An IoT Platform integrated into an energy efficient DC lighting grid

Dario Di Zenobio*, Kris Steenhaut*§, Steffen Thielemans§ and Massimo Celidonio‡
*Vrije Universiteit Brussel (VUB), INDI, Pleinlaan 2, B-1050 Brussels, Belgium
§Vrije Universiteit Brussel (VUB), Department of Electronics and Informatics (ETRO), Pleinlaan 2, B-1050 Brussels, Belgium
§imec, Kapeldreef 75, B-3001 Leuven, Belgium
‡Fondazione Ugo Bordoni (FUB), Viale del Policlinico 147, 00161 Rome, Italy
Dario.Di.Zenobio@vub.ac.be, ksteenha@etrovub.be, sthielem@etrovub.be and celi@fub.it

***Abstract*—Allowing users and managers of existing buildings to benefit from non intrusive Internet of Things (IoT) integration is a great asset. IoT integration opens a plethora of new services such as lighting and power-consumption management, indoor location-based services, surveillance etc. In this paper we show how a DC lighting grid can be combined with wireless components to facilitate the deployment of routers/sensors and actuators powered by the DC lighting grid. These control devices can be placed wherever in the building and communicate with the other devices in the network, wirelessly or via the PowerLAN available on the DC grid. For organizing communications with the wireless autonomous sensors and actuators, lightweight network stacks, including application layers based on CoAP or MQTT, are deployed.**

***Index Terms*—DC Lighting Grid, Power Line Communication, Wireless/Wired Sensor Networks, CoAP, MQTT, Building Automation.**

I. Introduction

Navigation apps on smartphones are hugely popular, enabling consumers to find nearby stores and restaurants, map out routes etc. Today, thanks to the increased presence of IoT and communication devices, similar indoor location-based services can be offered to occupants and facility staff of buildings, industrial plants, etc., inside which GPS-like technologies, may not work or be reliable, due to the absence of the satellites radio signal. These location-based services can support:

- *Indoor navigation*: Occupants or visitors can discover where they are in an unfamiliar building and get indications of the direction to follow. This capability is particularly useful in presence of alarms (earthquake, fires, etc.) when people must be guided towards safe areas.
- *Resource tracking*: Facilities staff can track the location of devices (e.g., waste paper bins, and cleaning carts) as they move within the building.
- *Resource location*: Occupants or visitors can find the closest resources, like open work areas, projectors etc.
- *Room scheduling*: Occupants can find an available conference room near them and avoid scheduling one that is relatively far away.

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These services can increase occupant productivity, save time for facilities staff, enhance the building experience, improve the safety actions inside the building and deter asset theft.

On the other hand, in a building it is today mandatory to reduce and monitor the energy consumption to increase awareness and realise savings. These savings are not only good for the end users, they are also good for the environment, and in some cases, needed for compliance with governmental initiatives. Many governments are indeed actively promoting various energy efficiency and conservation programs, with a target of increasing energy efficiency in buildings by 35% by 2025. In the USA, 30% of the energy used in an average commercial building is wasted, making the potential to realise savings enormous. The U.S. Environmental Protection Agencys Building Technologies Office (BTO) is targeting a 20% energy-use reduction in commercial buildings by 2020, and even greater savings by 2030 [1].

As well known, the Internet of Things (IoT) offers a cost-effective way to reduce the amount of energy wasted in commercial buildings, jointly to the opportunity to offer location based services. The IoT has the potential to dramatically increase the availability of information, and is likely to transform companies and organizations in virtually every industry around the world. As such, finding ways to leverage the power of the IoT is expected to factor into the strategic objectives of most technology companies, regardless of their industry focus. Furthermore, the potential for manufacturers from collecting key data from various physical spaces within the plant is enormous. Some of the key uses of IoT in manufacturing settings include sensors for alerting to problems on the production line, tracking of assets in the production process, and extracting data about the time and quantity of items dispensed by machines in the plant. Solution providers are looking at the design and marketing of new smart building IoT applications, equipment manufacturers are looking at bringing IoT added to the customers, and facility managers of buildings and real estate executives understand that they can capitalize the opportunities of IoT to capture value.

IoT speeds up the development and deployment of smart applications, dramatically increasing Return On Investment

(ROI) and providing the data framework that enables connected intelligence to uncover new opportunities through better management of building operations, security and energy. But, are current buildings (and more importantly, their owners) truly agile? Are buildings keeping up with adopting the latest technologies? Should IoT solutions wait for retrofitting actions in order to be ready to work? And what the impact of these retrofitting actions in terms of time and cost?

