Transition from closed system to Internet of Things

A Study in Standardizing Building Lighting Systems

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***Abstract*—Internet of Things (IoT) is triggering changes in lighting industry from the traditional closed and propriety systems to flexible, interoperable and service oriented systems. To address the challenges of this transition and catering the specific requirements of lighting networks, an Open Architecture for Intelligent Solid State Lighting Systems has been proposed. The architecture is open and extensible to future technologies with security and interoperability as its integral features. A side effect of this transition is the impact on stakeholders and changes in the lighting value chain and building sector. This paper provides an overview of the architecture and zooms into the challenges in one important area, namely installation and commissioning. It proposes potential solutions to prominent issues raised by the lighting industry.**

***Index Terms*—Internet of Things; reference architecture; lighting value chain; stakeholders; installation and commissioning**

I. Introduction

Internet of Things (IoT) is the current technology trend that creates radical changes in the markets by converging multitudes of vertical markets. Lighting industry is not exempted, but rapidly embracing this transition towards luminaires getting connected to internet and thereby enabling an Internet of Lights [1]. This transition aims at enabling efficient use of buildings with increased comfort and well-being of the users at significantly reduced operational costs and carbon footprint.

Traditional lighting systems are closed and proprietary and often come with very restrictive application program interfaces (API) and dedicated networks. A transition towards IoT enables using the network infrastructure in the building for control and powering the lighting systems. Connecting luminaires to a network with IP to all nodes enables flexibility and interoperability with other systems such as Building Automation Systems (BAS), smart grid and cloud services. It creates new ecosystems and stimulates investments and innovations. E.g. sharing occupancy data collected by presence detectors used for lighting controls with BAS for air conditioning or cloud for data analytics opens up new possibilities and services.

A transition from a closed system to a System of Systems by embracing IoT introduces new challenges. Ensuring reliability and guaranteed performance of today's dedicated lighting systems in an internet connected luminaires world is a key challenge. Making the system secure retaining interconnection and interoperation benefits of IP is nontrivial. To address these challenges, a project Open Architectures for Intelligent Solid State Lighting Systems (OpenAIS) [2] has been proposed. OpenAIS provides an IoT-centric architecture embracing today's IoT standards with extensions to cater the specific requirements of lighting networks. Considering the rapid changes in the IoT domain, the architecture is made extensible to future technologies, allowing evolution over time. Security is well supported as internal feature of the architecture ensuring data privacy, operational security and system integrity. Interoperability with BAS and other building systems, support for cloud storage and big data analytics, and integration of legacy technologies are among its core features. Moreover, it is an open architecture with open standardized interfaces stimulating innovation and vendor competition leading to an ecosystem of components and services. Thus OpenAIS provides a transition from the closed proprietary lighting systems to open service oriented systems.

A side effect of this transition is the impact on stakeholders and changes in the lighting value chain and building sector. This paper zooms into one such impact, namely on installation and commissioning process. It looks at the challenges introduced by IoT in this area and tries to answer the prominent questions raised by the lighting industry by proposing potential solutions.

The rest of the paper is organized as follows: Section II discusses related work. A brief overview of OpenAIS and the proposed architecture is given in Section III. Section IV provides details on the impact on installation and commissioning process and proposes potential solutions. Section V concludes the work and Section VI summarizes our future goals.

II. Related Work

A. Lighting systems

The most prevailing standards used in the domain of lighting systems and building control are BACnet [3], KNX [4] and DALI [5]. BACnet is a communication protocol for building automation and control networks. The BACnet protocol defines a number of data link/physical layers, including ARCNET, Point-To-Point, Master-Slave/Token-Passing, Ethernet, BACnet/IP, LonTalk and ZigBee [3]. It is widely used in today's heating, cooling and ventilation market, but not for lighting controls because of the complexity and the relatively high cost per light point. BACnet is designed to be used in closed networks and to the best of our knowledge no commercial product has implemented BACnet security even though there is a standard on paper. KNX is also standard for home and building control and more prevalent in Europe. The main physical communication medium is twisted pair (TP) wires. Other media such as Powerline (PL), Radio Frequency (RF), Infrared and Ethernet (KNXnet/IP) are also used [4]. Security was always a minor concern, as any breach of security requires local access to the network. However, this leads to many security vulnerabilities in KNX. DALI (Digital Addressable Lighting Interface) is a data protocol and transport mechanism for lighting control. A DALI system can be made up of control gear, control devices and bus power supplies [5]. However, there is no security defined for DALI.

