a standard based M2M architecture to support Smart City services for developing countries. In particular, the use of a large scale testbed for the development and implementation of selected Smart City services is presented. The use of a large scale testbed is necessary to fully investigate issues related with using M2M and IoT technologies to solve common problems faced in developing countries. These key challenges are related to dealing with an energy shortage, increasing need for healthcare services and encouraging the development of competency in use of M2M and IoT to solve real world problems. The primary development and implementations of services to deal with these challenges are presented through the use of application development within a

Smart City prototyping testbed. In addition, a prototyping environment is required to experiment with the diverse range of applications and heterogeneous smart devices that are necessary to meet the needs of various Smart City Stakeholders. The architecture used to support the various Smart City services was developed as part of the Testbeds for Reliable Smart City Machine-to-Machine Communication (TRECIMO) project. This project focused on addressing the need for inter-continental, automated testing facilities that provided clear insights on using both European and African solutions to deliver on the promise of realising a South African Smart City.

The rest of this paper is organised as follows: In section 2, we present an overview of M2M standards and related work in the area of Smart City services. Section 3 provides an overview of the TRECIMO reference architecture and the functional architecture of the federated testbed environment. Section 4 looks at both the implementation environment and developed services for Smart Home Energy Management, Healthcare and Education. Finally, Section 5 provides conclusions and future work.

2. Background and Related Work

Besides the numerous Smart City projects and testbeds that provide IoT functionalities, there are also standards trying to form a common standardized view on the ICT of M2M communication. This section provides the necessary background material concerning the use of M2M standards and the Smart City framework to ease the process of creating smart city services.

2.1 M2M Standards

In an effort to improve interoperability between different M2M solutions, standardisation bodies have conducted research into the creation of comprehensive frameworks that support various enabling technologies in order to make it of practical value. A standard of particular interest is the European Telecommunications Standards Institute (ETSI) SmartM2M. As it provides for a common, distributed middleware between different applications and devices [7]. The standard ETSI SmartM2M high-level architecture is shown in Figure 1.

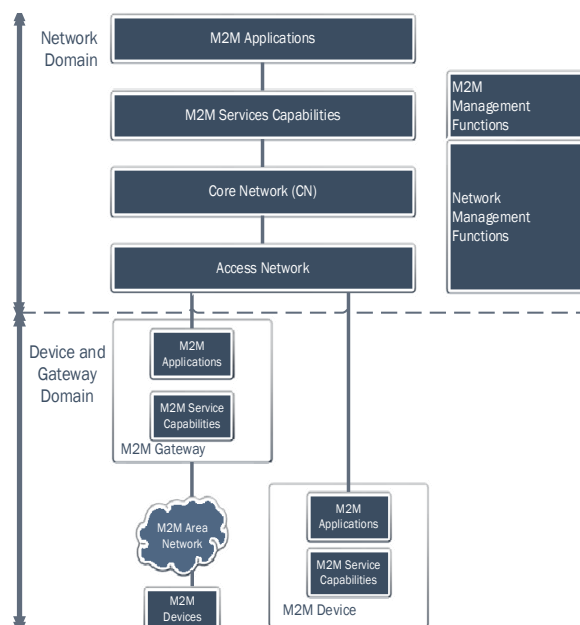


Figure 1: ETSI SmartM2M High Level Architecture

The high-level architecture is designed to allow applications running on remote servers to access shared M2M services such as device activation and network selection via a

standardised REST interface. Thus simplifying the process of creating applications for Smart City services. In addition, the use of the common middleware also allows for the reuse of data in different applications of a Smart City environment. As part of the process of creating the high-level architecture, investigations into different M2M usage scenarios was created. ETSI defines a few scenarios involving a class of applications that are interconnected in order to improve the quality of human life with regards to convenience and entertainment by utilizing M2M communication with networked consumer electronics and devices [8]. Interesting use cases for the connected user that are defined include surveillance data uploading and remote control of home appliances. These examples show a good range of applications that can be used in a connected home and validate the suitability of the ETSI M2M standard for use as the basis of the Smart City framework. In 2012, the oneM2M consortium was established transferring standardization activities from joined members, including ETSI, in the scope of an international M2M communication system. OneM2M specifies a high-level architecture at both the field and infrastructure domains, to support end-to-end M2M services [9]. For device management over M2M platforms, the Open Mobile Alliance (OMA) is providing a platform-independent device management (OMA DM) protocol for general devices [10]. The DM protocol defines an interface between the DM Server and the DM Client to manage and configure devices on top of HTTP transport protocol. Recently, OMA introduced the Lightweight M2M DM (LWM2M) [11], a device management protocol matching the constraint requirement for M2M domain by using Constrained Application Protocol (CoAP) [12] as the transport protocol. Further analysis of standardization efforts to specify a general M2M service layer is presented in [13]. As a result of these developments, it is essential to provide service providers and researchers with an environment to prototype new services which utilise these new standards.

