Lite4More: A Hardware and Software Solution to Improve the Commissioning of Lighting Infrastructures

Diogo Correia[1][a], João Gomes[1], Carlos Resende[1][b], Filipe Sousa[1][c], Jorge Filipe[2], Carlos Silva[2] and Antonio Sousa[2]

[1] *Fraunhofer Portugal AICOS (FhP-AICOS), Rua Alfredo Allen 455, Porto, Portugal*

[2] *Tridonic Portugal, Rotunda Eng. Edgar Cardoso 23, Vila Nova de Gaia, Portugal*

fi fi

antonio.sousa}@tridonic.com

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Abstract: The Internet of Things is being integrated into many aspects of our daily lives to optimise it. Smart building, in particular, smart lighting, is one of the aspects that can benefit power consumption and user well-being. However, such systems' installation and maintenance costs are hampering their dissemination. The commissioning of lighting infrastructures is a human and time-consuming task whose complexity increases with the size of the building under installation. The manual discovery of the luminaires in the building and their association with their digital counterparts is one of the main reasons for this, and the current state-of-the-art solutions do not properly address it. In this paper, we propose Lite4More, a modular hardware and software solution that can be easily adapted to different installation requirements and address the lighting infrastructure commissioning issue by automating it. Lite4More takes advantage of the Cloud, Edge and IoT device layers to, through the use of AI algorithms, guide the technician along the commissioning procedure, reducing on-site work and aiming to reduce the total time for commissioning.

1 INTRODUCTION

Internet of Things (IoT) solutions are disseminating and optimizing several aspects of our daily lives. In 2020, 11.7 billion IoT device connections were registered, and it is estimated a 13.5% growth until 2025 (Lueth, line). Such dissemination brings a lot of challenges, namely in the commissioning of such devices. Currently, these devices are delivered to customers with pre-installed and pre-configured software, and updating and configuring them is usually a manual and local procedure. The overhead of such a procedure increases with the (high) number of nodes present in IoT networks, so it is mandatory to automate it (Dautov and Song, 2020).

Focusing on the application of IoT on smart buildings, Xu et al. (Xu et al., 2019) identify the high installation and maintenance costs as one of the main blockers to the dissemination of smart building deployments. In the case of smart lighting, the main hurdle in installing and maintaining a large lighting infrastructure is the time and repetitive strain required to commission. This procedure can take up to several weeks and, in some cases, months, depending on the size of the installation.

The typical commissioning process consists of checking each digital address space one by one and activating the corresponding luminaire. Then, for each iteration, search the activated luminaires on the physical infrastructure and attribute an easy-to-read name to its address and location on the computing system. The commissioning time increases in a nonlinear way with the size of the infrastructure because two consecutive luminaires in the commissioning procedure may be located too far apart.

The industry and academic community are investing in smart lighting solutions, taking into consideration its benefits in terms of energy consumption (Hughes and Dhannu, 2008; Neida et al., 2001) and users' well-being (So and Leung, 1998; Nagy et al., 2015). However, the proposed solutions do not address the commissioning issues because they assume that the lighting infrastructure already exists and is fully commissioned.

[a] https://orcid.org/0009-0007-5443-4073
[b] https://orcid.org/0000-0002-1834-0420
[c] https://orcid.org/0000-0002-8278-9062

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Additionally, the majority of the smart lighting solutions support a specific set of communication protocols or devices, so they do not address the vendor lock-in issue and the high heterogeneity in terms of communication protocols available in smart lighting (Chinchero et al., 2020).

With this in mind, we propose Lite4More, a hardware and software solution that addresses these issues. Lite4More spans from the IoT device, i.e., the luminaires, to the Cloud, where a set of algorithms automate the localization and commissioning of the lighting infrastructures, minimizing human intervention on-site. As this is a work in progress, Lite4More currently supports Bluetooth Low Energy (BLE) and Digital Illumination Interface Alliance (DALI). Nevertheless, its implementation is based on microservices, which can easily be extended to other communication protocols (e.g., Zigbee, Thread, Matter) and installation requirements (e.g., the integration with other smart building infrastructures, such as heating, security, and access control systems).

The remainder of this paper is organized as follows. Section 2 reviews the literature about smart lighting and its commissioning procedures. Section 3 presents the proposed solution and the lessons learned so far. Section 4 concludes the paper and outlines future steps.

2 STATE OF ART

The academic and industrial communities are proposing smart lighting solutions targeting improvements in energy usage and users' well-being. However, only a few identify the commissioning problem of such systems, and almost none address it. This section overviews such efforts.

(Xu et al., 2019) provide a framework for designing solutions for smart buildings and applying it to a smart emergency lighting system. Despite identifying the high overhead in installing and maintaining IoT solutions in smart buildings, the authors do not try to automate and minimize such overhead. Instead, they state that the business models enabled by the proposed framework will deal with such a process. The authors also state that multiple communication protocols might be part of the installation, but the proposed solution for emergency lighting only uses LoRa, and it is unclear if it is extensible to other communication protocols.

(Pandharipande and Thijssen, 2019) propose a lighting data model for street light infrastructure in smart city applications, which aims to ease the integration with other city infrastructures and the development of smart applications. The authors are aware of the need for a commissioning process to set up the luminaires and the multitude of communication protocols needed to build such a system. However, they only tackle the support for multiple communication protocols via a pre-defined API, which does not clearly indicate how new protocols can be added to the system.

