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Large Scale Testbed for Intercontinental Smart City Experiments and Pilots – Results and Experiences

Louis Coetzee[1], Marisa Catalan[2], Josep Paradells[2],
Anastasius Gavras[3] and Maria Joao Barros[3]

[1]CSIR Meraka Institute, Pretoria, South Africa
[2]i2CAT Foundation, Barcelona, Spain
[3]Eurescom GmbH, Heidelberg, Germany

Abstract

The challenges that cities face today are diverse and dependent on the region they are located. Inherently cities are complex structures. To improve service delivery in these complex environments the cities are being augmented by "Internet of Things" (IoT) and "Machine to Machine" (M2M) type of technologies that lead to the emergence of extremely complex Cyber-Physical Systems (CPS), often referred to as "Smart Cities". To support choices for technology deployments in Smart Cities, one has to gain knowledge about the effects and impact of those technologies through testing and experimentation. Hence experimentation environments are required that support the piloting and evaluation of service concepts, technologies and system solutions to the point where the risks associated with introducing these as part of the cities' infrastructures will be minimised.

With this rational, the TRESCIMO (**T**estbeds for **R**eliable **S**mart **C**ity **M**achine to **M**achine **C**ommunication) project deployed a large scale federated experimental testbed across European and South African regions, allowing for experimentation over standardised platforms and with different configurations. Among others, the main requirement for the testbed federation was to cater for the different contextual dimensions for Smart Cities in Europe and South Africa. The testbed is composed of a standards-based M2M platform (openMTC), using standard FIRE SFA-based management tools (FITeagle)

and including a variety of sensors and actuators (both virtual and physical). Furthermore, a Smart City Platform attached to openMTC hosts applications for a variety of stakeholders (i.e. experimenters or typical end-users). A series of experiments were conducted with the TRESCIMO testbed to validate the plug-and-play approach and Smart City Platform-as-a-Service architecture. This architecture is positioned to provide smart services using heterogeneous devices in different geographical regions incorporating multiple application domains. This chapter elaborates on, and validates the TRESCIMO testbed by presenting the experimental results and experiences from two trials executed in South Africa and Spain.

7.1 Introduction

Urbanization is a universal phenomenon with cities experiencing a significant growth in population. This in turn is increasingly stressing services provided in cities. Aspects related to the economic, societal and environmental challenges need to be effectively addressed to ensure quality of life of citizens as well as economic and environmental sustainability. Example challenges include finding means to address unstable power supply in cities in developing countries (i.e. South Africa) or ensuring a cleaner and greener environment for both developed (i.e. Spain) and developing countries.

Smart Cities have been touted as a possible solution in addressing challenges in cities. A Smart City is associated with an environment containing sensors and actuators able to observe and influence, and appropriate communications mechanisms into back-end platforms hosting applications. Using the data acquired from the environment, applications can make smarter decisions to the benefit of the city and its inhabitants.

The concept of interfacing with the physical world and linking the data with digital services is referred to as Machine-to-Machine (M2M) and Internet of Things (IoT). In realising a Smart City through M2M and IoT the technological challenges are ranging from developing cost-effective sensors, supporting and maintaining these sensors, creating or using appropriate network connectivity means, utilising fit-for-purpose platforms as well as developing domain appropriate applications need to be resolved. Other aspects related to scale, heterogeneity, interoperability, and adherence to evolving standards complicate the context even more.

Introducing technology just for technology's sake is not appropriate, especially in an environment with financial constraints and with gaps in available resources (people as well as technological infrastructure). In a situation where technology is introduced, care should be taken to ensure the required societal and environmental impact as well. To minimize risk when introducing smart services in a city, especially when moving from a lab to a real world context suitable experiments need to be conducted first. With these experiments a better understanding of the challenges and potential for impact and innovation become possible.

Testbeds for **R**eliable **S**mart **C**ity **M**achine to **M**achine **C**ommunication (TRESCIMO) is a project aimed at understanding the complete context (both technology as well as society) when smart city solutions are created and rolled out in a city. The context also refers to instances where services and solutions might be geospatially far apart and if a service and architecture developed for one area can be utilised effectively in another area. TRESCIMO created an intercontinental research facility using state of the art standards and technologies for experiments associated with the real world.

Section 7.2 presents the TRESCIMO architecture and describes the trials executed in Spain and South Africa. Furthermore the section elaborates on the components used for the trials. Section 7.3 presents the trial experiments and results, while Section 7.4 presents views on the results. Section 7.5 concludes.

7.2 TRESCIMO Architecture

TRESCIMO created experimental facilities in the context of Smart Cities dealing with mass urbanization in both developed and developing worlds. These facilities aimed to identify and implement appropriate architectures for Smart Cities. The facilities also serve as means to investigate the utility and impact of services related to smart and green technological social innovation (e.g. the societal impact in energy management or greener environments).

Four dimensions were considered in TRESCIMO: a federated research testbed, a Platform-as-a-Service Proof-of-Concept, and for validation a Smart Energy trial and an Environmental Monitoring trial. Figure 7.1 depicts the reference architecture for TRESCIMO. Software components were developed that integrate and federate in a plug-and-play manner to experiment with, and address a variety of requirements [4–7] .

Figure 7.2 depicts the architecture and software components used to realise the reference architecture presented in Figure 7.1.

The software components in TRESCIMO utilises state of the art standards (e.g. oneM2M, CoAP, Core-Link, and OMA LWM2M device management) or innovates by leveraging prior art where no clear standards have yet emerged. Based on the needs of a particular set of use-cases the components can be

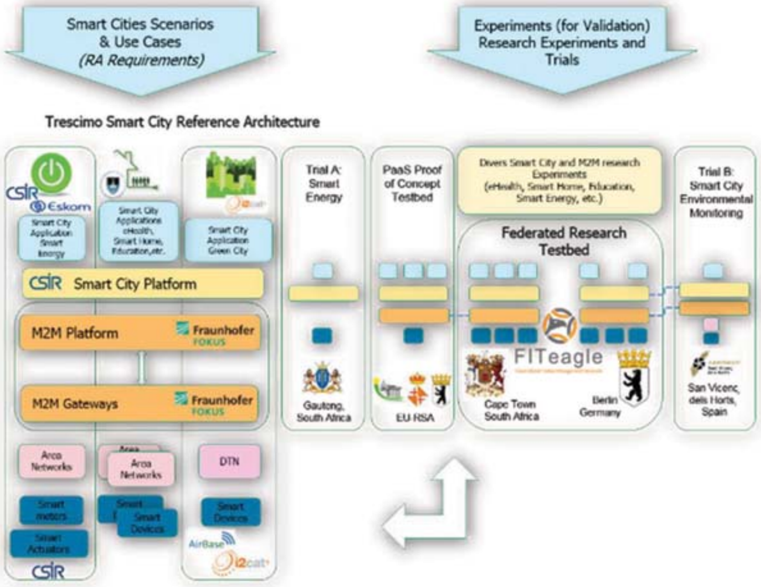


Figure 7.1 Reference architecture and experiments.

