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Technological Architecture for Open Smart Cities

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Abstract— **Rapid urban growth as a result of migration from rural to urban areas, reaching a urbanization rate of 68% by 2050, has put pressure on management, planning and development of cities, which has generated major problems such as pollution, urban inequality, bad mobility among other challenges. In recent years a new paradigm has emerged to face these challenges and it is the concept of smart cities and lately of Open Smart Cities One of the fundamental pillars to transform cities into smart cities is to have an enabling ICT infrastructure. In this paper, the state of the art of technological architecture to achieve Open Smart Cities is presented.**

Keywords——**6LoWPAN, Central Management System (CMS), Gateways Open Smart Cities, IPv6, Smart Public Lighting Network (SPLN)**

I. INTRODUCTION

Approximately 68% of the world's population will live in urban areas by 2050, according to a projection of global urbanization, undertaken by the United Nations (UN) in 2018 [1], [2]. The phenomenon of the urbanization area, once predominantly rural, has completely changed human interaction with the environment. This, not entirely planned urban growth, has caused detriment to the quality of life of the population as a product of different aspects such as the increase in vehicular traffic, congestion, the increase in environmental and noise pollution, as well as many aspects of insecurity.

To solve the problems generated by urban growth, various forms of high-tech electronic devices have sprung up around the world, each proposing to solve a certain complication of everyday life. These technological applications are the result of the spread of the so-called Internet of Things (IoT) [1].

The key features such as instrumentation, intelligence and interconnection (3I) of Open Smart Cities are provided by Internet-of-Things (IoT) [1], [2].

While the concept of smart cities has been used for the last decade, new concepts of smart towns on a smaller scale, as well as smart states and countries on a larger scale are evolving for the same reason, i.e. better utilization. and limited natural resources [3].

The unlimited number of integrated technologies in an Open Smart City eliminates the static requirements that define smart service levels. Without focusing on the disparity in terms of the determined technical description of an Open Smart City, the components that make up an Open Smart City include: application of electronic technologies, use of ICT technologies, integration of government systems and the proliferation of best practices to enhance the use of the of innovative technology [4], [5] and [6].

In this paper we present an analysis of the state of the art from the technological point of view of the different systems that make up an enabling infrastructure applied in an Open Smart City. The organization of this document is as follows: Section II describes the concept of Open Smart Cities. Section III describes the concept of an Intelligent Public Lighting System. Section IV describes IoT technologies applied to an Open Smart City. Section V describes the concepts of a WSAN-IoT sensing and actuation wireless network, low-frequency communications infrastructure options for IoT, and 6LoWPAN networks. Section VI describes the concept of a Central Management System and its main benefits. Section VII describes the concepts and regulations applied to access points or gateways and wireless controllers of luminaires and WSN network routers. Finally, section VIII provides the conclusions and future lines of research.

II. OPEN SMART CITIES CONCEPT

The concept of an Open Smart City was created in response to the increasing complexity of today's city, where infinite opportunities are detonated as a result of the generation of a large amount of information and the multiple synergistic relationships between the various urban systems.

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Open Smart Cities allow the inhabitants to make a productive use of urban information. In this sense, it seeks to overcome the more classic definition of a smart city which proposes it as “a technologically instrumented city, with integrated systems, where a large amount of information collected by sensors is used to manage and control urban life in real time” [7], that is, as a problem of technological solution. And it proposes “a city where residents, civil society, academia and the private sector collaborate with public officials to mobilize technology and data, in an ethical, responsible and transparent way, to direct the government of the territory in a fair way, seeking the common good, through balanced economic development, social progress and environmental responsibility” [8].

Figure 1 shows the main principles of an Open Smart City [9].

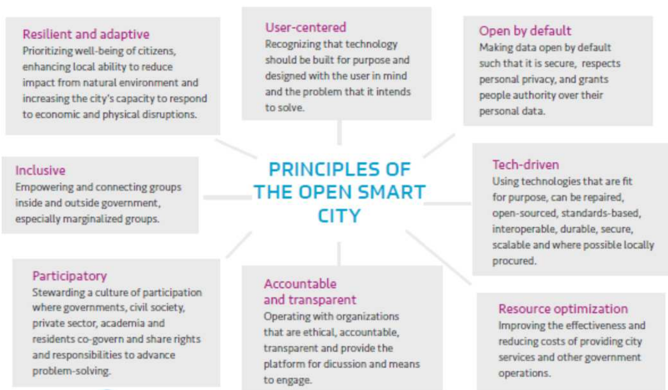

Fig. 1. Main principles of an Open Smart City [9]

The Open Smart City paradigm seeks to ensure that the cities of the future are not only smarter, but also more open and accessible from all points of view: technologies, communication protocols, relationship with citizens, access to information, participation and transparency. Cases of application of these concepts are Montreal, Toronto, Bristol, Helsinki, New Orleans, New York, among others.