There are a wide range of products coming into the lighting market. Daintree Networks based on ZigBee PRO [6], Enlighted Inc. wireless network based on IEEE 802.15.4 [7], Gooee a full-stack IoT solution, Litecom lighting management system from Zumtobel [8], Philips Connected Office Lighting [9], etc. are examples of propriety IP-based lighting systems. There were also a number of projects related to building automation systems and lighting. EnLight [10] was a EU project which developed an architecture and a decentralized lighting control by applying the publish-subscribe design pattern which gives scalability and network-stack-independent eventing system. GreenerBuildings [11] was an EU FP7 project to develop energy-aware adaptation of public buildings using smart objects and cloud systems for increased robustness and failure resilience. SCUBA [12] was an EU FP7 project to address the challenges of fragmented BAS market by creating a novel systematic engineering approach via an integrated design tool chain and an online integration and control framework.

B. *IoT architecture and framework*

There are several competing alliances led by world's prominent semiconductor, electronic and telecom industries resulting in various IoT platforms and frameworks. The AllSeen Alliance lead by Qualcomm with more than 200 members is the most popular one [13]. The AllJoyn [13] is an open source framework from AllSeen with a set of system services that enable interoperability among products and applications across manufacturers using a D-Bus message bus. There is also an AllJoyn-based Lighting Service Framework (LSF) to provide an open and common way of communicating among connected lighting products. The Open Interconnect Consortium (OIC) with more than 150 partners is another prominent one [14], with a competing framework called IoTivity [14] hosted by the Linux Foundation. It aims at defining a common communication framework based on industry standard technologies for IoT and provides the certification and branding for reliable interoperability in IoT. OIC enables RESTful manipulation of resources across devices. OIC has acquired a major player UPnP Forum [15], that pioneered the networking software protocols of today's Smart Home. UPnP is deployed in billions of home entertainment devices and internet gateway devices. The acquisition will boost their efforts for standardization in IoT. OneM2M [16] is another standard driven by telecom companies based on based on the design of the ETSI M2M. Machine-to-Machine (M2M) communication is migrating towards IP based technology and oneM2M aims at developing technical specifications for a common M2M Service Layer that can be readily embedded within various hardware and software to connect the wide range of devices worldwide with M2M application servers. Open Mobile Alliance (OMA) [17] has come with standards for managing light weight and low capability devices on a variety of networks. The OMA Lightweight M2M (LWM2M) [17] includes device management and service enablement for LWM2M Devices and defines the application layer communication protocol between a LWM2M Server and a LWM2M Client. It specifies a simple RESTful object model and API for reading, setting and executing resources on any device. Internet Protocol for Smart Objects (IPSO) [18] published their Smart Objects which are built on top of the LWM2M. It defines a number of standard device functions 'objects' that are useful for lighting systems.

There are also several works for providing IoT reference architectures and models. The international Telecommunication Union (ITU) recommendations include ITU-T Y.2060 [19] that provides an IoT Reference Model with four layers, namely application layer, service support and application support layer, network layer and device layer. The EU FP7 project has come with an Architectural Reference Model (ARM), for creating open interoperable systems and integrated environments and platform [20]. The IoT ARM consists of an IoT Reference Model providing the highest abstraction level for the definition of model and an IoT Reference Architecture for building compliant IoT architectures. The IoT Reference Model includes Domain Model, Information Model, and Functional Model together with Communication Model and Trust, Security, and Privacy Model as the sub-models of the Functional Model. The EU FP7 IoT@Work project [21] focusses on industrial and automation environments to create self-managing resilient networks employing middleware and service oriented application architecture. The IoT World Forum [22] has published an IoT reference model with seven which are Physical Devices and Controllers (the things), Connectivity, Edge (Fog) Computing, Data Accumulation, Data Abstraction, Application and Collaboration and Processes.