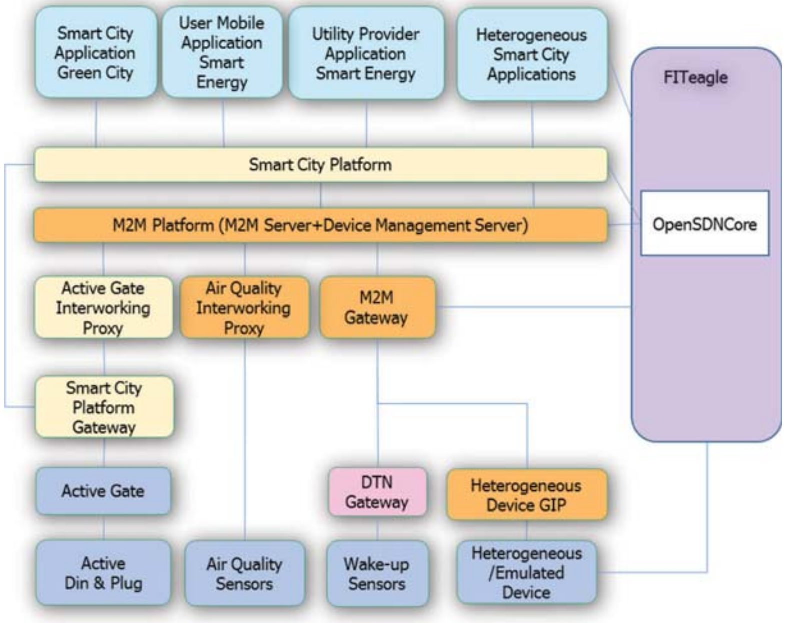


Figure 7.2 Integrated prototype architecture.

integrated by deploying an appropriate combination of software components. To validate the architecture and associated concepts a Smart Energy trial and a Smart Environmental Monitoring trial were conducted. The Smart Environmental Monitoring trial was executed in Vicenç dels Horts, Barcelona, Spain, while the Smart Energy trial was ran in Sandton, Fourways, Sunninghill and Randfontein in Johannesburg, South Africa.

7.2.1 Smart Environmental Monitoring Trial

The Smart Environmental Monitoring trial utilises components as depicted in Figure 7.3. The trial uses smart sensors (wake-up devices and air quality sensors), gateways with delay-tolerant features to activate the wake-up sensors, an openMTC gateway and platform (oneM2M compliant), the Smart City Platform (SCP) and a visualisation application (Green City application). The aim of the trial was to deploy a solution that monitors non-critical environmental and pollution parameters in a city without the need for deploying or relying on purpose built infrastructure.

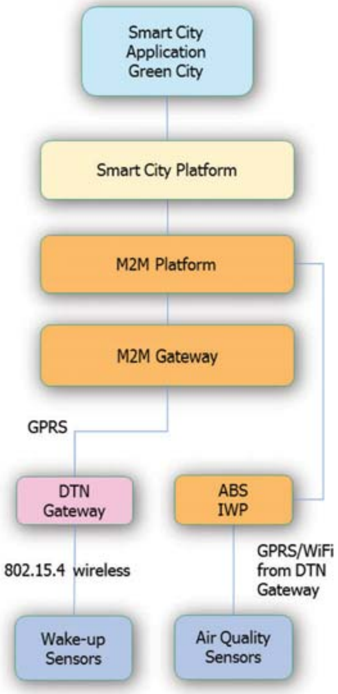


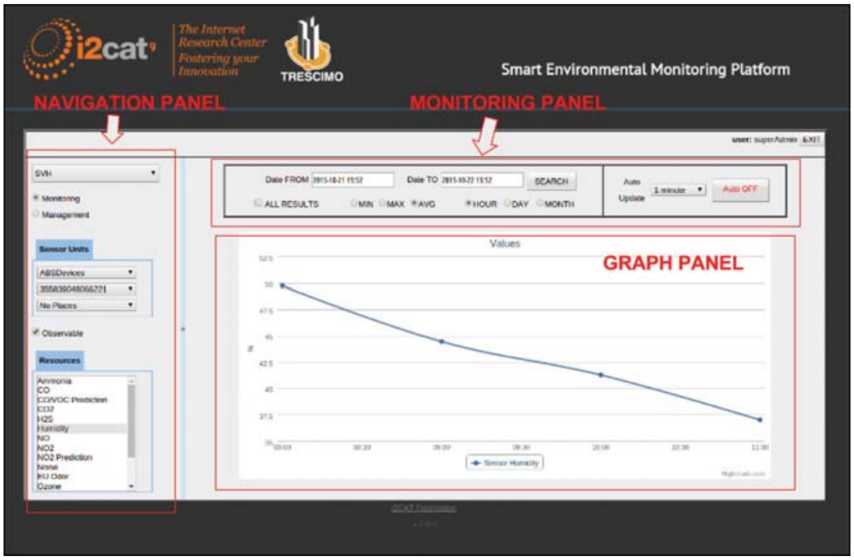
Figure 7.3 Smart Environmental Monitoring use-case architecture.

The system is based on a Delay Tolerant Network (DTN) concept, where a gateway, installed in a public transportation bus, is used as the sole element to collect the data from sensors installed in the city close to the route followed by the bus. To prevent battery powered sensors (installed in light posts, bus stops and other street furniture) from battery starvation while continuously waiting for the next gateway to collect their information, an energy-efficient radio wake-up mechanism has been implemented. This mechanism uses two separate radio interfaces in the low-power sensor nodes and the sensor: an 868 MHz interface that consumes less than 3 μW in listening state; and an IEEE 802.15.4 radio interface that is only active to transmit or receive data. Sensors are mostly in a "sleeping" state (only the low-power radio is active) and isolated (no network is present). When a collector device (the gateway installed on the bus) comes close to the sensors, the communications interface in the sensor is enabled, triggered by the low-power radio, and observations are captured and communicated to a gateway from where they are transferred via the M2M platform, through the SCP and finally to the environmental visualisation dashboard. The radio wake-up mechanism has been designed with enhanced features allowing device addressing and an extended range of tens of meters. In addition, air quality sensors, equipped with a WLAN or GPRS interface, were installed in buildings owned by the municipality since they require continuous power. The DTN-based gateway provides a WLAN interface to collect the data from nearby air quality sensors.

The Smart Environmental Monitoring trial dashboard is presented in Figure 7.4. It provides functionality to a user to view observation readings over time for a specific resource (either the ones associated with the delay-tolerant network or those connected directly to the backend).

7.2.2 Smart Energy Trial

Figure 7.5 depicts the components used for the Smart Energy trial. The trial used Internet enabled energy measurement devices (referred to as Active devices) and a gateway linked to the Smart City Platform via a Smart City Platform Gateway application. The Smart City Platform hosts a web dashboard application for the energy utility as well as a mobile enabling application which is linked to a mobile app. The applications are capable of visualising the consumption and actuate individual devices by switching them on or off based on user demand. The communication between the Active devices and the gateway uses a 6LoWPAN network, while communication to the Smart City Platform uses the 3G cellular network.



SVH

● Monitoring
○ Management

Sensor Units: ABSDevices; 355830048066271; No Places

☑ Observable

Resources: Ammonia, CO, CO/VOC Prediction, CO2, H2S, Humidity, NO, NO2, NO2 Prediction, Noise, HU Odor, Ozone

Date FROM 2015-10-21 11:52 Date TO 2015-10-22 11:52

☐ ALL RESULTS ○ MIN ○ MAX ● AVG ● HOUR ○ DAY ○ MONTH

Auto Update 1 minute

Figure 7.4 Smart Environmental Monitoring dashboard.