2.2 *Smart City Framework*

Industry and Academia are currently conducting research into protocols, applications and platforms for Smart Cities. Many of the platforms developed tend to be based on custom architectures that are not standardised, creating challenges in interfacing applications developed for diverse Smart City deployments. Others are lab-based testbeds, which suffer from various shortcomings such as limited scale of testing, heterogeneity of underlying experimentation substrate or lack of end user involvement in service experimentation.

The following are the key requirements that a Smart City service prototyping environment must achieve:

- **Standardized Federated Interfaces:** M2M/IoT testbeds are interesting for different parties, and consequently the prototyping environment will be utilised by users of several domains. For instance, researchers can experiment with new technologies, vendors can test new features that utilise existing protocols or standards and operators could test the deployment of new services or firmware. Providing a standardized interface is needed to ease access to and usage of the testbed. A possible interface could be one of the established interfaces utilised by research communities.
- **Flexibility:** The wide range of users and use cases and the complexity of the required infrastructures and technologies create a need for high flexibility of the testbed. This is due to the fact that different scenarios could require completely different setups. So it is desired that each scenario could be setup before the user starts their experiment. Additionally, it is necessary to cater for a broad range of devices that are typically available for use in a smart environment.
- **Cost effective hardware and software:** Smart city deployments are currently considered costly to be install, manage and maintain. In developing countries it is necessary to be

able to investigate means of lowering the costs by utilizing embedded technologies and cloud services.

- Allow for interconnection of diverse applications: Smart Cities will utilise a wide range of heterogeneous devices. It is expected that the development and evaluation of protocols and other technologies will be undertaken in the system design to support the applicability of all devices. Utilising standard-based middleware will allow for easier integration of applications, devices and data [14][15].
- Support computational analysis tools for smart applications: This will create a situation where data from M2M applications can be analysed using common data analytics services.
- Allow for integrating Open data sources: As more information is being made available from governments and organisations via Open Data portals [16], it is necessary to support the integration of relevant independent data sources into Smart City services, for example, electrical grid states from energy service provider can be used by a Smart Home energy management system.
- Scale to support multiple capacity: The fact that the number of devices involved in the M2M connection is expected to increase in the next years, also requires that the testbed can scale with the different number of devices that are used in the experiment or when the increasing of the devices is investigated it needs to scale in the experiment itself.
- Consistent developer experience: To provide a simplified, common set of Application Programming Interfaces (API) to reduce the complexity of developing and deploying applications regardless of the hardware setup. Using APIs supports the process of building systems from semi-independent components in a scalable way.

3. TRECIMO Smart City Reference Architecture

The TRECIMO reference architecture, which is based on the ETSI M2M architecture in Figure 1, was defined in previous work [14]. The reference architecture was designed to allow different Smart City applications and devices to use a common infrastructure stack and provide common services. The architecture is used to develop applications that were implemented as part of a Smart Energy trial in the Gauteng (South Africa) and a Smart Green City trial in Sant Vicenç dels Horts (Barcelona, Spain) respectively. Additionally, Smart City applications for other domains such as eHealth, Smart Home, Safety were developed using the TRECIMO federated Testbed.

There are many other projects aiming to build experimental infrastructure for IoT and Smart City. For example, the FIESTA project [17] deals with the interoperability of testbeds and applications which are focused on the semantic of IoT communication. The EXOGENI framework [18] aims to federate independent cloud sites to have a “distributed networked infrastructure-as-a-service (NIIaaS)”. Our approach is to have a federated testbed like the EXOGENI framework but be specialized to M2M/IoT related use cases and provide a standard compliant stack which can be deployed with the help of the federated interface.

