

Future Internet Concepts for Demand Management

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Abstract — the “Internet of Things” (IoT) is a concept where animate and inanimate objects have the ability to collect and exchange data over a network without requiring human-to-human or human-to-computer interaction. Through the utilisation of IoT and the future Internet, fine-grained, near-real time energy demand management is increasingly becoming a reality. This is achieved through real-time billing, predictive energy costs and demand response signalling using IoT as a data platform. Installing smarter technologies at the end-user premises and communicating measurements over different network technologies provide access to information and subsequently for smarter decision making about energy management in the household.

This paper presents an international research and experimental initiative linked to the Future Internet (TRECIMO) which facilitates the validity of using these technologies as base for energy demand management. The initiative utilises a philosophy of informing customers about their energy usage behaviour through data received from smart devices that are integrated with a machine-to-machine (M2M) platform. The paper discusses opportunities presented by IoT in the management of energy use in the residential sector.

Index Terms — *Testbed for Reliable Smart City Machine to Machine Communication Platform, TRECIMO, testbed, machine-to-machine (M2M), smart devices, home energy management, OneM2M, OpenMTC, IPv6, COAP, ICT, Smart City Platform*

1 INTRODUCTION

South Africa is experiencing unprecedented capacity constraints on the power networks due to aging infrastructure, increase in demand and unplanned maintenance. The constraints on energy infrastructure are not unique to South Africa. In order to deal with their issues of energy management, many countries have adopted a Smart Grid strategy (e.g. the Netherlands and Germany). South Africa is

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also researching aspects of Smart Grids. One such aspect is to determine the value of a combination of IoT and demand management as measured through testbeds [1]. The Smart Grid entails grid modernisation across the entire value chain of the grid.

The key strategy adopted is smart technologies for better energy management of utility customers. Advances in Internet technologies have created new opportunities for utilities and other industries to manage information and communication. Internet-connected sensing devices provide opportunities to better communicate and effectively manage energy usage in the residential sector. These opportunities provide cities and utilities the ability to develop an integrated Information, Communication and Telecommunication (ICT) platform to form a smart city.

In a typical Smart Grid scenario, data (as generated from smarter sensing technologies, e.g. Internet of Things devices) is either sent over IP networks (which delivers data immediately) or collected in a delay tolerant mode by mobile devices of individuals. In delay tolerant mode the data is stored locally, to be delivered when a suitable network is reached. Sense is made from the acquired data, leading to smarter decisions. In this context, a “smarter decision” might be what type of devices in which area for what duration to control?

Rolling out smarter Internet enabled technologies require an approach allowing for experimentation, testing and validation (before mass-scale rollout can commence). A Testbed provides means to experiment, test and validate technologies in a connected real world environment. In a context where connectivity is not always guaranteed a Testbed utilising delay tolerant networks is required. This paper presents current research with localised South African technologies and platforms, linked to international equivalents to test the validity of using smart technologies for demand management.

The next section introduces TRECIMO, an international research collaboration project with the aim of creating federated international experimental facilities. Section 3 presents planned research related to energy as facilitated through the experimental facilities. Section 0 describes the TRECIMO reference architecture and details related to the South African trial. The trial is centred on energy. To this effect, details related to a typical experiment are presented. In the creation of components that facilitate trials of this nature, numerous technologies and standards need to be considered. Section 5 introduces a selection of applicable technological components. Section 6 contains a discussion of aspects and

components related to measuring energy management in a trial of this nature. Section 7 concludes.

2 TRESKIMO

Testbeds for Reliable Smart City Machine to Machine Communications (TRESKIMO) is a project under the European Union's FP7, Future Internet Research and Experimentation initiative. TRESKIMO is a collaboration effort between the European Union and South African partners to be executed over a planned duration of two years (2014-2016). South Africa's consortium partners in the project are CSIR, Eskom and the University Cape Town (UCT). The European partners are Technical University Berlin, Fraunhofer Fokus, Eurescom, i2CAT and Airbase sensors.

