REPLICATE	Project no. 691735 REPLICATE PROJECT Renaissance of Places with Innovative Citizenship And Technology	This Project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement N° 691735

REPLICATE PROJECT

REnaissance of PLaces with Innovative Citizenship And Technology

Project no. 691735

H2020-SCC-2015 Smart Cities and Communities

Innovation Action (IA)

D5.9 Development of ICT Smart City Platform concept and of integration of demonstration IT Systems

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1. EXECUTIVE SUMMARY

Our Bristol Smart City Platform (SCP) enables access to a variety of data sources, pertaining (amongst other things) to energy consumption in our smart homes, status monitoring of electric vehicles (EV) charging points, tracking of EVs and electric bike journeys etc. It allows a variety of stakeholders, such as the Council, SMEs or citizen interest groups, to develop solutions generating data and offers a way to store and integrate it meaningfully with other data streams on the platform. The overall architecture allows the development of solutions that capitalise on data access in order to build insights into patterns of energy and mobility services use and, where appropriate, react to ensure smooth city operations.

At the heart of the platform a layer of FIWARE middleware enables registration and collation of smart devices with associated periodic or event driven data. Those smart devices could be, for instance, energy usage monitors, energy controllers, air quality sensors, mobility sensors, lighting. These are generally grouped together under the title of Internet of Things (IoT) devices. That layer is responsible for contextualising the received data (e.g. adding metadata descriptions, linking to existing records of related information for a known entity etc.) and storing it appropriately in efficient back-end databases. We currently use MongoDB for this purpose but any database technology could be used to similar effect.

The overall network architecture ensures that data is transferred to the platform through secure connections. In the smart home context this is implemented as a virtual private network (VPN) between each monitored end point – i.e. each smart home installation in this instance that includes a Loxone mini-server, smart appliances and a smart plug per home – and the SCP platform. This type of privacy protection is necessary as the data of energy consumption is personal and potentially reveals presence (e.g. low demand indicates occupant is out), or other pattern of behaviour (e.g. the occupant is cooking or showering) and thus protected by the General Data Protection Regulations (GDPR) legislation. There is also a data sharing agreement (DSA) between Bristol City Council and data consumers establishing what data can be collected and how it is stored, used, retained and deleted. One of the main rules of the DSA is that data are anonymised (such that we don't see identifiers such as name, address and postal code.

The FIWARE layer of the SCP can also receive and respond to requests for data related to those devices from which analysis and decision support systems may act upon the provided information, such as our energy demand management system (EDMS). As

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Energy Providers and Network Operators must balance Energy Supply and Demand at all times, the flexibility of Energy Demand has become a valuable resource with financial and ecologic incentives. Our objective within REPLICATE is to demonstrate how by using our SCP along with and EDMS we can orchestrate the demand flexibility of small consumers into larger, more powerful optimisations.

The platform allows us first to combine the data from smart energy devices from multiple domains (currently homes and charge points). Upon establishing a baseline monitoring it is then possible to develop energy community programs (e.g. by retrofitting micro generation capabilities) with both monitoring and control logic, where self-learning management algorithms can cope with uncertainty in demand predictions.

Other application areas include monitoring of EV charging point operations by the Council's mobility teams. EV Charge Points implement the Open Charge Point Protocol 1.5 or 1.6, a method that among others sends messages to Charge Your Car's (CYC) back office when status changes. CYC is the network of charging points used in the area. Charge points are unlocked using a CYC radio-frequency identification (RFID) card that lives in the Co-Wheels vehicle, which is itself opened using the Co-Wheels membership club card.

BCC uses FME, a data integration and workflow service, to get the status of all charge points in the network every 2 minutes. Using FME, the data from REPLICATE charging points is filtered and the related data uploaded to SCP using FIWARE's bulk upload functionality on a service and devices that have already been provisioned (i.e. have been verified and enabled to access the network). BCC has also piloted the latest Open Charge Point Protocol 2.0 format for this. After data has been imported into the SCP, it is then possible for NEC to get this data for EDMS and Route Monkey for performing route optimisation via their app. Separately, BCC manually downloads monthly energy usage of REPLICATE charge points and sends this to NEC and Route Monkey in CSV format, to enable development of further analytics.

The SCP however allows for a wider range of urban applications to be developed. For example, we are deploying a mixture of limited high-accuracy environmental sensors, combined with larger volumes of devices of higher data point resolution (but potentially of lower quality measurements). This intervention is focussed on air quality monitoring and in particular on collating measurements from mobile groups (e.g. taxi drivers, cyclists), selected points of interest (e.g. schools) and selected areas in the city (e.g. from monitors installed on project area lampposts).

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To that effect we are combining deployments of proprietary scientific equipment monitored by the Council, along with citizen sensing kit created in Barcelona ('Smart Citizen'), the Array of Things lamppost sensors developed in Chicago as well as our own 'Ladybird' mobile air quality sensors, co-developed by the REPLICATE partners and citizens here in Bristol. We are looking preliminarily at around a dozen proprietary sensors to be deployed in lampposts around the city and about 120 Smart Citizen devices to be used by citizens at selected households/facilities. A number of the portable Ladybird monitors will also be deployed at selected routes across the city.

The use of our own sensors allows us to demonstrate the advanced network management capabilities of our region's infrastructure, as Zeetta's NetOS platform is used to enable safe access of these devices to the SCP. As opposed to leaving each such device to access a public and potentially unsafe network access point (NAP), through which access to the SCP would be attempted, those are now networked through dedicated virtualised NAPs that are managed by software. This allows greater flexibility in managing a potentially large volume of such devices and balance the anticipated traffic better, as well as control their access from a security perspective. This would be a key capability in any attempt to scale up the solutions to city-wide level.

Finally, Using the FiWare platform technology for this project has proved perfect as it is already open and contains useful API features that enable us to link to a wide variety of commercial, open source and bespoke developed visualisation and application development platforms. Relevant dashboards for a variety of viewpoints is feasible to be created and further work on this will commence in the near future.

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2. REPLICATE

The main objective of REPLICATE project is the development and validation in three lighthouse cities (**San Sebastián** - Spain, **Florence** - Italy and **Bristol** - UK) of a comprehensive and sustainable City Business Model to enhance the transition process to a smart city in the areas of the energy efficiency, sustainable mobility and ICT/Infrastructure. This will accelerate the deployment of innovative technologies, organisational and economic solutions to significantly increase resource and energy efficiency improve the sustainability of urban transport and drastically reduce greenhouse gas emissions in urban areas.

REPLICATE project aims to increase the quality of life for citizens across Europe by demonstrating the impact of innovative technologies used to co-create smart city services with citizens, and prove the optimal process for replicating successes within cities and across cities.

The Business Models that are being tested through large scale demonstrators at the three cities are approached with an integrated planning through a co-productive vision, involving citizens and cities' stakeholders, providing integrated viable solutions to existing challenges in urban areas and to procure sustainable services. Sustainability of the solutions is fostered in three areas: economic and environmental and finally, fostering transparency in the public management.

In addition, the Model features the replicability of the solutions and their scale up in the entire city and in follower cities, particularly in three follower cities (**Essen** - Germany, **Lausanne** - Switzerland and **Nilüfer**-Turkey) that are involved in the project and therefore, have access to know-how and results achieved on the project so they can apply the developed model. At the moment, there are 2 observer cities, Guanzhou (China) and Bogota (Colombia).

3. INTRODUCTION

3.1 Relation to Other Project Documents

The definition of the work plan of the REPLICATE project is essential for achieving an effective innovation management system. Apart from the reference documents described below the deliverable has no specific relation to other project documents.

3.2 Reference Documents

This document is based in the following projects level documents:

Ref.	Title	Description
REPLICATE Grant Agreement signed 240713.pdf	Grant Agreement	Grant Agreement no. 691735
DoA REPLICATE (691735)	REPLICATE Annex 1 – DoA to the GA	Description of the Action
REPLICATE Consortium agreement signed December 2015 (7th December version)	Consortium Agreement	REPLICATE project – Consortium Agreement
REPLICATE Project Management Plan	D1.1 Project Management Plan (v.1) (29/04/2016)	REPLICATE Project Management Plan
REPLICATE District Management Plans	D1.4 District Management Plan San Sebastian D1.5 District Management Plan Florence D1.6 District Management Plan Bristol	REPLICATE District Management Plans
REPLICATE Communication Plan	D11.1 Communication Plan	REPLICATE Communication Plan

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Where there are contradictions, the documents listed above supersede this deliverable. The Grant Agreement is the contract with the European Commission so takes precedence over all other documents.

3.3 Abbreviations List

GA	Grant Agreement
CA	Consortium Agreement
DoA	Annex I–Description of the Action
EC	European Commission
H2020	Horizon 2020
PC	Project Coordinator
PL	Pilot Leader
PMP	Project Management Plan
TC	Technical Coordinator
WP	Work Package
WPL	Work Package Leader
EDMS	Energy Demand management System
SDN	Software Defined Network
IOT	Internet of Things
BIO	Bristol is Open
SCP	Smart City Platform
VPN	Virtual Private Network

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4. DELIVERABLE DESCRIPTION

This document explains the Development of the ICT Smart City Platform concept in Bristol and the integration of demonstration IT Systems. This information is explained under these sections:

Section 1 – Executive summary from Bristol ICT Platform

- This is the executive summary from the Bristol ICT platform group led by University of Bristol, Zeetta Networks and Bristol is Open. We aim to give a strong, comprehensive introduction to the ICT work in the Bristol Replicate Project.

Section 2 – Summary of the Replicate Project

- This is a summary of the Replicate Project provided to give a reference point for the overall project and its governing principles.

Section 3 – Introduction to the Document

- This introduces the document and provides a reference for abbreviations and referenced documents.

Section 4 – Description of the deliverable document

- Description of the deliverables document for the Bristol ICT Platform.