When furbishing a new office building or new industrial plant there are no problems to install an Ethernet-like backbone to support wireless IoT solutions. Memooris data report [2] seems to suggest that in the race to adopt IoT technologies, the buildings industry is more tortoise than hare. He concluded that mainstream penetration, i.e. 50% of all building systems devices connected, is unlikely to be achieved before 2025. In the market there is information technology speed, and buildings industry speed. Making wholesale changes to existing buildings, by their nature, is difficult. Moreover, around 75% of the projected building stock of 2050 exists today. Also, businesses must consider the cost impacts. The average cost to deploy a basic Building Management System (BMS) is at least $2.50 per square foot [3].

Looking at the financial benefits, rather than the costs, can likely spur more building owners and facility managers to adopt and implement IoT technologies in their building portfolios, considering that it is reasonable to expect savings in the range of 10% to 25% when implementing proactive energy-management programs in mid-sized buildings. The ROI from properly-applied IoT sensors, switches, and analytics can occur in six months to five years, it depends on parts and installation, including communications infrastructure, smart solutions cost and intelligent platform already available in the building. To this aim, the possibility to have a smart system that can manage not only IoT applications but the greater part of services in the building can facilitate the ROI and can accelerate the retrofitting action.

As it will be shown and discussed below, the solution proposed in this paper, named EDISON-IoT (E-IoT), permits to reach many of the mentioned goals, not only in the main areas of the building but everywhere, in any corner, by using a mixed wired-wireless solution that avoids shadowed zones with no connection to the network.

In two buildings in Italy, owned by Sielte S.p.A, located in Roma industrial area, respectively a group of offices and an industrial plant, an E-IoT test bed has been implemented almost 18 months ago. It allowed saving about 10 percent in energy consumption during the first year and around 30 percent it is expected thereafter, following further enhancements. Through technology, buildings are gaining lives of their own. With the amount of available data about everything, from occupancy to airflow rates and energy use, buildings are becoming data-rich environments. The technical solutions used in the E-IoT test bed area accelerating the development of upgraded version of the intelligent platforms already implemented with reduced impact of time and cost.

In the following the E-IoT system will be firstly described in general terms and secondly some aspects, in particular the ones regarding the wireless-wired solution, will be illustrated in more detail.

II. E-IoT Platform for Smart Buildings

The creation of smarter buildings through the deployment of Internet of Things is getting a lot of attention. Many smart lighting solutions have been proposed of which the vast majority uses wireless communication. In [4] an IEEE 802.15.4 Wireless Sensor and Actuator Network (WSAN) has been proposed with commercial LED drivers, motion and light sensors. The solution is kept low-cost as compared to KNX, Z-Wave, EnOcean and other intelligent building solutions. In [5] a similar WSAN is used in combination with a DC-based power distribution system for LED lighting. In [6] a multi-hop Bluetooth smart lighting solution is presented. Consumer-based intelligent lamps are also becoming increasingly popular. Some of these communicate over Bluetooth, others like the popular Philips Hue communicate over IEEE 802.15.4 Zigbee and require a network bridge [7].

The solution proposed in this paper provides a platform designed to meet the unique needs of todays connected world. With E-IoT it is possible to deliver powerful, smart building IoT solutions in a fraction of the time when compared to other approaches. The E-IoT open platform can accommodate data originated by sensors, alarms, smart devices, in a unique physical network, already existing and spread everywhere: the lighting electrical infrastructure.

A. The E-IoT Platform

The E-IoT platform is based on the EDISON project solution [8]–[10], a European PSP-ICT project, that re-introduces the concept of a DC smart grid in the building, integrating Solid State Lamps (SSLs) with very efficient power supply modules and advanced ICT devices. The idea of using DC power for the main lighting network in the building, or in part of it, is not new. In the early days of electricity distribution, direct current was the standard (T.A. Edison was the main supporter). Now that a lot of modern equipment, and in particular Solid State Lamps (SSLs), smart boards, sensor nodes, etc. require low-voltage DC, the rationale is swinging back towards DC distribution in the building. This approach avoids that a considerable amount of power is lost in the process of conversion from mains AC to low-voltage DC in consumer equipment. Another benefit for the main AC power grid is that the amount of Total Harmonic Distortion created by all this consumer equipment is largely removed by the DC grid and the active Power Factor Correction (PFC) grid converters. Furthermore, the DC lighting solution paves the way to a simplified development of IoT application for intelligent buildings, as explained earlier.