Through the international collaboration research into Future Internet technologies and specifically their application for societal impact are conducted. The research is conducted and validated through the creation of testbeds (i.e. large scale, distributed experimental facilities deployed in the real world).

To validate the effectiveness and utility of the research components, a national testbed (federated with a similar European facility) addressing a societal challenge is planned [2]. In South Africa, energy will be the focal point, while a green environment will be the European partners' aim.

TRESKIMO has the following high level objectives [3]

- i. Strengthen the interconnection and extension of existing experimental facilities across continental boundaries with a specific focus on Smart Cities and Smart Energy;
- ii. Integrate software-based cross-industry horizontal M2M (machine-to-machine) frameworks with real world sensors and IoT device deployments;
- iii. Evaluate the usage of autonomic communication methods for end-to-end M2M communication in Smart Cities;
- iv. Use delay tolerant communication to support opportunistic information transmission;
- v. Leverage existing standards in the field of M2M (European Telecommunication Standards Institute Technical Committee M2M and oneM2M) and foster their global adoption;
- vi. Deployment and federation of testbeds across countries and continents, with a focus on developing countries and structurally challenged areas.

3 SMART ENERGY IN TRESKIMO

Eskom SOC Ltd, the power utility in South Africa, is a key partner in the EU-SA consortium and is primarily focussed on the smart energy domain of the TRESKIMO project.

One of Eskom's key focus areas are customer engagement and grid optimization. In order to achieve a holistic approach, Eskom has undertaken several demand response initiatives, as listed below:

- vii. Demand Management Program (such as solar water heating, CFL lighting, heat pumps, efficient showerheads, smart appliances, battery storage, etc.).
- viii. Customer Power Conservation Program.
- ix. Internal Energy Efficiency (Substations, network losses in buildings, thermal efficiencies, etc.).
- x. Advanced Metering Infrastructure and the Utility Load Manager.

Demand Side management programs can support the broader objective of reducing demand and thus ensuring the base load is managed for long term sustainability. Peak demands are largely managed by AMI (Advanced Metering Infrastructure) and peaking generation capacity.

It is believed that the ability of a utility to predict and manage the complexity of the network will result in better management of its customers and reducing the potential risk of outages. Through TRESKIMO the validity of such a departure point can be verified.

As part of TRESKIMO, Eskom will facilitate the creation of the testbed facility in a domestic area. The smart energy testbed will enable a trial of 30 customers where smart devices (smart plugs and home gateway controller) are to be installed.

The aim of the trial is to test customer behaviour and response to demand response signals where the customers will be sent instant messages to remotely switch-off applications via a mobile application as installed on the customer cellphones.

Through the testbed facility created in TRESKIMO, finer grained objectives specifically related to the South African energy crunch and a future Smart Grid are identified. The following subsection elaborates on these.

Eskom Key Objectives:

Beyond the larger TRESKIMO objectives, finer grained objectives are pursued. They are:

- xi. To investigate and monitor the impact of IoT on demand management;
- xii. To use 30 experimental sites to test behavioural interventions;
- xiii. To determine the effectiveness of, and functional requirements of, smart plug devices in the residential sector;
- xiv. To observe the behaviour of residential customers on real-time feedback on energy usage;
- xv. To determine the effectiveness of using a mobile and web based application on changing usage behaviour;
- xvi. To analyse the practical application of the IoT as an enabler of demand management.

4 EXPERIMENTAL TESTBED SETUP

To achieve the higher level TRECIMO objectives, the creation of experimental facilities are required, and to subsequently host the planned energy (South Africa) and green environment (Europe) experiments, a reference architecture was developed that supports both European and South African requirements.

