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Upgrading urban services through BPL: practical applications for Smart Cities

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Abstract. Current initiatives related to smart cities in LATAM reveal an increasing interest in the improvement of cities and the wellbeing of their citizens. In addition, specific working groups have been created for this purpose. In this sense, the communication technologies set the basis for gathering, transporting, and managing the large amount of data generated in cities to provide a wide range of services. Within the many alternatives available, BPL positions as a promising technology, since smart cities can greatly benefit of its higher data rates and low latency. In addition, since the medium is already deployed and most of the assets and sensors are connected to the same medium, the cost of the communication systems will be reduced in price and simplicity. The work presents four practical applications: smart buildings, urban lighting, energy assets management and broadband access, in which the possibilities and advantages of BPL are further addressed. Finally, some conclusions and key aspects relating BPL to the success of smart cities are identified.

Keywords: Smart city, Broadband Power Line Communications, urban services, communication technologies.

1 Introduction

Latin America is the region with the highest concentration relative to urban population, but it is also one of the most lagging behind in when it comes to Smart Cities. However, there is notably increase in related initiatives, which shows that there is a growing interest in this field. Medellin, Buenos Aires, Mexico and Santiago are at the top of the list of smart cities in Latin America. Other cities such as Bogotá, São Paulo and Rio de Janeiro are also deploying initiatives in the field of smart cities, showing that these trends have come to stay. In addition, specific groups in relevant international groups, such as the SG20 Regional Group for Latin America (SG20RG-LATAM) at the International Telecommunication Union (ITU), has been created and is responsible for studies relating to Smart Cities and Communities and Internet of Things (IoT) and its applications [1].

When referring to technologies for Smart Cities, it is usual to associate them to wireless options. Recent trends related to IoT are usually conceived as wireless. But the reality is that there are still wired alternatives with very remarkable advantages that can play an interesting role in the Smart City context. One of them is the electric cable, nevertheless, the power wire, with more than 100.000 km deployed throughout Latin America, is an option to consider. Specially in those assets already connected to the grid (traffic lights, urban lighting, buildings, energy resources, …) a communication system can be easily deployed through Power Line Communication (PLC) devices without relying on external batteries. Specifically, this work addresses the potential of the broadband version of PLC – Broadband Power Line Communications (BPL) for smart cities applications in LATAM region. BPL technology allow high transfer data rate, being able to offer rates of up to hundreds of Mbps and significantly shorter response times of less than 50 ms, while using a communication media already deployed as well as robust and secure, hence leading to less installation costs when stablishing the communication system.
The remaining work in this documented is grouped as follows: Section 2 reviews the concept of smart city and particularly, within the LATAM region; Section 3 introduces the fundamentals of PLC and highlights the benefits of BPL; Section 4 describes the opportunities of BPL for the smart city and, finally, Section 5 summarizes the main conclusions of this work.

2 Smart Cities of XXI Century

Beyond the concept of "digitalization", Smart Cities are conceived as enablers of better-living for their citizens as well as increasing sustainability through technology-driven initiatives. The Inter-American Development Bank (IDB) understands that smart cities "*use connectivity, sensors distributed in the environment and computerized intelligent management systems to solve immediate problems, organize complex urban scenarios and create innovative responses to meet the needs of their citizens… [using] technologies to integrate and analyses an immense amount of data generated and captured from different sources that anticipate, mitigate and even prevent crisis situations.* In this sense, the communication infrastructure of the city set the basis for a whole set of applications and services.

2.1 Needs of Smart Cities in terms of communications

Digital technology can indeed make a city better. Energy efficiency can be improved through the street lighting control and the management of the energy resources. Citizens can be connected using mobile applications with cameras while receiving alerts and useful information as well as send data to the government. Safety can be improved in the streets and buildings through cameras and sensors. Also, the traffic can be benefited from the installation of cameras combined with motion sensors installed on the streets. Pollution can be controlled and effectively reduced with sensors and air quality monitoring systems. In the same line, smoke, toxic gases, and temperature sensors associated with ambient cameras and warning systems can prevent environmental disasters. At the core of these applications are a communication infrastructure, sensors, an integrated operation and control center and communication interfaces [2].

