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SimulCity: Planning Communications in Smart Cities

MIGUEL A. RODRIGUEZ-HERNANDEZ, ANGEL GOMEZ-SACRISTAN, AND DAVID GOMEZ-CUADRADO

Instituto ITACA, Universitat Politècnica de València, 46022 Valencia, Spain

Corresponding author: Miguel A. Rodriguez-Hernandez (marodrig@upvnet.upv.es)

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ABSTRACT Communication networks have become a critical element in the development of smart cities. The information flows generated by thousands of sensors and systems must be managed to assure the adequate guarantees of quality, availability, and security. This paper introduces the SimulCity tool, which assists in the design of a smart city's communications convergent network. SimulCity allows a flexible simulation of different scenarios where multiple heterogeneous sources of human type communications (HTCs) and machine type communications (MTCs) compete for limited bandwidth resources. SimulCity evaluates the impact of new services on the performance of a municipal communications network and, consequently, assists the modification of network values to optimize bandwidth and reduce costs. Several network characteristics can be easily configured in SimulCity, such as the definition of traffic sources, the parametrization of different network mechanisms, access admission control, quality of service (QoS), and traffic in the multiprotocol label switching (MPLS) network. SimulCity was used to simulate different projects in the smart city of Valencia (Spain). Specifically, SimulCity was used to study the impact on the Valencia City Council's communications network of several new services: the solid waste collection supervision, the street lighting management, the control of regulated parking areas, and the upgrade of voice and video communications systems of the city government buildings. The results obtained have allowed the analysis of the impact that these new services have on the existing network and to perform an adequate dimensioning of the future municipal communications network.

INDEX TERMS Smart city, communications, simulation, QoS (quality of service).

I. INTRODUCTION

Cities are powerful engines for economic and social growth thanks to the opportunities offered in contrast to the rural environment: cities have greater diversity and quality of employment, as well as better infrastructures and services. These opportunities have generated large inhabitant concentrations in urban areas. These concentrations translate into an increasing demand of resources such as energy, water, health services and education. Thus, a sustainable management of the cities and urban areas has become a key element in the policy of administrations around the world.

The smart city concept [1]–[4] emerges as a global response to the multiple challenges of this complex urban system that must be faced by municipal managers to improve efficiency and sustainability, and to offer more and better services to the citizens [5], [6].

Information and Communications Technologies (ICTs), and especially those related to the Internet of Things (IoT) [1], [7]–[11], play a crucial role in dealing these challenges while taking advantage of new opportunities. ICTs increase efficiency and innovation, facilitating the integration of municipal services, cooperation between sectors and aid in decision-making in the key areas of urban development: economy, governance, environment and society [12]. This efficient management of available resources and services requires intelligence in certain physical and logical infrastructures but also collecting and managing an increasingly high volume of information most of them in real time. This information, of very diverse nature, must be processed and interpreted [13]–[15] in order to monitor the city, to be able to identify synergies and to improve efficiency.

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In addition, this information must be securely transmitted [16] to be processed at local premises or in an external cloud [17].

In this complex environment, the telecommunications network of a smart city must be able to support abrupt increases in traffic generated by thousands of heterogeneous devices, ensuring the quality and availability of underlying services. Also, the assessing of the impact that the introduction of new smart services has over the telecommunications network is an area of growing interest.

Aspects such as geographical coverage, low consumption and devices cost, together with the appearance of new technologies, like 5G [7], [11] and novel traffic patterns, are not sufficiently characterized and generate new challenges that need to be addressed. This paper delves into the aspects related to the performance evaluation of various services under a reference architecture. Therefore, the heterogeneous sources of traffic that appear in a smart city were characterized, and a model for a convergent communications network was defined in accordance with ITU recommendations Y.2011/Y.2012/Q.3900 related to the Next Generation Networks (NGN).

Different tools related to the development of smart cities have emerged in recent times. Some examples are: CityPulse [13], a framework to integrate, manipulate and process data; PriorityNet [18], an app for establishing priorities in ultra-dense networks; UbeHealth [19], a personalized ubiquitous cloud healthcare system; SmartCityWare [17], a middleware service for cloud and fog smart city services; or CrowdSenSim [20], a simulation platform for mobile crowdsensing in urban environments. The SimulCity tool proposed in this work is included within this ecosystem of applications associated with smart cities.

Simulations are an important phase during the design process of IoT systems [21]. There are numerous of simulators [22] and testbeds [21] related with IoT, and SimulCity could be included in the category of network simulators [22]. SimulCity stands out by its flexibility in the modeling of traffic sources with arbitrary behaviors and by its generation of different results for the adequate sizing of the smart city access network. The comparison of SimulCity with other IoT simulators is a complex task, but to the best of our knowledge, at present there is no available simulator, specifically designed for smart cities, that allows the assessing of the impact of the implementation of new services supported on the existing communications network infrastructure. In SimulCity, the communications architecture of a smart city and the devices and sensors that compose the smart city are defined. The development of this work included the analysis of different data sources, the modeling of theirs traffic patterns and the analysis of the impact of their integration into the smart city communications architecture.

SimulCity was designed to simulate, in a flexible way, scenarios where multiple sources of voice, video and Machine Type Communications (MTC) share resources in the defined network model. SimulCity also allows the configuration of the traffic management mechanisms (access admission control, Quality of Service (QoS), police functions, traffic in the MPLS network) to evaluate performance of the communications in the smart city network.

As a practical application, SimulCity was used to simulate different service scenarios that are in the process of deployment in Valencia (Spain). Specifically, the simulated projects are the ones related with the solid waste collection supervision, the public lighting management, the control of regulated parking areas and the update of the voice and video communications system of the municipal buildings. The impact of these projects collected in the Initiative ''Impulso VLCi'' of the Valencia City Council is analyzed by using SimulCity. The results obtained allowed an adequate municipal communications network dimensioning prior to the deployment of the projects.

The structure of the document is as follows: sections II and III provide a general description of the SimulCity tool and its modular structure. Section IV describes different initiatives to deploy IoT devices in the City of Valencia. Sections V, VI, VII and VIII analyze the impact on the municipal communications network of the different projects studied individually: urban waste management, public lighting management, regulated parking spaces management and unified corporate communications. Section IX proposes the global solution to the municipal communications network that includes all the previous projects. Finally, Section X reflects the most relevant conclusions.

II. SIMULCITY OVERWIEW

The simulation tool SimulCity allows assessing the communications performance in a smart city using Metro Ethernet accesses and heterogeneous traffic sources that compete for a limited bandwidth. SimulCity responds to an operational need for the evaluation of performance and dimensioning of the access Metro Ethernet, before the implementation of projects that incorporate a high number of devices that inject traffic into the smart city network. The existence of a single access infrastructure requires traffic management mechanisms to maintain quality objectives in accordance with international recommendations.

In the SimulCity functional specification phase, the priorities were:

- Flexibility in traffic sources design and scenarios definition.
- Ease use and configuration.
- Graphic environment.
- Free to use software.
- Exporting results to other analysis tools.

SimulCity has been designed in a modular way using the OMNeT++ [23] framework and C++ code. OMNeT++ is a free use, flexible, extensible, modular, component-based C++ simulation library and framework for building network simulators widely used in the scientific community. OMNeT++ libraries contain models for the internet stack, wired and wireless link layer protocols, and many other

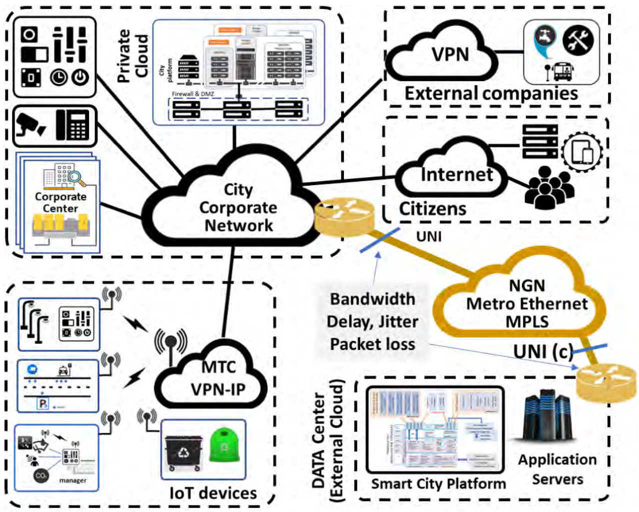

FIGURE 1. Simplified architecture of a municipal communications network.

protocols and components; additional modules can be programmed in C++. OMNeT++ works in Windows, Linux and Mac platforms and can import and export different data formats. SimulCity does not require any special hardware and the simulations presented in this paper were performed over a Windows PC with Intel Core i7-4790k CPU and 16MB of RAM.