4.1 TRECIMO Reference Architecture

The “societal” component of TRECIMO investigates challenges in deploying smart services Smart Cities, and highlights a number of scenarios applicable to a Smart City. The objective is to provide a “foundation” for the development of technical building blocks which could result in a Smart City architecture that can be deployed successfully in both developed and developing countries. For this purpose, a reference architecture was developed. The figure below illustrates the TRECIMO Smart City reference architecture.

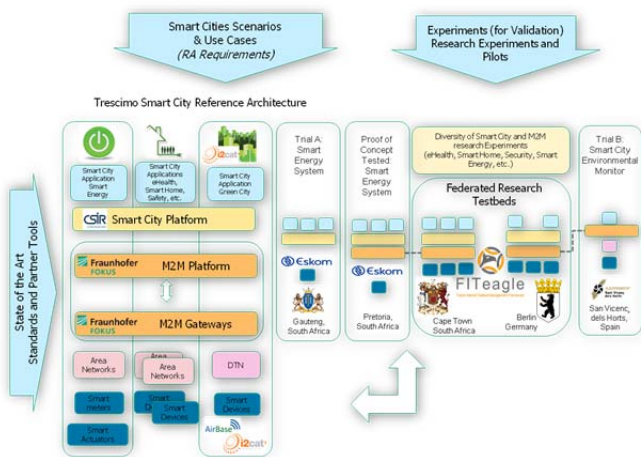


Figure 1: TRECIMO Smart City Architecture [4]

The first three grouped columns on the left illustrate the full reference architecture, the remaining columns to the right show the various implementation configurations that are used in the project. The blocks are colour coded to indicate which are present in each configuration. This paper focuses on the technologies used in the configuration labelled “Trial A: Smart Energy System”.

4.2 Smart Energy: Experimental Testbed

In the design of the experiments for the trials a methodology was followed that linked aspects from both Europe and South Africa. The methodology included the creation of scenarios, use-cases, activity diagrams and expected measurable dimensions [5].

The experimental set-up is defined by the relevant scenario and associated use-case. The use-case has been developed to understand a specific behavioural intervention during a demand management event.

4.2.1 Smart Energy Scenario Description

Scenarios and use-cases are the departure point for real-world utilisation of the various TRECIMO technologies. An example of one such scenario and subsequent use-case is as follows:

“Grant feels intensely, even personally, aggrieved by the several steep electricity price increases over recent years and has a vague sense of corruption going on in the national utility which he has picked up through the media. Despite his negative sentiment, he very seldom thinks specifically about his household's electricity consumption, except when he has to pay his monthly bill. Normally, within minutes of paying his bill he has already forgotten about his electricity. He has lived with a prepaid as well as a credit meter system, but it has always been the same. The bill arrives in the mail or he needs to load units (“what are units?” he wonders) onto the meter and he feels both angry at the price and despairing that he just cannot understand which devices are using all the “units”.

At a braai, a regular social occasion for Grant, a friend shows him and some other friends an app downloaded to his phone from the Google Play store. The app is linked to his meter and gives him daily updates, at his chosen time, of his total consumption so far that month. Grant installs the app, along with the others, and once he gets home registers his meter by typing in the meter identification number. Grant is impressed as the app immediately shows him a graph showing his consumption over the past day.

The next day the app sends him an updated graph of his consumption. Looking at the app he notices options to change the frequency of updates and several other functionalities. By receiving the daily updates he found himself thinking about his electricity in general through the day, and, judging by his updating consumption graph it seems that he is now consuming a little less. He has now enabled the function which compares his consumption to historical norms for a household like him and has begun to make efforts to reduce consumption where he is consuming more than the norm.” [6]

The use case diagram below describes the above scenario.