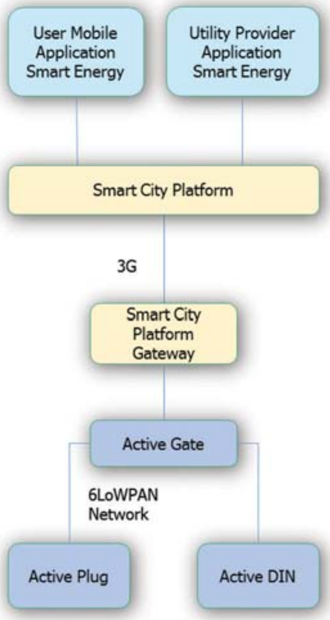


Figure 7.5 Smart Energy use-case architecture.

Last Updated:
23-09-2015 10:04:59

Figure 7.6 Energy mobile application.

Figure 7.6 presents a view of the mobile app for household owners. The app presents consumption per individual appliance or aggregated consumption for all appliances in a household. Figure 7.7 presents a web dashboard for an alternative view on the household consumption.

7.3 Trial Results

In addition to verifying the TRESCIMO plug-and-play methodology and Smart City Platform-as-a-Service concept, two trials with different aims were conducted.

The Smart Environmental Monitoring trial verified the feasibility of deploying infrastructure-less and energy-efficient data acquisition systems for Smart Cities and demonstrated the functionality of the TRESCIMO architecture in a real deployment. The Smart Energy trial focused on verifying the technological feasibility as well as gaining deeper understanding of customer behaviour when smart energy solutions are installed in households.

Through the validation and execution of the two trials numerous experimental results were obtained.

Data last received on: Thu Oct 01 2015 11:52:01

Device was ON a minute ago

Figure 7.7 Energy web dashboard.

7.3.1 Smart Environmental Monitoring Trial

Figure 7.8 depicts the various components chosen from the TRESCIMO technology stack for the Smart Environmental Monitoring trial.

7.3.1.1 Scenario and experiments

The trial was deployed in Sant Vicenç dels Horts, a Spanish city of about 28000 inhabitants close to a cement factory. Due to this last aspect, the municipality has a special interest in solutions to monitor environmental parameters and pollution in the urban area. The following devices were installed in the city:

- Five devices (provided by Airbase) dedicated to air quality and pollution monitoring;
- Thirty four low-power wake-up devices equipped with batteries and various environmental sensors (light, barometric pressure, temperature and humidity);

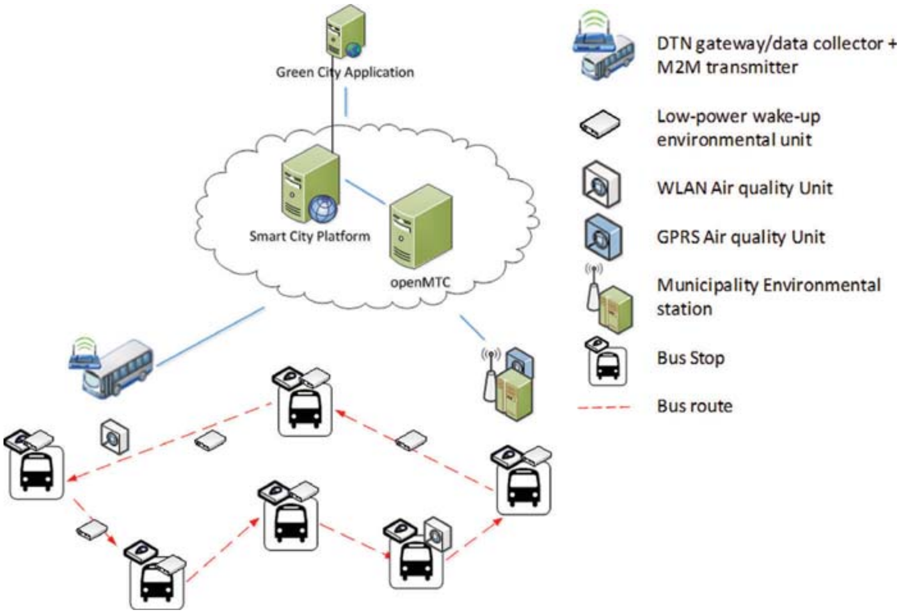


Figure 7.8 Smart environmental monitoring trial use case.

- One gateway device installed in a public transportation bus and two devices installed in additional vehicles to support the evaluation.

Figure 7.9 shows the placement of the sensor devices (in green the wake-up sensors and in yellow the air quality units) and the routes followed by the bus (data collector). The trial began in October 2015 and has been kept running after the finalisation of the project in December 2015.

Figures 7.10 and 7.11 depict several devices as installed in the city on light poles, bus stops and buildings.

Two types of experiments were conducted for the trial:

- **Acquisition of data from the sensors distributed in the city**. The objectives of this experiment are: 1) to prove that data can be collected in a delay-tolerant manner; 2) to study the performance of the DTN and wake-up based system in a real scenario and 3) to provide environmental data, that is useful to the municipality as a potential end-user of the solution, for surveillance or informational purposes. This information will serve also as input for future experimenters (e.g. to test or validate algorithms against real data).

Figure 7.9 Routes followed by the bus and location of the sensor units: low-power wake-up (green) and Airbase air quality (yellow) devices.

Figure 7.10 Sensor devices. Barometric wake-up device (*left*). Temperature, humidity and light wake-up device (*center*). Airbase WLAN air quality device (*right*).

Figure 7.11 Delay Tolerant Network devices. Bus passing close to a low-power wake-up sensor device installed in a bus stop. Detail of the equipment (gateway) installed in the bus.

- **Communication from the collector to the low power devices**. The aim is to validate the bidirectional communication between the collector and the wake-up sensor devices. Bidirectional communication allows the collector to gather data and to interact with the devices (e.g. for reconfiguration, performing firmware updates over the air or polling) in a delay-tolerant manner.

For the Smart Environmental Monitoring trial, the following Key Performance Indicators (KPI) have been identified:

- **Acquisition of data from the Wake-up and Airbase sensors and functionality validation of the full stack**. The data monitored from the sensor devices should be collected and forwarded through the TRESCIMO architecture. It should be possible to view the information using the client web interface (Figure 7.4).
- **Device energy consumption (for the wake-up sensors)**. Wake-up devices should provide proof of low consumption and maximizing of their battery lifetime and, thus, minimize the cost of maintenance of the installed devices.
- **Communication range (for the wake-up sensors)**. This parameter is directly linked to the scalability and flexibility of the solution. The range must be large enough to confirm that a moving vehicle can collect the information without the need for stopping or reducing its speed.

Furthermore, the range of the solution determines the size of the area where sensors can be installed and, thus, the amount of devices that can be supported by each route. Before installing the wake-up units in Sant Vicenç dels Horts, individual tests were performed in a controlled scenario with the transmitter and the receiver in Line of Sight (LoS) conditions to get an idea of the optimal performance (best case) in terms of range that can be expected. The minimum range observed in these experiments was about 36 meters and almost 50% of the devices responded to wake-up signals at a distance of 50 meters or greater. The expected performance in the real scenario should be close to these values.