The TRECIMO framework interconnects two M2M testbeds located in Berlin, Germany and Cape Town, South Africa. The testbeds allow the testing of multiple use cases of Smart City services in both developed and developing countries. Additionally, the federation of both testbeds allows the sharing of resources (i.e. sensors, actuators and aggregated data) between different services and users regardless of their location. Currently, the testbed is used by researchers from the Technical University Berlin, the University of Cape-Town and the Council for Scientific and Industrial Research (Pretoria, South Africa). Nevertheless, the TRECIMO testbed is extendable and open to other research institutes willing to benefit from the prior learnings and implementations.

3.1 Design Consideration

Differences and similarities between South Africa and Europe have been captured in previously published work [19]. The obtained insights help to understand how and what needs to be introduced, and what challenges need to be resolved to create effectively a South African Smart City.

The approach is to have a virtual deployment of an IoT stack that can be used for Smart City experiments. This approach enables the testbed to have the required flexibility and scalability. Also, the requirement for quick experiment setup can be achieved by using virtual deployments. The virtual deployment is done by OpenStack, an open source platform which is used worldwide and supported by a huge community and several companies. The orchestration part that handles the deployment of possible topologies of the infrastructure is handled by OpenSDNCore. It is developed by Fraunhofer FOKUS and provides Network Function Virtualization (NFV) and Software Defined Networking (SDN) functionality. The developed functionalities of OpenSDN are along with the latest ETSI NFV standardization ambitions. Generally, the TRECIMO testbed provides technologies to allow building Smart City services with an affordable investment.

3.2 Functional Architecture

The testbed utilises the same high-level architecture as the trials to ensure that the developed applications in the Testbed will be evaluated in conditions that are can be used practically in the real world. The functional architecture of the Federated Testbed, as depicted in Figure 2, consists of the following building blocks:

- OpenVPN: A virtual private network (VPN) is used to interconnect the three testbed sites securely. Each testbed site has a gateway client that connects physical and virtual servers to the TRECIMO VPN.
- FITeagle: This is a Semantic Resource Management Framework that provides an extensible and distributed open source, Slice Federation Architecture (SFA) compatible management framework for federated Future Internet testbeds. This is responsible for resource provisioning in order to meet the needs of a particular experiment. The FITeagle framework [20] is offering interfaces to the FIRE community and handles all aspects of the experiment life cycle including Authentication (AuthN) and Authorization (AuthZ).
- OpenMTC M2M middleware [21]: This is an ETSI/oneM2M standard compliant platform that serves as a horizontal convergence layer that supports multiple vertical application domains such as automation, energy, eHealth, etc. OpenMTC features are aligned with the ETSI M2M Rel. 1 specifications [7] and the oneM2M Rel. 1 specifications [9], providing an implementation of Common Services Functions (CSF) at both the Front-end gateway and Backend server. While it is possible to virtualize all the functionality of the OpenMTC gateway, connectivity challenges in the developing world make it more prudent to have a physical gateway. The main challenges include limited connectivity and power outages. For the purposes of experimentation, both physical and virtual gateways are implemented. A Raspberry pi is used for the physical gateway as it is cost effective, readily available and power efficient [21].
- Smart City Platform: Provides common application services such as real world data modelling, analytics and visualisation of data for Smart Cities. It is connected to the OpenMTC through the use of an interworking proxy. The proxy interfaces with the REST interfaces provided by the M2M middleware and publishes its own REST interface to be used by the Smart City platform.

- Gateway Interworking Proxies (GIPs): These are used to connect non-ETSI standard compliant devices to the testbed network. GIPs interface the devices with the M2M gateway in order to create and push data resources into the M2M gateway. The presented testbed consists of heterogeneous physical devices that are available as part of the experimental infrastructure.
- Smart Infrastructure Services hosted on Open Stack: The open stack servers are used to host software-based components of the TRESIMO architecture [22]. Examples of virtualised components include: virtualised devices, OpenMTC M2M middleware and Smart City Platform. The use of infrastructure as a service (IaaS) allows for easier scaling of resources to meet the needs of a particular experiment.
- Virtual devices: These are emulated versions of physical devices used for prototyping M2M applications. This allows experimenters to generate a large number of devices in order to test for issues that related to applications that need to manage a large number of devices.