Section 5 – Description of Bristol strategy regarding the Smart City Platform

- This section provides an overview of the Bristol City strategy regarding the Smart City Platform and the outcomes of the replicate project.

Section 6 – Architectural Design Evolution of the Bristol ICT Platform

- Architectural Design Evolution of the Bristol ICT Platform, charting the changes in the design as the project progressed. It gives a reference for the changes made and why the ICT group found it necessary to adjust the architecture.

Section 7 – ICT Actions taken

- This section describes the actions taken by the partners in the Bristol ICT platform delivery.

Section 8 – Data Governance

- Bristol data governance covers the security and GDPR compliance of data passing through the ICT platform.

Section 9 – Innovations, Impacts and scalability of the ICT platform

- The Innovations, Impacts and scalability of the ICT platform as recorded and reported by the lead members of the Bristol ICT platform, specifically the technologies used in the solution.

Section 10 – Conclusions

- Conclusions from the Bristol ICT platform partners.

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5. BRISTOL STRATEGY REGARDING THE SMART CITY PLATFORM

From a strategic perspective, for Bristol to become a truly smart city it needs to have robust digital infrastructure in place. This includes key smart city building blocks, such as:

- Data
- Network Infrastructure
- Edge Technology and Sensors
- Energy demand management
- Governance
- User Interfaces and Services

Together these provide the technical foundations on which everything else is built and ensuring they are in place is a key strategic priority. There is also a strategic requirement for coherent city-wide integration and scale.

The Bristol Operations centre is currently developing the Cities actual Smart City Platform to do just this. Some of the learning from the REPLICATE Smart City Platform is being used to help this development as the REPLICATE SCP is acting as a testbed for the different technology and their functionalities, within a safe environment.

The Final Bristol operations Centre Smart City Platform (SCP) will integrate existing smart city smart city capabilities and assets. It will also provide the capability to coordinate data, applications and services at one or more levels across city operational domains. The goal is to provide a strong technology platform to underpin the council's city-wide digital agenda.

This ability to deliver dynamic, real-time city management across key areas such as transport, energy and safety is a key strategic objective as we recognise that more effective city management will lead to better outcomes for citizens and reduced service delivery costs.

In the future we hope to further develop the SCP as a 'decision-support' tool, providing real-time analysis and insights that enable decision-makers to take an evidence-based approach to managing complex issues such as air quality and traffic management. It is anticipated that this capability will be enabled through the use of data analytics, predictive analytics and artificial intelligence/machine learning.

Given these plans to refine and develop the SCP, a technical system based on an open standards and systems architecture is a critical requirement. This will ensure that as a city we are able to extend/adapt the capabilities of the SCP as required without being lock-in to propriety solutions from a small number of providers. This will lower the barriers to entry for great, innovative smart city solutions from a wide range of providers including local SMEs and entrepreneurs. Strategically, this is not just about technology; it is about ensuring that a smart city is an inclusive city which citizens can co-create and benefit from.

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6. ARCHITECTURE DESIGN EVOLUTION

6.1 Introduction to Bristol ICT Architecture Design

The Bristol ICT Architecture was initially designed to incorporate a series of building blocks that could serve the interventions, the data partners and the data consumers. There was a requirement for a common data platform with a common data model, a data hub or store, an IoT context broker and a networking layer.

In the following section you can see how these blocks remain in situ even though the design moves around them. The flow of traffic changes as we understand more about the interventions and their demands for connectivity. The physical limitations and challenges of the Replicate areas would require a rethink of our architecture but the flexibility we introduced was a big improvement on our first two designs.

In the final design you can see the original principles now surrounded by a richer and more complex architecture that reflects the rich and varied nature of the project interventions. The blocks themselves are also more flexible which makes the whole set up more flexible and easier to Replicate.

6.2 Initial Design

The Initial architecture for the Bristol smart city platform developed by Zeetta and BCC. It shows connectivity through the platform from Partners through Infrastructure to the Data Platform. It is an infrastructure driven design that was aiming for maximum utilization of the network.

- For Replicate, Bristol is developing a highly advanced ICT platform that is intended to support the applications and provide the basis for future smart cities' ICT infrastructure.
- However, it is clear that many of the applications are either unaware of the benefits of the platform or are aware of significant challenges to using it.
- There is a risk that we will end up with a situation where every application implements its own solution to the detriment of the project as a whole.
- We believe that we need a better dialog between the applications and the platform to maximize the use by, and the benefits to, the applications.

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- The initial view of the Bristol ICT platform, its scope and its intended benefits in order to start a dialog with each application about how it can help.
- Hopefully this dialog will allow applications and platform work together to ensure that the applications get the best possible functionality out of the ICT platform and that the smart city can leverage the commonalities to get a whole that is greater than the sum of its parts.

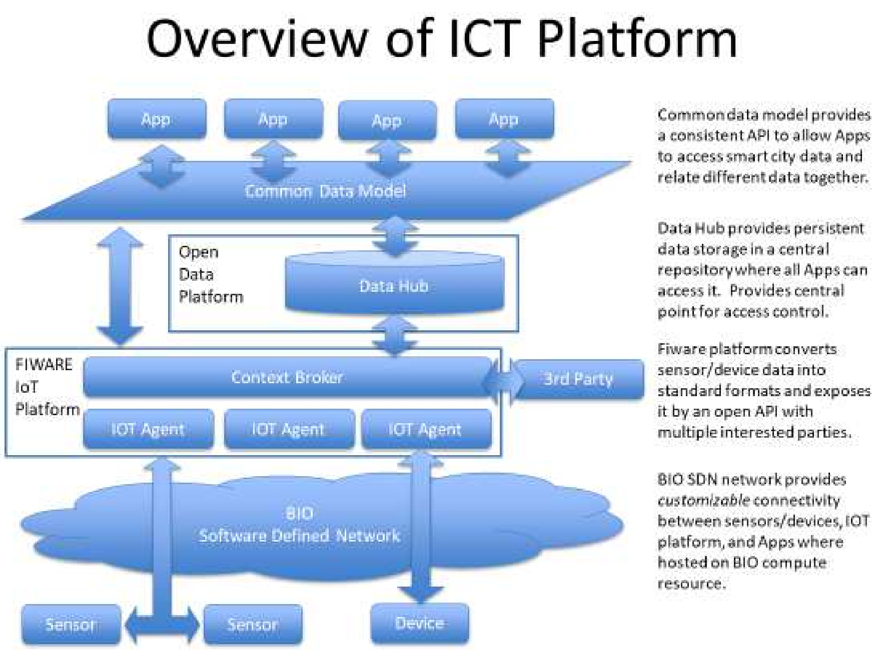

Figure 1: ICT Platform Overview

Assumptions:

- Connectivity from multiple apps and platforms can be provided across a citywide infrastructure on a private directly connected network.
- All traffic can be forwarded to the central platform and through a FiWare platform that can act as a broker between apps and users.
- A Data HUB is available that can hold and present data through to a common Data model that can be used to present data to a common data model.
- That an Open Data Platform exists that will present common and uniform data outputs to multiple users and applications.
- Interventions and applications will use the ICT platform to avoid a siloed system.

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Testing:

- During 2017 the proposal above was tested at multiple team days and workshops.
- In the summer of 2017 a Questionnaire was sent out to all interventions to ascertain the effectiveness of this approach.
- The questionnaire revealed that the majority of the interventions with a designed architecture were now operating in a data silo. With no plan of how to forward data through the SCP

Recommendations

- The ICT group saw the need to redesign the principals of the platform so that there was increased flexibility.
- This would allow for increased activity on the data plain with multiple routes to push data into the SCP data hub.

6.3 Second Scope Design

After discussing connection options and designs with the various partners it was ascertained that the initial design could not support the partner interventions. A secondary set of connection types was proposed to meet the data requirements.

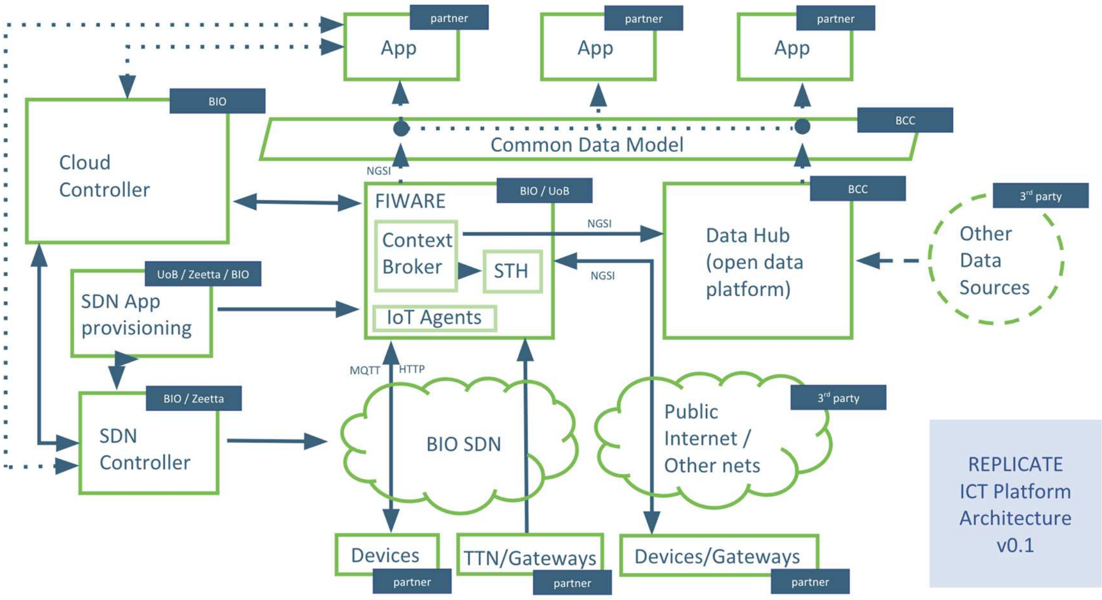

Figure 2: ICT Platform architecture

Description: The platform integrates the FIWARE with both the SDN infrastructure and also the public internet. As shown in figure 2 the devices and gateways are able to transmit the data both within the SDN infrastructure as well as the public internet. This provides a fully-fledged solution for the data requirements and connection types within the project.