DC lighting solutions are vastly gaining popularity for the above mentioned reasons. A prime example is the newly completed and award winning ”The Edge” office building in Amsterdam, The Netherlands in which the intelligent LED lighting system is connected and powered by Power over

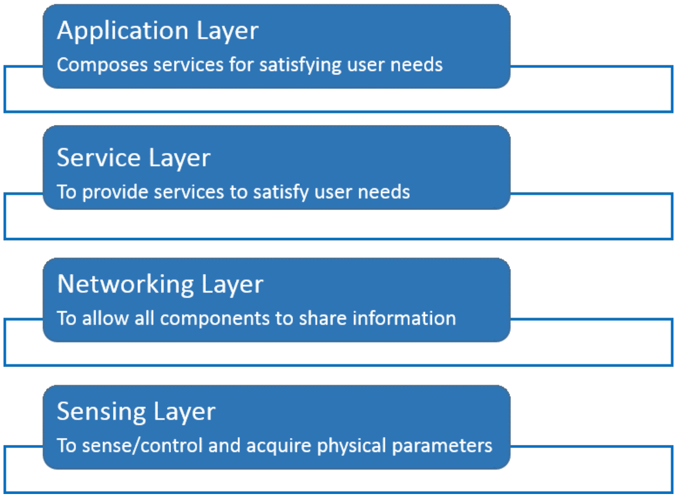

Fig. 1. E-IoT global architectural model

Ethernet (PoE) [11]. Although having advantages, like the large amount of bandwidth, there are also clear disadvantages. A vast amount of Ethernet cabling is necessary for powering all lamps, because of the very restricted current limitations. Furthermore, this approach is not feasible when retrofitting while retaining the existing lighting cabling.

In the EDISON solution, already implemented in more than 100 buildings in EU, the lighting infrastructure operates as a low-voltage DC micro-grid on top of the existing lighting cabling.

From electrical point of view, the EDISON electrical network requests 3 wires: 2 of them for powering the lamps and electronics, the third one for both to bear data transmission and to allow the control of LED lamps through the traditional wall switches, resistive dimmers, etc. This approach is valid in almost all electrical networks installed in the buildings: the ones using 4 wires and the ones using the more traditional tri-polar cable (Brown, Blue and Y/G). In any case, the Yellow/Green (Y/G) wire or ”earth wire” must not be connected to earth, because the EDISON resulting lighting system is classified as a Safety Extra Low Voltage (SELV) system from a regulatory perspective [12], [13]. The ”free” wire (Y/G) is devoted to data communications and control of the sensors and actuators. To avoid possible hazards due to future interventions of operators uninformed about the EDISON solution, it is required that all points of access to the wired network have a yellow warning indicating the presence of a SELV lighting system and, therefore mandating that the Y/G wire shall not be connected to earth. However, to avoid errors, it is suggested to cover the Y/G wire at the ends with a black cover strip as is further detailed in [14]. The set of power supply and data/control wires forms the Power Local Area Network (PowerLAN), a fundamental asset in the E-IoT architecture. This basic asset, combined with smart boards (i.e. Arduino, Raspberry Pi, etc.) forms the core of the lighting control sensing/actuating layer. On top of that, a networking layer, a service layer and an application layer are built, as shown in Fig. 1, which follows a reference architecture for Internet of Things. In short:

1) The sensing layer offers a communication network operating on the existing wiring (PowerLAN) to be able to get information from the sensors and actuators connected via that wiring.
2) The networking layer allows all components to communicate with each other, e.g. via the PowerLAN, WIFI, Bluetooth, Ethernet, Powerline etc.
3) The service layer provides services to satisfy user needs. In a first implementation, it exposes them through a RESTful (REpresentational State Transfer) Application Programmers Interface (API) following web based standards as described in detail in [15] and as applied in a similar project presented in [16]. This implies that the resources (sensors and actuators) are represented by Universal Resource Identifiers (URIs) and that can be accessed through the well known Hyper Text Transfer Protocol (HTTP) methods or via similar lightweight Constrained Application Protocol (CoAP) requests [17] [18]. In an ongoing implementation the RESTful approach will be combined with a Publish/Subscribe approach as proposed in [19], involving CoAP observations or by introducing the Message Queue Telemetry Transport (MQTT) protocol as will be explained in section III.
4) The application layer composes the services in order to satisfy the user needs.