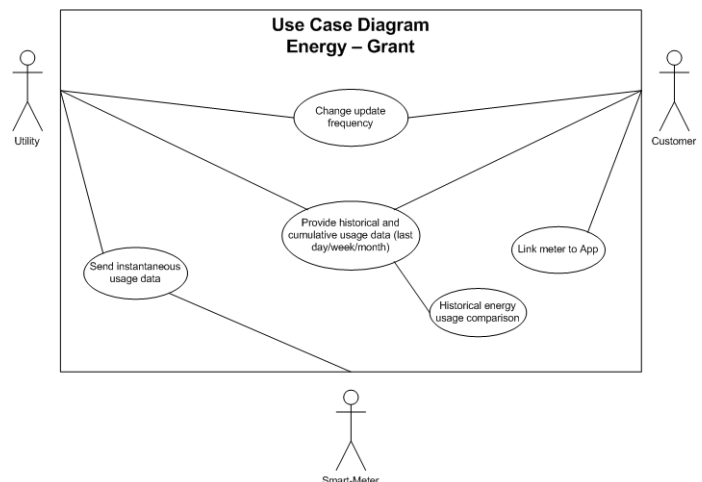


Figure 2: Use Case diagram for the Energy Scenario [6]

4.2.2 Smart Energy: Activity Diagrams

The M2M functionality that will be tested is described in the following activity diagram. The activity diagram further defines the data exchange mechanism between the various elements in M2M communication platform. The goal to be achieved through this process is to enable the customer to make informed decisions about his energy usage.

The activity diagrams showing the functionality are illustrated below in figures 3-1 to 3-5. [6]