- **Communication time window and amount of data that can be transmitted or received during the wake-up process**. These figures can help to determine how much information can be sent from the sensor devices to the collector in the bus (data gathering) and in the opposite direction. These figures establish the capabilities of the system to support device configuration or firmware updates over the air.

For the evaluation of the trial, the following tools and inputs for the analysis are used:

- Tracking of the data monitored by the sensor devices; namely, environmental parameters, battery consumption, and timestamp when the collector module in the DTN-gateway acquires the data. This information is stored during the trial and can be retrieved from the Smart City Platform (SCP). It can be visualised by a user through the web visualisation dashboard interface (Figure 7.4).
- Tracking of the GPS location data on the buses. Location and timestamp observations are sent each time a wake-up process is triggered so that it can be correlated with the wake-up process and with the reception of the sensor data. This information is stored during the trial and can be retrieved from the Smart City Platform (SCP).
- Tracking of the functionality of the wake-up mechanism. The following parameters are recorded for each wake-up process: timestamp when the wake-up node responds to the triggered radio signal, number of attempts performed until a successful wake-up is received, distance to the sensor node, and unsuccessful and unexpected wake-ups. The distance to the sensor node when a data message is received is an indicator of the effective communication range. Unsuccessful wake-ups are determined when the transmission of the wake-up signal exceeds a given number

of retries, which is a configurable parameter in the DTN-based gateway. This information added to the statistics about the number of attempts performed for the nodes in the trial provide insight into the performance of the wake-up mechanism. Unexpected wake-ups indicate the reception of data from a node that has not been prompted; this can help to detect interferences from external sources that might affect the performance of the overall system.

7.3.1.2 Evaluation results

Key results obtained from the evaluation of the Smart Environmental Monitoring trial taking into account the aforementioned Key Performance Indicators are presented in the following subsections.

7.3.1.2.1 *Visualisation and monitoring of the data transmitted by the sensor devices*

A subset of data monitored during the trial is shown to illustrate the end-to-end performance of the system. The monitored samples were obtained by the wake-up low power sensors and the Airbase air quality devices. Note that data is sent by the devices, collected by the gateway, forwarded by the openMTC platform and stored in the Smart City Platform (SCP); thus, the full TRESCIMO architecture can be validated. Further results have been reported in the project deliverable which is publicly available [3].

Figure 7.12 illustrates the visualisation of data monitored by the wake-up sensor devices during the period from November to January. Sensors were programmed to capture instantaneous data samples only when the wake-up is performed. Thus, connectivity gaps at night and on Sundays are visible. The operation of the system during the trial months was also affected by the unavailability of the bus due to mechanical problems and maintenance operations. This prevented the gateway from collecting data from the sensors for hours or even days at a time. The information gap observed in the web application from the 20th to the 28th of November 2015 is a result of this.

Figure 7.12 displays the changes of the temperature in Device_16. The device is installed on a light pole that has direct solar exposure. The first week of November has been especially warm in Barcelona and its surroundings. This explains the high values (above 30°C) monitored by the temperature probe. It is noticeable how the maximum temperature dropped during December and January, as would be expected for the winter season.

Figure 7.13 displays the NO_2 hourly average measurements captured by one of the Airbase air quality stations. The Airbase devices allow data sampling

Date FROM 2015-10-25 11:33

Date TO 2016-01-19 11:33

● AVG

● HOUR

Auto Update 1 minute

● Monitoring

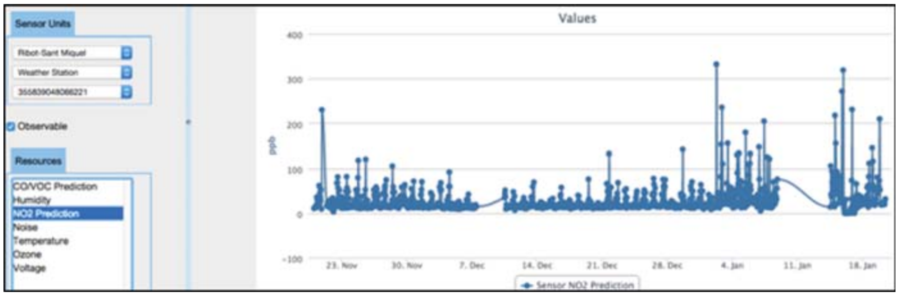
Av. Torrelles

Light Pole

Device_18

☑ Observable

Figure 7.12 Temperature measurements captured by a low power wake-up device in Sant Vicenç dels Horts.



Ribot-Sant Miquel

Weather Station

355839048066221

☑ Observable

NO2 Prediction

Figure 7.13 NO_2 measurements captured by the Airbase air quality device.

and storage while no network is available. Devices were configured to obtain a measurement every 10 minutes. Spikes whose values are slightly over the recommended healthy limit are noticeable. According to the EPA Air Quality Level [2], values above 101 ppb over one hour period are considered unhealthy for sensitive groups. Though spikes appear in a spurious manner, a continuous surveillance of the air quality will be useful to the municipality to control their repeatability and analyse their possible causes.

7.3.1.2.2 *Performance of the DTN and wake-up system*

As commented previously, one of the enhanced features of the deployed wake-up system is the support for device addressability. Each wake-up sensor device has been programmed with a predefined IEEE 802.15.4 short address and a 2-bytes wake-up address. In the trial, devices use a unique wake-up address to verify the unicast capabilities of the wake-up system. Multicast/broadcast addressing has been also validated by configuring the wake-up addresses of devices in close proximity with the same value. The usage of unicast and multicast addresses will be an interesting capability when a large number of sensors are installed in the city and different kinds of services are deployed. In this way, it is possible to wake up a sensor or a group of sensors on demand (for example, for configuration needs), while the rest of devices in the vicinity remain in low power mode.

To obtain empirical results in a controlled LoS scenario, the gateway has been configured to wake-up the sensor devices when its distance to the units is equal or less than 50 meters. This distance assumes a straight line of sight; however, in a real deployment the distribution of streets, driving directions and objects (buildings, other vehicles, and traffic signals) act as obstacles in the communication between the gateway in a moving bus and the wake-up sensor. To improve the success rate of communication in such uncontrolled scenario, the gateway can execute several wake-up attempts.

Figure 7.14 illustrates the average wake-up distance and the standard deviation (in meters) for the sensors involved in the trial from the beginning of November until the end of April. As observed, the deviation is considerable

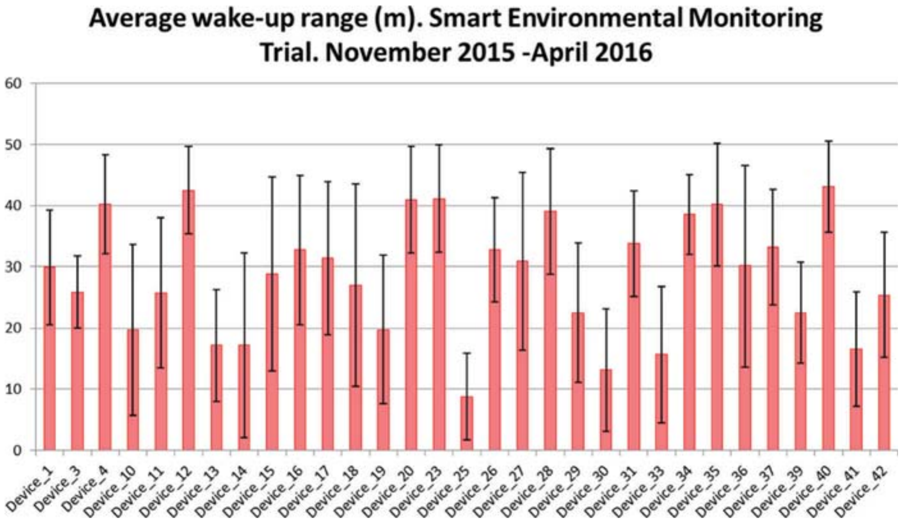


Figure 7.14 Average wake-up range of the DTN and wake-up based solution (in meters).