Figure 1 describes the typical communications architecture of a smart city where most municipal buildings are connected using their own infrastructure based on different technologies, mainly optical fiber. For economic and security reasons, small buildings, municipal or external companies are connected to the municipal corporation through virtual private networks (VPN) contracted with a telecommunications operator using Metro Ethernet, FTTH, mobile, xDSL, etc. Connectivity with IoT devices is done, generally and mainly for security reasons, through MTC operator VPN solutions. The municipal corporation also has internet accesses for the relationship with citizens, remote access for corporation members (i.e. teleworkers), and other devices or external systems. Finally, the technological infrastructure of the Smart City Platform resides in an external data center connected by a Metro Ethernet access plus a MPLS network.

Following the architecture of figure 1, SimulCity was designed allowing as more outstanding functionalities:

- Definition of configurable traffic sources in terms of number, type and behavior that generate flows to the Smart City Platform.
- Assignation of each source type to a certain Class of Service (CoS).
- Configuration of the parameters of the Metro Ethernet links, allowing the evaluation of the increases in communication costs derived from the introduction of new municipal projects.
- Configuration of the queue management mechanisms and traffic discarding.
- Configuration of the MPLS network behavior according to different delay and packet loss criteria.
- Simulation of a network scenario during an arbitrary time with different boundary conditions.
- Obtaining results of used bandwidth, delay, jitter, packet loss for individual sources and for the whole set of sources.

SimulCity can evaluate the influence in bandwidth, delay, jitter and packet loss due to sources traffic pattern, class of service selection, Metro Ethernet parameters, queues management and MPLS behavior over different network scenarios.

The results obtained with SimulCity can be used, through an iterative process, to achieve the appropriate values of communication access bandwidth and minimize costs.

III. SIMULCITY STRUCTURE

SimulCity is composed by several modules. In this section, the three main modules are described: The traffic source configurator, the Metro Ethernet UNI interface, and the global scenario definition.

A. TRAFFIC SOURCE CONFIGURATOR

SimulCity implements three configurable types of traffic sources: voice, video and data.

For voice traffic sources, SimulCity implements a burst on-off model fully configurable with the necessary attributes to make it as realistic as possible. For this purpose, the model for VoIP (Voice over IP) sources proposed in [24] was used. The model is based on two general states that define when the source is active and when it is not, and two others on/off attributes that appear when the source is active in order to simulate speech and silence times. In this way, voice packets only are sent when the source is active, and its attribute is on. The voice codec can be chosen among the following: G.711, G.729, G.723.1, G.726 and G.728.

Video sources are implemented through two states: one in which video frames are sent (25 frames per second by default following the European standard) and another one in which traffic is not sent. The size of frames depends on the frame type, implying that the generated video bitrate is variable. The H.264 codec [25], [26] is simulated with a variable bitrate using the Kush Gauge algorithm [27]. The Kush Gauge algorithm considers the frames resolution, the frames per second and a movement factor to calculate the video bitrate.

The data source works like a flexible data burst generator that sends data files, which can contain both text and images. Each burst is considered a session, in which files are configurable both in number and in size. MTC service requirements of the 3GPP TS 22.368 [28] was used as reference for the model definition, considering the structures heterogeneity and data formats. SimulCity proposes for MTC a "modeling by traffic sources" that allows managing each source individually. This solution offers greater flexibility, but in turn requires a processing capacity proportional to the number of simulated sources.

B. METRO ETHERNET UNI INTERFACE

The main elements and functionality of the Metro Ethernet User Network Interface (UNI) were defined to simulate the behavior of the access interface provided by a WAN network operator including CoS mechanisms and queue management. For greater realism, the Telefonica (Spanish telecom operator) Macrolan Service [29] was simulated using as a reference the functionalities of the switch-router Cisco Catalyst 3650 [30]. This solution does not detract the generality of the tool since no manufacturer-specific configuration parameters are used. Access parameters are independent of the operator and follow the recommendations of the Metro Ethernet Forum standards [31].

Traffic is classified at the input of the router. Three categories of traffic were considered, as in Macrolan Service: multimedia, gold and silver. Multimedia traffic includes VoIP traffic, gold traffic includes video and real time data traffic, while silver traffic includes best effort traffic.

A simple module was implemented to carry out the tasks of QoS policing. This module accepts as parameters the values of CIR (Committed Information Rate), CBS (Committed Burst Size), PIR (Peak Information Rate) and PBS (Peak Burst Size). The policing module works by means of a two rate Three Color Marker algorithm as defined in recommendation RFC 4115 [32]. In this way, each kind of traffic has a different guaranteed traffic, with a possible bandwidth excess.

A basic queue simulation model with four queues was developed: the first one for multimedia traffic, the second one for gold traffic, the third one for silver traffic, and the last one for critical traffic such as management and control. The real-time traffic queue is small (10-100 packets) in order to minimize delays and jitter, while the queues dedicated to non-real-time traffic are long (500-1,000 packets) to minimize the loss of information. However, the queue lengths are also completely configurable by the user. The multimedia queue is a priority queue, while the other three queues are managed with a weighted round robin policy with configurable weights.

Also, a Metro Ethernet Access (UNI(c)) that implements the QoS evaluation tasks has been defined at the input of the Private Cloud.

C. GLOBAL SCENARIO DEFINITION

The global scenario of SimulCity simulates an end to end scenario that includes one or more Municipal Corporate Centers, a MPLS network and the Private Cloud where the Smart City Platform and other consolidated servers are hosted. Figure 2 displays the implementation in OMNeT ++. The router at the input of the Private Cloud is used to configure the QoS, because this is the place where traffic from all the Municipal Corporate Centers join, and congestion may occur. The speed of the link between the Municipal Corporate Center module and the MPLS network is configurable; the speed can be selected among three values: 10Mbps, 100Mbps and 1Gbps. The speed of the link between the MPLS network and the cloud is also configurable and can adopt any value.

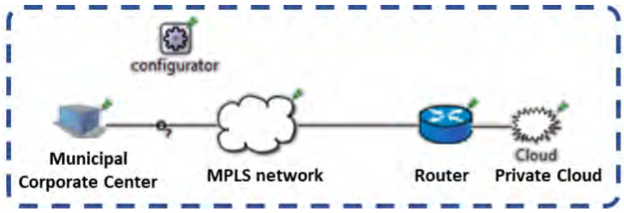

FIGURE 2. Global scenario definition in OMNeT++.

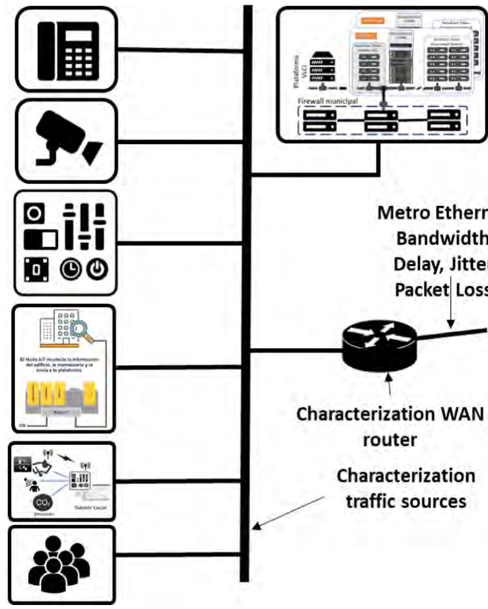

FIGURE 3. Municipal corporate center.

The Municipal Corporate Center module is responsible for two main functions: the characterization of the traffic sources and the implementation of CoS mechanisms. Figure 3 shows the Municipal Corporate Center architecture with an arbitrary number of sources:

- Voice sources for telephony services.
- Video sources for access control services, traffic management, video surveillance, etc.
- Data sources for IoT devices, municipal information systems, user access, building control, etc.

To assist in the implementation in OMNeT++ and to obtain statistics, a specific module was defined for the Municipal Corporate Center. This module is composed by three submodules (one for each service type: voice, video and data), a switch that aggregates all the traffic generated by the Municipal Corporate Center and the output router.

The MPLS network module simulates the network from the output of the Municipal Corporate Center until the input of the Private Cloud. The main function of this module is to simulate the delay and the packet losses that may occur during the MPLS process. It allows building scenarios with several corporate centers, as in the case of a non-centralized architecture where each municipal building has own access to the Private Cloud. Figure 4 shows a general scenario with this architecture.