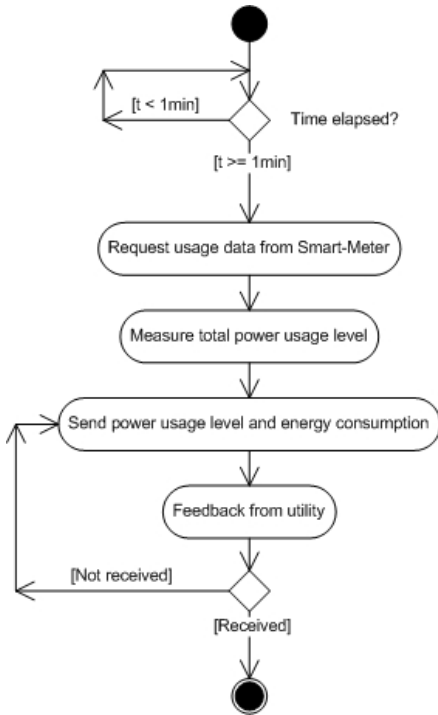


Figure 3-1: Activity Diagram – Send Instantaneous Usage Data

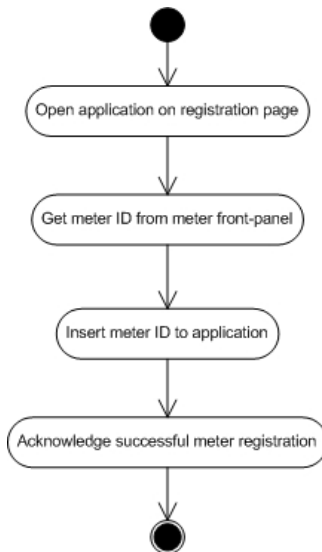


Figure 3-2: Activity Diagram – Link meter to Application

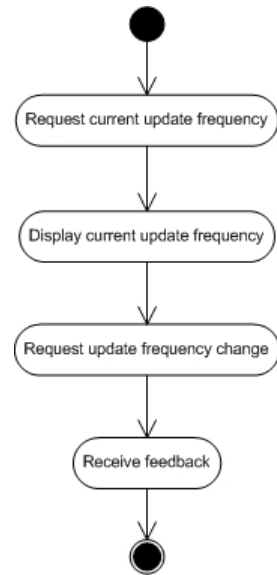


Figure 3-3: Activity Diagram – Change update frequency

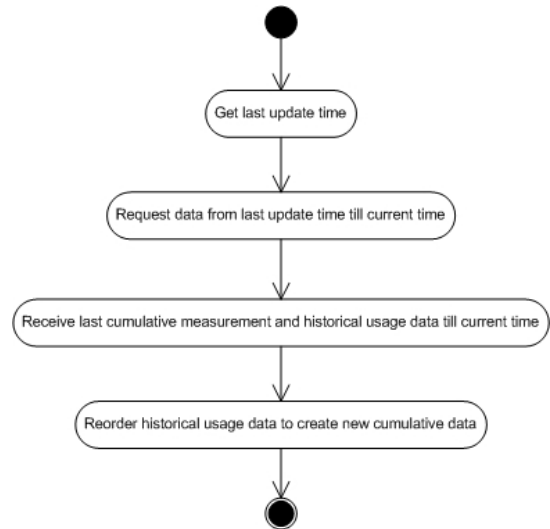


Figure 3-4: Activity Diagram – Provide historical and cumulative usage data

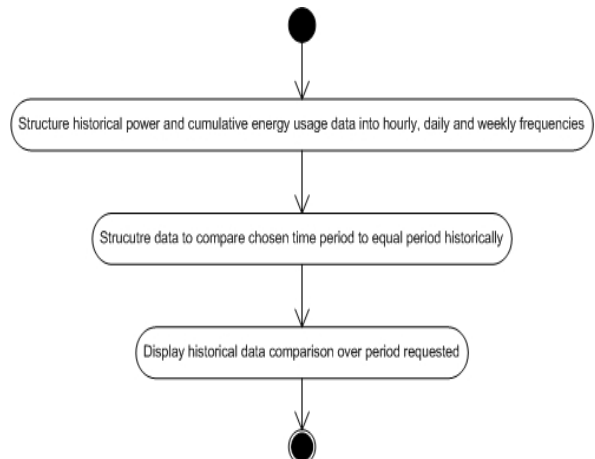


Figure 3-5: Activity Diagram – Historical energy usage comparison

4.2.3 Smart Energy: System Requirements

The table below describes the key elements from the activity diagrams above that will be measured through the experimental set-up on the testbed.

Table 1: Smart Energy System Requirements [6]

Domain	Requirements
Smart Energy	<ul style="list-style-type: none"> • Ability to measure intervals of time. • Ability to control remote appliances. • Ability to measure energy consumption of households. • Ability to measure energy consumption of individual appliances. • Mobile application for individual user. • Data analytics to interpret and visualise historical data collected from users. • Ability to detect when resources need to be scaled according to system loads.

This section highlights the methodology followed leading to specific requirements that should be measured as part of a trial run on an experimental testbed. To actually create the experimental environment cognisance of numerous standards and technologies need to be taken.

5 ADVANCES IN TECHNOLOGIES AND STANDARDS

In creating an end-to-end architecture able to address the above use-cases, while being interoperable with various technologies from different stakeholders, the need for standards compliance is clear. Furthermore, the intent to federate these implemented architectures over continents supports the need for implementations based on standards. There are a multitude of standards emerging. Presented below is a subset of potentially applicable standards and technologies for home energy management and M2M integration.

Sensing and actuating devices need to be distributed at the deployment locations, and therefore need some method of local communication. A low power wireless network was implemented in an attempt to minimise installation effort. IEEE 802.15.4 specifies the physical layer and media access control for low-rate wireless personal area networks. It is the foundation for a number of higher level specifications including 6LoWPAN (used in this application), ZigBee and WirelessHART. The physical layer implementation defines three possible unlicensed frequency bands:

- xvii. 868.0 - 868.8 MHz: primarily used in Europe, has a maximum rate of 100 Kbit/s, and allows one communication channel.
- xviii. 902 - 928 MHz: primarily used in North America, has a maximum rate of 250 Kbit/s, and allows up to 30 communication channels.
- xix. 2400 - 2483.5 MHz: permitted worldwide, has a maximum rate of 250 Kbit/s, allows up to 16 communication channels, and used in this application.