III INTELLIGENT PUBLIC LIGHTING SYSTEMS (IPLS)

Intelligent public lighting systems have always been of great importance to the community by providing security and comfort to anyone, therefore they are public goods; However, it is not excluded that there are attractive business models for individuals and a common need in the development of cities: parks, avenues, public squares [10].

Several cities around the world have recognized Smart and Connected Public Lighting Systems as a first step towards the development of an Open Smart City. In addition to increasing the city's energy efficiency and reducing energy costs, carbon emissions and maintenance costs, connected public lighting can also provide a strategic backbone for the establishment of a Wireless Sensorization Network or Internet of Things (IoT), for a range of other city applications, including public safety, traffic management, waste management, automation of inspection processes, tourism, smart parking, environmental monitoring, among others.

Open Smart Cities use connectivity, sensors distributed in the environment and computerized intelligent management systems where wireless controllers of the luminaires and the access points or gateways (gateways) form a meshed radio frequency network (Mesh) with medium and low range characteristics energy consumption. In order to guarantee efficient and sustainable management, Open Smart Cities technologies integrate and analyze an immense amount of data generated and captured from different sources that anticipate, mitigate and even prevent crisis situations. These mechanisms make it possible to proactively offer better services, alerts and information to citizens [11].

The smart street lighting solution must be based on an enabling infrastructure of telecommunications or Wireless Sensor Network (WSN) and must consider all the sufficient and necessary components and hardware and software devices to centrally manage all the luminaires considered in these terms of reference.

IV. IoT TECHNOLOGIES IN OPEN SMART CITIES

A. Introduction

The paradigm of "Open Smart Cities" adopts solutions for the improvement of the quality of life of citizens, having more and more relevance and prominence. From the “technological” point of view, the concept of “Internet of Things (IoT: Internet of Things)” is normally used for the development of Open Smart Cities or Open Smart City, which can be described as a city that applies IoT technologies in order to provide it with an infrastructure that guarantees:

- Sustainable development.
- An increase in the quality of life of citizens.
- Greater efficiency of available resources.
- Active citizen participation.

The IoT is a cutting-edge technology that offers the possibility of simultaneously connecting to the Internet a large number of digital devices endowed with various abilities: such as detection, performance and computing capacity with the Internet, seeking to make the Internet more enveloping and penetrating thus offering multiple new services in the context of an Open Smart City, as seen in Figure 2. Attractive IoT services and Big data analytics are enabling Open Smart Cities initiatives around the world. These services are transforming cities by improving infrastructure and transportation systems, reducing traffic congestion, providing trash waste management, and improving the quality of human life, among others [12].

An Open Smart City is a complex ecosystem characterized by an intensive use of information and communication technologies, highlighting the digitization of signals, data transmission, mobile telephony, fiber optics or fixed and mobile broadband, which have transformed radically the world of communications, trying to build more attractive and more sustainable cities. The main enabling services for an IoT network incorporate application developers, service providers, citizens, governments, internet service providers, the community of researchers and platform developers [12].

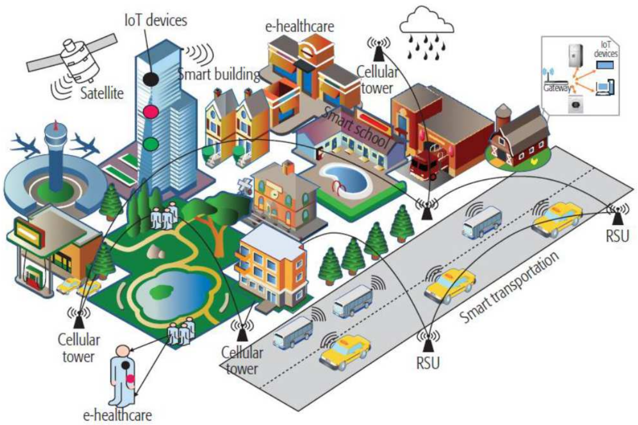

Fig. 2. Example of an Open Smart City based on IoT [12]

One of the important aspects to consider to build a smart urban IoT network infrastructure is to carry out a series of surveys of existing technologies, their applications, architectures and open standards, in such a way as to support municipalities decisions when they need to make investments in this ambit. Figure 3 shows a diagram of the open technological architecture composed of Sensors and Actuators, an Enabling IoT Network, a Management Center and Applications of an Open Smart City [13].