B. The Wired-Wireless Architecture

The EDISON architecture is depicted in Fig. 2. It uses the AC mains as power backbone to drastically avoid wiring problems related to the use of low-voltage DC. Connected to a Central Power Control (CPC) Master, located close or into the Power Distribution Panel Board, there are remote devices, named CPC Slaves (CPCSs), integrating multiple AC/DC converters smart boards, Input/output modules, etc. These devices are installed at the level of junction boxes of the electrical infrastructure, in different areas of the building. The number and the power of these modules are chosen in order to match the requirement of high power conversion, to make the AC/DC conversion more efficient, with the need of a distributed local DC grid that takes into account the constraints of the existing electrical infrastructure. The information exchange between the CPC Master and the CPCSs is achieved by power line modems over the AC mains or via Wi-Fi. The CPCSs communicate via the EDISON PowerLAN with the Remote Stations (RSs) which control the lighting sections. Wireless communications (i.e. Wi-Fi, Bluetooth, etc.) are supported by the RS, provided by a smart board to manage data and controls with proper interfaces. In this device a DC powerline modem operates as a transceiver module (named RTS in EDISON), designed to send/receive serial data over the DC powerline network. RTS modules perform the built-in packet-level repeater function. This feature can greatly extend the coverage of the communication network. To this aim RTS

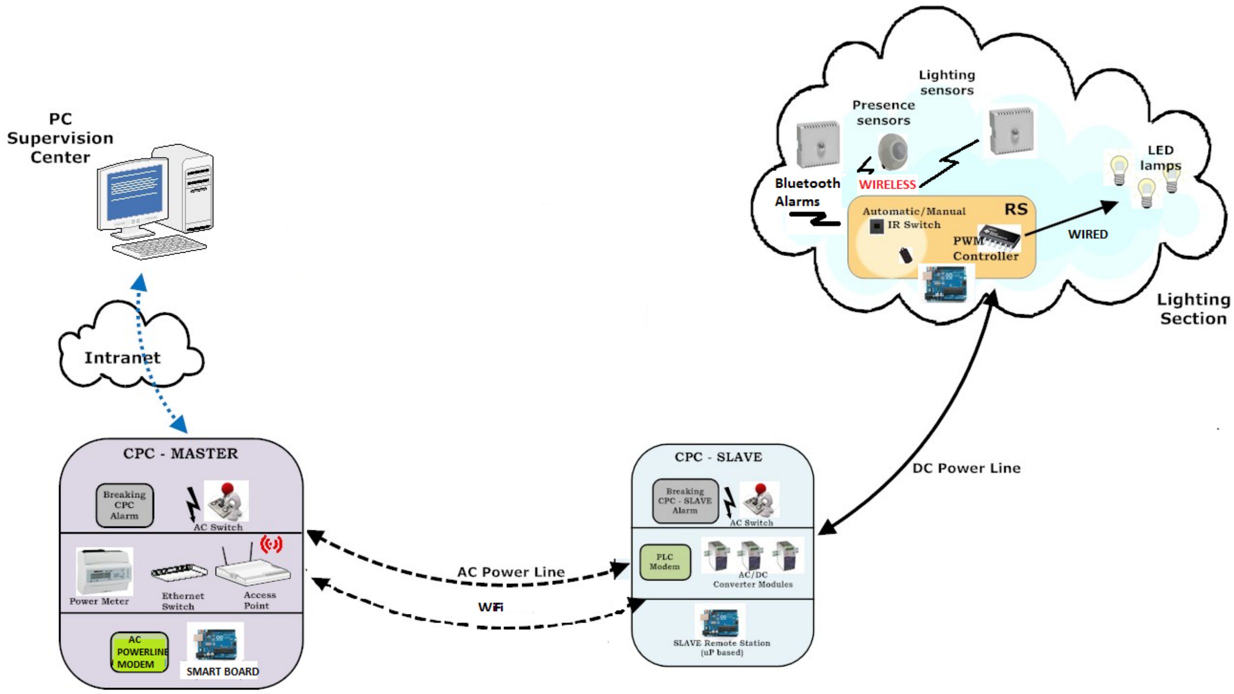

Fig. 2. E-IoT general architecture

modules have both physical and logic addresses, in order to access different nodes in the network.