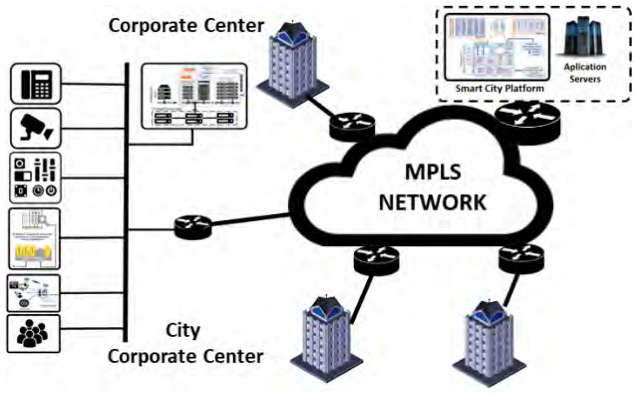

FIGURE 4. MPLS network architecture with several corporate centers.

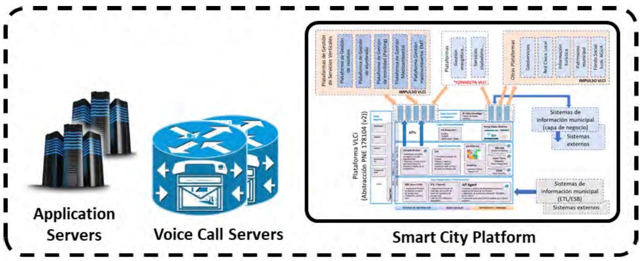

FIGURE 5. Private Cloud with remote servers.

The characteristics of the link between each Corporate Center and the Private Cloud can be customized: it is possible to select the speed of the link, the delay (the time to cross the MPLS network), and the possibility to discard a frame. These parameters are updated when a new packet is sent, and they can take fixed values or random values following several statistical distributions.

The Private Cloud module stores the consolidated servers. The consolidated servers act in the simulation as statistics collectors, to calculate delays, packet losses and jitter for each service. The implementation of this module is very similar to the Municipal Corporate Center module. The servers are classified according to the type of traffic they receive: voice, video or data. This classification simplifies the calculus of the delay, the jitter and the received and sent packets. Figure 5 shows this module.

IV. INITIATIVES IN THE VALENCIA CITY COUNCIL

Currently, there are different municipal initiatives in the Valencia City Council that involve the deployment of IoT devices and the modernization of communications infrastructures and services. These initiatives include the possible migration of the current telephony network based on TDM to a unified communications solution [33] with centralized servers sharing the same hosting architecture as the Smart City Platform.

A generic municipal architecture was shown in figure 1 that includes users and devices directly connected to the City Corporate Network, users and devices connected through MTC VPN-IP mobile services, users and devices connected through VPN-IP services, and users and devices connected through the internet.

Among the 17 smart projects currently actives in Valencia, the four more illustrative projects for the purpose of this work were selected:

- Monitoring of non-perishable urban solid waste.
- Management of the municipal lighting network.
- Efficient management of parking spaces for persons with reduced mobility, for loading and unloading services and taxi stops.
- Unified Municipal Communications.

A study was carried out with the SimulCity tool to obtain a prior estimation of the effects on the municipal communications of these projects' deployment. In this way, the objective is to show the functionalities of the SimulCity tool by evaluating the impact on the municipal communications infrastructure of the different projects' execution. The evaluation process was divided in two iterative taps. In the first tap, each project was studied individually in order to obtain a first individual evaluation and dimensioning of the communications requirements. In the second tap, all the projects are jointly evaluated, and the dimensioning of the municipal communications network is obtained. In the two taps the selection of the optimum dimensioning is obtained by iterative simulations and the background traffic is supposed null because in Valencia it is managed by a different operator.

In the following sections, each of the projects is individually evaluated with SimulCity and the results obtained are used to size and to evaluate the municipal network with all the projects.

V. URBAN WASTE MANAGEMENT PROJECT

The monitoring of waste containers state allows the municipality to provide a better service to citizens and to design optimal waste collection routes [12], [34]. The Valencia City Council has a total of 5,154 containers of non-perishable waste: 1,783 paper containers, 1,599 plastic containers, 1,663 glass containers and 109 oil containers. The implementation of a smart urban waste management system pursued improvement in the service operation based on:

- Optimal collection routes depending on the filling, resulting a minimization of costs.
- Environmental impact reduction, avoiding container overflows and optimizing collection frequency.
- Service information availability on the Smart City Platform for exploitation.

The scope of this project, in the first phase, is to provide a complete solution for 237 containers of inorganic solid waste, 127 for glass and 110 for plastic, in two districts that are far from the Valencia city center: the district 17 and the district 19. This project includes the provision and installation of sensors for urban waste management, the connectivity between the sensors and the VLCi Platform and a management & administration software. The exact locations of

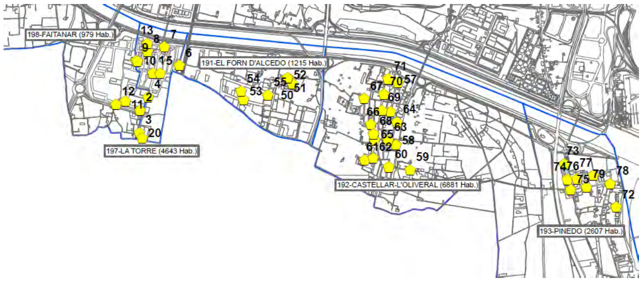

FIGURE 6. Partial Valencia map with exact locations of some waste containers to sensorize.

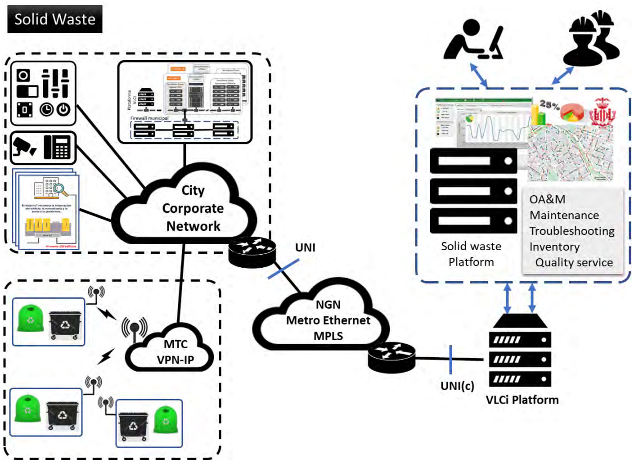

FIGURE 7. Communications architecture for waste management project.

around 40 containers, among the 237 to sensorize, are shown in the partial Valencia city map displayed in figure 6.

Figure 7 shows the communications architecture proposed for the urban waste management project. Due to the random containers distribution, it was considered the use of MTC VPN-IP accesses contracted to a cellular network operator with a private Access Point Name (APN) to guarantee the security of the solution. The access technology may be GPRS, 3G, 4G or NBIoT, depending on the type of sensors and network availability. The connectivity between the City Corporate Network and the VLCi Platform was made through a 1Gb/s Metro Ethernet access.

The filling detector was composed of an ultrasonic sensor for real-time measurement of the filling level and a temperature and vibration sensor. The filling level information allows improving the waste collection service, and the temperature and vibration information allows a rapid detection of vandalism actions.

SimulCity was used to evaluate the traffic generated by the waste containers sensors towards the VLCi Platform, getting information about the bandwidth, packet loss, delay and jitter. Also, SimulCity could be used for the evaluation of the operator's MTC VPN access to the City Corporate Network. In the SimulCity simulation, only the 237 containers included in the first phase of the project were considered. Each container sent information every 2 hours, and the transmission start time of

TABLE 1. Values used in waste management simulation.