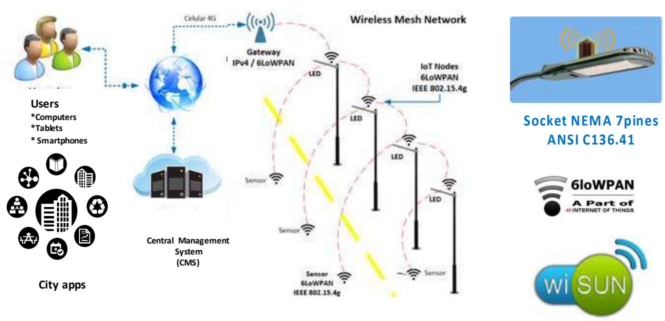

Fig. 3. Wireless IoT Sensorization Network [13]

An enabling infrastructure of an Open Smart City is made up of the following modules:

- Wireless sensorization and actuation network (WSAN: Wireless Actuator Sensor Network) IoT.
- Central Management and Control System (CMS: Central Management System).
- Access Point or Gateways.
- Wireless controllers for luminaires and WSN network routers.

B. *Activities of Standard Bodies - Standardization Bodies.*

IoT offers diverse applications in an Open Smart City, thus demanding numerous requirements. For example, IoT-based solutions are expected to be low cost, low power consumption, high Quality of Service (QoS), greater coverage, greater flexibility, high security and privacy, ultra-dense deployments, and multi-vendor interoperability.

Different protocols and standards can be found in the IoT world, as seen in Figure 4, where it shows a taxonomy of an Open Smart City based on IoT.

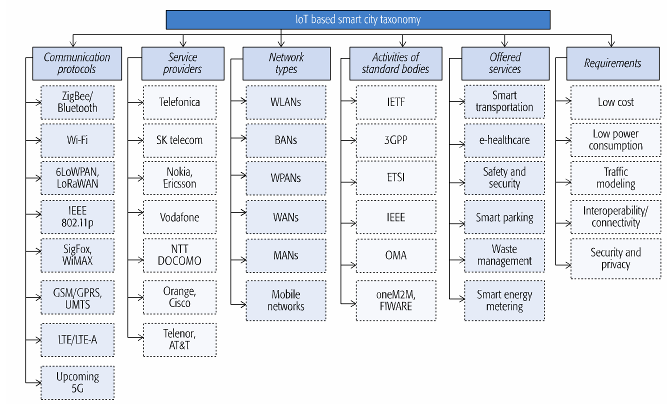

Fig. 4. Taxonomy of an Open Smart City based on IoT [12]

The various applications of an Open Smart City not only require large-scale deployment of numerous types of IoT devices, but also require device interoperability.

Consequently, the most prominent governing bodies, such as the Internet Engineering Task Force (IETF), the Third Generation Partnership Project (3GPP), the European Telecommunications Standards Institute (ETSI), oneM2M (Machine to Machine), Institute Electrical and Electronic Engineering (IEEE) and Open Mobile Alliance (OMA) are actively involved in the development of standards to support large-scale Open Smart Cities applications.

V. WIRELESS SENSORING AND WSAN-IoT ACTUATORS

A. *Introduction*

Some of the new technologies, due to their simplicity and low cost, break the traditional paradigms of the communication service provider. Figure 5 presents the different types of technologies applied to IoT.

The technology to implement a technological architecture of an Open Smart City must be modular, expandable, with widely adopted open standards, which can be combined with other platforms and connected with the population through user-friendly applications [14].

Municipalities and cities can benefit from an Internet of Things (IoT) connectivity infrastructure that enables the development of smart solutions in a ubiquitous way. Figure 6 shows the technologies and standardization of IoT protocols applied to Open Smart Cities [15].