in all the cases; however, this is an expected result in a real mobile scenario where the performance of the communication can be affected by a multitude of external and variable factors. Most of the sensor devices show effective wake-up distances greater than 20 meters. A small number of devices show a poorer result. This can be explained because of their location on street edges, turnarounds or behind traffic signals. Collectively, the mean range observed for all the devices over the full trial period is greater than 28 meters. This confirms that wake-up technologies are a feasible option to retrieve information from the city. Wake-up nodes installed behind a traffic light or a street crossing sign experience a lower performance in terms of effective range and higher percentage of unsuccessful wakeups. Unsuccessful wake-ups can occur due to two reasons: (a) the maximum number of wake-up attempts is reached or (b) the bus goes out of the wake-up range of the sensor. The first cause can be explained by the bus turning a corner without direct visibility to the sensor device, especially if the bus comes from a non-preference road or there is a traffic light that forces a stop for a long duration. In the second case, it should be noted that the amount of time the vehicle is in the range of the sensor and, thus, the possibility to wake the device up and establish communication will decrease with higher speeds. On average, the percentage of unsuccessful wake-ups is below 8%. This can be considered a good performance in a real deployment and under non-ideal and variable conditions. Finally, in almost all the cases a maximum wake-up range exceeding 48 meters was observed. The significant wake-up range validates the promising capabilities of the wake-up mechanism implemented and deployed in the trial. These results serve as input to determine what the best locations for the sensor devices are. The results provide insight into the optimal settings to maximize the performance of the wake-up system and to infer some recommendations that can be useful for future deployments.

7.3.1.2.3 *Consumption of the wake-up sensor devices*

In the trial, the battery consumption of the low-power devices is reported as a parameter in every data message. A trend over time can be visualised and monitored. The energy usage of the device sensors over the long-term can thus be monitored. Figure 7.15 provides a screenshot of the Smart Environmental dashboard interface showing the average daily battery consumptions from November to January for a sensor device (Device_41). The fact that no relevant battery drops are observed in this period confirms that the device energy consumption is performing as expected and that the devices are in a low-power mode status most of the time. Note that the nominal value of the battery used for the wake-up sensor devices is 3.6 Volts.

Date FROM 2015-11-05 00:00

Date TO 2016-01-19 10:51

Auto Update 1 minute

Figure 7.15 Battery evolution of the low power wake-up devices.

7.3.1.2.4 *Performance of the data collection process and device update capabilities*

Tests were performed to determine the communication time window and the amount of data that can be transmitted in the uplink direction (from the sensor device to the DTN-based gateway). To conduct this test the sensor device was configured into a mode where packets are sent in a continuous manner to the coordinator in the gateway. Tests were performed at several speeds to simulate different scenarios. To allow for repeatability of the test and provide more flexibility to control the speed of the mobile gateway, a particular vehicle was used for this evaluation. The experiments were performed using one of the sensors of the deployment installed on a lamp post and in the middle of a straight street (to maximize the visibility between the gateway and the sensor device). From the results obtained it can be concluded that the infrastructure-less system implemented in the trial allows the devices to store and, at a later time, send a considerable amount of data (between 30 and 40 kB) at a speed of 30 km/h between two consecutive bus journeys. This is interesting for a real world deployment as the frequency of public transportation might be notably low; for example, as in the case of the trial, some buses do not drive over the weekend.

To validate the bidirectional functionality, it was confirmed that the gateway is capable of changing the sampling rate and the wake-up address of the sensor units in a delay-tolerant manner. Furthermore, it was possible to send a message to the unit to reboot it and to query its current firmware version and configuration settings. By default, the wake-up sensor device operates in low-power mode; thus, once the wake-up is performed, a data request to the coordinator in the gateway is performed requesting data. At that moment, the configuration message is sent to the sensor unit. Once received, the wake-up device needs to confirm the instruction with an acknowledgement (either positive or negative) that the operation has been completed and the setting has been updated or discarded. When several consecutive packets need to be transmitted to the environmental equipment (e.g. to perform an over-the-air firmware update), the DTN-gateway would send a message to the gateway to indicate that it must switch to active mode (always listening) so that data is transmitted faster. As the IEEE 802.15.4 link is peer-to-peer and symmetric, the amount of data that can be transmitted during a wake-up process is equivalent to the results obtained in the bulk data tests performed from the sensor unit to the gateway.

7.3.2 Smart Energy Trial

In the Smart Energy trial (Figure 7.16), 30 Eskom households were equipped with the Active devices for monitoring the energy consumption (one ActiveGate using 3G backhaul to the Smart City Platform, two ActivePlugs for appliances and an ActiveDIN used for higher current appliances such as a geyser or pool pump).

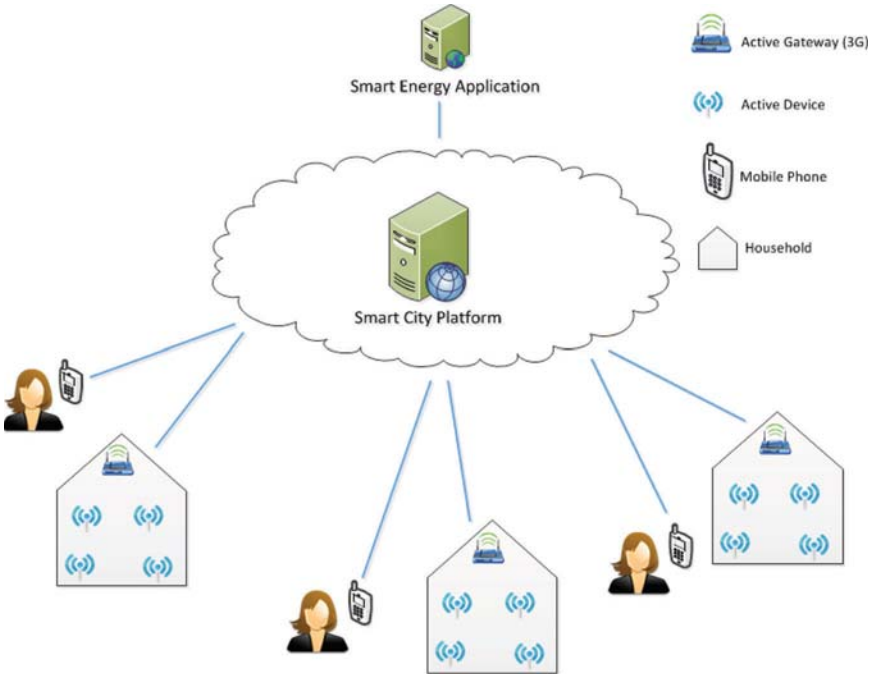


Figure 7.16 Smart Energy trial use case.