Parameter	Value
Waste containers	237 containers
Burst Interval	2 hours
Frame length	random: exponential(120-210bytes)
Start time	random: uniform(0-2hours)
CoS	Silver (CIR=1Mb/s)
Simulation time	20 hours

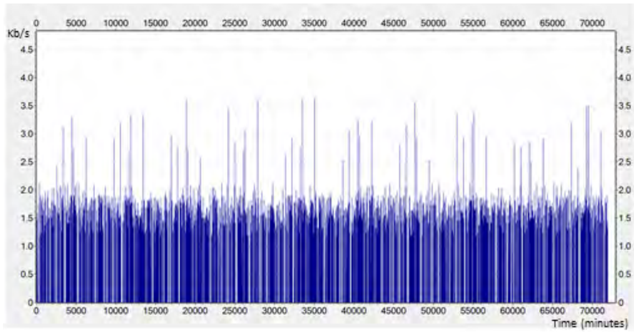

FIGURE 8. Bandwidth used by waste management sensors.

each container was selected in a random way to avoid synchronisms in the transmissions. The amount of information transmitted was assumed low and with small variations, it was modeled with an exponential random variable that varies between 120 and 200 bytes. The assigned CoS was silver, and the simulated time was 20 hours. Table 1 summarizes the values used in SimulCity for solid waste management project simulation.

Figures 8 to 11 display the results obtained with SimulCity.

The bandwidth used by the containers sensors is shown in Figure 8 where the traffic distribution is almost homogeneous, with a very low bandwidth, that does not exceed 4 Kb/s. The homogeneous distribution of traffic is achieved by randomizing the time in which each container transmits its first information because each container sends information every 2 hours.

Figure 9 shows the delay from the UNI interface to VLCi Platform. The delay is practically negligible because there is no congestion in the network. The only delay observed is generated by the MPLS network.

Also, since there is no congestion, there must be no packet losses. Figure 10 confirms this hypothesis.

Figure 11 shows the results of jitter with very low values. In this case, neither the flow control mechanisms nor the queues in the routers act. The jitter is only generated by the MPLS network. Again, this result is because there is no congestion in the network.

From the SimulCity simulations of the waste collection project it was possible to verify the scarce impact that the containers sensors impose on the municipal communications network, provided that an adequate configuration of the devices involved is carried out. Although the simulation

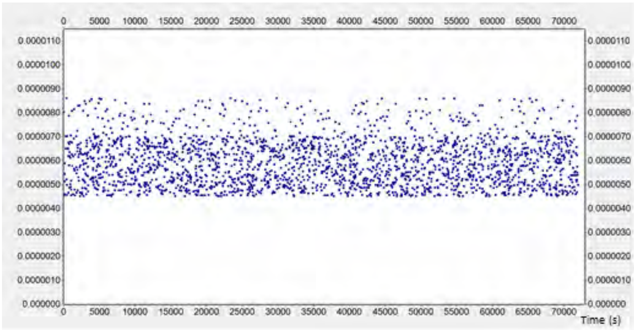

FIGURE 9. Delay between UNI and VLCi Platform in waste project.

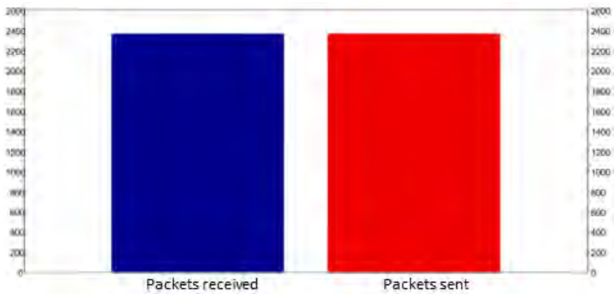

FIGURE 10. Received and sent packets in waste project.

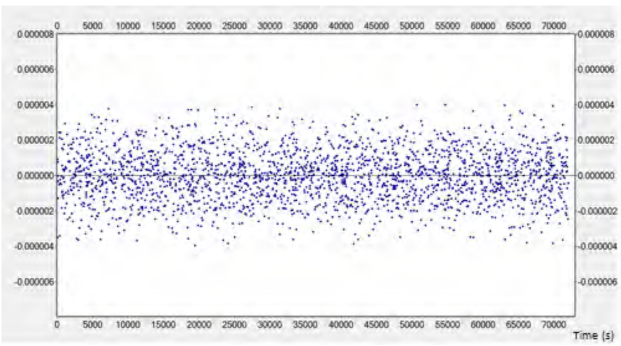

FIGURE 11. Jitter between UNI and VLCi Platform in waste project.

was performed with a specific configuration of parameters, the flexibility of SimulCity allows the evaluation with other configuration of parameters.

VI. STREET LIGHTING MANAGEMENT PROJECT

The cost of public lighting is one of the most important expenses of cities. In recent years, different initiatives have been developed trying to reduce this cost such as the installation of LEDs, or the design of specific low consumption devices [35], or the development of platforms to control the intensity and type of lighting at each moment [20], [36]. The energy savings alone would justify the need to monitor and control all the public lights in a smart city. There are also other interesting factors associated with lighting such as light pollution [37], the influence on road traffic [38], or the inconveniences by service interruptions due to breakdowns or copper theft.

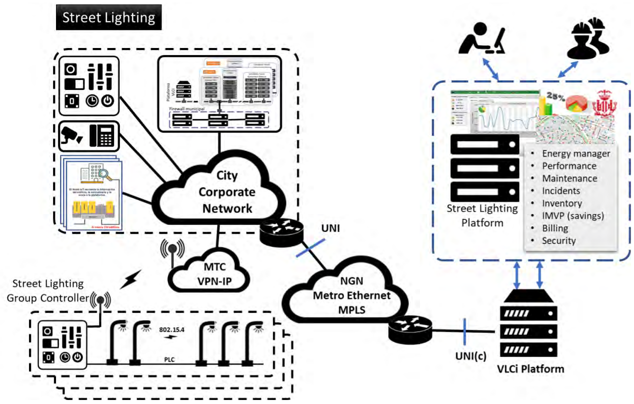

FIGURE 12. Communications architecture for street lighting project.

The Valencia public lighting system is made up of a total of 744 group controllers, which manage more than 107,000 street lights. The Valencia City Council is developing a project to provide intelligence and communications to all the street lights and group controllers. Thus, the Valencia City Council will have a lighting system that will allow managing the service, reducing energy consumption, and minimizing troubleshooting times and reaction times in cases of copper thefts, especially in the most remote areas from the city center.

The functionalities of the solution will allow, among others:

- Remote turn on/off for all types of street lights.
- Independent intensity regulation of each street light.
- Automatic adaptation of public lighting to meteorological, traffic, pedestrian, etc. conditions.
- Cost reduction in energy consumption and maintenance tasks by managing alarms in real time.
- Quick detection of incidents (for instance copper theft).

The architecture of the proposed solution, shown in Figure 12, is based on a two-level network (street lighting network) where the first level is a Wireless Sensor Network (WSN) among street lights, and the second level is composed by group controllers. Each group controller is responsible for managing a set of street lights and the communications with the VLCi Platform.

The connection between the group controller and the street lights is made through a WSN architecture, typically based on 802.15.4 or PLC standards. A device called street light controller is installed in each street light to manage the lighting parameters, energy consumption and alarm sending.

The connection between a group controller and the VLCi Platform could be performed using MTC VPN-IP accesses contracted to a cellular network operator with a private APN to guarantee the security. The connectivity between the City Corporate Network and the VLCi Platform was carried out, as in the case of the waste collection project, through a leased Metro Ethernet access of 1Gb/s.

The chosen street light controller allows, in addition to manage the street light itself, the connection of external

TABLE 2. Values used in smart lighting simulation.

Parameter	Value
Group controllers	744
Lights per group controller	random: uniform (100-200 lights)
Burst Interval	10s
Frame length	random: uniform (6,000-12,000bytes)
Start time	random: uniform(0s-10s)
CoS	Silver (CIR=2Mb/s)
Simulation time	30 minutes (1,800s)

devices such as environmental sensors or video surveillance cameras. In case of a video surveillance system, the connectivity between the group controller and the City Corporate Network would be made deploying new municipal fiber optical accesses or through a wired VPN contracted to an operator.

The evaluation with SimulCity of the lighting service was carried out for the complete network, that is, 107,000 street lights distributed in 744 group controllers. The parameters used in the simulation are expressed in Table 2.

The number of street lights assigned to each group controller is variable with an average number around 150. This random number was simulated with a uniform random variable distributed between 100 and 200 lights. Therefore, the information frame size of each group controller was defined as another uniform random variable between 6,000 and 12,000 bytes, this size corresponds to the load structure and the data context of the sensors assigned to the control center. The information is transmitted every 10 seconds and, to avoid synchronism among the group controller transmissions the transmission start time of each group controller was generated in a random way with uniform distribution between 0 and 10 seconds. The CoS assigned to this service was silver with a CIR of 2 Mb/s. The simulation lasted for 1,800 seconds and 180 frames from each group controller were transmitted.