B. *Low Frequency Communications Infrastructure Options for IoT*

The Sub-1 GHz frequency bands present certain advantages for the implementation of IoT networks, such as:

- Coverage: lower frequency radio waves propagate better than higher frequency ones; therefore, they can achieve greater coverage, especially inside buildings.

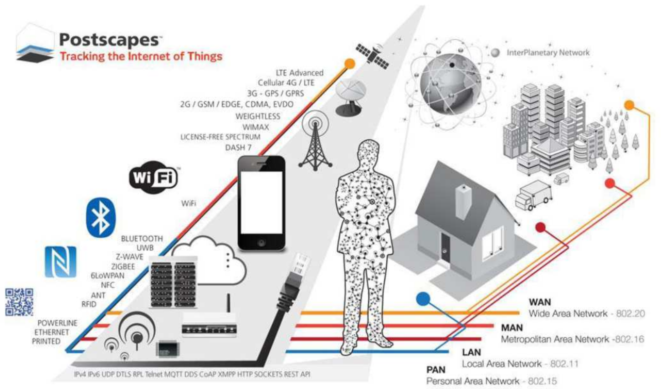

Fig. 5. Technologies applied to IoT 14]

- Low power consumption: For the same signal output in power, a Sub-1 GHz transceiver requires less power compared to the 2.4GHz spectrum, for example.
- Interference: There are fewer applications operating at low frequencies and it is possible to operate in an exclusive band in accordance with the telecommunications regulations of each country on the matter.

Sub-1 GHz solutions are also used in the implementation of Open Smart Cities infrastructures where each wireless node is part of a network.

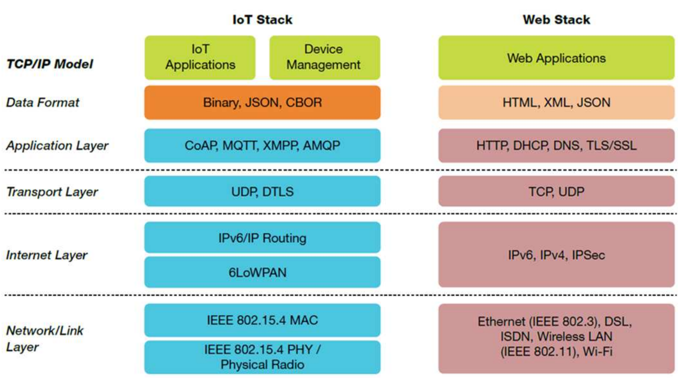

Fig. 6. Standardization of IoT Protocols [15]

C. LPWAN networks

One of the main problems for IoT and M2M (Machine to Machine) communications is long-range, low-power communication. LPWAN (Low Power Wide Area Network) technologies have long-range capabilities, they need to use high receiver sensitivities, down to -130 dBm compared to -90 to -110 dBm in many traditional wireless technologies. This implies a higher energy per bit and therefore a slower modulation rate.

An LPWAN can be used to create a private IPv6-based wireless sensor network, but it can also be a service or infrastructure offered by a third party, allowing sensor owners to deploy sensors in the field without investing in technology or infrastructure.

The 6LoWPAN (IPv6 over Low Power Wireless Personal Area Networks) protocols developed by the IETF have been designed to be used in devices with low processing capacity, and with the option of battery power and that operate on the 802.15.4g physical layer protocols. (Smart Utility Network) and IEEE 1901.2 (Narrowband PLC [16].

These protocols allow to form meshed networks that provide wide coverage, where an end node can be connected to one or more nodes that can route the transfer of information and offer greater tolerance to failure and availability than other types of topologies. Furthermore, these mesh networks can reduce the costs of the enabling infrastructure due to their flexible architecture.

The LPWAN ecosystem comprises providers such as Semtech Corporation (US), LORIOT (Switzerland), NWave Technologies (UK), SIGFOX (France), WAVIoT (Texas, US), Actility (France), Ingenu (San Diego, USA), Link Labs (Maryland, USA), Weightless SIG, and Senet, Inc. (Portsmouth, UK), ResIOT (Italy) and others as service providers and companies. Other stakeholders in the LPWAN network market include telecom operators such as Vodafone (U.K.) and Orange (France), among others, who integrate these smart devices and sell them to end users to meet their unique business requirements. It operates at very low transmission speeds, has long battery life, and has a low duty cycle to coexist in a shared spectrum.