Assumptions: To deliver such architecture the SDN infrastructure requirement is a prerequisite. The integration of SDN and FIWARE can be plugged to any IoT solution as long as the hardware requirements are met.

Testing: The SDN IoT solution has been tested and demonstrated by UoB and Zeetta over the BIO infrastructure at the end of 2017. Additionally, the full FIWARE SDN integration has been tested and demonstrated with a sensor network of 20 devices for the REPLICATE general assembly in 2018.

Recommendations: The solution would be easily replicated to other SDN infrastructures. However, there is still place for improvement by introducing containerization to the solution (i.e. docker, kubernetes etc.)

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6.4 Final Design Architecture Overview – Bristol

During the later phases of the project the platform was viewed more clearly as part of its overall context, with more explicit links to the City Open Data Platform (hosted by OpenDataSoft) and EDMS as well as external infrastructure in smart Homes and Smart Mobility workstreams.

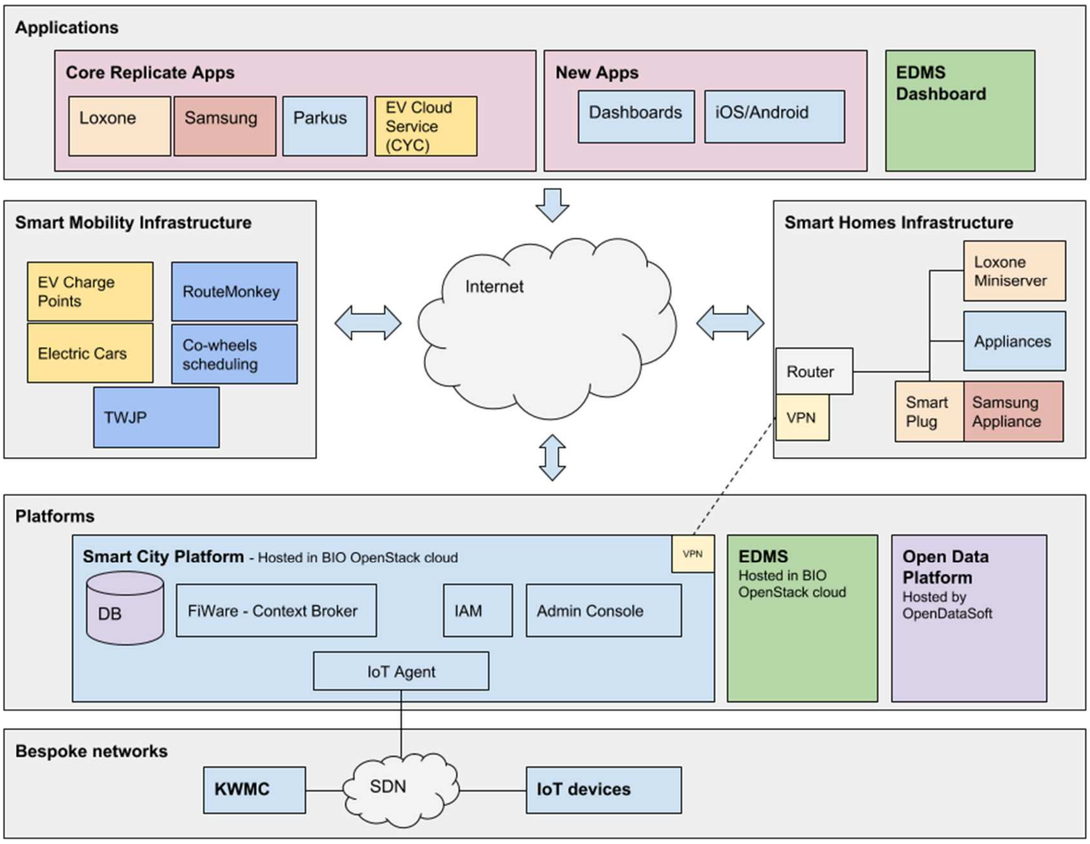

Figure 3: ICT Platform – Design 3

The system was re-engineered to be internet facing so that interventions could connect to the data backend. Within the platform itself the solution was also re built to provide increased flexibility.

Description: The final ICT platform architecture is comprised of 5 building blocks:

- Context Broker (CB): The CB element is the main feature of the platform, accommodating multi-tenant users and the data from different IoT deployments. The operation of the CB is initialized by creating credentials for the user which are used for sending and retrieving the data being generated from the IoT Devices. The implementation of FIWARE requires a service id and a service path which are unique, and must be used within any IoT data protocol. The CB implements a publish/subscribe philosophy able to accommodate a large number of users, assuming the resources permit.
- IoT Agents: This element is responsible for the convergence of different IoT data protocols. As highlighted in Figure 3, this includes protocols such as HTTP, MQTT and CoAP which are already enabled on the platform. This component allows extendibility, providing an API that can be used for developing new data handling agents.
- Database: The third component, used to store the user's data, is a NoSQL database integrated with the CB component. The CB is able to isolate the data using the service id and therefore store the information using the service id as a key. The database is mainly used for historical data and analytics.
- ICT Admin Tool: This software is a front-end application for managing the FIWARE platform. It is able to create users and register devices. Also, it will be used to provide user information to partners in order to retrieve data (i.e. EDMS)
- The platform also incorporates an access control element and links to an external VPN solution to provide for secure communications with external data sources

Assumptions: The platform is able to create multiple FIWARE users. In order to accommodate different IoT data protocols each user of a FIWARE service is also linked to a specific agent for communication. The goal is to collect securely the data from the users (i.e. smart homes, electric bikes etc) and provide the information to authorised systems such as the EDMS.

Testing: Stress testing has been done by UoB to evaluate the platform capabilities. Therefore, UoB provides scripts for FIWARE deployment and also suggestions for system requirements.

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Recommendations: The platform requires resilience and robustness. Therefore, a plan for the aforementioned requirements needs to be presented during the next steps of the project. Additionally, the users of the platform would benefit by a global user interface where the historical data and analysis could be provided as a service.

7. ICT ACTIONS

7.1 Infrastructure Deployment

The city of Bristol provides a smart city infrastructure, which is a ring of optical fibres connecting multiple locations together. In these locations there is server infrastructure, network switching and controllers, distributed computing and data storage. The data reaches our network from the cloud via VPNs connecting to our main firewall at the University of Bristol. The FIWARE instance is located on virtual machines within the network nodes.

Architectural Design

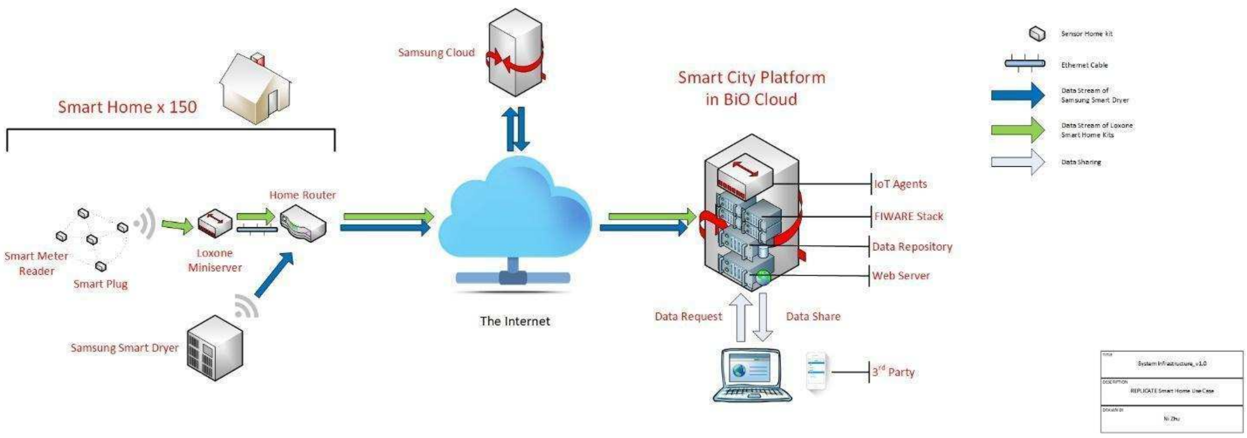

Figure 4: ICT Architecture Design

Bristol is Open ("BIO") have provided a city-scale wide-area network over which secure connections are laid to the 150 homes provided by the smart-energy trial and the electric car charging infrastructure.

- BIO have provided the virtual machine infrastructure on which the data warehouse, which will provide data for the two year-long monitoring period is built. The secure connections are achieved using a virtual-private network (VPN) and connects to instances of smart home servers in each house, together with data-backhaul devices in the EV charge points.

- The washing machines and tumble driers are also connected to the system, both via the home-hub and the electronics vendor's Cloud infrastructure via the Energy Data Management Service (EDMS) being built by NEC.

- The purpose of the smart-city infrastructure is to connect to EV recharging points and to household goods to monitor, gather data and control those devices.

- We are doing this to look at timestamped energy usage data per unit of time (in Kilowatt hours, kWh) to understand, city-wide where and when the high-energy demand peak times each 24-hour period, and with a view to in the future, changing user behaviour such that peak-time usage can:
  a) Be discouraged by empowering citizens to use energy in a more holistic and environmentally conscious way.
  b) Be levelled by offering to control peak-time demand via automating the on/off functions of white good remotely using the EDMS. Citizens would opt in, and the EDMS would decide the start and finish times of the washing cycle, based on its knowledge of the city energy demand regime, selecting the best, lowest, most-optimised times based on when the lowest energy demand was occurring.