III. OVERVIEW OF OPENAIS

OpenAIS is a EU Horizon 2020 project with key players from the lighting industry and IoT. It envisions creating an open ecosystem to enable a wider community to deliver the smartness of light and allow easy adaptability to cater for the diversity of people and demands. It foresees that the lighting systems as well as the building management systems will converge to an all-IP based configuration, with Internet of Things concept at the heart of new lighting system architectures. The key objectives of OpenAIS are [2]:

- Define an open architecture for lighting systems with standardized open APIs

- Make the system interoperable with Building Automation Systems, cloud services and other systems
- Increase the building value and reduce the carbon foot print by combining IoT, LED technology and Smart Grids
- Easy Life across the value chain, i.e. easy to specify, buy, install, maintain and use

A. OpenAIS system requirements

The important OpenAIS system requirements are following:

- System should perform well irrespective of the connectivity choices, mixed network installations or size of the network
- Switching or dimming should be reliable and well synchronized
- System should support advanced control features and grouping
- System should provide security as an integral feature of the system
- System should keep initial cost low by reusing available standard technologies and software stacks
- System should be extensible to new technologies and upgrades by third parties
- Standardized system API should be available for easy installation and commissioning
- System should support integration into Building Automation System and lighting related technologies such as emergency lighting.
- System should provide service access via cloud

B. OpenAIS reference architecture

OpenAIS provides a reference architecture, i.e. a template for specifying concrete system architectures. The architecture is designed to support a wide range of deployment scenarios and use cases and to fit to the requirements of future office buildings [2]. An example of a system realization out of the reference architecture is shown in Fig. 1. A typical OpenAIS system consists of luminaires, (standalone) sensors and UISwitches which are connected together to a local network either using a wired or a wireless network. Within local networks all devices use the same network technology and they need not be fully separated geographically. The access layer may contain standard IT components such as switches, routers and access points and OpenAIS devices such as gateways that translate legacy and non-OpenAIS devices to OpenAIS interfaces and border routers to connect wireless network, e.g. 6LoWPAN, to the wired backbone.

The OpenAIS devices has two set of functions: An application layer containing Sensor, Actuator, Control, DataCollect, Group, or/and Gateway functions and an infrastructural layer containing Discovery, Communication, Update, Security, Configuration, Device management and Exception management. The application functions implement the domain specific functionality of the lighting system whereas the infrastructure functions use the standard technology as much as possible.

OpenAIS support centralized, fully distributed or any intermediary control models. In centralized models, the Control

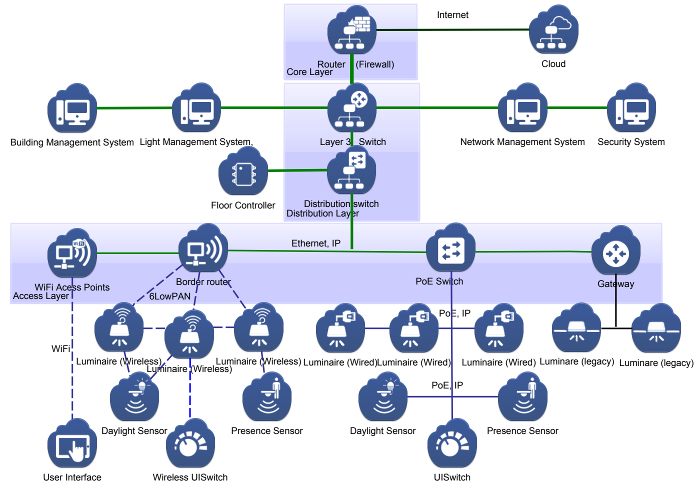

Fig. 1. A system realization example.

function can be allocated to one central controller that handles everything whereas in fully distributed they are allocated in all luminaires. In larger configurations dedicated lighting controllers per group, area or floor are possible. Such standalone controllers are optional elements and can be even allocated on other IT-devices like servers or even in cloud. This flexibility in Control function deployment is supported by the provision for stacked control; a feature that allows for different levels and overriding of Control functions. It also allows extending the control behaviour, i.e. a new Control function with a higher functionality can be added to extend existing functionality without replacing the existing one. There are also other mechanisms for extensions supported in OpenAIS. E.g. the system behaviour can be extended without updating the software, by adding multiple identical Object instances to the device with specific bindings. OpenAIS also supports modular software upgrade and plugin modules for extending the device functionalities.