Figure 7.17 Active devices (ActiveDIN on the *left*, ActivePlug *center* and ActiveGate on the *right*).

ActiveGate is a processing and routing platform, while the ActivePlug and ActiveDIN are energy management devices. Figure 7.17 depicts the ActiveDevices. In addition, a household owner had the Smart Energy mobile app installed on his smart mobile phone.

The three devices (ActivePlug, ActiveDIN and ActiveGate) communicate using a 2.4 GHz 802.15.4 radio module based on the STM32W108 System-on-Chip (SoC) from STMicroelectronics. The RF microcontroller (the STM32W108 SoC) performs the low power wireless mesh networking function and hosts a CoAP server with the device resources. The application is built in the Contiki-OS framework.

ActiveGate uses an Odroid-U3+ single board computer with a 1.7 GHz Exynos4412 Prime ARM Cortex-A9 quad-core processor, 2GB RAM, and various external interfaces. The ActiveGate runs Ubuntu 14.04 LTS Linux as operating system. The ActivePlug and ActiveDIN use STPM01 metrology circuitry for measuring voltage, current, power, line frequency as well as active, reactive, apparent, and fundamental energy consumption and an ARM Cortex-M4 microcontroller for managing the metrology, load switching, and interface functions. The Cortex-M4 microcontroller from Atmel contains a bare-metal application (no operating system) that continuously reads the energy metrology chip and performs the energy related calculations. The results are sent to the RF microcontroller at a rate of 2 Hz.

7.3.2.1 Scenario and experiments

Four aspects as related to the energy trial were investigated:

- Energy consumption awareness;
- Behavioural change;
- User experience using the mobile application, and
- Technology performance metrics.

To gain understanding into the homeowner, questionnaires were utilised (one during installation and another during decommissioning). The questionnaires also served as platform for the trial participants to voice their opinions regarding the particular technology solution and similar systems in general. Technology performance metrics were obtained through experiments and measurements through the stack using the various physical installations.

7.3.2.2 Evaluation results

7.3.2.2.1 *Energy consumption awareness*

Table 7.1 presents results as extracted from the pre-trial questionnaire in relation to awareness. It should be noted that all the participants were from a high "Living Standards Measure" category and also had pre-existing smart meters installed.

Trial participants responded as follows in the post-trial questionnaire (Table 7.2):

An important aspect highlighted is the participants' energy consciousness. In the context of the energy constraints during the trial this is insightful as it implies that through this technology people can become even more cognisant of energy limitations.

7.3.2.2.2 *Behavioural change*

As the trial participants already had smart meters installed, comparisons over the course of the trial with readings from the year prior to the trial were possible. Results indicate that no clear and consistent change in consumption was visible. The consumption was varied and ranged from significantly increased consumption, significantly decreased consumption, and very small changes. This indicates that users in general did not utilise (or were not able to utilise) the smart mobile app to control their load. However, load control

Table 7.1 Pre-trial questionnaire summary

	Yes	No
Awareness of energy consumption: *Do you track your consumption?*	62%	38%
Response to behaviour change request: *Do you respond to TV and radio power alert requests to switch off appliances when requested?*	80%	20%
Willingness to change behaviour: *Would you change your consumption patterns for reduced rates or rebates?*	85%	15%
Device control: *Do you have timers for control of devices installed?*	71%	29%
Control preference: *Do you prefer to switch your non-essential loads yourself?*	86%	14%

Table 7.2 Post-trial questionnaire summary

	Yes	No
Energy Consciousness: *Are you more energy conscious than before the trial?*	69%	31%
Change in consumption: *Did you notice any changes in your consumption?*	Reduction: 54% Increase: 0%	No change: 46%
Motive for change: *What will potential motive for change be in response to reduced rates or rebates?*	Financial: 31% Security of Supply: 46% Social: 8% Security of supply and financial: 46%	
Control preference: *Do you prefer to switch your non-essential loads yourself?*	85%	15%
Communication Medium: *Would you prefer to receive messages via your cell phone or rather alerts via TV or radio?*	100%	0%

was possible and utilised by some participants as illustrated in the following two figures. Figure 7.18 depicts consumption readings on a geyser (hot water boiler) where the household occupant did not control its appliance. This is in contrast to Figure 7.19 where the occupant did choose to intervene and control when the geyser should be switched on.

7.3.2.2.3 *Mobile app*

Trial participants only had access to information from connected appliances via the mobile app as depicted in Figure 7.6. The web interface as presented in Figure 7.7 was used by the project partners to verify operation of the trial components. Results indicate low utilisation of the mobile app. This can be attributable to challenges experienced with the mobile app itself. For example it was reported that quite often login via the app was problematic. Furthermore a low general interest was observed in gaining access to the current state of consumption. User utilisation varied considerably. Results indicate that four trial participants made use of the app (two significantly more than the other two), while most trial participants did not.

Participant 7 logged in 196 times with 45 “on” and “48” off commands. Participant 12 logged in 79 times with 42 “on” commands and 40 “off” commands. Participant 18 logged in 208 times, with 95 “on” and 79 “off” commands. The fourth participant logged in on 51 occasions and executed 14 “14” on and 16 “off” commands. Viewed in conjunction with Figure 7.20, participant 7 and 18 experienced good uptimes of the complete system.

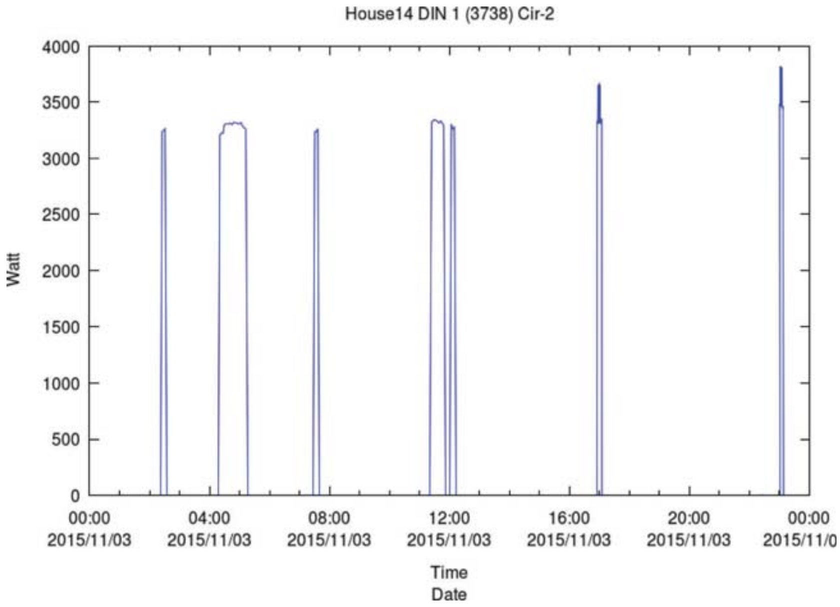


Figure 7.18 No appliance control.

