Urban Operating Systems for Sensor Network Management in Smart Cities

M.I.E. Olga B. Mora and Dr. Victor M. Larios, *IEEE Members*

Abstract—To meet growing urbanization challenges, technology offers solutions for the optimization of processes and services in cities via the development of a Smart City. Sensor networks, data repositories, and data analytics are current processes that are used to manage Smart City infrastructure, where complexity, resilience and interoperability are key issues for emergent Urban Operative Systems. This concept can allow for dealing with complexity based on similar principles of computer operating systems. Hence, the work of this thesis is related to creating the foundations of an Urban OS for a Smart City. To validate this concept, we will use the Smart Cities Living Lab at CUCEA UDG. The aim is to implement a sensor network to track different variables of a 50-hectare surface representing a micro city to create city dataset prototypes to measure the Smart City status. To achieve this goal, an Urban Operating System is proposed to carry out the administration of the different types of interconnected devices, referencing the Internet of Things (IoT) in the field of Smart Cities.

Index Terms— Internet of Things, Sensor Networks, Smart Cities, Urban Operating Systems, Intelligent Utilities.

1 Introduction

Guadalajara city will develop the first urban system for smart cities to provide a solution as part of the infrastructure of a network of sensors and actuators that were previously implemented. The variety of services provided within a city make this system highly complex. The Mexican project "Operating system for urban mobility" won the Audi Urban Future Award 2014. Regarding mobility, the data platform allows cities to design their transportation network according to needs and allows drivers to flexibly adapt to the latest status [1]. Living PlanIT is a company of English origin that developed the unique Urban Operating System, [2] and Urbiotica is a Spanish company that has developed similar technology [3]. However, to-date, there is no fully functional system, and previously developed systems belong to the private sector. We will develop a proposal for an urban operating system utilizing open technology. The system will focus on providing services to citizens, as the platform must answer to citizens needs and provide information in real-time regarding the services requested by citizens. The UOS must be resilient to recovery from failures, as a city cannot function without power, traffic light systems, hospitals, and schools for extended periods of time. The Big Data open standards will be implemented to create an ecosystem for urban innovation and sustainability.

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2 Concepts & challenges of the Urban OS

A system is a set of elements or parts that interact with one another to achieve a particular goal. In particular, Smart Cities can be considered to be Complex Systems where all the variables are interrelated to different degrees. Hence, to optimize a set of processes for a city, we must use complex systems theory to fit the best solution [4]. A Smart City is a complex system involving multiple factors and with many coexisting interrelated processes. In addition, it provides a space in which it is possible to initiate new business models, and it constitutes an excellent setting for innovation in the environment. One of the layers related to the Urban OS is the IoT and the management of sensor/actuator networks in the urban environments. Therefore, the IoT represents challenges that must be considered in an Urban OS reference model, as discussed in the following paragraphs. An urban operating system incorporates processes that are connected to a domain of the IoT within a Smart City. The IoT presents several challenges, such as communication, security, availability, resiliency, energy efficiency, network bandwidth, focus on the citizens, Big Data and standards. These challenges will be described in the following paragraphs.

2.1 Reliable communication

Reliable bidirectional signaling is essential for collecting and routing data among connected IoT devices. Using IoT data streams, devices may interact with a server to collect data, the server may talk to the devices, or the devices may talk to one another. In any scenario, data must be transmitted from point A to point B quickly and reliably. The communication of processes in an urban environment is critical, and this resource and its management is of high priority.

2.2 Security issues

Security is a huge umbrella and is paramount to the connectivity of the IoT. For example, when sensors and actuators are connected to the Internet and are able to communicate with other devices, security becomes issue. Actuators may open or lock the doors of a house or an office, and in the IoT vision, other devices, such as a smart phones, can be used to control the lock. If security is not carefully managed, doors may be exposed to any person able to hack the communication protocols, allowing them access to control doors. Specific elements to consider in security are the following:

Authorization: When sending or receiving a stream of data, it is essential to ensure that the IoT device or server has the proper authorization to send or receive the stream of data.

Open ports: An IoT device is dangerously vulnerable when it is listening to an open port to the Internet.

Encryption: End-to-end encryption is required between devices and servers.

2.3 Availability of OS components

It is important to immediately know when an IoT device drops off the network and goes offline. In addition, when that device comes back online, it is neccesary to verify the status of the device. In smart cities, policies should be established for resilience and failure management of sensors and actuators. However, as the number of components in a smart city grows, IoT devices over the Urban OS should converge on a self-organized strategy with evolutive and adaptative capacities.