All the communications among CPCs and RSs are operated via PowerLAN and DC powerline modems, in this way only 2 wires of the lighting infrastructure are actually used. In parallel way, the RS smart board can directly manage all the data collected through wireless communications, mainly Wi-Fi, Bluetooth or Frequency Shift Keying modulation, used in physical layer for local control (switch ON/OFF the lamps).

III. E-IoT Application Protocol Overview

Several popular IoT application layer protocols are geared towards constrained devices that face unreliable, low bandwidth connections for their access network [19]–[22]. Today, CoAP and MQTT are amongst the most popular.

MQTT is a TCP based publish-subscribe protocol in which clients can publish data on a given topic or subscribe to a topic in which case the server will automatically send new data to the registered subscriber. The MQTT publish/subscribe model allows reaching multiple nodes with a limited overall number of exchanged messages. It can free the resource constrained device from resource hungry operations like polling to get the updated data. Publishers and subscribers are completely decoupled from each other thanks to the usage of the MQTT broker. As its name states, MQTTs main purpose is telemetry, or remote monitoring. Its goal is to collect data from many devices and transport that data to a broker that will feed it to devices needing that data. Typical applications for MQTT include power usage monitoring, lighting control and office automation.

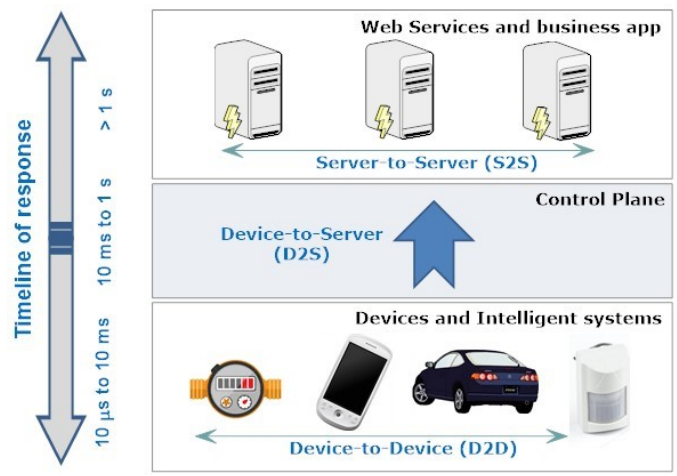

Fig. 3. Response times in function of type of devices involved in the communication chain. MQTT can be situated in the D2S class with delays up to 10ms to 1 second. Figure based on [23].

CoAP supports a request-response model like HTTP. It also supports a publish/subscribe-like model through an extended GET method (observe mode). It uses URIs instead of the topics used in MQTT. It operates on top of UDP and has its own reliability mechanism. Fewer implementations are available than for MQTT, for which at least 10 different ones are available.

Depending on the load and the positioning of the broker, the latency of protocols like MQTT can vary from several milliseconds to seconds. Fig. 3 depicts the effect of involving one or several servers in the communication chain as opposed to direct device to device communication.

In the E-IoT pilot, in order to have a very simple approach considering the applications usually requested in commercial offices and industrial plants, the choice has been oriented towards the MQTT protocol, which targets device data collection. In this framework the EDISON multilevel architecture permits a reduction of bottlenecks thanks to the remote intelligence largely spread in the building. In fact, the first E-IoT approach, the one implemented in the pilot in Italy, has been to conserve fast local communication at PowerLAN level (wired network) for the local lighting control and to use MQTT for exposing the measurements to other parties on the network.

IV. The E-IoT Test Bed

As above mentioned a first test bed has been implemented to combine the EDISON smart lighting solution with other IoT applications. The testbeds primary objective was to reduce the power consumption of a generic (and existing) lighting system, while spending as little as possible for the installation and deployment of the communication network.

All the devices needed for operating the EDISON solution were designed, developed and deployed, taking into account the constraints and the advantages of the DC power supply in that particular area. All the EDISON components (CPC Master and Slaves, RSs, etc.) were designed (i.e. interfaces, number of Inputs/Outputs, etc.) in order to satisfy the requirements of an integrated IoT and smart lighting system. The IoT smart devices for lighting control collect data through interconnected sensors and actuators and react in real time (milliseconds) at the request of particular events. Thus, having a reliable communications network infrastructure (PowerLAN) as backbone, and a wireless extension locally, a ubiquitous networking system steered by smart devices has been implemented at affordable cost. Traditional networks (i.e. Ethernet) with high performance and reliability are expensive and difficult to manage in an industrial environment. These factors made the platform offered by E-IoT the respondent candidate for a network infrastructure that can meet the expectations.