Focusing on the communication infrastructure, it is required that the smart city ensures not only the existence of broadband networks that can support digital applications, but also the availability of this connectivity throughout the city and to all citizens. This communication infrastructure can be a combination of different data network technologies using cable transmission, optical fiber, and wireless networks. In summary, communication technologies should allow the following [3]:

- Interconnection between very different devices.
- Hybrid communications systems, where wired and wireless systems must live together.
- Fast communications.
- Robustness in communications.
- Flexibility and scalability in infrastructure.
- Security in communications and devices

In addition, some important requirements that a city should consider when selecting a technology for their network foundation are listed as follows [4]:

- End-to-end solutions: the network should encompass wired and wireless indoor spaces and wireless outdoor and network backbone coverage and provide a service-delivery platform for functions such as identifying end users and the applications and resources they access.
- Standards-based: the network should support security standards, and consider the use of both licensed and unlicensed frequencies.
- Easy to deploy: the access points should be configured themselves for optimum performance, eliminating the need for personnel to configure each device manually.
- Highly reliable: the selected solution should be “self-healing” and automatically selects an alternate path through the network if a link fails and avoids congested areas.
- Unified, easy management: the communication system should enable the management of the wired and wireless outdoor networks and wireless indoor networks as one unified network.
- Scalable: the network should enable the city to build and expand outdoor coverage incrementally, without reconfiguring the installed base. Scalability of a mesh network is a function of the number of channels available, which is why the network should use different channels for access and backhaul
- Secure: the network should incorporate integrated security technologies to maintain the confidentiality of private information, protects against the spread of viruses, and provides different levels of access to municipal constituents.

2.2 Smart Cities in LATAM

According to [5], Latin America is the most urbanized region of the developing world. Two thirds of the Latin American population live in cities of 20,000 inhabitants or more and almost 80% in urban areas and is projected to increase up to 89% by 2050. However, it is also one of the most lagging regions when it comes to Smart Cities. Following the annually Smart City Index prepared by the Institute for Management Development, which ranks cities based on economic and technological data, the Latin American city that has advanced the most in this field is Medellin, which ranks 72nd in the world, followed by Buenos Aires (88th), Mexico (90th), Santiago (91st), Bogotá (92nd), São Paulo (100th) and Rio de Janeiro (102nd) from a list with a total of 109 cities listed and headed by Singapore [6].

Large cities such as Buenos Aires, Medellín or Rio de Janeiro are making budgetary efforts to modernize both their urban infrastructure and the services they provide to citizens, from smart traffic lights to improve mobility, and the installation of surveillance cameras to improve public safety [7]. Santiago is addressing air contamination and traffic congestion through different initiatives moving towards clean mobility (electric vehicles, bike sharing). Medellin has implemented an Intelligent Mobility System of Medellin (SIMM) that uses cameras, networked traffic lights and traffic lights with vehicle detection sensors to detect traffic violations and capture traffic information. Bogota has also moved towards sustainable mobility with the increase of the public transportation system while to connected horizontal and vertical signage, smart traffic lights, and monitoring cameras. Rio de Janeiro has implemented an integrated risk management system which includes connected weather radars and a rain gauge network installed in mobile phone towers. Itu has implemented a selective garbage collection system, able to identify need for repair or replacement of containers and the optimization of the routing of collection while reducing collection time and fuel expenses [6]. These are just a few examples of the initiatives which show a growing interest in the field of smart cities in Latin America.

3 Broadband Power Line Communications

3.1 Fundamentals of Power Line Communications

Power line communications (PLC) use the power lines typically employed for electricity transmission and distribution for the transmission of communication signals by adding a modulated carrier signal over the electricity signal at 50/60 Hz. According to the bandwidth of use, PLC can be classified into three main groups:

- Ultra-narrow band PLC (UNB-PLC): this technology operates in the frequency range from 30 Hz to 3 kHz. Its main drawback is that it provides low data rates (up to 100 bps) but for long distances (up to 150 km). Some typical and proprietary examples of this technology are ripple control systems and TWACS [8].