Among its main applications, we can mention [16]:

- Intelligent public lighting.
- Parking space occupancy sensors.
- Backup burglar alarm (mobile jammers widely available)
- Cases of use of social housing (for example, smoke alarm).
- Pet tracking.
- Fill level of the garbage collection bin to optimize the collection route.
- Agricultural sensors.
- Detection of forest fires.
- Among others.

There are a series of standards and providers that compete in the LPWAN space, among which the standardized networks Cellular, 6LoWPAN, IEEE 802.15.4 and ZigBee, Bluetooth/ BLE v.5.1, DASH7, DSRC, GSM/GPRS, LTE/LTE-Advanced M-Bus, NB-IoT, Powerline Communications (PLC), RFID, Thread, Wi-Fi IEEE 802.11n, IEEE 802.1.5.4g, Wi-Fi IEEE 802.11p WAVE, Wi-Fi IEEE 802.11ah HaLoW, Wi-Fi IEEE 802.11ax Wi-Fi 6, Wireless HART, Wi-SUN Alliance, Z-Wave, among others.

The choice of these communication standards for IoT will largely depend on the connectivity needs required by the Open Smart Cities applications.

VI. CENTRAL MANAGEMENT SYSTEM (CMS)

A. Introduction

A Central Management System is a set of computer, electronic and telecommunications technologies that automates, supervises or performs control over long and short distances of equipment and/or devices, with input/output signals, technical facilities, isolated or geographically distributed in remote facilities, recording operating parameters of a sensor network. Any abnormal situation is immediately detected, being possible to send alarm signals to the CMS, thus achieving tools for monitoring and control of all technical and administrative operations [16].

A CMS establishes the bases for user interaction with the equipment installed in the field, making supervision and control activities more user-friendly, in addition to allowing the management of databases and the generation of reports associated with energy consumption and operating states of the installation without requiring any advanced programming by the user, by having mechanisms and templates already available for such needs.

B. Benefits

The main benefits of a CMS are as follows:

- Control and reading of intelligent energy consumption.
- Detection of problems in a sensorized network, improving the response time and the service offered.
- Reduction of operating costs.
- Reduction of maintenance and inventory costs.
- Compatible with multiple technologies and manufacturers.
- Compatible with customer information systems and citizen participation platforms.
- Adapt the existing smart lighting infrastructure to a network of an Open Smart City.
- Use of standard technologies.
- Remote monitoring.
- Smart asset management.

Among the world's leading vendor manufacturers of an Open Enabling Network on Smart Street Lighting: Paradox Engineering - Smart Urban Network, Itron (Silver Sprint Networks) - Gen 5 Network, Cisco - Filed Area Network 6LowPAN + Kinnetics and Engie - FlashNet (Wi-SUN version) + Intelilight.

VII. ACCESS POINT OR GATEWAYS AND WIRELESS LUMINAIRES CONTROLLERS AND NETWORK ROUTERS WSN

A. Access Point or Gateways

A gateway for sensorized networks is responsible for maintaining the sessions and subscriptions of all the connected devices of an IoT solution. The IoT Device Gateway enables secure, two-way communications between connected devices and the platform through MQTT, WebSockets, and HTTP. Communications protocols such as MQTT and HTTP allow the company to use industry standard protocols instead of a proprietary one that could limit interoperability in the future [16].

As a publish and subscribed protocol, MQTT inherently supports scalable and fault-tolerant communication patterns, as well as allowing a wide range of communication options between devices and the device gateway.

These message patterns can range from communication between two devices to broadcast models, in which one device sends a message to many others on a common topic. In addition, the MQTT protocol exposes different levels of Quality of Service (QoS) to control the retransmission and delivery of messages as they are published to subscribers.

Combining publish and subscribe capabilities with QoS not only enables IoT solutions to control how devices in a solution interact, but also creates greater predictability in how messages are delivered, confirmed, or retried in case of network or device error [16].