C. OpenAIS network architecture

OpenAIS supports both wired and wireless networks and mandates IPv6 communication for all end nodes. IPv6 is the main decoupling points in the architecture. The underlying PHY/MAC/IP stack choices are not mandated; instead default choices have been proposed, which are 6LoWPAN/Thread [23] for wireless and Ethernet for wired networks. The envisaged network stack is depicted in Fig. 2.

UDP is used for transport in conjunction with the CoAP (including CoAP Observe and CoAP multicast) [24] to support constrained devices. For transport layer security DTLS is used. All interfacing between the applications will be through RESTful web service interfaces. For this OMA LWM2M [17] on top of CoAP is selected. The data model will be derived from the basic models defined in LWM2M/IPSO [18] and build on those. Also note that all functions required for the lighting and building control market are not supported in LWM2M. Hence there are a set of modifications and additions

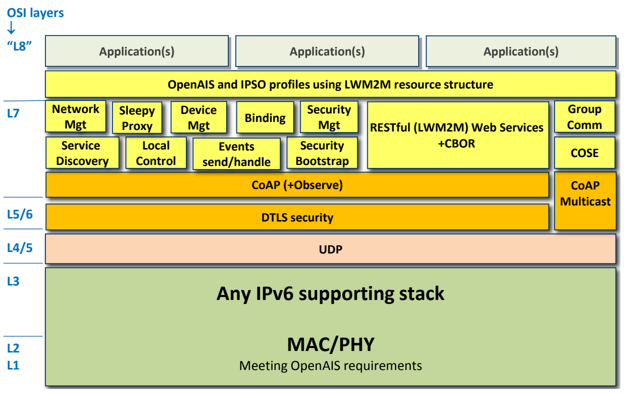

Fig. 2. OpenAIS network stack.

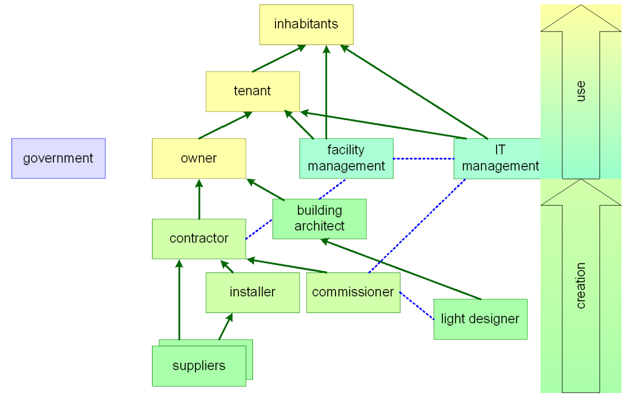

Fig. 3. The current lighting value chain.

needed. E.g. support for peer-to-peer communication, secure group communication, out-of-the-box operation, role-based authorization, etc. needs to be added. Network joining is an important function that needs to be defined in the network architecture. However, as OpenAIS is independent from specific PHY/MAC/IP-stack choices, OpenAIS proposed only a set of requirements for secure and reliable joining of the network. The requirements include provisions for automatic discovery of wireless networks, automatic allocation of a global-scope IPv6 address, automatic rejoining etc.

D. OpenAIS security architecture

OpenAIS security architecture supports authorization, authentication, confidentiality and security of the communication and the integrity of the system against attacks. It reuses the LWM2M specification as far as possible. However, additional changes required for the lighting specific applications such as support for role based access control, peer-to-peer and group communication and bootstrap process (not depending on internet connectivity to a central server) are needed.

The OpenAIS authorization policy for client-server interactions like peer-to-peer and device-to-server type communication, demands that only authorized clients are allowed to access server resources. For this, the authorized clients are categorized into one of multiple roles (e.g. lighting operational, commissioning, maintenance etc.) and six access levels (0 to 5) are provided to support role-based access. To implement the authorization policy, OpenAIS use the Access Control Lists and the Security Object from the LWM2M specification. The method used for end-to-end security depends on the content of the security Object used to secure the communication. To protect all communication above access level 2 (Lighting operational), OpenAIS uses standard network communication security mechanisms. Unicast requests and responses for resource with access level greater than 2 are secured using DTLS [25]. For all multicast communication, CoSE based object security must be used [26]. Object Security format used in multicast communication and for unicast communication within a group for Level 2 resources is currently being standardized within IETF ACE working group [27].