The simulation results are shown in the figures 13 to 15. The bandwidth utilized by the street lighting project is shown in Figure 13 where high values of bandwidth appear with peaks close to 6.7 Mb/s and an average rate around 5.44 Mb/s. Despite the small contribution of each light controller, the total bandwidth is considerable because the high number of involved devices (107,000 street lights).

Figure 14 shows the delay from the UNI interface to VLCi Platform. The delay, like in the previous project, is practically negligible.

The individual simulation of the project implies that there is no packet loss, which is the same thing that happened in the waste management project simulation. Regarding jitter, the results of Figure 15 shows the impact of the flow control mechanisms and queues on the UNI interface of Metro Ethernet access. In this case the jitter of the MPLS network is negligible.

The simulation of the lighting project with SimulCity allowed the evaluation of a two levels IoT solution,

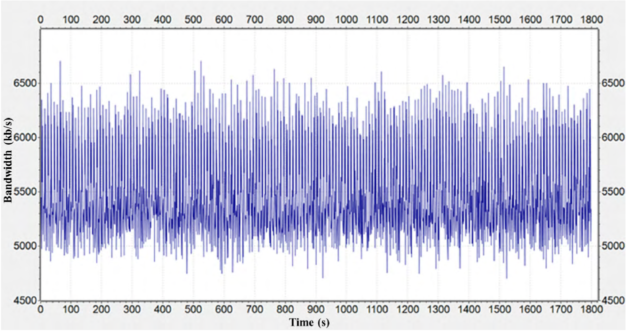

FIGURE 13. Bandwidth used by street lighting project.

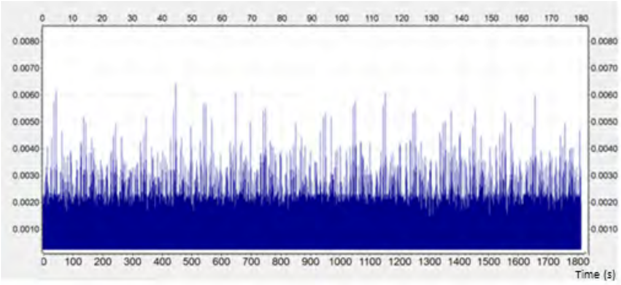

FIGURE 14. Delay between UNI and VLCi Platform in lighting project.

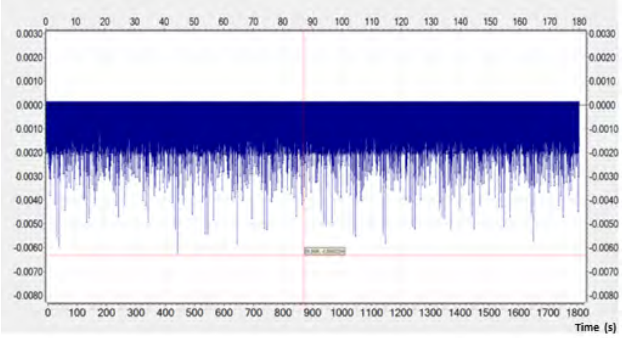

FIGURE 15. Jitter between UNI and VLCi Platform in lighting project.

a WSN network that allows communication between street lights group controller plus a group controller that consolidates traffic and connects with the VLCi Platform. The evaluation showed a considerable traffic load with peaks close to 7 Mb/s. This traffic must be considered in the design of municipal communications network.

In this simulation a transmission period of 10 seconds was chosen in order to quickly identify copper thefts in the areas far away from the city center. Commercial systems usually establish transmission periods of 30 seconds or more.

VII. REGULATED PARKING SPACES MANAGEMENT PROJECT

The automatic control of regulated parking spaces in cities and their correct use is an important problem that is being addressed by different authors [15], [39], [40]. Currently,

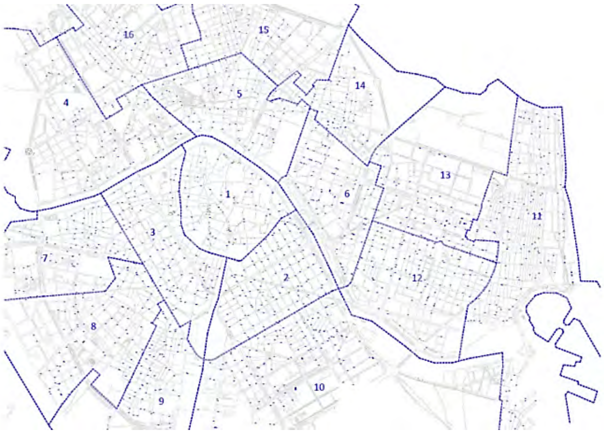

FIGURE 16. Valencia map with locations of parking spaces to sensorize.

Valencia has around 1,600 parking places reserved for persons with reduced mobility (PRM), 1,500 places for loading and unloading goods (L/U) and 225 places for taxi stops.

The number of potential users with disabilities is estimated at 7,000, there are around 3,000 taxis in the metropolitan area of Valencia, and the number of loading/unloading vehicles is not available.

This action proposes the implementation of a smart management system for regulated parking spaces in the city with the following objectives:

- Control the correct use of parking spaces for persons with reduced mobility.
- Control the use of loading and unloading spaces by detecting the occupation start time and the occupation duration time.
- Provide information in real time about taxi availability at taxi stops.

This solution will allow knowing in real time the status of each space, the time of permanence and if the space is occupied by an authorized user or not.

Figure 16 shows a Valencia map with the location of the parking spaces to sensorize in each neighborhood. The parking spaces (barely visible blue points) are distributed throughout the whole city.

The deployment of parking sensors requires the use of devices with a long-life service (typically between 8 to 10 years) and resistance against weathering and mechanical aggressions since they are installed directly on the road. With these restrictions, the communication solutions must efficiently manage the energy and offer adequate coverage with the attenuation produced when positioning the vehicle over the sensor.

The architecture of the proposed solution, shown in Figure 17, is usually based on a two-level network where the first level is a Wireless Sensor Network (WSN) among street parking sensors and the second level is composed by controllers. Each controller is responsible for managing a set of street parking sensors and the connectivity with the city corporate network.

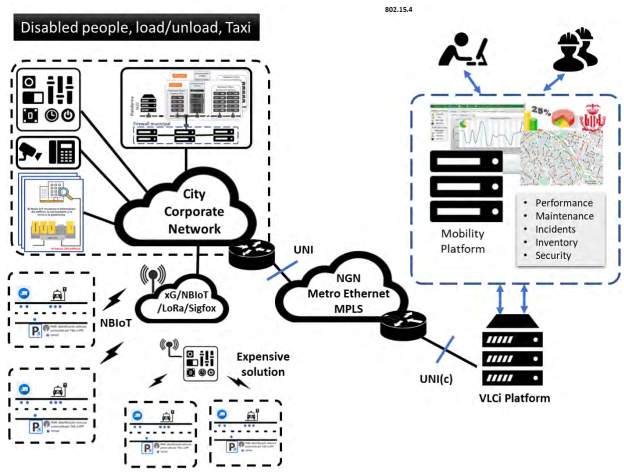

FIGURE 17. Communications architecture for parking project.

TABLE 3. Values used in regulated parking simulation.

Parameter	Value
Parking spaces PRM	1,600 spaces
Parking spaces loading/unloading	1,500 spaces
Parking spaces taxi	225 spaces
Burst Interval PRM	random: exponential (6-120 minutes)
Burst Interval loading/unloading	random: exponential (5-50 minutes)
Burst Interval taxi	random: exponential (5-30 minutes)
Frame length	random: exponential(120-210bytes)
Start time	random: uniform (0-1s)
CoS	Silver (CIR=1Mb/s)
Simulation time	10 hours

A preliminary study of coverage showed that the implementation of this architecture is very expensive because of street parking sensor distribution, where each controller only covers a few of them.

An innovative solution will be deployed connecting street parking sensor directly to City Platform using NBIoT MTC VPN-IP technology. The solution reduces cost by approximately 30%.

The complete network has been simulated with 3,325 regulated parking spaces (1,600+1,500+725), distinguishing among parking spaces for the persons with reduced mobility, loading and unloading, and taxi. Different traffic patterns were assigned to each group of users, although for all parking spaces it was assumed the information was only transmitted when changes in parking occupation happen. Three types of traffic patterns associated with each user type were simulated. The simulation parameters used in SimulCity are described in Table 3.

SimulCity can display the bandwidth used by each parking type in an individual way and the aggregate bandwidth used by the 3 types of parking spaces. Figure 18 shows the aggregate bandwidth in the output of the UNI interface, the bandwidth values are less than 20 Kb/s.