The main protocols applied to Access Points or Gateways are mentioned below: MQTT (Message Queue Telemetry Transport) ver. 5.0, MQTT-SN v 1.2 (MQTT for Sensor Networks), CoAP (Constrained Application Protocol), AMQP (Advanced Message Queuing Protocol), WebSockets Protocol - RFC 645, HTTP/2 Protocol - RFC 7540, XML (eXtensible Markup Language - Language Extensible Markup or Extensible Markup Language), JSON (JavaScript Object Notation), RESTful, XMPP (Extensible Messaging and Presence Protocol - Extensible Messaging and Presence Communication Protocol), XMPP-IoT112, LLAP (Lightweight Local Automation Protocol - Light Protocol for Local Automation), OMA LWM2M (Lightweight M2M), SOAP (Simple Object Access Protocol).

Of all these protocols mentioned above, those that meet the Open Source requirements are the following: MQTT, MQTT-SN, CoAP, AMQP, WebSocket Protocol, HTTP/2 Protocol, XML, JSON, RESTful, XMPP, XMPP-IoT, LLAP , OMA LWM2M and SOAP.

B. Wireless Luminaire Controllers and WSN Network Routers

Both nationwide and globally, there is a set of regulations applied to wireless controllers and WSAN network routers that are used in RAPI luminaires. Among them there are [16]:

- NCh3426: 2017 - External device type photocell for driver or ballast control:
- ANSI C136.41 - Roadway and Area Lighting Equipment - Dimming Control between an External Locking Type Photocontrol and Ballast or Driver.
- IEEE 1451 Standard for Smart Transducers - Standard for Smart Transducers.
- Family of Standards 1451.
- IEEE 1905.1-2013 Standard for a converged digital home network for heterogeneous technologies.
- IEEE 1377-2012 Standard for the utility industry measurement communication protocol application layer.
- IEEE P1828 Standard for systems with virtual components.
- IEEE P1856 Standard Framework for Prognosis and Health Management of Electronic Systems.

The Chilean standard NCh3426: 2017 describes the methods for controlling the level of luminous flux through an external device type photocell for intelligent public lighting equipment. Mechanical, electrical, and marking requirements are established for dimming, receptacles, and photocell coupling. This Standard is used to specify a type of base for photocells for outdoor lighting that is compatible with on, off and intensity control devices. As well as monitoring the luminaire.

Figure 6 shows a connection diagram of a remote management control device that includes a motion sensor. One of the most powerful applications of photocell bases that comply with this standard is the possibility of performing a massive replacement of luminaires initially installed with a photocell (or bypass cell), to later install remote management systems in specific areas or progressively, without changing or intervening the luminaire [16].

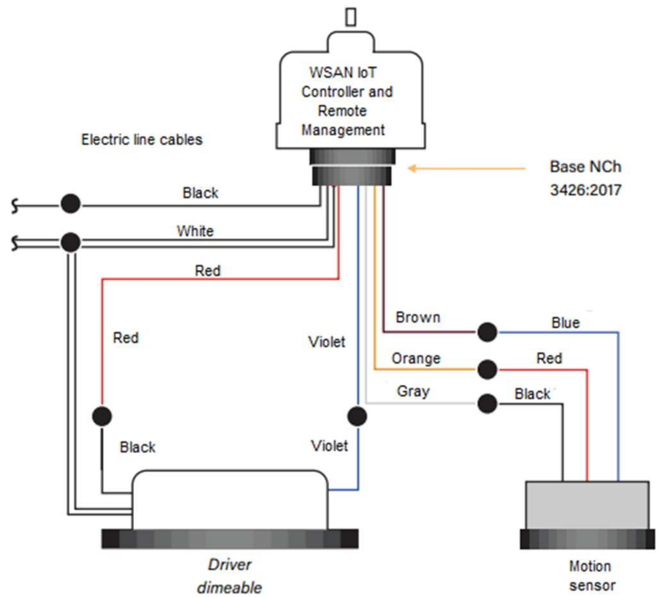

Fig. 7. Connection diagram for a remote management device using a base that complies with NCh 3426: 2017 [16]

VIII. CONCLUSIONS AND FUTURE WORK

In this paper we present an analysis from the technological point of view of the different systems that make up an Enabling Infrastructure applied to an Open Smart City, where its main requirements must be that it be an open system, with low power consumption, operating in the low frequency bands (less than 1 GHz), and that make use of the IPv6 communication protocol and are interoperable.

The choice of communication standards for both IoT and the gateways to be selected will depend largely on the types of services to be installed within an Open Smart City.

As future work, a Pilot System will be applied to an Open Smart Campus inside the University of Santiago de Chile.

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