IV. Impact on Lighting Value Chain

OpenAIS project tries to integrate and create new value from IoT. Converting the traditional individual lights to connected smart lighting systems, involves new stakeholders, e.g. app developers, to the lighting value chain. In this section we look at the traditional lighting value chain and then look at the impact on lighting value chain by zooming into one of the activities, namely installation and commissioning activities.

A. Traditional lighting value chain

The current lighting value chain is given in Fig. 3. Two phases in the lighting value network are the creation and use phases. The creation phase can be divided into design and build sub phases. The design sub-phase is the first step in the building and renovation work, where the building owner assigns an architect to make the design for the building. The lighting designers inform the architect about current state-of-the-art light solutions. The government provides rules and regulations for energy performance, building permits, etc. During the build sub-phase, construction starts once the project has been awarded to a contractor who holds the budget. Generally light installation and commissioning starts after construction and installation of power distribution and electrical equipment. The installation of a lighting system starts with a light installer (typically an electrician) who mounts the luminaires in the building and connects them to the power cabling. Suppliers deliver components for the lighting system to the installers. Commissioners check the light installation against the light design and then perform advanced commissioning which includes grouping of luminaires, sensors and controls according to the design, day light setting etc. After light installation, other installations like IT and Fire alarm systems are done. Then integration for the Building Management System (BMS) is carried out.

The next phase is the use phase which includes the use and maintenance of the building and lighting system. In this phase the system is handed over to the building owner. The tenant, typically a company for office buildings, rents (part of) the building from the building owner. The inhabitants are the employees that make use of the building. Facility management (FM) manages health and safety, security, maintenance, cleaning, and space allocation. IT management involves implementing and maintaining IT infrastructure.

B. Installation and commissioning

We have seen that the traditional installation and commissioning activities starts with installation of the lighting system. The installers also do a basic testing if the wired and wireless devices are working and on/off of lights work. Then a hand over to commissioners takes place.

Commissioning can follow a pre-programming workflow in which devices are pre-programmed for their targeted operations. As soon as they are mounted and connected they start working. Although the pre-programming path works quickly and reliably, site issues such as changes in layout, mistakes in mounting and replacement of broken/missing devices make it less attractive. Alternatively a direct install workflow can be followed which requires more effort, as the mapping of devices to the location needs to be done manually, but is very flexible.

Before commissioning, site documentation on grouping and binding, parametrization, system credentials and location identification (not mandatory for direct workflow) are needed. A crucial step in commissioning is establishing the relationship between the actual location of the device location and the device ID. This is then used to program the devices with the correct set of groupings, bindings and parameters. After functional verification for correct bindings by checking status change of the rooms and groups, a handover to offsite commissioning takes place. Offsite commissioners perform commissioning refinements based on customer request and then hand over to owner/facility management.

C. Challenges with IoT

Fundamental challenge is the paradigm transition from closed system with dedicated cabling to an open system sharing resources with other systems. The involved stakeholders have specific skills and knowledge related to the old paradigm. The new paradigm requires other skills, such as network configuration skills.

Typically IT is installed after the lighting network is installed in the building. Analysing the installation and commissioning workflow, this would make the process more complex and time consuming. A key challenge of moving towards IoT is to simplify the commissioning process and reduce the commissioning time, ideally to eliminate the need of a commissioner visiting the site!

While moving towards IoT, the use/sharing of IT infrastructure in the building for lighting and building management systems is envisaged. This arises several new questions related to IT networks which are not familiar to the traditional lighting industry. Let us focus on one of the prominent network issues - the network availability and its impact on a) installation and commissioning activities and b) normal operation of the lighting system. We have conducted a workshop to collect the prominent questions the traditional lighting industry asks, which are summarized below:

Regarding the network availability during installation and commissioning activities, the questions are:

- When is IT available and live (power and network configuration) during installation and commissioning?
- Is the internal network in the building working at this stage?
- Is the external communication to internet also available (e.g. to support cloud service-based commissioning)?
- What happens if IT issues arise during installation and commissioning?