Figure 19 shows the delay from the UNI interface to the VLCi Platform. In this case due to the low flow required,

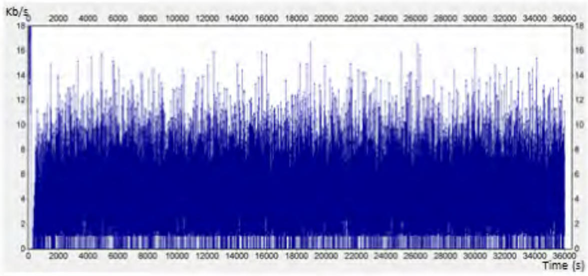

FIGURE 18. Bandwidth used by parking sensors.

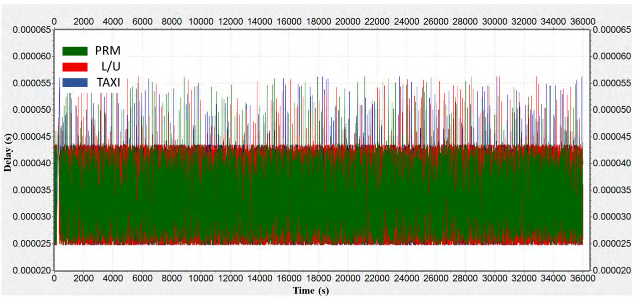

FIGURE 19. Delay between UNI and VLCi Platform in parking project.

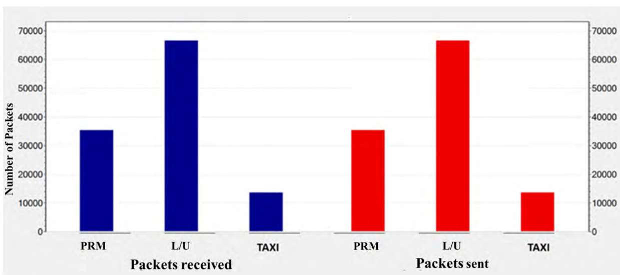

FIGURE 20. Received and sent packets in parking project.

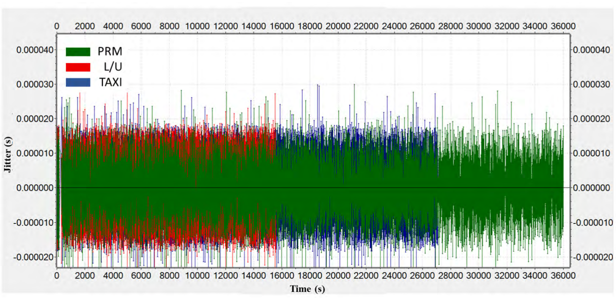

FIGURE 21. Jitter between UNI and VLCi Platform in parking project.

the delay is negligible for the transmissions due to the kinds of parking places.

With this configuration there is no packet loss as it is shown in Figure 20. The jitter of the data sources observed in Figure 21 is also negligible.

The simulation of the regulated parking project verified the low impact of the communications associated with the automatic management of the regulated parking spaces on the municipal communications network. Additionally, SimulCity could be used to develop new algorithms to maximize the useful life of batteries in places with low rotation, such places for persons with reduced mobility in peripheral neighborhoods.

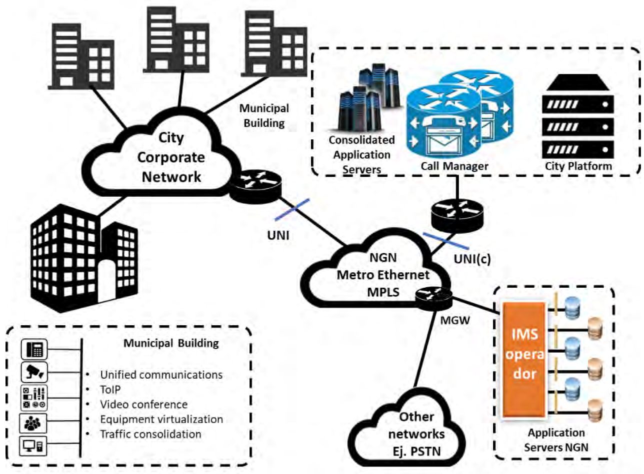

FIGURE 22. Architecture for unified communications.

VIII. CORPORATE UNIFIED COMMUNICATIONS

The current voice telephony infrastructure of the Valencia City Council is based on a TDM system. In this section a study about the modernization of the corporate telephony network is made. The objective is the migration of the current telephony network to a unified communications solution [33] with a telephone over IP (ToIP) architecture and centralized servers sharing the same hosting architecture as the VLCi Platform. This solution involves the migration of approximately 4,500 corporative users to this new ToIP service, as well as the migration of the citizen attention phone "010" that has 10 agents. Also, the unified communications solution includes IP videoconferencing service in HD quality (1,280 × 720 pixels) with a capacity of up to 20 users.

Figure 22 describes the architecture of the proposed solution for the new unified communications service. The municipal buildings are connected to the City Corporate Network, either through fiber optic direct links or through a VPN-IP operator link with a VLAN.

The connection with the public network can be made from the telephony server to the operator's NGN network, which removes the ISDN primary accesses currently installed in Valencia Town Hall with the corresponding cost savings.

A G.711 codec was selected for ToIP, which is the most commonly used codec in VoIP servers. Two telephony profiles have been defined, one for corporate users and another for the call center lines. The behavior of corporate telephony users was modeled using the traffic flow class I of Recommendation ITU-T Q.543 [41] which follows a Poisson distribution with 0.03 Erlangs and 1,2 BHCA (Busy Hour Call Attempts). To simulate this traffic in SimulCity, each source was configured with a random activity period exponentially distributed between 1 and 3 minutes, and a random

TABLE 4. Values used in unified communications simulation.

	Corporate phone lines	"010" Service lines	Video
Activity period	exp(1-3 min)	exp(1-6 min)	exp(10-60 min)
Inactivity period	exp(0-120 min)	exp(0-10 min)	exp(0-240 min)
Coder	G.711	G.711	H.264
Users	4,500	10	20
CoS	Multimedia	Multimedia	Gold

inactivity period modeled with an exponential distribution between 0 and 120 minutes.

The voice sources of the municipal call center ("010" service) were dimensioned with the values proposed in [42]: 120 BHCA, average call time of 180 seconds and a response target time of 10 seconds for 10 agents. Using an Erlang-C model, these values generate traffic of 6 Erlangs, with a waiting probability of 10.13%, and with a 10 seconds answer probability of 91.89%. Ten "010" service lines were modeled in SimulCity with random exponential distributed activity and inactivity periods. The activity periods and inactivity periods are longer and shorter, respectively, than the ones in corporate telephony. The parameters utilized to simulate the unified communications are resumed in Table 4.

The definition of the IP videoconference service was done considering the technical information of a commercial service [43]. High quality HD video (1,280x720 pixels) was selected, with a movement factor of 1 (equivalent to predictable image) and 25 frames per second. For these values, the resulting binary rate typical of an H.264 codec fluctuates between 1.2 and 2.5 Mb/s [27]. Table 4 shows the values used in SimulCity to configure the videoconference simulation.

The CoS assigned to voice traffic was multimedia, while the CoS assigned to video was gold, the quality immediately lower. The traffics were simulated separately, to check the individual bandwidths in permanent regime. The simulation time was 6 hours. A first estimation of the CIR for each of the three services was made from these first simulations.

In order to show the impact of the unified communications in the municipal communications network bandwidth, a 1-hour transitory regime was defined for the generation of corporate telephony traffic, so the 4,500 corporate lines were activated in a uniform way throughout this hour. For the call center sources, the activation window was reduced to 15 minutes. Finally, the activation window for video sources was also established in 15 minutes.

After performing the simulations, several results were obtained. The bandwidth used by the voice sources is shown in Figure 23 where the maximum bandwidth is around 9,5 Mb/s for corporate lines and less than 900 kb/s for the "010" service.

Figure 24 shows the bandwidth evolution of video transmissions according to the defined traffic pattern; the bandwidth is limited to 45 Mb/s. A transitory regime was introduced intentionally to show the bandwidth increasing/

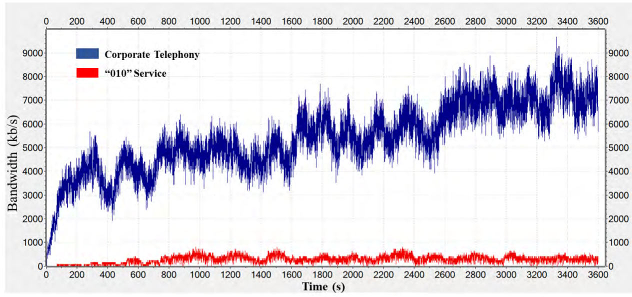

FIGURE 23. Bandwidth used by voice users.