- Narrow-band PLC (NB-PLC): operates in the frequency range up to 500 kHz, depending on the region and it can provide high reliability of data transmission up to several hundreds of Kbps and can reach up to hundreds of km. NB-PLC had experienced a remarkable rise for smart metering due to their good overall performance and efficiency, setting an inflection point in the rise of smart grids. Most deployed standards of NB-PLC are: PRIME (ITU-TG.9904), G3-PLC (ITU-T G.9903), IEEE 1901.2 and ITU-T G.hnem.
- Broadband PLC (BPL): this technology operates in the frequency band from 1.8 to 250 MHz, reaching data rates up to hundreds of Mbps for relatively short distances - up to few km. Traditionally, BB-PLC has been used for internet access and but it is currently experiencing a wide presence in smart metering, substation automation and control, and related applications within the smart grids due to the high available data rate, the secure & cybersecure as well as the robust transmission media that it provides.

The biggest advantage of PLC is that there is no alternative with such as an extensive infrastructure already deployed, leading to reduction of deployment costs while guaranteeing a secure communication at rationale speeds. In addition, PLC systems are robust and secure. In contrast to wireless alternatives, PLC allows an immediate establishment of communication during the installation process, does not need antenna tunning or adjustment of antenna direction required and the communication is also possible in difficult environments (e.g., metal-shielded cases, deep underground installations, etc.), where no other access technology can provide a solution [9]

On one hand, PLC presents some valuable advantages for smart city applications, as it has a wide potential coverage due to the electricity wires, making every line-powered device a potential target of value-added services through PLC. Moreover, the installation is already deployed, easy to manage, and stable. On the other hand, the greatest disadvantages of PLC are mainly related to the medium, due to existing disturbances, noises, and attenuations, and consequently, the global capacity of PLC in terms of bandwidth is less than other technologies [10].

3.2 The role of BPL

Since the beginning of the 21st century, BPL technologies have been widely used within homes for internet communications, as an alternative or complement to WiFi networks. Currently, these technologies offer speeds of one megabit per second (Mbps). The success of NB-PLC in smart metering suggest a technological evolution towards higher bandwidths and lower latencies, in line with stricter requirements regarding real time management and cybersecurity. This has made BPL increasingly considered in monitoring and control applications within the smart grid in the recent years.

Added to the benefits to the power grid system, other smart services, such as the management of electric vehicles (EVs), energy resources, building automation, traffic and lighting control, disposal management, among others, all of them typical systems of smart cities, can be greatly improved with the higher data rates and low latency inherent to BPL, since they could be performed through BPL in real time while assuring cybersecurity and integrity of the data.

4 Opportunities of BPL for the Smart City

4.1 Smart buildings

Smart Buildings are buildings which integrate and account for intelligence, enterprise, control, and materials and construction as an entire building system, with adaptability, not reactivity, at the core, in order to meet the drivers for building progression: energy and efficiency, longevity and comfort [11]. By means of available data from different sources, smart buildings become adaptable and resilient.

Smart buildings use technologies with automated controls, networked sensors and meters, advanced building automation, energy management in conjunction with information systems and data analytics software. Among the different applications within a smart building, Figure 1 shows a visual summary of some of them [12]. The following can be highlighted:

- Building energy management: entails the management of loads as well as the generation sources, if included. Heating, ventilating, and air-conditioning (HVAC) systems, which represent a very notable percentage of the electricity consumption, specially in commercial buildings, shall be considered as energy assets as well. All the connected devices (computers, machinery, office appliances, lighting, etc.) are loads of the building, that define the load profile of the building. This load profile can be efficiently managed through an energy control center (CC) when combined with internal data from the building, generation, and storage systems, for instance; and with external data, such as the energy market. As generation sources, renewable energy, such as photovoltaics, and storage sources can be integrated into smart buildings to reduce retail electricity purchases, peak load demands in buildings while moving towards energy self-sufficiency [13]. EV charging stations can be included in the energy management, so that the energy control center of the building can identify the most appropriate time slot to recharge EV with the surplus renewable energy from the building.
- Building management system: this system can include applications such as building entrance control, capacity control, parking slots management and lighting control. These systems get the information from a network of sensors deployed all over the infrastructure: humidity, heat, and lighting sensors; presence detection; people counters, cameras, etc. These sensors get the information and send it through the proper transmission media towards the management control center. In advanced system, the communication can be bidirectional, and some orders can flow from the control center towards actuators installed in specific areas. For instance, if too many people are withing the same area, the center station can decide to decrease the temperature or activate the ventilations system, if

necessary. Sometimes it is common to see a general building management system on which the rest of the subsystems/applications depend (energy, surveillance, …) depending on the complexity of the system itself.