The pilot area, an industrial plant for fiber production and fiber quality control, in which E-IoT has been deployed, is around 2000 m2, the number of sensors is greater than 200, the number of actuators around 50 and there are more than 100 RFID devices. This complex system is managed by 22 RSs, 12 CPCS, 1 CPC Master and 1 Supervision Center, that operates as local server. Most communications between sensors and actuators are wireless (WiFi, Bluetooth) via the RSs, apart from the lighting control system which uses the PowerLAN. All the devices connect to a data concentrator server (the CPCS via the RS). Since the IT infrastructure uses the data, the entire system is designed to easily transport data into the service buses provided by the EDISON platform. MQTT enables the requested applications based on monitoring of a lot of sensors to be concentrated into a single location (the Supervision Center) for analysis.

The industrial process of fiber quality control has been strongly facilitated and the production cost has been reduced. Machines and smart boards handle 65% of the value chain autonomously, with some 100 automation controllers in operation from one end of the control line to the other. Parts being controlled communicate with the Supervision Center by means of a product code, which tells the machines the actions to be made and which steps need to be taken next. All processes are optimized for IT control, resulting in a minimal failure rate. Employees are essentially supervising production and technology assets, including handling unexpected incidents.

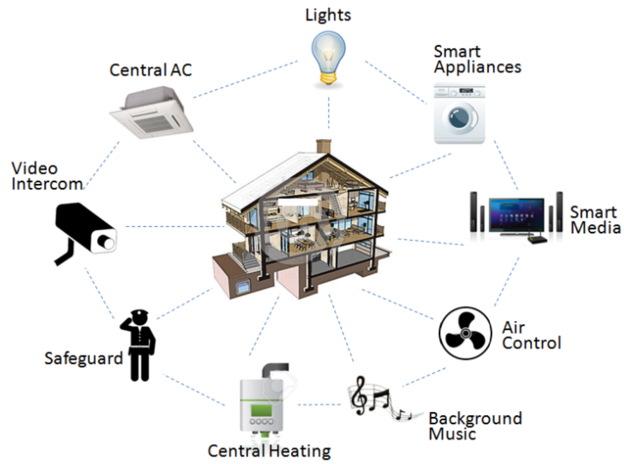

Fig. 4. E-IoT and services

Apart the advantages in the industrial area there are a lot of positive improvements in the office usual life. Considering the topography of the facility where the solution E-IoT has been implemented (office building, internal garages, main entrance, etc.) the advantages in the daily life are multiple as illustrated in Fig. 4. The badges can be taken as an example. As known, they allow an employee to enter places like parking garages and offices. But usually, the employee has to take some action, such as wave them near a sensor. E-IoT let people come and go while barely slowing down. The building knows who they are, because the ID cards have quietly communicated that information. In the same way offices can immediately detect the presence of someone who is not an employee. There may also be restricted access rooms, such as data centers. In such places, motion sensors can detect and immediately report if someone has entered the room.

The E-IoT system permits, inter alia, to have a valid support in fire protection and evacuation, an instant recognition of who is/was in the building and where. About electrical installation technology, energy-saving lamps have been replaced by LEDs saving tons of CO2 and thousands of dollars in electricity bills. Moreover, lights will automatically shut off when leaving a room or when exiting from work. In addition, the room temperature can be reduced when leaving from work and increased in advance of coming home. On the other hand an energy provider can read the energy consumption for a day, week, or month.

V. CONCLUSION

The E-IoT platform allows quick development and bringing to market of innovative IoT applications, at a reasonable cost, and at a fraction of the time compared to other approaches. This result is thanks to the integration of a largely distributed network built on the lighting infrastructure, with IoT devices, and to the synergies between energy management and IoT systems. The main infrastructure is ready and easily available, facilitating rapid application of intelligent solutions. The distributed intelligence can be shared as well as the abundance of sensors. The DC power supplies are commonly available and there is no need of extra installations. The immediate consequence is the ability to benefit from an integrated wired-wireless solution that can help to achieve significant energy saving, reduced operational cost, perform risk management and enhance employee productivity. Furthermore, the E-IoT flexibility permits to easily upgrade the system at reasonable costs.

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