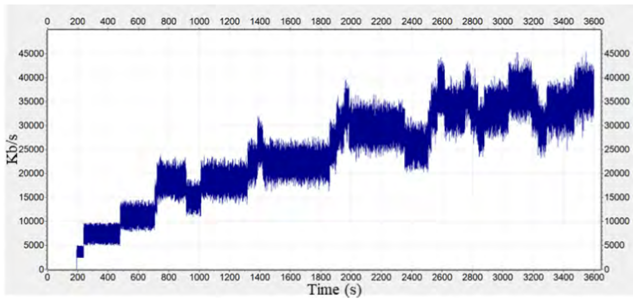

FIGURE 24. Bandwidth used by video sources.

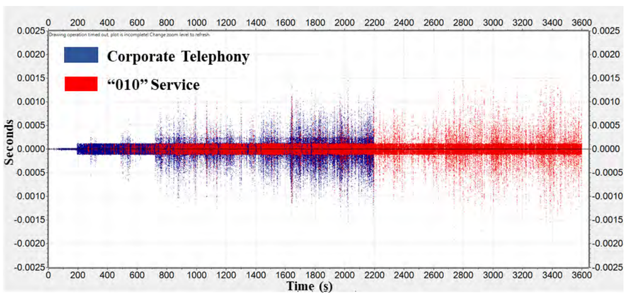

FIGURE 25. Delay of the voice sources.

decreasing during the activation/deactivation periods of the videoconference sessions.

Figures 25 and 26 show delay and jitter of the voice sources at the telephony server. The effects of the control and queue management mechanisms increase the delay and jitter when traffic increases, but delay and jitter are under the requirements of the international recommendations, which are 10 and 150 milliseconds respectively [44], [45].

Another SimulCity facility is the ability to display the results in histograms to facilitate their interpretation. As an example, figure 27 shows the distribution of the received video packets versus delay. The maximum delay in video packets is 2.6 milliseconds, again inferior to the 30 milliseconds required by international recommendations.

Figure 28 shows the total bandwidth at the UNI interface that includes voice and video. It was represented the initial transitory of 1 hour when the different sources are activated. The resulting traffic in permanent regime has high values,

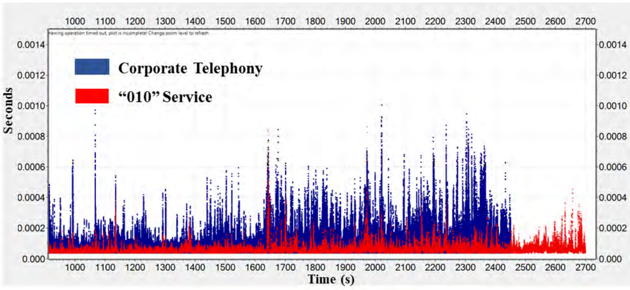

FIGURE 26. Jitter of the voice sources.

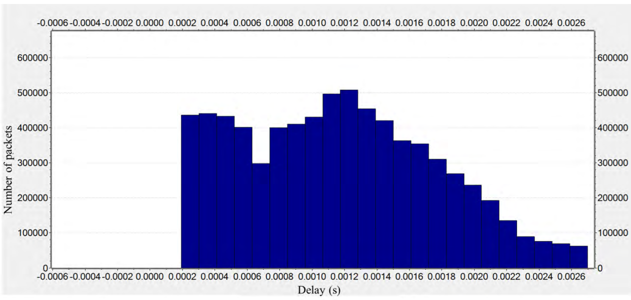

FIGURE 27. Histogram of delay vs number of video packets.

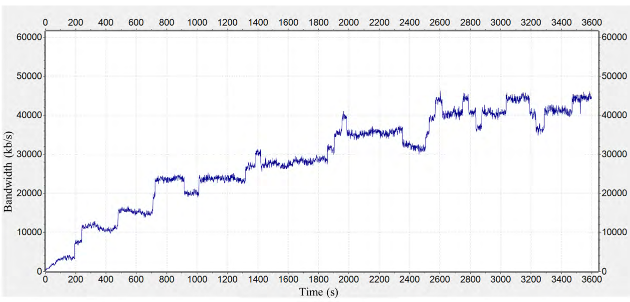

FIGURE 28. Bandwidth in UNI interface (video + voice).

with peaks close to 50 Mb/s. This bandwidth should be considered in the design of municipal communications.

The simulation of the unified communications project in SimulCity verified the great impact that voice and video communications generate on the municipal communications network. In this case SimulCity can contribute in an essential way to the adequately bandwidth dimensioning to maintain the required QoS with minimum costs. QoS and costs are directly related with the CoS and bandwidth contracted to operator.

IX. GLOBAL SCENARIO

The complete evaluation of the municipal communications network was performed simulating with SimulCity a global scenario composed by the three IoT services previously described (waste, lighting and parking) and the new voice and video services. The total number of devices transmitting information is 8,836, as well as around 110,000 sensors. The simulation time was reduced to 15 minutes due to the high number of devices, and because the devices' specifications are like the ones in previous sections. The simulation of the global scenario spent 29 minutes on a PC with Intel Core i7-4790k. Table 5 shows the specifications of all simulated devices and the QoS type assigned to them.

TABLE 5. Sources used in the simulation of global scenario.

Project	Sources	QoS
Corporate telephony lines	4,500	Multimedia
"010" Service lines	10	Multimedia
Videoconference	20	Gold
Waste Sensors	237	Silver
Lights group controllers (with 107,000 street lights)	744	Silver
Parking persons with reduced mobility	1,600	Silver
Parking loading and unloading	1,500	Silver
Taxi Stops	225	Silver

TABLE 6. Flows (CIR and PIR).

CoS	CIR	PIR	Medium rate
Multimedia	7 Mb/s.	14 Mb/s.	6,491 Mb/s
Gold	40 Mb/s.	60 Mb/s.	36,416 Mb/s
Silver	6 Mb/s.	12 Mb/s.	5,466 Mb/s

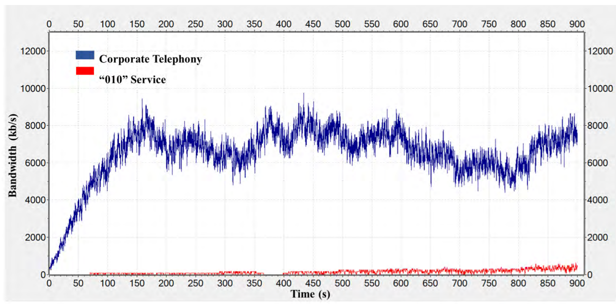

FIGURE 29. Bandwidth of the voice sources in global scenario.

The configuration of the flows by QoS was done using the values previously obtained in the individual simulations. The values of CIR were estimated from the average bandwidths of the individual simulations rounded to the upper Mb value. Table 6 show the CIR and PIR values used in simulation.

After performing the simulation, the results are presented both individually for each kind of traffic and jointly for all sources. Figure 29 displays the bandwidth used by the 4,500 voice corporative lines and the 10 call center lines. Again, the predominant traffic corresponds to the corporate telephony. On the other hand, figure 29 shows an initial transient of about 150 seconds before permanent regime in the rest of the time.

Figure 30 displays the bandwidth used by the video sources. The bandwidth mean value (38 Mb/s), when the 20 videoconference systems are actives, corresponds to the

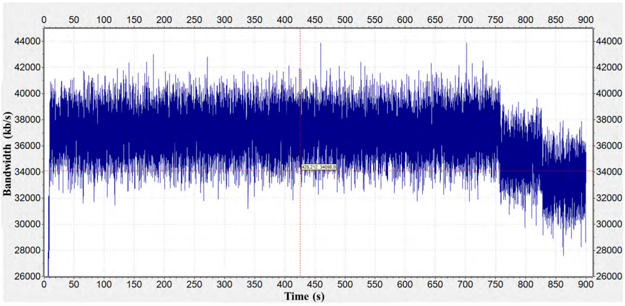

FIGURE 30. Bandwidth of video sources in global scenario.