The specification also defines the media access control that includes a management interface, physical channel access and network beaconing. The network model defines the following node types:

- xx. A full-function device (FFD) as a common node that can communicate with any other node and relay messages, implemented in devices such as ActivePlug and ActiveDIN.
- xxi. A full-function device, acting as a private area network (PAN) coordinator. This is referred to as a border-router in our application, implemented in the ActiveGate device.
- xxii. A reduced-function device (RFD), designated for nodes that have limited energy and resources. These nodes cannot act as PAN coordinators, and may also be implemented such that they are in a sleeping/powered down mode most of the time.

IEEE 802.15.4 networks may be implemented as star or peer-to-peer topologies. This implementation is as a peer-to-peer topology.

Due to the exhaustion of the IPv4 address space, it makes sense to design the future internet devices to make use of IPv6 from the start. In this implementation, the ActiveGate device acts as an IPv6 router between an upward IPv6 network (connecting multiple gateways) and a localised IPv6 device network for the sensors and actuators. The border-router provides a 64 bit IPv6 network space to the devices which use their unique 64 bit identifiers as the host part of their IPv6 addresses. This allows all devices to be directly addressable from a public IPv6 network.

In order to make use of IPv6 on an 802.15.4 network, an adaptation layer is required. This is due to the 127 octet maximum physical payload size limitation of 802.15.4 and the 1280 octet minimum size payload requirement of IPv6. The Internet Engineering Task Force (IETF) published specifications (RFC6282) for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN) to ensure interoperable implementations. These included compression and management mechanisms [7].

A routing protocol is required to create and maintain routes in the low power RF network as these networks are typically characterised by high loss rates, low data rates and instability. The IPv6 Routing Protocol for Low power and Lossy Networks (RPL) was designed and specified (RFC6550) for devices with constrained resources and constrained connectivity. The protocol enables the automated

configuration of IPv6 addresses (by specifying the network prefix to each node) as well as management of routes. Routes are defined as Destination Oriented Direct Acyclic Graphs (DODAGs) that allow upward and downward data flow. This implementation has the border-router set up as the Direct Acyclic Graph (DAG) root.

CoAP (RFC7252) is used at various levels of the system due to its suitability for Machine-to-Machine (M2M) communications: multicast, low overhead cost and simplicity. To facilitate the implementation on constrained devices, a number of design choices have been considered including: i) the use of UDP as the transport layer protocol to avoid the overhead of connection oriented protocols; ii) efficient packing of protocol information in the header, which can be as small as 4 bytes. It maps easily to HTTP, enabling simple proxy implementations. The sensing devices publish their resources in the CoRE link format with CoAP as the service protocol. CoAP is used by an interworking proxy to collect these and push them into the M2M Gateway, and to facilitate communication between the M2M Platform and the Smart City Platform [8].

RFC6690 defines the Constrained RESTful Environments (CoRE) Link Format. In particular, the Well-Known 'core' URI is implemented in the sensing and actuating devices to provide a list of resources that are available, as is indicated by CoAP [9].

Communications from the gateway to the Smart City platform is through a cellular network using 2G or 3G connectivity from existing network providers via a machine-to-machine platform. The gateway devices also use an IEEE 802.11a/b/g/n dual band (2.4GHz and 5GHz) radio for diagnostics and local user interaction. The gateway presents as a WiFi access point to which smart phones, tablets or computers could connect to access demand management information.

The machine-to-machine platform provides standard services such as store and forward, security, and federation. The ETSI M2M standard has formed the base of several M2M platforms. This standard has been expanded into the OneM2M standard (created through the integration of needs from a large number of industry players). Within the TRECIMO environment, an implementation of OneM2M (Fraunhofer Fokus' OpenMTC) is utilised [10].