This also offers the citizen access to potential lower electricity unit costs on off-peak tariffs, thereby saving them money. Lower Energy demand at city scale means less electricity needs to be generated at peak times, power stations can level their output, reducing CO_2 emissions and as a knock-on impact, reducing climate impact and improving air-quality. Bristol's current estimated population is 459,300 [1], so 150 homes represents approx. 1 in 3000 homes (0.033%), so for example if this trial demonstrated a carbon saving of 1 tonne per annum, then the whole city potential scalability would be 3000 times that figure.

7.2 Creation of SDN Tools

Zeetta Networks is helping to make networks work the way they ought to work. In recent years, the telecoms and data networking sectors have seen the advent of Software-Defined Networking (SDN), where a network is 'virtualised' and controlled by software to enable its management through programmable APIs and user-friendly Graphical User Interfaces (GUIs). The focus of network operations has shifted away from the hardware,

[1] https://www.bristol.gov.uk/documents/20182/33904/Population+of+Bristol+November+2018.pdf/e65be8b1-93a7-153d-da6d-62fbef265a04

cabling and physical connections to the ability to visualise, monitor and manage the network in a flexible way through software. Furthermore, there is now a growing demand for Open Networking solutions, where a network owner is able to deploy devices from a multitude of manufacturers rather than being locked in to a particular manufacturer's (often more expensive) devices.

Zeetta Networks supports and extends the Open Networking philosophy beyond data centres to core and access networks, towards a future where the whole 'end-to-end' network is as agile as it needs to be. In order to help our customers, make the most efficient use of their network resources, Zeetta has developed and patented technologies that provide more flexibility and freedom than any other solution, and give network owners the ability to manage their services and budgets more effectively in the process. The ease with which a network can be sliced and spliced is entirely due to the patented technologies that form the foundation of NetOS®.

Our software platform, NetOS®, creates and maintains a virtualised representation of the aggregated network topology which can be viewed on a single console, allowing you to manage and re-configure it as required. This virtualised network topology can be based on a single network or it can be the result of 'splicing' together multiple sub-networks including optical, packet, wireless and even low power IoT radio sub-networks. Once spliced together, this 'network-of-networks' can then be 'sliced' to make any number of sub-networks which can in turn be assigned to different network users or tenants, each of whom can be provided with full visibility and control over their own network slice. It's a simple yet extremely powerful way to manage complex networks

For the Replicate project Zeetta has worked to define and deploy these toys to enable the easy connection and management of IOT devices. An approach we refer to as "Zero Touch IOT". As shown in the demonstration 6.3, we aim to take all of the data we have about the network and the devices connected to it and pass them to the service owner. Whether it be the network provider or the IOT provider or the smart city platform owner.

The NetOS application and its user GUI are described below to provide an insight into the richness of the SDN platform.

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7.2.1 NetOS® Graphical User Interface (GUI) Overview

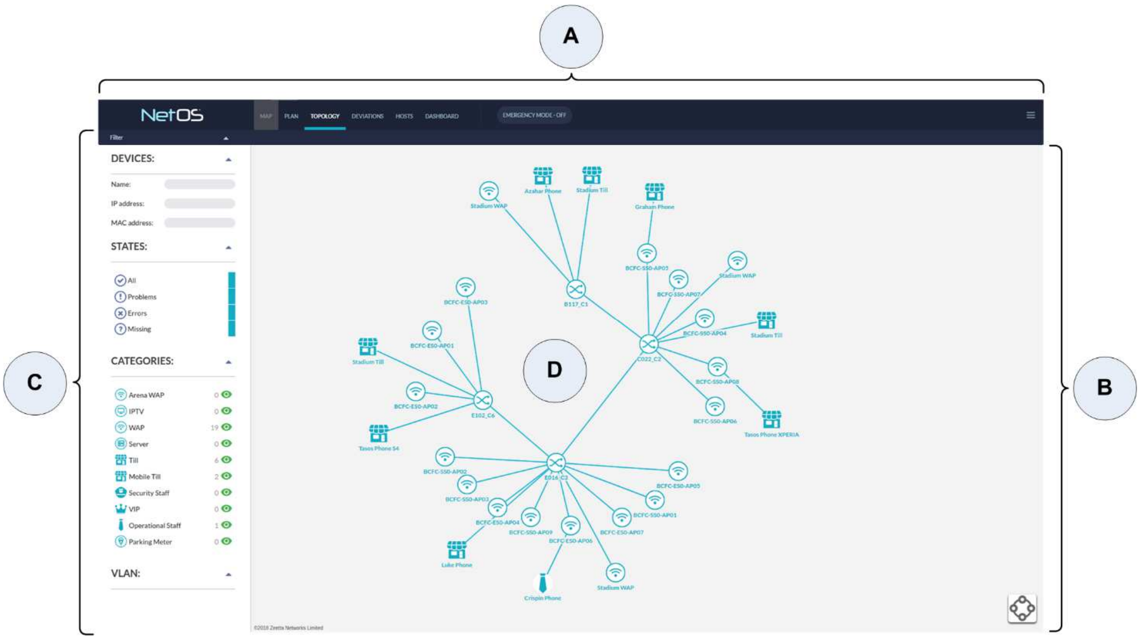

Figure 5: ICT Platform – Admin Gui View

The GUI display screen is divided into four main areas which are:

(A) Top Menu

(B) Right side menu

(C) Left side menu

(D) Main display

There are 5 TAB options available on the GUI:

(1) MAP Google maps linked view of network geography

(2) PLAN – Location of devices on a site plan.

(3) TOPOLOGY – Topology view of network.

(4) DEVIATIONS – Deviation information details.

(5) HOSTS – Edit, add and delete categories.

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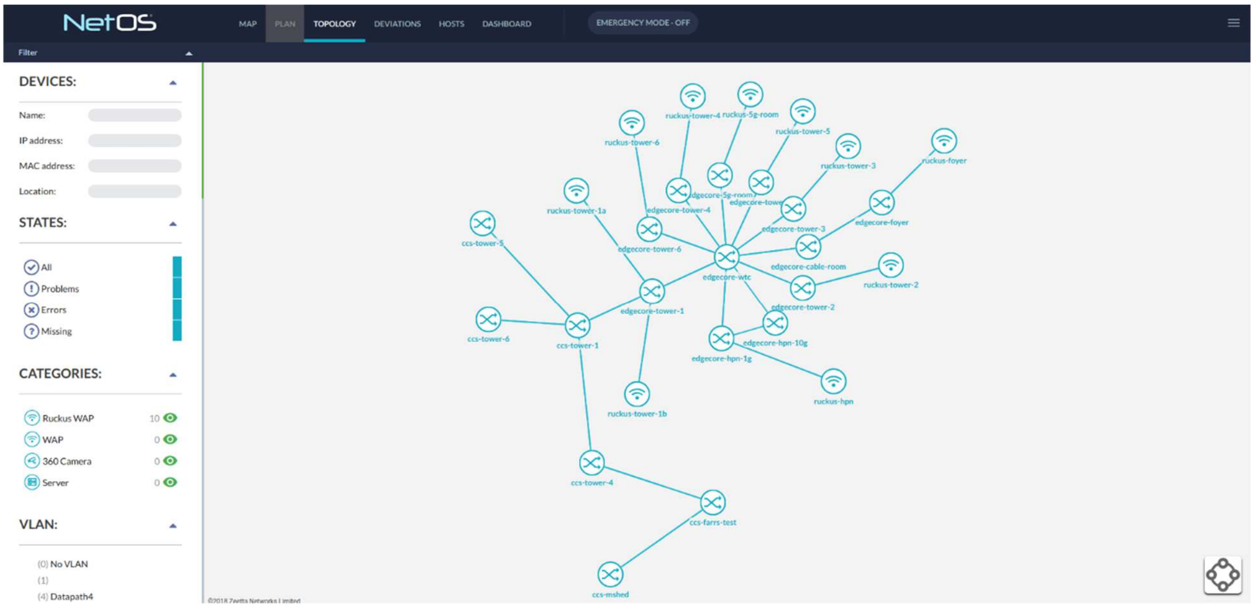
Topology View

Devices and Controls

The topology view Displays a simplified diagram of the NetOS® network components and shows how they are interconnected on the installed network. Each host device, WAP, switch, and link connection (wireless or wired) is identified with a representative graphic icon.



Example Topology View (Sample Devices and Buttons)

Figure 6: ICT Platform – Topology View

Device States

Network devices are constantly monitored by NetOS® core and their state indicated graphically on the browser display. A change in state is shown both by colour and pattern which are used to represent healthy and deviant conditions. There are three healthy states and five deviation states.

The healthy states shown below:

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- Active
- Inactive
- Selected

Deviations states are as follows:

- Connection Problem.
- Connection Error.
- Connection Missing.
- Link Missing.
- Link Unexpected.