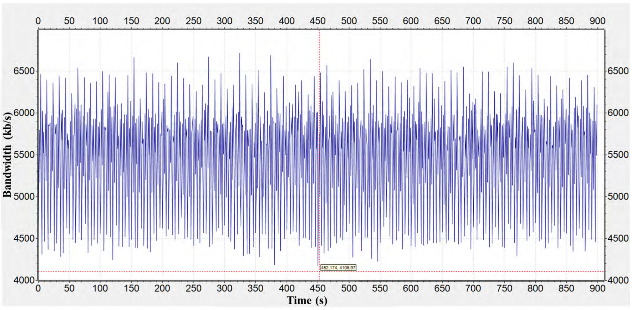

FIGURE 31. Bandwidth of all IoT sensors in global scenario.

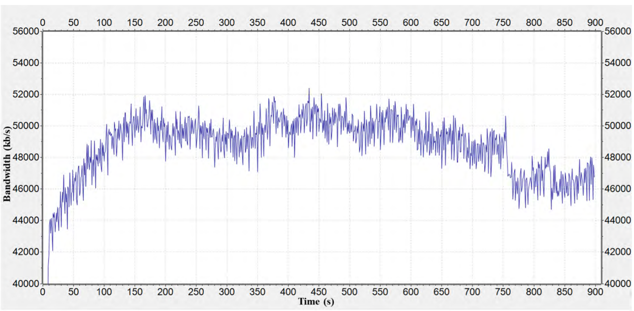

FIGURE 32. Total bandwidth at UNI interface in global scenario.

product of 20 videoconferences multiplied by the bandwidth mean value of a video source (1.9 Mb/s).

Figure 31 shows the bandwidth utilized by the IoT projects: waste, lighting, parking for persons with reduced mobility, loading and unloading and taxi. The predominant traffic corresponds to the lighting control project due to the high number of elements involved.

Figure 32 shows the total bandwidth at the UNI interface. The bandwidths, as discussed in previous paragraphs, were dimensioned to avoid packet losses. It should be noted that the maximum flow is around 52 Mb/s.

Figure 33 shows the histogram of the voice traffic delay. The delay, which has been represented in a logarithmic scale, varies between 35 and 180 μs, values under the 10 milliseconds required by the international recommendations.

Figure 34 shows the histogram of the video traffic delay. This delay is distributed between 200 microseconds and

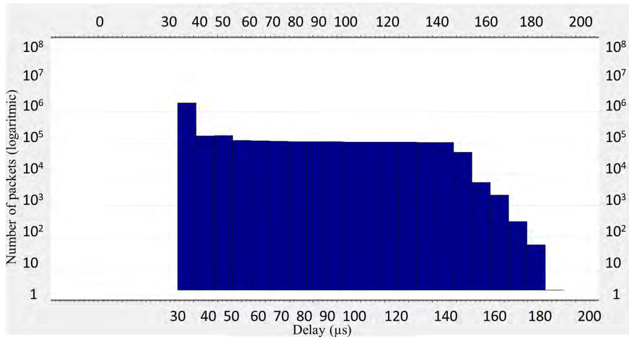

FIGURE 33. Delay of voice traffic in global scenario.

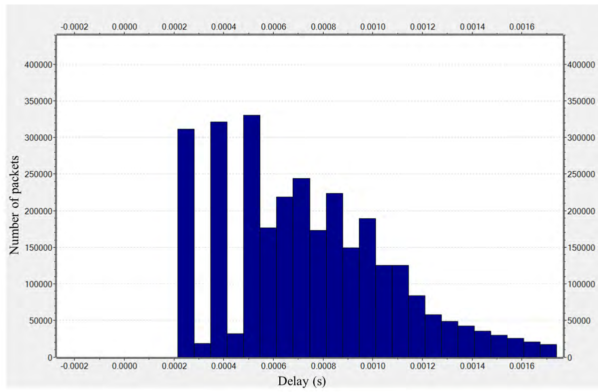

FIGURE 34. Delay of video traffic in global scenario.

1.7 milliseconds, also very far from values that could degrade the QoS. This delay distribution can be explained by the impact on the queues due to the simultaneous activation of video sources.

The SimulCity simulation of the global scenario with several types of devices involved in the smart city allows the adequate dimensioning of the communications to contract to the operator. SimulCity allows the optimizations of the necessary bandwidths associated to each CoS: multimedia, gold and silver. In this way, the performance of the proposed solution can be evaluated previously to contract communications with operator. Results offered by SimulCity for a busy hour environment are within the expected and the traffic profile is clearly dominated by corporate telephony and videoconference services. The IoT services represent a residual part of the traffic, except when the number of devices to manage is very high, as in the case of the lighting project.

X. CONCLUSIONS

This paper focuses in the designing of a simulation tool called SimulCity to overcome the complexity of designing a smart city communications network, where numerous and heterogeneous devices compete for a limited bandwidth. SimulCity was developed on OMNeT++, allowing to define and simulate a generic communications architecture, composed by different modules that can be configured according with different scenarios.

SimulCity was applied to different projects that the Valencia City Council is currently deploying. SimulCity was used to measure the flows of the Metro Ethernet interface that connects the Valencia municipal network with the smart city VLCi Platform that resides in a data center belonging to the Telefónica operator.

The evaluation of the municipal communications network with SimulCity was carried out in 2 phases. In the first phase, each of the services was studied in an independent way, parameterizing the sensors traffic patterns and analyzing their influence over the municipal communications network. The second phase consisted in the iterative dimensioning of the municipal network through the simulation of the global scenario that included very numerous and very different sensors and devices.

Three IoT projects related to the Impulse VLCi initiative of Valencia City Council were evaluated: smart collection of the non-perishable solid waste project, smart lighting management project and regulated parking project. For each project a communication architecture and a traffic pattern for the sensors were defined. The simulation of each individual project scenario generated specific information about the traffic associated to each project. Only the smart lighting management produced a considerable volume of data to transmit, due to the high number of street lights involved in the project and the need for continuous monitoring to prevent copper theft. The ToIP and videoconference over IP also imply the need of large bandwidths.

SimulCity simulated the global traffic behavior from many devices: around 110,600 IoT devices, 4,500 corporate telephony voice lines, 10 call center agents for citizen service, and 20 corporate video conferencing users. The results obtained allowed to optimize bandwidth for each CoS defined and adjusted to the real needs of the Valencia municipal corporation.

The flexibility, capacity and ease configuration of SimulCity make it a very powerful tool for dimensioning the communications of any smart city.

The best performance evaluation of SimulCity will be obtained when the Valencia Smart City is deployed, and real traffic measurements are available. Thus, as future line of work, it will be of interest the comparison of the results obtained with SimulCity with the measured traffic data from Valencia Smart City. This comparison would be the final validation of SimulCity.

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MIGUEL A. RODRIGUEZ-HERNANDEZ received the M.S. degree in telecommunications engineering from the Universidad Politecnica de Madrid, Spain, in 1990, and the Ph.D. degree in telecommunications engineering from the Universitat Politècnica de València (UPV), Spain, in 1995.

In 1991, he joined the Department of Communications, UPV, where he is currently a Professor. He has authored or coauthored more than 100 technical papers in journals and international conferences. His research areas include signal processing in communications and ultrasonic, traffic characterization, and services in smart city environments.

ANGEL GOMEZ-SACRISTAN received the M.S. degree in telecommunications engineering from the Universidad Politecnica de Madrid, Spain, in 1984, the master's degree in advanced studies in telecommunications, in 2006, and the Ph.D. degree in telecommunications engineering from the Universitat Politècnica de València (UPV), Spain, in 2018.

He was an Executive Manager with the Telefonica Spain Corporate Clients Engineering Department, Telefonica Research and Development, and an Associate Professor with the Department of Communications, UPV. He is currently a Senior Consultant in the Valencia Smart City Project. His research areas include next-generation networks, traffic characterization, and services in smart city environments.

Dr. Gomez-Sacristan's awards and honors include the 2011 Prominent Character of the Telecommunications Sector in the Valencian region, and the *Cum Laude* Postgraduate Doctoral Degree.

DAVID GOMEZ-CUADRADO received the M.S. degree in telecommunications engineering from the Universidad Politecnica de Valencia, Spain, in 2014.

He was an Engineer with the Telecom Network Management Center, Generalitat Valenciana Regional Government, specifically in OA&M tasks related to hospitals, healthcare centers, and school networks. He is currently with Eficit as an IT Manager, designing and implementing LAN and WLAN telecommunication networks solutions for government and private companies.