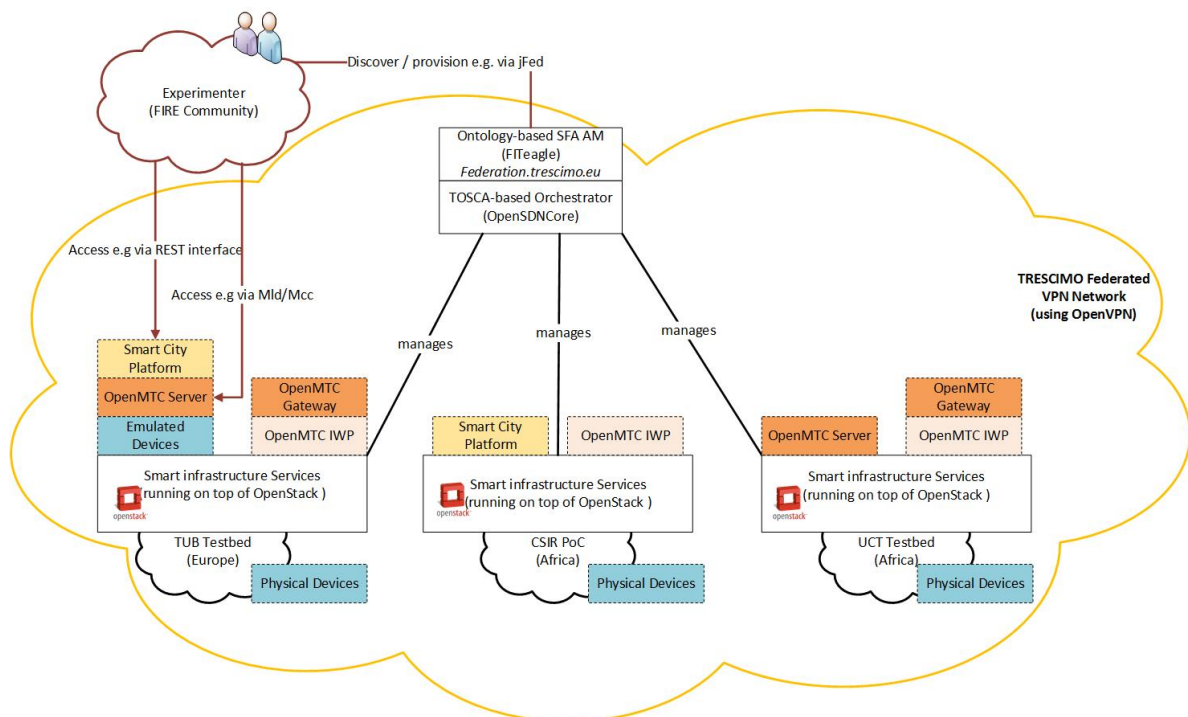


Figure 2: Functional Architecture of Federated TRESIMO Testbed

4. Experimentations Deployment

In the TRESIMO project [23], the federation of testbeds allows for experimentation with enabling technologies, standardized platforms and applications for Smart Cities with different conditions. This testbed provides an effective option to prototype software and hardware before implementing large scale deployments. The TRESIMO testbed was designed to allow different Smart City applications created by different service providers. In this paper, the applications presented were selected in order to investigate the use of data and resources between different users and stakeholders. This work illustrates a new concept of building Smart City services based on incorporating data from different applications.

4.1 Energy Consumption

The use of non-intrusive IoT technology, allows consumers to manage the energy consumption of devices within their homes. For consumers, it provides an opportunity to lower monthly energy costs while for energy providers it allows for a reduction in the

demand for energy. This is critical in developing countries, as there is already an insufficient supply of electricity. However, it is important to note that in general, the more real-time the feedback provided to the consumer, the better the average annual electricity savings per household [24].

This experiment is designed to provide useful feedback to consumers about power “hungry” appliances in the Smart Home. To achieve this, an energy monitoring application was developed. This application obtains energy readings from sensors connected to each appliance in a home and reflects it as a percentage of the total home consumption. Figure 3 shows the graphical user interface of the gateway application developed to collect results for the experiment. The application also displays the power consumption of a selected device over a period of time. The system will allow users to become more aware of their energy consumption and may lead to improved energy utilisation within the Smart Home.