Map View

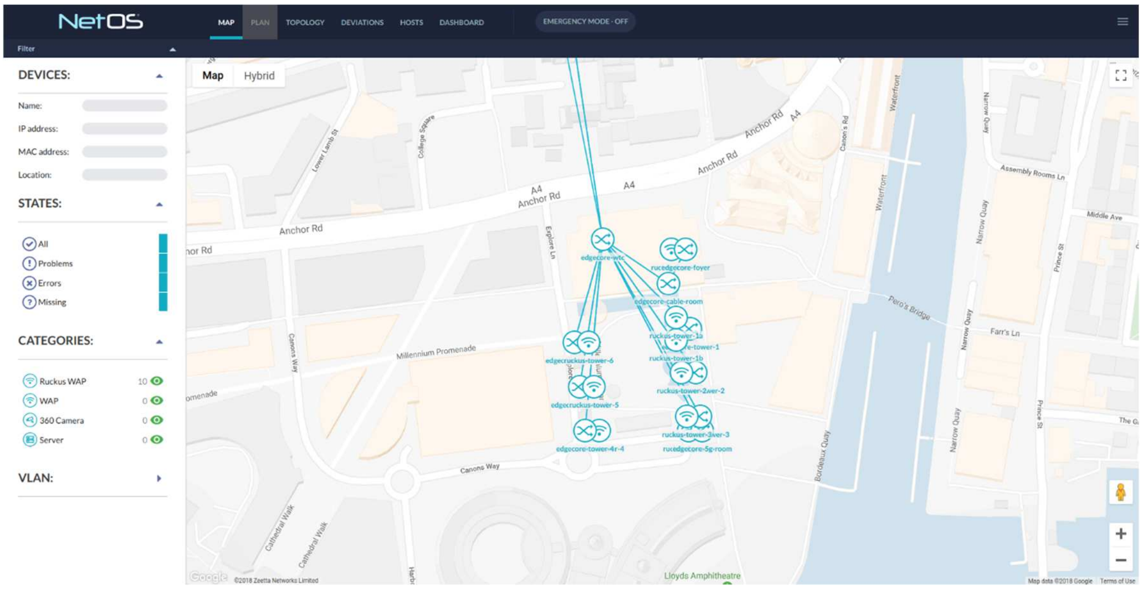

Figure 7: ICT Platform – Map View

The Map view shows a graphical representation of a connected network on a google map. Giving the operator an exact location based on coordinates for the physical devices and the connections between the devices.

Plan View

Plan view displays an interactive architectural site plan as shown in the diagram below. Each floor of a plan is configured in the NetOS® core and denoted as a Level. Level numbers start at the lowest floor (Level 0) and increment to the highest floor.

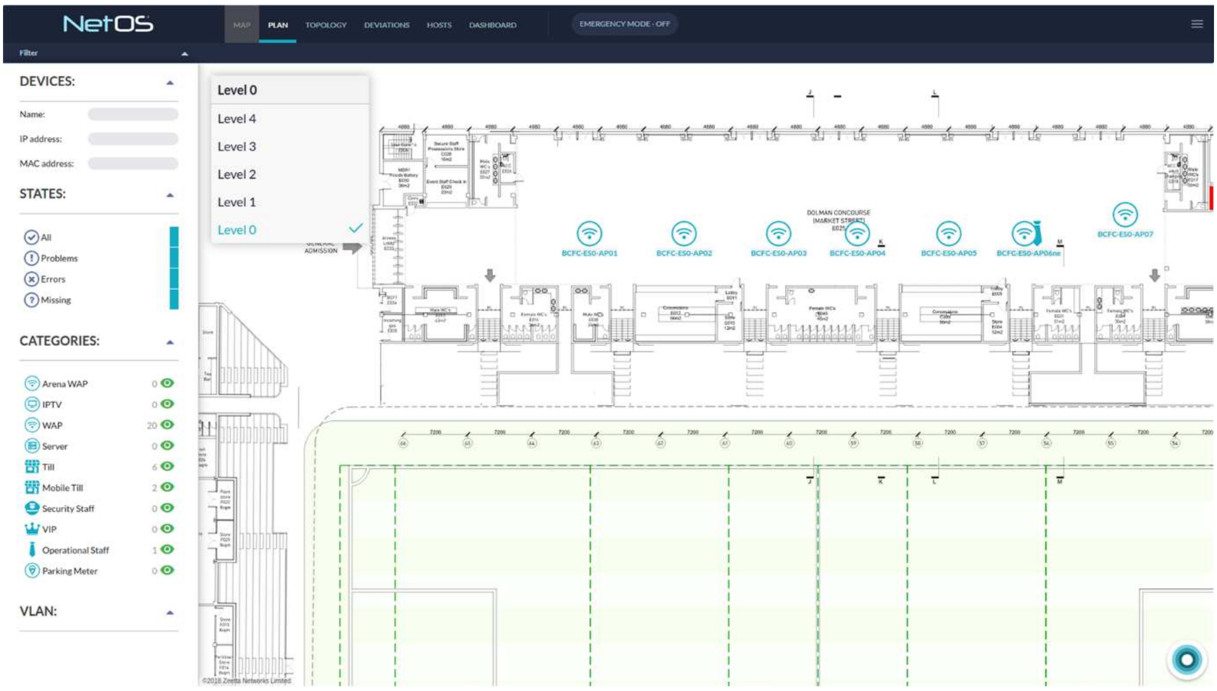

Figure 8: ICT Platform – Plan View

The Plan view enables accurate location of multiple devices and device types on a building plan enabling quicker fault finder and accurate provisioning. IOT devices can be tied to particular devices in particular areas, services can be enabled based on the location of the connection.

Deviations View

The deviations section shows an operator when their network has changed from the expected topology. It will show new devices, devices that have moved on the topology and devices that are no longer connected. This forms the basis of the fault finding on NetOS and also provides a real time record of changes taking place.

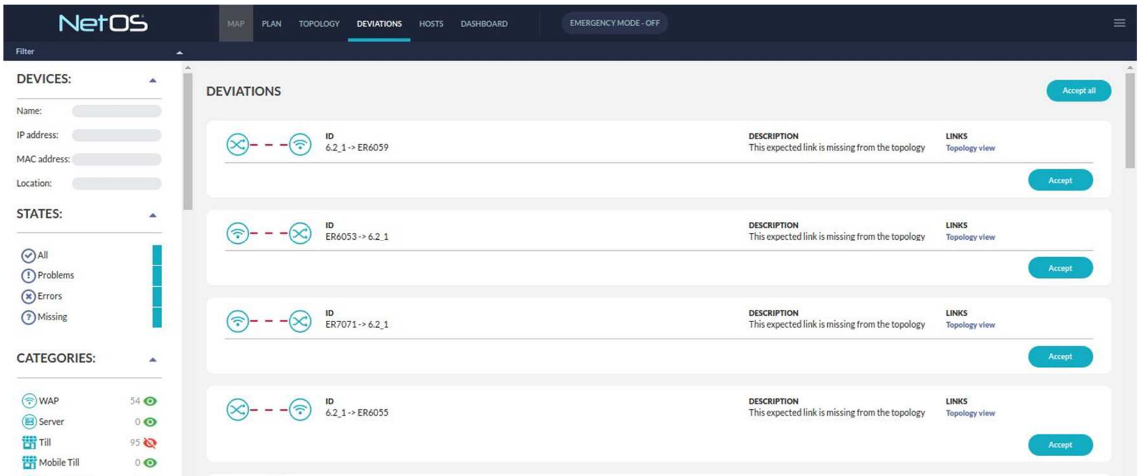

Figure 9: ICT Platform – Deviations View

The deviations view clearly shows:

The device and the next device it is connected to, with the status of that link.

The status of the link is visually represented as missing or unexpected

The operator can jump to the Topology view for further investigation

Deviations can be accepted to show the change is expected.

Hosts View

The Hosts view provides a list of devices that are visible on the network. A new category of hosts can be added by the operator so that any device with that mac address or mac-address prefix can be identified when connected. Once identified a rule base can be applied to traffic to and from that device.

Categories listed under the Hosts Tab.

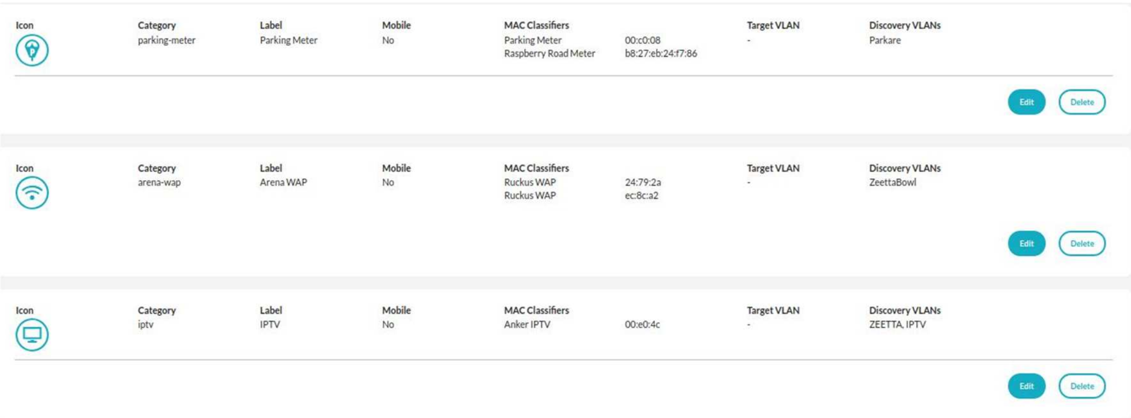

Figure 10: ICT Platform – Hosts View

Adding a new host category from the GUI.

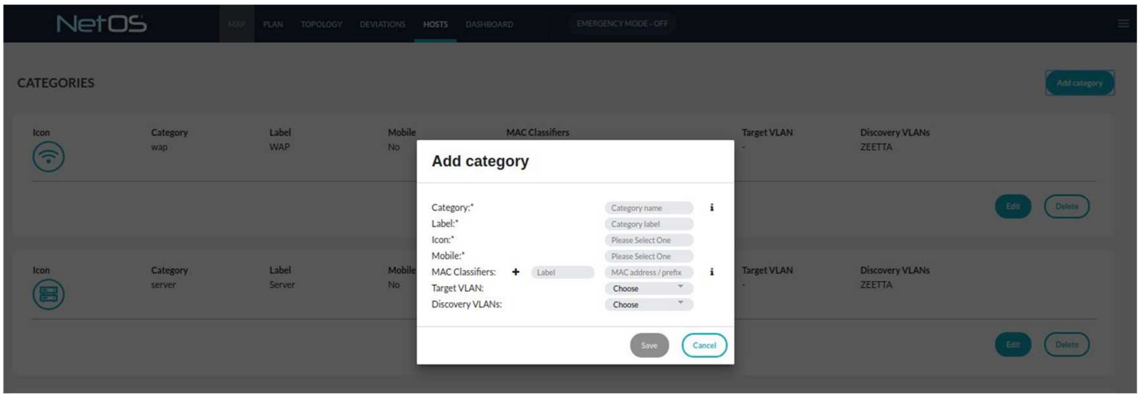

Figure 11: ICT Platform – Adding New Host

Once created the host categories give a one touch approach to accepting new IOT devices onto the network.