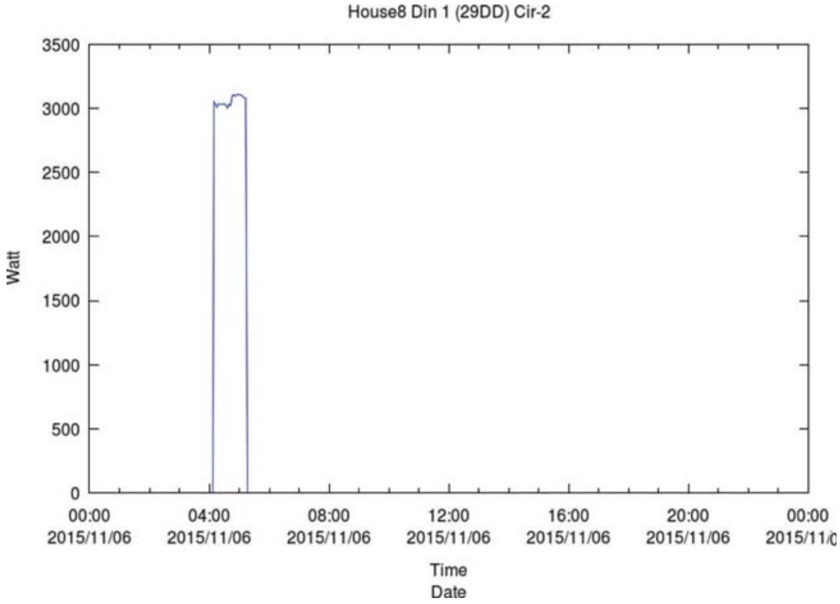


Figure 7.19 Controlled appliance.

7.3.2.2.4 *Technology performance metrics*

The technology performance metrics reveal a number of interesting aspects. These are attributable to the stability of the technology and communication effectiveness, as well as constraints related to trial participant access during the trial. Figure 7.20 depicts the measured uptime per household during the duration of the trial. The uptimes vary considerably within households. The uptimes are calculated based on the number of observation data points captured in the database (i.e. data flow throughout the complete stack from sensor to application). This measurement is a good indication of the overall performance of the technology stack. However, no conclusions can be made as to which component impacted on the performance when challenges were experienced. For instance, what in the stack prevented data flow (i.e. was it a failure in backhaul connectivity, a device that has gone down or unavailability of other components in the stack)?

Throughout the duration of the trial, updates of software on the accessible ActiveGates were done. This included monitoring and control software able to detect if a software component has failed and, thus, needs to be restarted. However, this functionality and new software releases could only be installed on those devices having adequate communication. Uptimes in

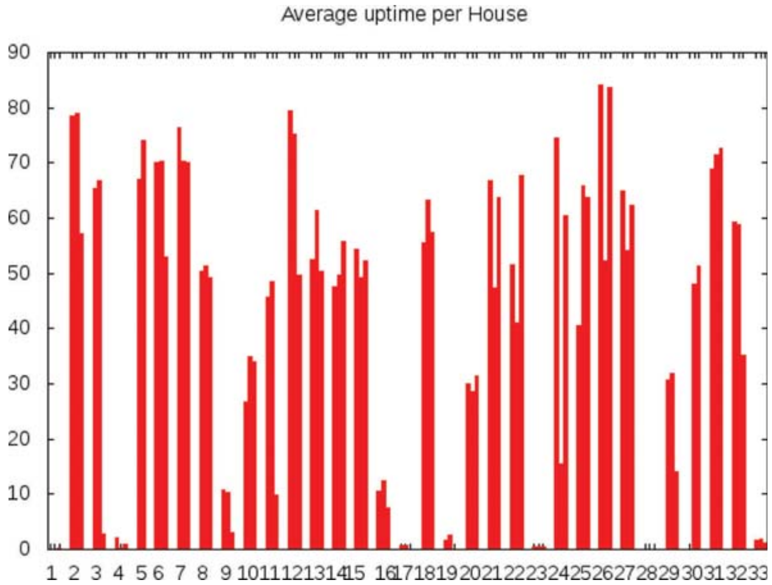


Figure 7.20 Average uptime per house.

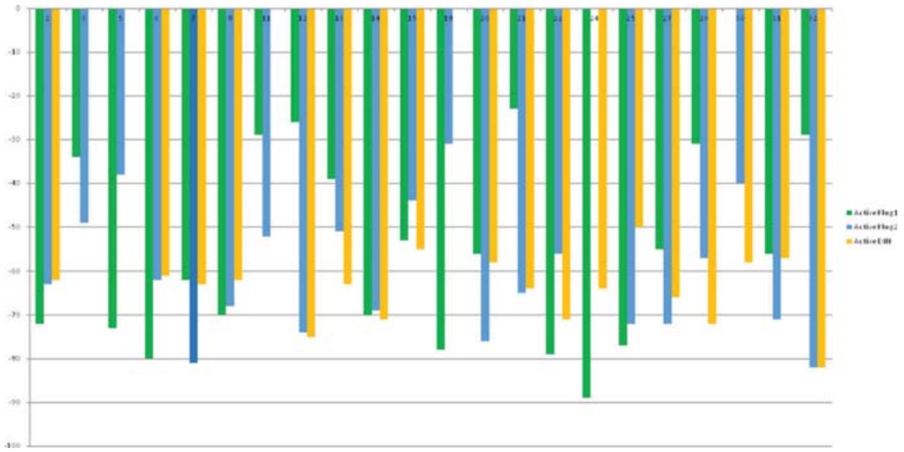


Figure 7.21 6LoWPAN.

general improved for installations with good communication, while those with poor communication (who would have benefited more from the updates) were limited to the initial configurations and releases. The Active devices made use of 6LoWPAN connectivity within a household. A significant variation in signal strength is visible between devices in a household as well as between households. Figure 7.21 depicts RSSI measurements in some households. Within households the signal strength varied significantly.

7.4 Discussion

7.4.1 Smart Environmental Monitoring Trial Observations

In relation to the system performance, the results of the Smart Environmental Monitoring trial obtained so far are promising and confirm the expectations. It demonstrated that solutions based on radio wake-up systems and DTNs allow for information collection while minimizing the number of devices that need to be deployed and maintained. Sensor devices have been designed to ensure energy-efficiency and maximize the battery lifetime and as a consequence reduce the operating expense (OPEX). Furthermore, the improvements achieved by the project with the enhanced wake-up system led to communication ranges of more than 40 meters (28 meters on average). Experiments confirm that the range is sufficient to retrieve data from a moving vehicle. Finally, addressing techniques permit to univocally determine the sensor device to be woken up; this opens the possibility to deploy differentiated services in the city without real-time requirements (e.g. waste collection, environmental monitoring and water irrigation) using the same approach. The results not only validate the approach but also the interconnection and integration of delay tolerant features with the openMTC platform.

With this concept, the performance of the system deployed in the TRESCIMO project provides a significant outcome since it shows that an alternative way of building a Smart City is possible. Until recently, sensing a city required deploying sensors on the street and a set of devices (forwarders) that can collect data from sensors and transfer the data to a collecting point (gateway). From there, data is sent to a central element where data is stored and can be processed. The deployment of forwarders and gateways in the city is costly since they need to be connected to the mains and in the case of the gateway to have connectivity to the network. The solution used in the Smart Environmental Monitoring trial solves some of the difficulties listed. It suppresses the use of forwarders and instead uses gateways installed on vehicles (public transportation buses in this case) that move along the city. The installation and maintenance of a gateway is much simpler since it can be done when the bus is in the garage where sufficient power is readily available. The main limitation of the solution is the lack of real-time reporting. This is the reason why this solution is described as being delay tolerant. However, there exist many smart city services without real-time requirements (e.g. environmental monitoring, garbage collection, street furniture maintenance, water irrigation, and smart meters) to which this solution is applicable. The approach can have a further impact since the bus can be equipped with sensors that measure relevant parameters while the bus is moving. This offers an enhanced paradigm for data acquisition; often sensors capture data at a fixed location while through the instrumented bus sensing becomes possible along a variety of routes.