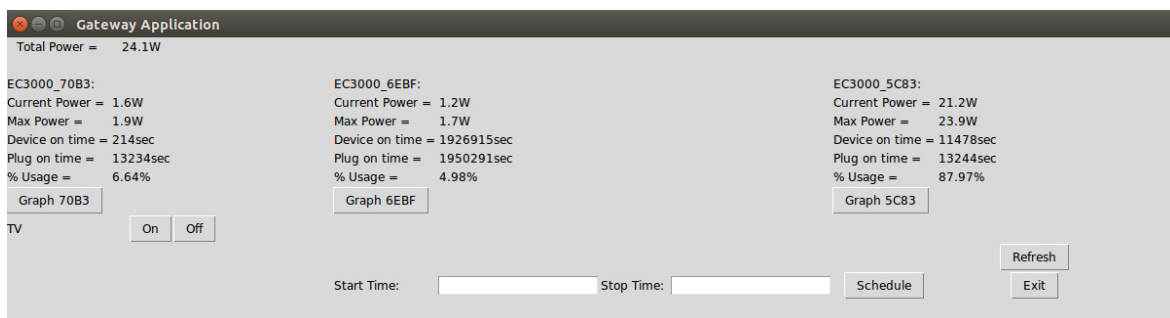


Figure 3: Gateway Application for Device Energy Consumption

4.2 Demand Side Management

Energy providers utilise demand response signals to encourage consumers to shift energy usage from peak periods to off-peak periods. Currently implementation of demand side management is typically archived through the use of energy grid warning and load shedding. However, it is essential to create a system that would enable utilities to more effectively encourage consumers to shift unnecessary consumption to off-peak periods. This will reduce the need for severe measures such as load shedding.

In this experiment, users are enabled to remotely control appliances in the smart home based on notifications received. To archive this, an application that allows users to receive messages from the home and control appliances in the home was developed. This application allows the user to remotely control appliances in the smart home by utilizing FS20 plugs to control the appliances connected to them. The application sends notifications to the members of the household based on specified events in the Smart Home and requests from other stakeholders such as service providers. We focused on energy management, where a utility provider is able to send requests to users to reduce energy consumption. This involves the ability of the utility provider to deliver power alerts to residents when their overall consumption has exceeded a given limit. To meet this, the energy application makes use of a push notification service that allows notifications to be delivered to an end-user application installed in the mobile device. The notifications sent to the resident contains details on how much the resident needs to reduce his consumption by and the consequences of not reducing consumption. Figure 4 shows the user interface of the Pushover application. In scenario 1, the user responds to the request to reduce consumption by taking actions to reduce energy consumption. In scenario 2, the resident does not comply with the demand response within a given time. As a result, the utility provider forcibly switches off appliances, followed by a notification message to the resident. The testbed environment allowed for testing with more than one household connected to the same energy provider.

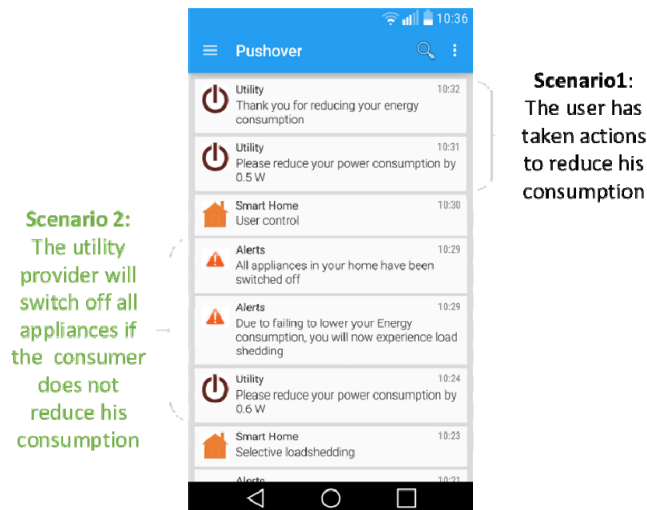


Figure 4: Pushover Application for Smart Home

4.3 Educational M2M System

This scenario, considers students learning about IoT and M2M concepts and then provisioning some service or components over the federated testbeds in order to gain practical experience with utilising these concepts to solve real world problems.

This application provides an on demand M2M infrastructure for students to do in class experiments by utilizing resources (i.e. devices and servers) from different testbeds. In this use case scenario, a university teacher wants to provide an on demand M2M infrastructure for his class, thus enabling the students to experiment on the state of the art technology. The teacher thereby uses the jFed experimenter client (<http://jfed.iminds.be/>) developed in the scope of the Fed4Fire project [25]. This client utilizes the SFA interface of the TRESIMO testbed provided by FITeagle. After login with a valid X509 certificate, the teacher creates a new experiment and specifies the topology to be used in class. After successfully creating the topology, the teacher then provides the students with details of the accessible resources and their endpoints. Figure 5 shows the result of the successful provision of selected resources across two testbed site.