Simplifies deployment in large IOT networks

Simplifies management with a clear view of the devices and the connectivity.

Allows for IOT tools like FiWare to receive clear device information

Provides a rule base that can be applied to create whitelists, blacklists, bandwidth restrictions

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7.3 SDN and IoT Integration

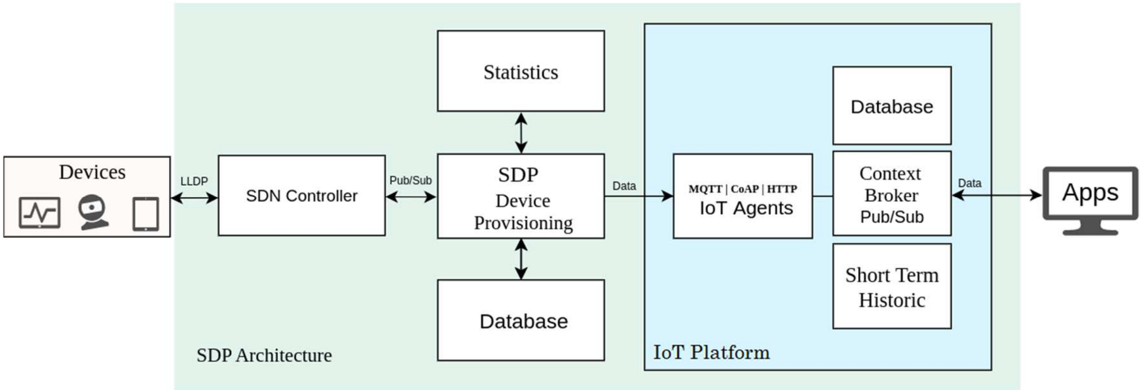

Figure 12: ICT Platform – SDN IoT Integration

The proposed architecture is a different approach of organizing the provisioning and authorization of devices within an IoT infrastructure. Mainly due to the reason that we combine the IoT platform with the SDN capabilities. By introducing SDN topology discovery concepts and enhancing the IoT platform with SDN control, the current architecture can become more scalable, hence the performance of large deployments can be much faster and efficient.

Making the aforementioned process dynamic utilizing software is assisting scalability in IoT. However, we intend to provision at a network layer and provide a dynamic provisioning architecture where the network is taking decisions. Within this architecture the Integration operates as a middle-ware between the devices and the IoT platform leveraging the advantages of SDN.

Figure 12 shows the IoT provisioning architecture of this system and its main components. The architecture is composed by five main building blocks. Within the REPLICATE project the architecture maps to the NetOS network operating system as the SDN controller, the FIWARE IoT Stack as the IoT Platform and the SDP framework developed by UoB integrating the two above elements. The architecture is comprised of five core building blocks:

1. **IoT Devices**: Includes any kind of computing device that has one or more smart sensors attached and it is able to connect wirelessly to a network and has the ability to transmit data. For example, devices such as air quality sensors, water quality sensors, wearables and actuators.

2. **SDN Controller - NetOS**: It is a modular open building block that provides network programmability. This building block is directly communicating with the IoT devices via Link Layer Discovery Protocol (LLDP).
3. **IoT Platform- FIWARE**: The IoT Platform building block provides a set of APIs that enables the development of Smart Applications in multiple vertical sectors. The specifications of these APIs are public and royalty-free. The IoT provisioning architecture uses an IoT Agent component which enables the communication between other IoT platform components (i.e. context broker) and the IoT devices. Basically, the IoT agent provides a southbound interface enabling different IoT data protocols (i.e. Message Queue Telemetry Transport--MQTT, Constrained Application Protocol--CoAP and Hypertext Transfer Protocol--HTTP) to communicate with a set of heterogeneous IoT devices. The IoT agent uses two headers to manage IoT device's request:
    1. Service ID that represents a tenant to manipulate a specific service
    2. Service Path that enables access to specific information entities retrieve a service. Furthermore, the information is also stored to a database and to a component named Short Term Historic that enables short term queries.
4. **Software Defined Provisioning (SDP)**: The SDP framework is a middle-ware component that enables the communication of the FIWARE and NetOS controller. More specifically, SDP creates a stream which contains the IoT device identification, device MAC address, service and service Path information. This stream will provision the device and establish a secure communication between the device and the IoT platform. Also, the framework stores statistics and all the functionality of the provisioning process to a database.
5. **Applications (Apps)**: This block includes any IoT application that requires device flexibility and scalability. For experimentation purpose, the IoT application is implemented using an emulated WSN that is monitoring environmental values such as temperature, humidity etc. The applications use the publish subscribe pattern to retrieve real time data.

7.4 Data Backend Integration

BIO have provided the infrastructure platform onto which data is backhauled and stored. The smart homes send data back to our FIWARE instance via Loxone Mini-Server connectivity and over a VPN linking individual users with the smart city platform. Individual machines record and report their energy use and data is collated in the FIWARE backend.

7.5 Demonstrations

7.5.1 Demo of Citizen Sensing IoT Integration for General Assembly

The citizen sensing program and the Bristol Approach to engagement with communities is a core theme of the Bristol Replicate project. During the General Assembly in Bristol we were able to demonstrate the use and integration of SDN with an IOT platform that will make the delivery of large scale IOT deployments faster and easier.

In the section below, we describe the actions and functionality of a platform developed by the University of Bristol that connects devices that are connected on the NetOS platform through to FiWare. This gives a level of management and interaction that enables for greater ownership and control of a deployment. From our engagement work we know that this is crucial for any Citizen engagement with sensors.

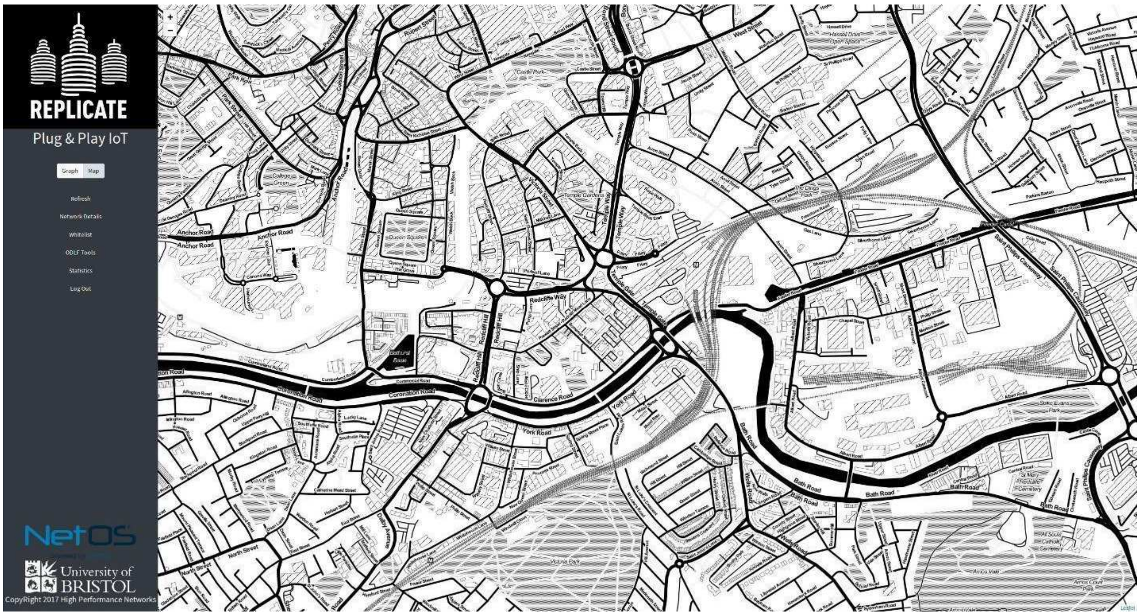

Figure 13: ICT Platform – Front End Map of UoB GUI

One of the key enablers of Internet of Things (IoT) is integration. Therefore, equipping IoT with other technologies is a feasible way of enabling large deployments and also making the process secure. IoT deployments are happening for both industrial and

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research purposes, nevertheless there are several obstacles that need to be addressed for successful large deployments. One fundamental yet very critical barrier in IoT is the efficient management and provisioning of the devices. Successful scalability of IoT deployments require dynamic provisioning of the devices (mostly automated) with minimal administrative effort. In Replicate project we target to tackle this challenge by integrating SDN with IoT deployments and improve the CAPEX and OPEX of IoT. Additionally, we demonstrate at a city level to present our findings.

During the General Assembly and project review meeting in 2018 UoB and Zeetta demonstrated the IoT solution. The demo was undertaken using Pycom IoT sensor devices, a ruckus Wi-Fi switch and an SDN enabled edge core layer 2 switch. The demo is illustrating the IoT provisioning mechanism as well as the device control and monitoring. A paper published in 5GWorld Forum 2018 conference presented scientific results that show the benefits of the integration between SDN and IoT. For the Replicate project we have developed the solution over a real smart city setup to enable the replicability of this solution.