2.4 Energy efficiency

Thousands of IoT devices signaling and sending data between one another utilize large amounts of power and CPU consumption. It is important for a Smart City that the actuators and sensors in the network save energy to reduce the carbon footprint and comply with environmental sustainability.

2.5 Effective use of network bandwidth

In addition to power and CPU, bandwidth consumption is another challenge for IoT connectivity. The bandwidth of a cellular network is expensive, especially with hundreds of thousands of IoT devices on a network sending request/response signals to the server. As mentioned regarding communications, sensor/actuator networks could lead to the communication of thousands of devices. It is important to properly manage the bandwidth to support all of the IoT devices working and cooperating in the Smart City to optimize services for the citizens [5]. By 2020, an estimated 20 to 30 billion connected devices will be in service worldwide. Therefore, a city connected to the IoT, utilizing an urban operating system, requires proper design and development. The concept of a “Smart City” consists of a developed urban area that creates a sustainable economic environment and a high quality of life by excelling in multiple key areas: economy, mobility, environment, people, living, and government [6]. Smart cities will drive the evolution of cities and will be vital to those seeking new ways to manage resources and deliver services.

2.6 A focus on citizens as the core of the Urban OS

City leaders must identify how to connect smart city ideals to the day-to-day concerns of citizens, including developing new forms of engagement using analytics to better understand actual needs and demonstrate improvements in critical areas such as public safety, health, mobility, and economic security.

2.7 Resilience as an attribute of smart cities

Resilience can be characterized as the ability of cities and communities to bounce back from catastrophic events and other threats to the stability and well being of the city. New approaches to increase resilience will strengthen smart city programs and provide additional insight into issues such as security and social inclusion.

2.8 The potential of big data for the overall status of the Urban OS

The ability to harness real-time, highly granular data across a wide range of city operations and services is changing the way the urban environment is managed and experienced. For this reason, the benefits offered by big data are a key element of many Smart City strategies and a
critical component to update the status of the Urban OS.

2.9 The development of smart city standards

Several initiatives are in progress to identify how standards can accelerate the adoption of Smart City solutions, reduce the risks to cities and suppliers, and make it easier for successful projects to adapt to new contexts [7]. Figure 1 shows a schematic of an integrated operating system to be developed, which features a network of sensors. Restful or MQTT facilities will be used for convenience during development. Information obtained from the sensors will pass through of the above services, will be housed in a cloud, and subsequently counted using a non-relational database and an open data framework in conjunction with the database. Finally, a simulation and optimization of the obtained information is performed by analyzing the data. This architecture is used for various services in a Smart City; the Sentilo platform in Barcelona utilizes this type of architecture [8].

The IoT concept aims to make the Internet even more immersive and pervasive. In addition, smart cities requires sensor/actuator networks to adapt the environment to the needs of citizens. Hence, an Urban OS is a challenge encompassing many disciplines, as discussed in the next section.

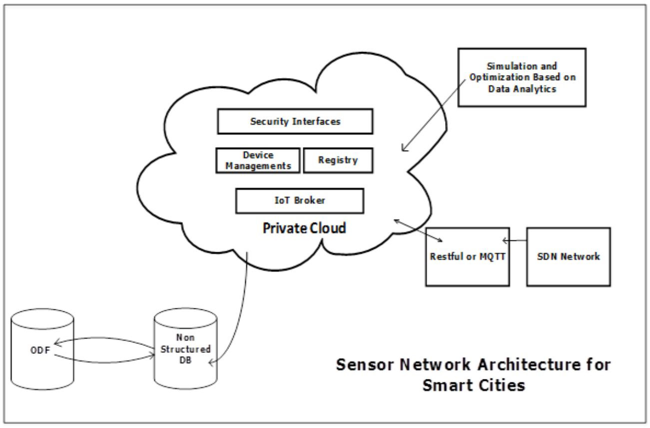

Fig. 1. Typical sensor/actuator network

3 General and specific aims

This project focuses on enabling a single platform to manage and identify the status of sensors and to generate a report based on real-time information of the number of operating sensors. As such, we considered the analogous definition of an operating system that processes information in real-time based on a collection of programs incorporating specific processes that generate output for the end user (in this case citizens). This paradigm is termed an Urban Operating System (OS).

4 Proposed methodology

For this thesis, smaller-scale project development will be performed in a living laboratory for smart cities, located in the center of technological innovation at CUCEA.

Properties of an urban operating system to be met are the following: *Resilience:* the ability to restore services if they are attacked. Resilience does not provide fault correcting (robustness), but provides a route to reintroduce elements that fail. *Interoperability:* new components may be added to the system at any time and should preferably be extensible at runtime.