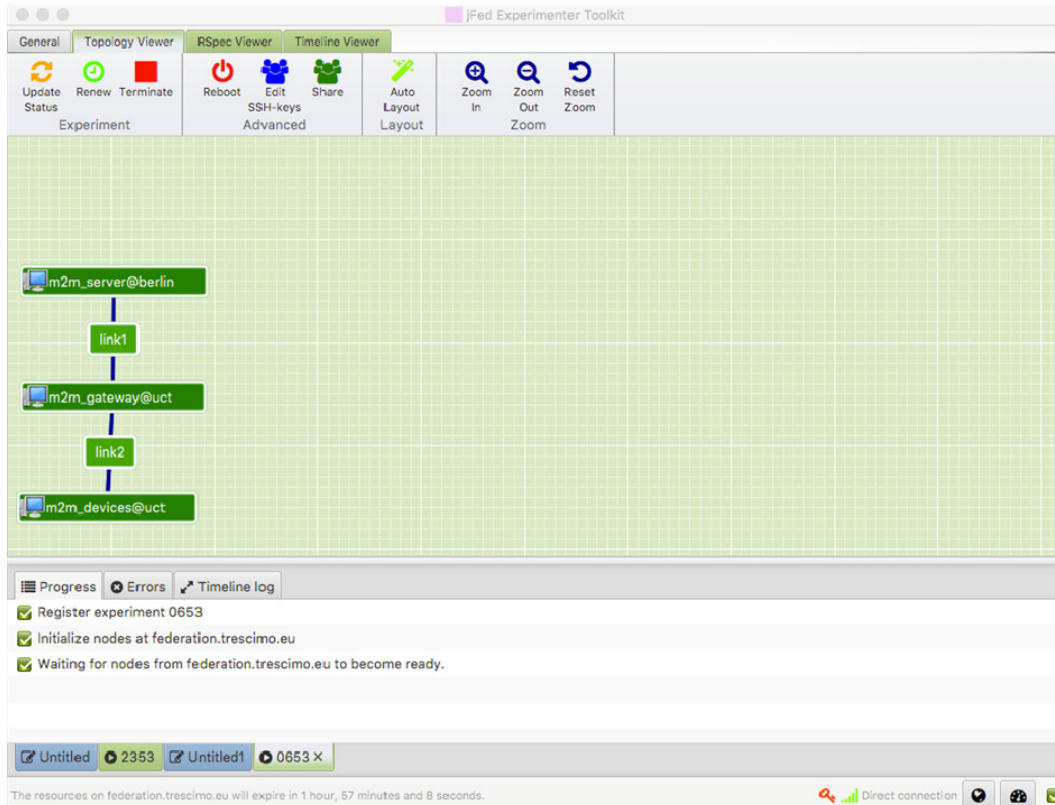


Figure 5: Successful Provisioning of Resources

5. Conclusions and Future Work

Cities and communities are striving to become more efficient in an attempt to cater to increased populations with limited resources. This work focuses on creating an environment for prototyping Smart City applications that utilize standardised M2M middleware and related research issues.

The presented architecture is part of the collaborative research among partners from European countries and South Africa involved in the TRESKIMO project [23]. In this project, a federated testbed to be used for smart city research has been established between the University of Cape Town (Cape Town, South Africa), Council for Scientific and Industrial Research (Pretoria, South Africa), and the Technical University Berlin (Berlin, Germany). It was demonstrated that the federated testbed supports Smart City experimentation through the development and deployment of various applications.

The use cases considered during the project were in the context of different domains of Energy, Health and Education. Addressing the similarities and differences from both developed and developing world supports leveraging the experience in designing new solutions. In the TRESKIMO project, we used the possibility to provision a specific topology to run few experiments. In these experiments, we used resources from the South African side. These resources were devices deployed at the UCT and a virtual gateway which was connected to a server instance hosted at the TUB. The needed infrastructure was provisioned via the SFA interface.

The distributed Testbed established between TUB, UCT and CSIR will enable experimenters at both universities and CSIR to share resources such as physical devices and Infrastructure- as-a-Service (IaaS). External experimenters from other Universities and the research community are able to access this testbed using FIRE tools.

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