The life cycle of the demo is comprised in 5 steps:

- Deploying the devices over an SDN infrastructure. This is a physical deployment were the sensor devices targets the monitoring of a specific state (i.e. environmental monitoring, earthquake monitoring, speed, light, water quality etc.)
- The devices therefore connect to a Wi-Fi access point to send the data at an IoT platform endpoint
- To do so the devices need provisioning, therefore the solution is utilizing the advantages of SDN scans the device network for MAC addresses and then uses them to enable the secure M2M communication.
- Additionally, the IoT application provides the capability to monitor the devices and check the bandwidth that they are sending. This allows to control and constrain a device or a group of devices to rules. These rules can be bandwidth control, blocking specific MAC addresses that we do not allow etc.
- Finally, the sensor network will be able to send the data and then visualise, act and generate some intelligence. Furthermore, the real time capabilities of the framework are able to re configure the rules to which the IoT devices obey to.

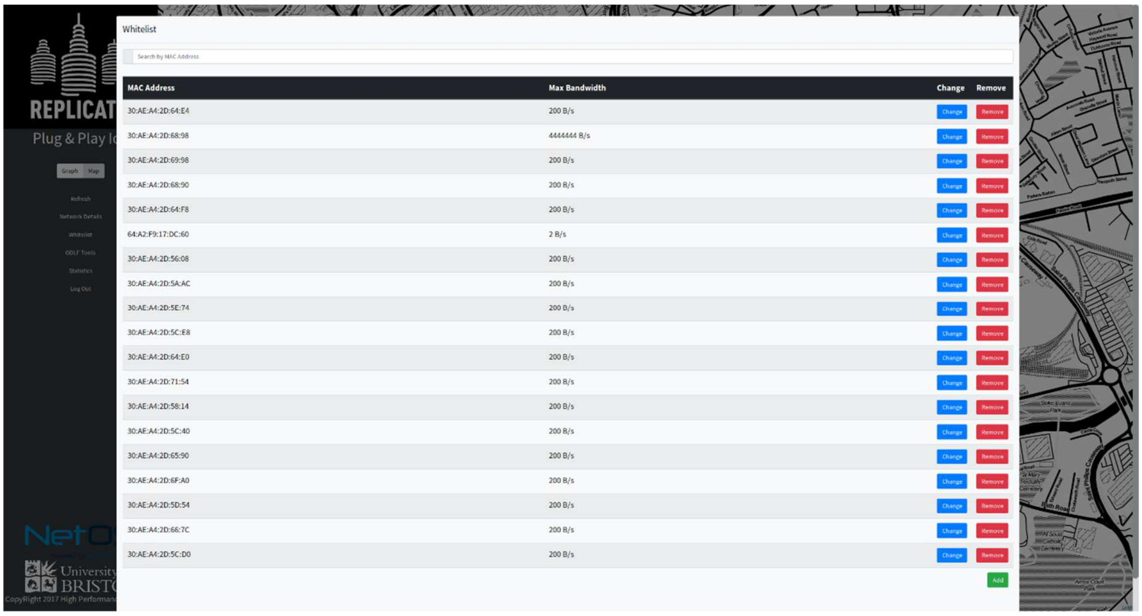

Figure 14: ICT Platform – Devices List to Control Layer 2

In Figure 1 the main page of the front end is shown. As visible the Map is a real time indicator of where the devices exist. Additionally, it depicts the physical and layer 3 addresses of the devices. Figure 2 shows the user interface that is developed to allows a networking interaction with the devices. For example, if there is some manual preference to provision or limit some specific device this is enabled through the specific UI.

7.5.2 Demonstration 2 Data Backend for Smart Homes and Mobility

A demonstration of the data backend was given at the EU General Assembly in Bristol on 24 October. This showed energy consumption data from the Smart Home being fed into and stored on our instance of FIWARE. The data is compiled by the Loxone Mini-Server and sent as a string of code from each home. It can be configured to poll for data as often as is required, for the demo the data updated every 5 minutes.

7.5.3 Demonstration 3 – Energy Demand Management System

We have setup a demonstration to show the interaction between the Energy Demand Management System (EDMS) with devices in the Smart Homes. The endpoints on the side of the Smart Home are the smart plug and the meter reader, as well as a smart dryer. The default way to communicate with the EDMS is via the REPLICATE ICT platform, which is based on FIWARE. However, in case of the smart dryer, technical restrictions required to do the interaction via the vendor cloud – in this case the cloud system of Samsung. A simplified technical diagram of that interaction is shown in the figure below.

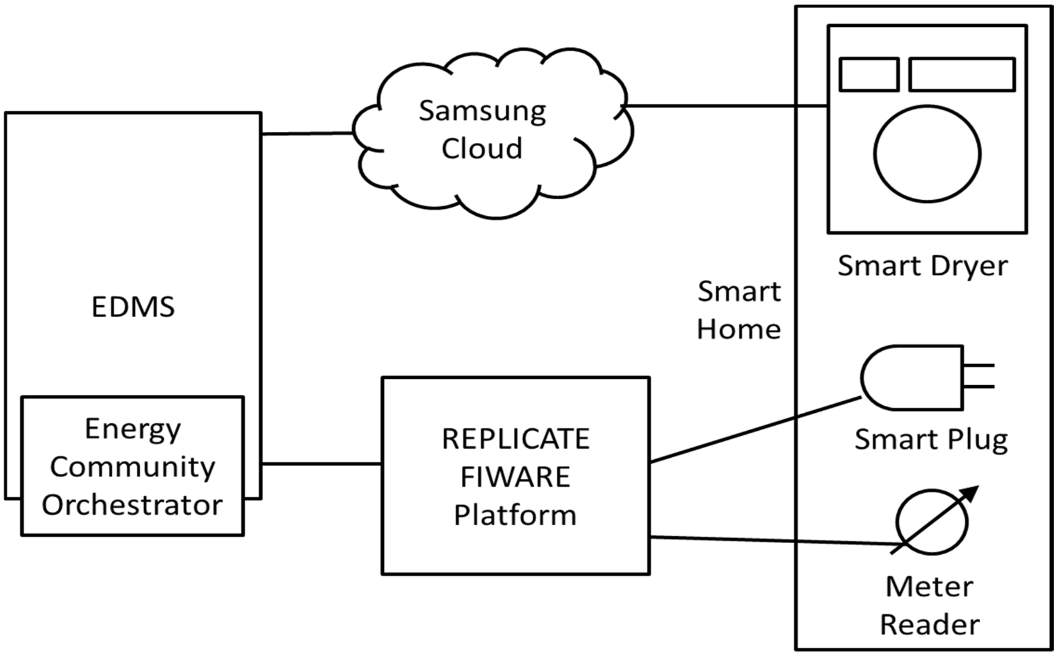

Figure 15: ICT Platform – Energy Demand System

On the EDMS side, the point of user interaction is the Energy Community Orchestrator, which is the name of the graphical user interface for monitoring and control. Here a map of the city of Bristol is provided with icons representing REPLICATE devices, like shown on the left-hand side of the figure below.

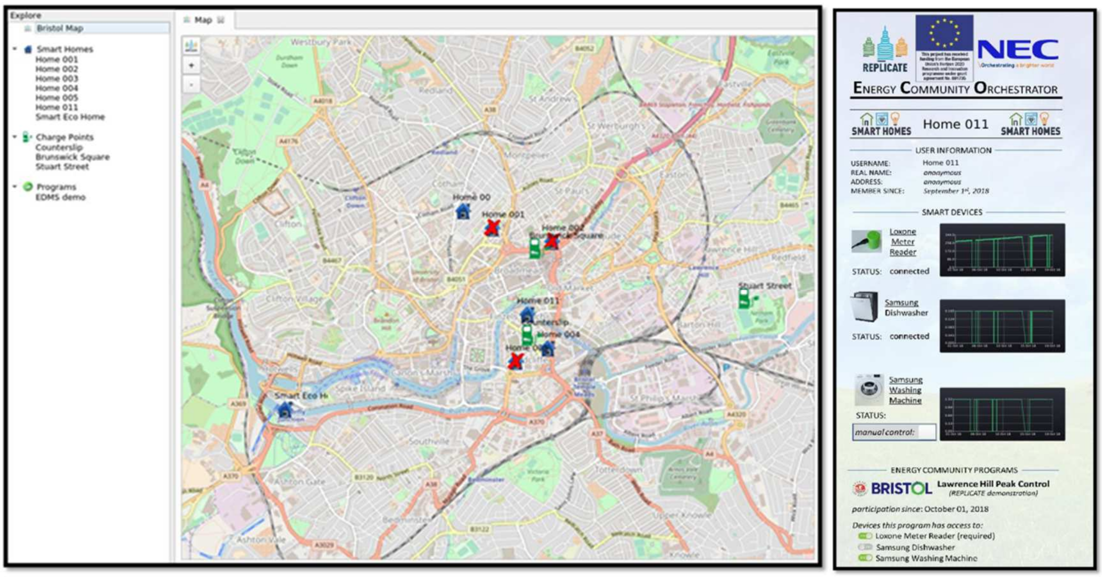

Figure 16: ICT Platform – Location of Replicate Devices

The home used for the demonstration is represented as one of the icons on the map, and by double-clicking this icon a view of the home is shown, including visuals of energy consumption data like depicted on the right-hand side of the figure above. Interaction with the Smart dryer located at the demo site is possible via play and pause buttons. When clicking the buttons, the EDMS communicates with the cloud system of the device vendor, which causes the devices to start or stop operation accordingly.

8. DATA GOVERNANCE

8.1 Bristol Data

Bristol City Council own the data of who is in possession of which washing machine, tumble drier and/or dishwasher models etc... They maintain the records of householder name, surname, address, postcode and whether they have devices and/or Loxone Mini-Servers. The data sharing agreement between Bristol is Open and Bristol City Council affords obfuscated (using a reference number) data only, so we cannot identify individual homes. Instead data is passed between Loxone Mini-Server and downstream databases (EDMS, FiWare) as Home_001, Home_002 … Home_150. We do not know which Home_nnn relates to which address. This affords the homeowner anonymity and data being held on them is not personal and complies with GDPR requirements. Similarly, each home that uses Samsung SmartThings sends data to the Samsung Cloud as their SmartThings username and serial number of the device, Samsung appliances are not collecting address data. The individual users of SmartThings must download the application and accept Samsung's data sharing agreement before registration on Samsung's Cloud API.