- Surveillance systems: the degree of sophistication of surveillance systems implies that it is getting increasingly common to see independent systems. Real time images in HD as well as video recording, including data processing (facial recognition) is becoming more and more common. Some government buildings and businesses with high security needs are including the systems, hence, high available bandwidth and secure communication networks are required.

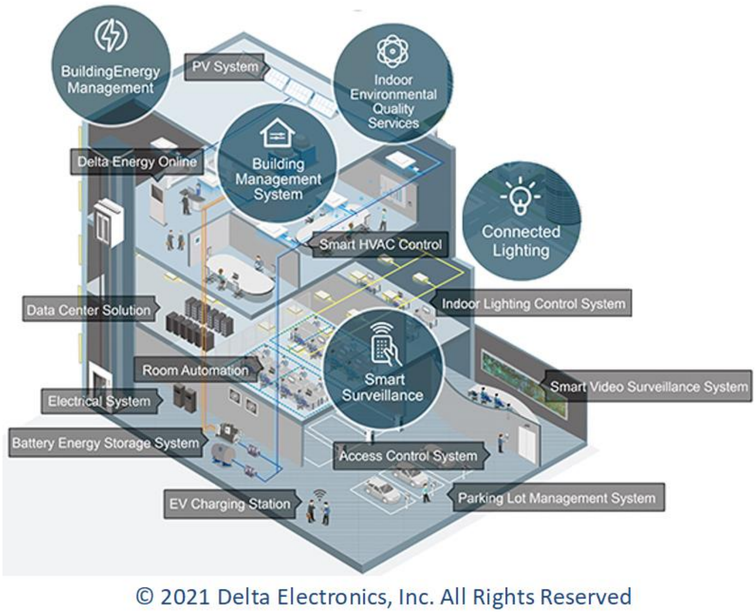

Figure 1. Overview of services and applications in a smart building. (Source: DELTA Building Automation Solutions [12])

The particularity of most of the services commented above is that they are connected somehow to the electricity wire of the building, either because they control energy resources (consumption, EV monitoring) or because they need electricity (lighting). In addition, secure communications and high bandwidth are also demanded (surveillance systems, control and monitoring). In these scenarios, BPL can serve as communication media with high bandwidth, robust and reliable, while providing an already installed infrastructure (the power wire of the building)

In line with the possibilities of BPL for smart buildings, there are some related initiatives: authors in [14] explore the efficacy of PLC as a sensor network backbone in a modern building by testing BPL modules. First results show a promising role for BPL as a viable physical and link layer for wired sensor networks. In the same line, in [15] two different BPL technologies are evaluated under different conditions of noise and attenuation, the results show a sufficient throughput on the application layer (18 Mbps in the worst case) for smart building applications. Finally, authors in [16] present the design of a BPL module suitable for installation in an electrical outlet to increase energy efficiency and power management or in local networks as a possible alternative to existing technologies.

4.2 Urban lighting

Streetlights are one of the most important assets to maintain and control, providing safe roads, inviting public areas, and enhancing security in homes, businesses, and city centers. However, lighting is indeed very costly to operate, with a share of about 40% of the total amount of electricity spent in a city [17].

LED (Light Emitting Diode) has being an inflection point in the lighting field, specially regarding efficiency, improved options (color, intensity and direction of the light beam) and durability. When combined with a smart control on the lighting management system, new advantages emerge, such as the ability of the system for reducing energy consumption and decreasing costs with the possibility of being operated and monitored remotely.

In fact, outdoor lighting is projected to register approximately 20% growth rate through 2025 due to the increasing smart city development initiatives worldwide [18]. The smart lighting solutions are widely used across highways and roadways, bridges and tunnels, as well as public places to optimize the lighting, reduce energy consumption and provide safety. In addition, the need among the government authorities to optimize the use of energy is further increasing the adoption of smart lighting solutions.