Questions related to the network availability during normal operation of the lighting systems are:

- How to ensure QoS in the (shared) network?
- How to overcome network failures?
- How to cope with IT misconfiguration?
- What can we do to mitigate RF interference?

D. Proposals for solutions

In this section we try to find some potential solutions to the raised questions. To simplify the commissioning process and reducing the time, a smart commissioning tool needs to be developed which can store the pre-programming workflow and assist the commissioner to easily localize, do grouping, binding and parametrization, set the system credentials and rectify onsite errors.

Let us now look the potential solutions to the raised questions. The IT network availability issue during installation and commissioning arises mainly due to phasing issue. To overcome this an easy solution is:

- Contractual agreement can be made to ensure that IT is available at the commissioning stage

However in many cases, this doesn't work. Therefore a potential solution is:

- The organizational preliminary network that is available after installing lighting specific network components can be made independent from standard IT network by using temporary devices (e.g. preliminary switches/routers, tablet with SIM that can directly connect to cloud, etc.)

Let us now look at the network availability (24x7) issues during normal operation of the lighting systems.

- Ensure QoS in a shared network:
  - It is a contractual issue - use either a separate network for lighting or ensure minimum bandwidth available for lighting purpose.
  - Use IPv6 priority flags to receive higher priority for lighting packets (but it may not be available always).
- Network failures:
  - Limit spreading of failures and use the fall-back controller provision.
  - Redundant network components and connections to circumvent failing parts.
- IT misconfiguration:

  - Triage is possible by using a tool that asks components to respond and if response is different, it can detect issues.
- RF interference:
  - Enable channel agility in PHY or have a tool (in the devices) that can detect issues and change channels.
  - Limit the hop count to a few hops. This introduces the need for additional border routers. However, it is cost effective when compared to the cost for debugging, as it solves several issues due to larger hop counts.

V. Conclusion

In this paper we have provided an overview of an Open Architectures for Intelligent Solid State Lighting Systems. The architecture is open and extensible to future technologies. The manifold provisions to support extensibility include extending the control behaviour with new Control functions, extending the system behaviour by adding multiple identical Object instances, extending the device functionalities using modular software upgrade and plugin modules etc. Security has been designed as internal feature of the architecture and it supports authorization, authentication, confidentiality, security of the communication and the integrity of the system against attacks. LWM2M specification has been extended for this and the Object Security format is currently being standardized in the IETF. The OpenAIS network stack reuses state-of-the-art IoT provisions. It mandates IPv6 communication and selected UDP for transport and CoAP and LWM2M on its top for application layer. The object model of OpenAIS is the extended version of LWM2M/IPSO models.

The paper also looks at impact of this IoT-based architecture on lighting and building value chain and its stakeholders. This paper zooms into one such impact, namely on installation and commissioning process and looks at the challenges there. One of the key issues found is the use/sharing of IT infrastructure in the building for lighting and building management systems and of networking issues. The paper tries to answer the prominent questions raised by the lighting industry by proposing potential solutions.

VI. Future work

During the project phase, OpenAIS tries to involve major lighting companies to standardize the open system architecture. The vision of recently formed Fairhair alliance (partner program of IEEE-ISTO) [28], supports the OpenAIS IoT approach and gives an opportunity to standardize (parts of the) OpenAIS specification in a wider scope. As the OpenAIS object models are built on top of LWM2M/IPSO models, standardization through IPSO alliance is also possible. The application level object security format is submitted for standardization in the IETF.

In addition to the standardization activities, to validate the OpenAIS reference architecture, a pilot project in a real office building with a paying customer has been considered. The end user will be an early adopter of the new system and benefits from the added value of OpenAIS system. It will also give OpenAIS an opportunity to assess the total cost of ownership and the return on investment in this pilot project.

Acknowledgment

This research and paper is enabled by the OpenAIS project, supported by the Horizon 2020 programme of the European Union under grant agreement number 644332.

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