Modularity: any one component (module) can be replaced or added without affecting the rest of the system. Challenges to overcome in this thesis are the following: communication, security, availability, power consumption, and bandwidth [9]. The following figure shows the parts that make up the urban operating system, which will cons-ist of distributed systems, complex systems, a sensor network, the IoT telecommunications and security. Each of these elements are required to develop an Urban OS.

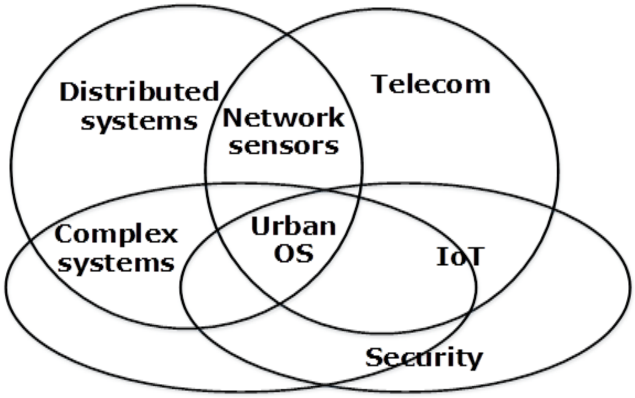

Fig. 2. Elements of an Urban OS

The Figure 3 shows the core OS functionality: process and thread management, memory management, and communication amoung processes on the same computer (divisions in the figure denote dependencies).

A city contains certain resources that are used in each process, such available streets or how much energy is distributed and managed, considering endless streets, infinite energy, or infinite water. The information of all processes in a city must be connected. The sensor network connects to the communication manager to control and optimize the water supply. For example, if a hose breaks and there is not a sufficient water supply, it is necessary to restore the service as soon as possible. In doing so, it should be known how much water should be allocated to water a garden in a portion of the city, which areas need to be watered first, etc. To achieve the proper performance of this process, it is necessary to develop an urban operating system to manage, monitor, communicate, and store processes as part of the services of a Smart City.

The core OS components are the following:

Process manager: Handles the creation and operations of processes. A process is a unit of resource management, including an address space and one or more threads.

Thread manager: Thread creation, synchronization and scheduling. Threads are schedulable activities attached to processes.

Communication manager: Communications between threads attached to different processes on the same computer. Some kernels also support communication between threads in remote processes. Other kernels have no notion of other computers built into them, and an additional service is required for external communication.

Memory manager: Management of physical and virtual memory.

Supervisor: Dispatching of interrupts, system call traps and other exceptions; control of memory management units and hardware caches; processor and floating point unit register manipulations [10].

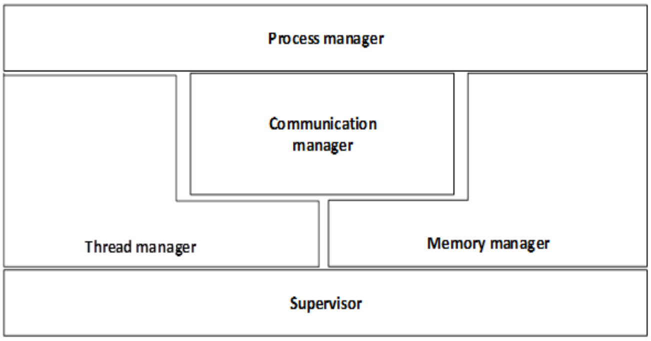

Fig. 3. Core OS funtionality

5 Expected results and perspectives

By the end of this project, we hope to have a model of an urban operating system for a Smart City prototype, international publications indexed validated by international scientific committees. This prototype will run for the first time in CUCEA as part of the development of the Living Lab for Smart Cities hosted by the Smart Cities Innovation Center at CUCEA UDG. Moreover, this project will significantly contribute to the IoT.

The following table shows the activities of the next 4 years, starting in January 2015.

Table 1 Schedule of activities

	2015				2016				2017				2018			
ACTIVITIES	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Bibliographic review	■	■	■	■	■	■	■	■	■	■	■	■				
State of the art					■	■	■	■	■	■	■	■	■	■	■	■
Problem formalization					■	■	■	■	■	■	■	■	■	■	■	■
Architectural design					■	■	■	■	■	■	■	■				
Experimental model deployment					■	■	■	■	■	■	■	■				
Results									■	■	■	■				
Analysis of results									■	■	■	■	■	■	■	■
Concluding remarks									■	■	■	■	■	■	■	■
Writing scientific publications (White papers, journals, conferences)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Thesis Report writing													■	■	■	■
Thesis dissertation													■	■	■	■

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