Another outcome from the project is the availability of an experimental network in the city. The equipment deployed in the city is and will remain available to any experimenter. In fact, sensors can be accessed quite easily to retrieve data from them directly since very simple mechanisms are used. Also, the gateways on the vehicles are integrated with the openMTC platform; so their resources could be accessible by a third party through the M2M platform.

A relevant outcome is the municipality recognition. The city is close to a cement factory and citizens are concerned about air pollution. This is an issue in the municipality and proof of this is the fact that the city has two fixed environmental stations, one from the autonomous government and one from the cement factory. This is very rare, since most of the municipalities in Spain have no monitoring station at all. The usage of the TRESCIMO technology provides detailed environmental monitoring. This allows citizens to be more aware of pollution in the environment. The municipality of Sant Vicenç dels Horts are pleased with the experience gained in the trial and is convinced that the model supports the building of "more cost effective Smart Cities" based on delay tolerant networks. Using a delay tolerant approach is more suitable for a medium size city than deploying and maintaining a purpose built infrastructure.

7.4.2 Smart Energy Trial Observations

Important aspects and learning were gained in the process of running the South African Smart Energy trial. Actual residential Eskom customers were included in the trial. This necessitated approval from a number of business divisions within Eskom. It also implied that intrusion into the participant's home and daily lives be kept to a minimum and that mechanisms were in place to provide training to the customer, provide continuous support (in the form of a call centre), minimize any possible risk to the participant's property and ensure that the household was restored to the same state upon decommissioning. In minimizing intrusion into the participant's home (a total of only three in-person engagements were done per participant), support and maintenance of devices and gateways could only be done online. This in itself created a problem when a device was offline as no means were available to reset a particular device. It also became clear during the duration of the trial the inherent tension in providing a near perfect operational environment where all risks were removed against a research and development context where failures and downtimes are expected (in hardware, communication, as well as services).

A number of challenges were experienced during the trial. Most significantly backhaul connectivity from the household to the Smart City Platform proved to be a challenge. The trial used cellular communication hosting a VPN connection. Cellular coverage in South Africa varies significantly. In the trial, bandwidth throughput to gateways varied from 1.3 Mb/s to only about 20 Kb/s. In some cases, no connectivity from household to backend was possible. Naturally, the low bandwidth was problematic as connectivity was intermittent, over-the-air updates were difficult and interaction through the gateways at times almost impossible. This however is a valuable observation and result from the trial. The assumption has been made that cellular connectivity would be sufficient, but it is not the case, thus requiring other connectivity solutions in addition to the cellular network. A DTN solution as for the Environmental Monitoring could have been useful, but it was not planned and thus not deployed in South Africa.

The 6LoWPAN signal strength in a household varied significantly and was in some cases very poor (depending on where the devices were installed relative to the gateway). This affected uptimes and data flow. The current gateway made use of an internal low gain antenna. The signal strengths indicate that this is not adequate. In lab setups and testing, gateway external antennas were used. With the external antennas, the stability and uptimes were excellent, in some instances six weeks went by without any communication failures. This implies that in future experiments the gateway will have to be fitted with an external 6LoWPAN antenna, in addition to an improved backhaul connection mechanism.

The trial was impacted by hardware failures, in particular Channel 1 in a number of ActiveDINs failed when under high load. This required an electrician to replace the ActiveDIN, or rewire Channel 1 to an unused channel.

The mobile app served as a means for the participant to access his own energy consumption. In minimizing possible disruption to the participant, a choice was made to use a trial specific email address for user authentication. This in retrospect was problematic as the user often defaulted into using his personal email with the result that he was not able to log in. Results from the trial were further skewed due to the downtimes experienced in connectivity. It can be noted that participants made use of the app where reliable connectivity was available. However, a broader set of results would have been possible if enhanced uptimes were obtained throughout the trial.

User experience from the trial was predominantly positive. Feedback indicated that opportunities exist to enhance the system (in hardware and software service reliability, connectivity, look and feel, and ergonomics of the devices), but also that the utilisation of next generation smart devices using the latest standards such as 6LoWPAN, CoAP can form the basis of smart demand side management solutions.

Through the trial, insight into the participant behaviour was obtained. Awareness of energy consumption was raised. Feedback from the participants also indicated that they would prefer to control their own environments and not have the utility do so remotely. Given this it is interesting to note that this was not a function often used by the participants.

7.4.3 General Observation

A key observation from the results presented is the utility and functionality of the TRESCIMO testbed. The aim was to come up with a plug-and-play approach supporting reconfiguration based on needs of a specific context. In the execution of the two trials, different components were used to experiment with and gather the results. The results obtained and the ability to execute the two very different trials supports the TRESCIMO approach and usability which were key requirements in the TRESCIMO vision.

7.5 Conclusion

The masses of people moving to cities are straining services provided by those cities. Smart City concepts are required to enhance the efficiencies of existing services, or to create new services. The impact and value of services are not always well understood. Similarly, the technologies and architectures required to actually implement those services are still evolving. To address these issues (i.e. to experiment with appropriate architectures in cities with applications introducing value) real world experimentation is required. TRESCIMO has created an international, intercontinental research testbed aimed at creating such an environment and to also validate the technologies, services and better understand the societal value introduced through these services.

The TRESCIMO architecture is based on standardized protocols and technologies where they exist, or by creating new innovative solutions for the technology stack where no standards exist or technology gaps are present. The architecture resulted from efforts to define and implement a reference M2M solution, which could be adapted and applied to very diverse use cases and scenarios and to different contexts. To prove the validity and flexibility of the solution, two trials were conducted, each with different aims.

In Spain, a Smart Environmental Monitoring trial was deployed that focused on the usage of an infrastructure-less system based on delay-tolerant networks to supervise environmental parameters and air pollution in Sant Vicenç dels Horts. The results of the trial led to promising results and have raised the interest of the municipality. The city is surrounded by several factories and, thus, pollution is a critical issue for its citizens. Furthermore, the proposed solution does not require a big investment in infrastructure and would be applicable to multiple services in the city that do not rely on real-time requirements. This aspect is very interesting for small and middle-sized cities that usually have limited resources. Finally, the results in Spain could in future open doors for new technology possibilities in South Africa; for example, the same approach used for infrastructure-less sensing can rapidly be deployed.

The South African trial focused on Smart Demand Side Energy Management. It explored the technical feasibility of components from the TRESCIMO technology stack for monitoring and managing instrumented appliances in a household. Furthermore, the trial interfaced with household occupants to better understand their needs and the perceived value of having access to Smart Energy management systems. The technology components used for the trial were validated and showed that such systems can be utilised in a developing world context. It further showed that these types of solutions have value to the occupant, given that the reliability of the technology is at an acceptable level.

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