Regarding technologies, wired technology captures the major share in the smart lighting market, accounting for more than 70% in 2018 [18], due to its robust nature coupled with high reliability and control, makes it an ideal solution for outdoor lighting applications. A further step in smart lighting can be seen in the infographic of Figure 2 where the street light set the basis of the smart city platform. This approach presents the streetlight as a multidisciplinary asset with basic and advanced light applications as well as the inclusion of several sensors (noise, traffic, air quality), cameras and assets (EV charging, digital signaling), which can provide additional services such as traffic monitoring; surveillance and safety; EV charging station; parking control; environmental quality;

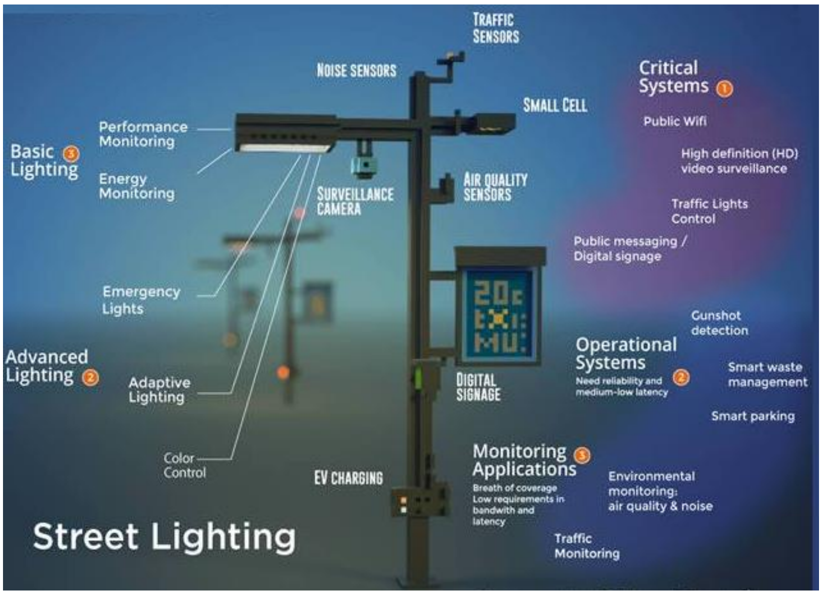

Figure 2. Smart Street Lighting as a Smart City Platform (Source: SmartCityExpo [19]).

Related experiences taking advantage of BPL for lighting can be found in the literature. For instance, in [20] a lighting solution based on BPL for the smart city is described, aiming at transforming outdoor lighting networks into high speed data networks for additional smart city services.

4.3 Energy assets management

In a smart city, the optimal management of the energy resources within the city is gaining importance, especially considering the current concern for the environment and increasingly stricter energy efficiency regulations. In this sense, two considerations can be done: first, the management of resources in terms of production of the energy in the cities and secondly, the elaboration of a comprehensive plan for generation, storage and distribution of the energy [21].

In the coming future, each home and building might have the chance not only to generate their own energy, but also it can have the plan to sell the produced energy.
In a smart city, there are, and there will be many assets related to energy somehow: starting with buildings and houses, through fleets of EVs to the city's own energy resources and prosumers. Hence, having a management system and a schedule for all these assets of the city could significantly cause a huge improvement in the context of the energy in the smart communities [22]. The data that should be collected from all the assets includes the generation capacity (from resources and prosumers), storage and a plan that determines how each source could distribute energy among all parts of the city. Therefore, an extensive, reliable, and robust communications network is required.

An example of a city smart energy management can be seen in Figure *3*, where the pilot of the smart city of Yokohama is represented. In this envision, the comprehensive energy management system (EMS) is established integrating ICT, energy resources (e.g., solar panel and EVs), and other smart infrastructure. The hierarchical bundling of EMS enables energy management at the level of individual EMS and demand-side management at the level of the overall system. This involves introducing HEMS (EMS for house) for homes, BEMS (EMS for building) for offices and commercial buildings, FEMS for factories (EMS for factory), and EV and charging stations for the transport sector [23].