9. INNOVATIONS, IMPACTS AND SCALABILITY

9.1 Innovation Solution

The aim throughout the Bristol project has been to build and innovate where we were able. We have been genuinely surprised by the lack readiness in the marketplace for much of the technology and have subsequently written a large quantity of new code. This has made the approach and the result innovative.

- REPLICATE gives us the ability to monitor energy consumption and control devices to smooth the energy demand curve.
- Smart technology has given us the ability for an energy company, or a social housing management company to control household appliances remotely. This allows households to opt into the control, both being able to switch devices on and off from their own smart phones, or to relinquish control and trust in the automated service to optimise their home energy demand and switch the device on at the time of lowest demand to prevent supply overburden.
- The ability to monitor energy consumption remotely has been around for a while within utility companies, many homes now have smart meters, and remote monitoring has removed the need for home visits by a human meter reader. The difference between smart meters and Loxone, is we can drill down into the data to attribute it to individual devices rather than 'whole property' via the smart meter alone.
- The citizen sensing program has opened up a whole new world of opportunity and innovation. Knowle West Media Centre have been able to tease out the real needs and fears of the community around sensing and Big Data. The citizens want to control and own the design and decisions around what is sensed and by whom. The consultancy and SME opportunities are here to exploit.
- The use of sensors packs in the citizen sensing program also opens up opportunities for using the SCP as a filter or funnel for sensor data. Mixing community data with data from central sources to help expand our knowledge and collaborate our results. What if a council could source input from its communities and not have to use expensive studies form consultancies?
- The platform itself has brought together a leading edge IOT platform (FiWare) and some unique code around the Software Defined Platform that has enabled

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multiple inputs and outputs for data on the project. The value of this data will be assessed during the monitoring period.

9.2 Social Impacts

Core to the belief in the Bristol team is that we need to understand the Social Impacts that the city wants from multiple perspectives. In the ICT team we have tried to maintain a flexibility that enables the delivery of social benefits that are relevant to the team and the city.

- REPLICATE provides easier ways of doing household chores and improves quality of life.
- There is great potential for bringing data together (such as air quality) from a variety of IoT devices (some hand-held citizen devices, others city council devices) to not only assess the issues in local areas, but also start the creation of a joint narratives, that can influence change both from the bottom up and the top down.
- SmartThings™ allows home owner to control their washing machine or tumble drier remotely. This removes the need to remain at home during laundry cycles. One can now place detergent and laundry in the washing machine, or wet clothes in the drier and go out. The smart phone control allows the device to be switched on remotely, from the supermarket, the gym, a friend's house etc.
- There is also the social value of comparing and contrasting technology, there is a certain 'wow factor' when explaining to your peers you are participating in a smart cities experimental initiative and contributing to a European wide project. Also, there is an impressive design quality to the devices, allowing home owners to showcase the latest technology at home.
- It is essential that any SCP can share data preferably through an open data platform. The Bristol SCP aims to expose data to a variety of different groups at different levels of granularity to a variety of platforms. An example of this is the link the BCC open data platform to share data more widely, the shared data for the Travel West platform or for the EDMS.

9.3 Environmental Impacts

The Environmental impacts of the Platform are heavily linked to the social impacts and give us the need to deliver benefits individually and at scale for a whole community. Again, our aim is the simplification and automation of core decisions for the municipality and the citizen.

- Lower energy consumption. The Samsung® washing machines are A+ rated for energy efficiency, and the EDMS allows control such that they operate off-peak tariffs. As a result, the demand on the national grid is reduced, which means the power generation elsewhere on the network means less generators are running, and ensuring sustainable power sources are relied upon more readily.
- Reducing National Grid demand reduces the burning of fossil fuels (coal, oil, gas) and therefore lower Carbon emissions, and reducing the impact on climate change.
- Reduced fossil fuel-based electricity generation improves air quality.
- Off-peak tariffs (during sleep hours) improves air quality as the cumulative effect of daylight hours, electricity generation and vehicle movements on air quality is reduced.
- The decommissioning, disposal and recycling of obsolete appliances has a positive ecological impact.
- Modern washing machines use less detergent, therefore improving surface water quality.
- The platform will provide the basis for future developments that could impact the control of multiple devices and sensors in the city. Impacting lighting, safety and traffic control.

9.4 Replication and Scalability Potential

The final design of the Smart City Platform is the most portable and scalable. The platform can now take and store data from the platforms on the internet and those on local networks. FiWare enables the homogenisation of the data and the Open Data Platform a showcase for the output. However, the core part of the platform is the flexibility that means any of these components could be changed and re-engineered to meet a specific requirement

- The platform has drawn a lot of interest at exhibitions and during visits to BIO, UoB and BCC.

- The smart city platform currently supports 150 homes, connecting each via a virtual private network (VPN). The network controller can support several thousand VPNs.
- This architecture could be replicated and rolled out to other smart cities. The connectivity between white goods and the cloud is VPN over home Wi-Fi, but could be carried over any wireless access point.
- Replicability to addition electrical appliances within connected homes is also possible, by increasing the number of smart plugs.

9.5 Economic Feasibility

The feasibility of replicating the architecture is impacted by the economic costs and outcomes. As the monitoring process continues, we would hope to see the benefit of our development work.

- BIO have not had to install bespoke hardware, the servers, network controllers and switches can be virtualised, making them more cost effective.
- We have made use of Opensource code where possible, reducing licencing costs.
- Proprietary Smartphone Apps have been used where possible.
- The EDMS makes use of Cloud services and connects to BIO's database via a VPN connection.

9.6 Impact on SME´s

The Replicate platforms impact on the engaged SME's cannot be overstated. From experiential learning about the IT requirements for this kind of platform to exposure to multiple partners and their different approaches to delivery.

- A number of local SMEs and suppliers have been engaged on the REPLICATE project.
- Loxone (Bracknell) have supplied the 150 Mini-server devices and been heavily involved in customising there product for the scale required on Replicate in Bristol. We have given some very strong feedback on their operability and security. Both areas will, if improved, improve their position in scale deployments.
- Narec DE have worked with the Smart homes project to supply Samsung white goods. For Narec it has been a useful step in understanding the current state of

the smart goods market and the issues an integrator will face. If the market can move towards a homogenised delivery and use of power then SME's like NAREC will be in a position to exploit this market.

- Zeetta Networks have supplied software-defined networking using their NetOS platform. Being engaged on the Replicate project has a massive impact on our software development. We are far more engaged in the smart cities space than we ever would have been and subsequently have had to design accordingly. The direct result has been multiple engagements with smart cities, like Digital Greenwich and enterprise customers like ENGIE who all see the SCP components as core to any platform.
- Select Electrics have provided Mechanical & Electrical services and network cabling where needed. Select have developed their own understanding of the smart white goods market and of app delivery.
- As this is a pioneering project, the chance to demonstrate new IOT products and services and participate in an EU wide project has distinct commercial kudos for those involved.

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10. CONCLUSIONS

The core idea of the Bristol Smart City Platform was to create novel smart city applications and develop real use cases of cutting-edge technologies. The main technologies used in Replicate are Internet of Things, Software Define Networking and Cloud computing. The Bristol SCP is a combination of all the aforementioned technologies and the ultimate goal is to deliver a Cloud platform that obeys to a novel architecture. This novel architecture is designed to facilitate the sharing of data from heterogeneous services across the urban landscape, regardless of who might provide it. To accomplish these objectives the project had to satisfy a number of prerequisites, and eventually developed and delivered a platform that can collect, optimize and provide data in real time.

Thanks to Replicate project, that is a R&D project, Bristol has gone beyond the original brief and has developed systems and software from scratch. Combining technologies coming from local innovation and research Bristol now has created a platform being utilised by 150 Smart Homes, EV bikes, Electric-cars, charge points and smart buses. Gathering data from all these sources to the cloud and using novel algorithms for processing the data, a cloud IoT platform has been developed to provide high Quality of Service (QoS) to the platform users as well as to the platform operator.

The Replicate project has a vast scope. Although connections were incredibly difficult to maintain on all levels and were delivered in parallel the effort done has permitted to achieve positive results. The citizens were being engaged right through the deployment phase and providing valuable input to what they wanted to see. All the partners were trying to develop their own applications to meet their own deliverables. In the middle of this was the development of the SCP. Assumptions were made and deployments were planned only to change, never fundamentally but always with a huge impact for the platform delivery.

Working with commercial companies, like Samsung, also creates issues, they may not want to support integration onto a potential future competitors' platform, may have technical officers all around the world, and be difficult to locate the necessary skills set especially as requirements change. It is not easy for SME's to re-imagine their development teams as a requirement change. Though the overall approach of multiple partners has had a lot of positive impacts due to the breadth of knowledge and approaches.

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The core learning has been two-fold. The development of any platform needs strong central ownership, not inflexible but able to manage the changes and deliverables in an agile framework. The actual interventions and the partners delivering them should be brought on board after the definition of the project has been thoroughly road tested with the users, be they citizens, councillors or other application developers. Running the definition alongside the delivery results in a form of retrospective agility where the platform is being re-built not redeveloped.

The brilliant work around the Smart City Platform has been in the gaining of knowledge from the citizen sensing and engagement. The feedback this has given into the partners and their ability to deliver a platform with new code. The IOT integration with FiWare supporting multiple projects has been ground breaking. To exploit and replicate this great work will need a greater degree of coordination and conversely, flexibility in the project definition and deployment.