Once reliable communication has been established (linking the physical environment with the broader Internet), a platform is required on which a collection of applications can be run. A large collection of such platforms exists, however standards are yet to be created. In the context of re-using existing building blocks, an in-house CSIR Smart City Platform is used. This platform provides the ability to link to a variety of application and communication mechanisms. Important aspects of the platform include:

- xxiii. The ability to discover devices and their respective resources from gateway devices;
- xxiv. Big data storage model, to support unstructured and semi-structured data originating from various sources;

- xxv. Semantic modelling capabilities - looking at the meaning behind data relationships;
- xxvi. Physical world modelling – the ability to specify data relationships based on physical associations;
- xxvii. CoAP and the CoRE link format is supported throughout the platform to facilitate current and future machine-to-machine interactions;
- xxviii. The ability to integrate open data (publically available, such as weather) as well as linked data (from private sources) for access by hosted applications.

The figure below illustrates the solution as described in this section.

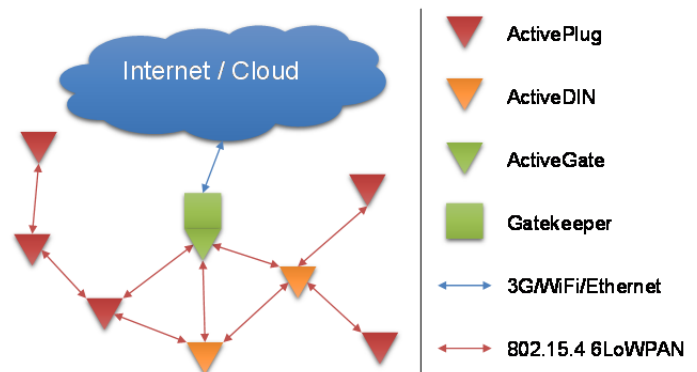


Figure 4: Solution diagram illustrating the interconnection of smart devices and the use of communication standards

6 DISCUSSION

The South African power grid is at present constrained due to the ageing infrastructure and assets. In order for the sustainability and security of supply the grid will need a more advanced system that will provide bi-directional communication to manage the delivery of energy. As a component in a smart grid, the IoT will become a significant technology as an enabler to communicate with multiple devices and specifically the consumer of electricity.

The largest constraint at the moment is the delivery of electricity during peak times. To enable residential customers to make better decisions it is envisaged that the platform above will provide real-time data to direct behavioural change and thereby optimise the delivery of energy.

The smart grid consists of many applications with smart metering being an important component to connect the customer through open standards to the grid. By providing granular level information the customer is empowered to make decisions about the energy consumption. A key enabler to this would be the development of several digital media applications. These applications would reside on HTML 5.0 based website and or mobile application. Through the application the customer will have a range of options on

better managing energy consumption. This is enhanced by the data collection through the M2M communication platform.

Smart devices connected to the home as well as being installed at different levels of the grid from sub-stations through both Transmission and Distribution networks to each home will provide data for decision making. Connected devices on the grid will provide value proposition to the customer in the future by incentive schemes that are communicated via M2M platforms to the customer. These may include specific discounts and time-of-use tariffs for the reduction of the customers' bill.

The use case for the above experimental testbed highlights energy management through automation and optimisation of information and communication technologies. By developing a networked interconnection of various devices or appliances (smart plug connected to an appliance) enables automatic savings by utilising the sensing and analytics through user interaction and engagement towards energy efficient behaviour.

7 WAY FORWARD

TRESCIMO facilitates the creation of real-world experimental facilities (utilizing internationally federated components). From the South African viewpoint, a trial related to energy scenarios will be executed.

The trial entails 30 residential customers as part of the experimental testbed. Each customer will receive a smart plug controller for automating the operation of selected appliances in their household. During the experimental process, an application will be available on both the web and mobile device to provide real-time information and action during times of energy constraints or on demand.

Dual objectives are pursued through the trial, one, to determine the feasibility and requirements of creating such a testbed (TRESCIMO's main objective) and two, to measure and the test customer behaviour and response to demand response signals (ESKOM's main objective).

The experimental testbed created through TRESCIMO will provide a potential strategy on leveraging IoT as a cost effective methodology for using the internet to manage the demand in the future.

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