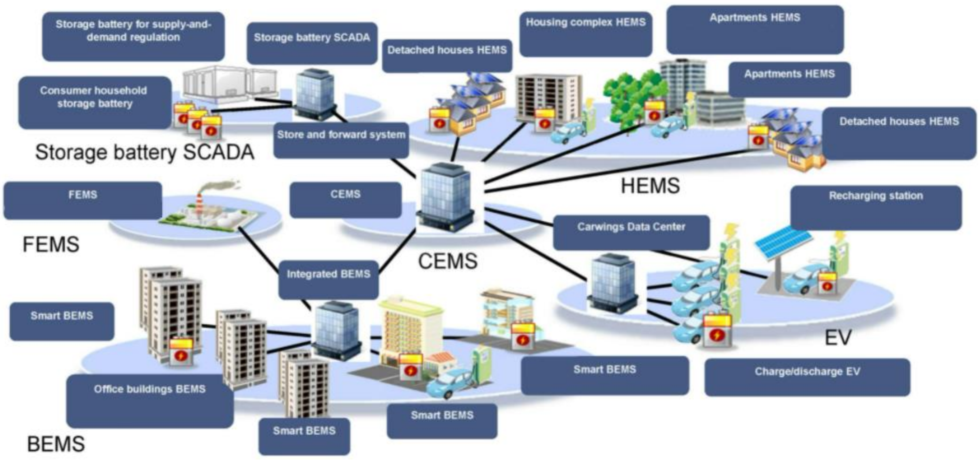

Figure 3. Overview of an energy management system for the smart city.
(Source: Toshiba [23]).

Considering that most of the energy assets will be connected to the power line, it seems natural to think of BPL as a powerful option for the management of resources. In this sense, related initiatives are taking advantage of the ubiquity of PLC in their cities. Smart City Mannheim, under the scope of the German government funded program 'E-Energy', was created to demonstrate how renewable energy can be optimally integrated into the grid as well as how the city can act as an energy store through the use of BPL [24].

4.4 Broadband access

The Inter-American Development Bank (IDB) designed the Broadband Development Index (BDI), which allows to easily measure the current status and development of broadband in the region of Latin America and the Caribbean [25]. This index not only helps BDI to identify the barriers towards the development of the broadband access in member countries, but also is a measurement of the quality of life in a region.
According to the IDB, the benefits of the broadband access can be broadly classified in two groups:

- Quantifiable benefits: those derived both from investment in infrastructure and from the creation of public policies to promote demand and the use of services made possible by broadband. Within these we find three types of benefits: benefits that users themselves would obtain from the service (e.g. tariff reduction); increased productivity of companies as a result of the adoption and use of the services that broadband enables; and improvement in activities during the working day (efficiency in tasks, remote work, …)
- Intangible benefits: externalities resulting from the impact of broadband in various sectors. Among them, the IDB includes the government spending reduction; greater transparency in government processes; improved communications at the country level; knowledge sharing; increase in literacy rates and educational levels; reduction of crime and violence, enabling telemedicine services, creation of new companies and new ways of relating on a personal and commercial level; improved productivity of companies and reduced environmental pollution, among others.

Based on the latest version of the index, it can be derived that the gap between the IDB region and the OECD is on average decreasing slightly. However, there is a very important gap in the development of digital infrastructure, which continues to be the main obstacle to the development of the digital ecosystem in the countries of the region.

In this sense, BPL can play an interesting role towards the broadband access. It has been historically employed for in-home internet access and considering the power grid extension, its network can be considered as a massive internet provider. Since the power grid extends to both urban and rural areas (particular in the latest, where often broadband access is less present), this advantage of the technology will be not limited only the urban areas.

5 Conclusions

This work presents the advantages of BPL for the smart cities through the practical application of four examples: smart buildings, urban lighting, energy assets managements and broadband access. In addition, related initiatives of BPL within the urban context are also described.
Through these applications it has been shown that BPL is a promising technology for the enforcement of smart cities since it provides real-time communications with low latency and guaranteeing cybersecurity while providing a robust and reliable communication backbone for the city. In addition, since the communication medium is already deployed and most of the assets are connected to the power grid, the commissioning of the system is reduced in time, costs and complexity.

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