(Gagliardi et al., 2020) propose and prototype an IoT infrastructure for smart city lighting that can adapt autonomously to traffic and weather conditions. Despite the system's field validation, the authors do not address the issue of autonomous commissioning. Additionally, the authors do not consider heterogeneity in terms of communication protocols for the devices in smart lighting and tie their solution to ZigBee.

(Füchtenhans et al., 2021) review the state-of-art on technologies and applications for smart lighting systems and, based on such review, elaborate on the benefits that can be obtained by applying smart lighting to warehouse order picking. The authors, however, fail to address the challenge of deploying such systems, namely the high overhead on the commissioning of lighting infrastructures. (Chinchero et al., 2020) also review the state-of-the-art on technologies and methods for lighting control systems for smart buildings. They propose an architecture that fails to address such a system's commissioning and installation overhead but, despite not providing the details, considers the multiple communication protocols that might be involved in such installation.

In (Cheng et al., 2020), the authors identify a set of challenges that need to be addressed by smart lighting systems and propose a solution to reduce lighting energy consumption based on sensors, a rule-based mechanism for lighting control and Zigbee. The overhead of the commissioning procedure is not identified as a challenge, so it is not addressed, nor is the heterogeneity in terms of communication protocols. (Lin et al., 2020) also propose a solution to address the energy consumption of lighting systems, but they focus only on the indoor personnel positioning challenge. (Chen et al., 2022) developed a solution to reduce the energy consumption of street road lighting. They use renewable energy sources and employ intelligent mechanisms that control the light intensity level based on traffic flow and the presence and absence of people. Still, again, they do not focus on the commissioning of such a system, and they tie their solution to ZigBee, disregarding the heterogeneity of communication protocols for smart lighting solutions.

(Ristimella, 2020) identifies in his master thesis, with the help of representatives of Helvar Oy Ab, the

Table 1: Overview on Academic and Industrial Smart Lighting Solutions.

Platform	Automated Commissioning	Smart and remote Lighting Control	Extensible to multiple communication protocols
(Xu et al., 2019)	No	Yes	Not clear
(Pandharipande and Thijssen, 2019)	No	Yes	Yes
(Gagliardi et al., 2020)	No	Yes	No
(Chinchero et al., 2020)	No	Yes	Yes
(Cheng et al., 2020)	No	Yes	No
(Chen et al., 2022)	No	Yes	No
(Signify Holding, 2023)	No	Yes	No
(SavantT Technologies LLC, 2022)	No	Yes	No
(OSRAM GmbH, 2023)	No	Yes	No
(Lightwave, 2023)	No	Yes	No
(Ristimella, 2020)	Partially	Yes	No
Lite4More	Yes	Yes	Yes

challenge of lighting localization and its importance in the commissioning of lighting systems. Ristimella proposes a localization mechanism for lighting systems, which complements a personal lighting control mechanism for public spaces. However, the localization mechanism relies on a technician carrying a Received Signal Strength Indicator (RSSI) and Passive Infra Red (PIR) scanning device along the space where the luminaires need to be identified. This procedure is impractical for big public spaces such as hospitals, airports or stadiums. Additionally, the solution does not address the heterogeneity of communication protocols for smart lighting solutions because it is tied to BLE and the ActiveAhead luminaries from Helvar Oy Ab.

Nevertheless, Ristimella's master's thesis is the only publicly known industrial effort to ease the commissioning of lighting solutions. Other companies in this field only advertise their efforts on smart lighting. (Signify Holding, 2023), (SavantT Technologies LLC, 2022), (OSRAM GmbH, 2023), and (Lightwave, 2023) are examples of such efforts in which the luminaire is complemented with a wireless communication protocol, which allows its integration with a web and/or mobile interface to control it. Another common characteristic of the existing industrial solutions is the support of a specific subset of devices and/or protocols, limiting the possibility of extending the solution to other communication protocols and devices.

Table 1 summarizes the studied smart lighting solutions in terms of the commissioning procedure, support for smart/remote lighting control, and the possibility of being extended to support other communication protocols, addressing heterogeneity and vendor lock-in. One can conclude that all the solutions provide support for smart/remote lighting control, but only the solutions proposed by (Pandharipande and Thijssen, 2019) and (Chinchero et al., 2020) support the extensibility to other communication protocols (the solution proposed by (Xu et al., 2019) is not clear regarding the supported of this feature). Regarding the capability to automate the commissioning procedure, only (Ristimella, 2020) proposes a solution that partially addresses this issue. Ristimella's solution still requires the technician to scan the building fully to identify the luminaires, which is not ideal. Lite4More not only addresses smart/remote lighting control but also proposes a more efficient autonomous commissioning procedure and an extensible architecture that can be adapted to different communication protocols as well as other installation requirements.

3 PROPOSED SOLUTION

Lite4More addresses the lighting infrastructure commissioning problem by employing a system architecture that spans from the IoT device (the luminaires) to the Cloud, which houses a set of algorithms and a user interface that automates and guides the technician through the commissioning procedure. Section 3.1 and section 3.2 overview such architecture and commissioning procedure, respectively. Section 3.3 concludes with the lessons learned so far.

3.1 System Architecture

Figure 1 presents Lite4More's architecture, which spans the Cloud, Edge and IoT Device Layers. The Cloud Layer is responsible for automating and controlling the luminaires, user interaction, and storage of the lighting network configuration. The IoT Device Layer comprises the physical lighting infrastruc-

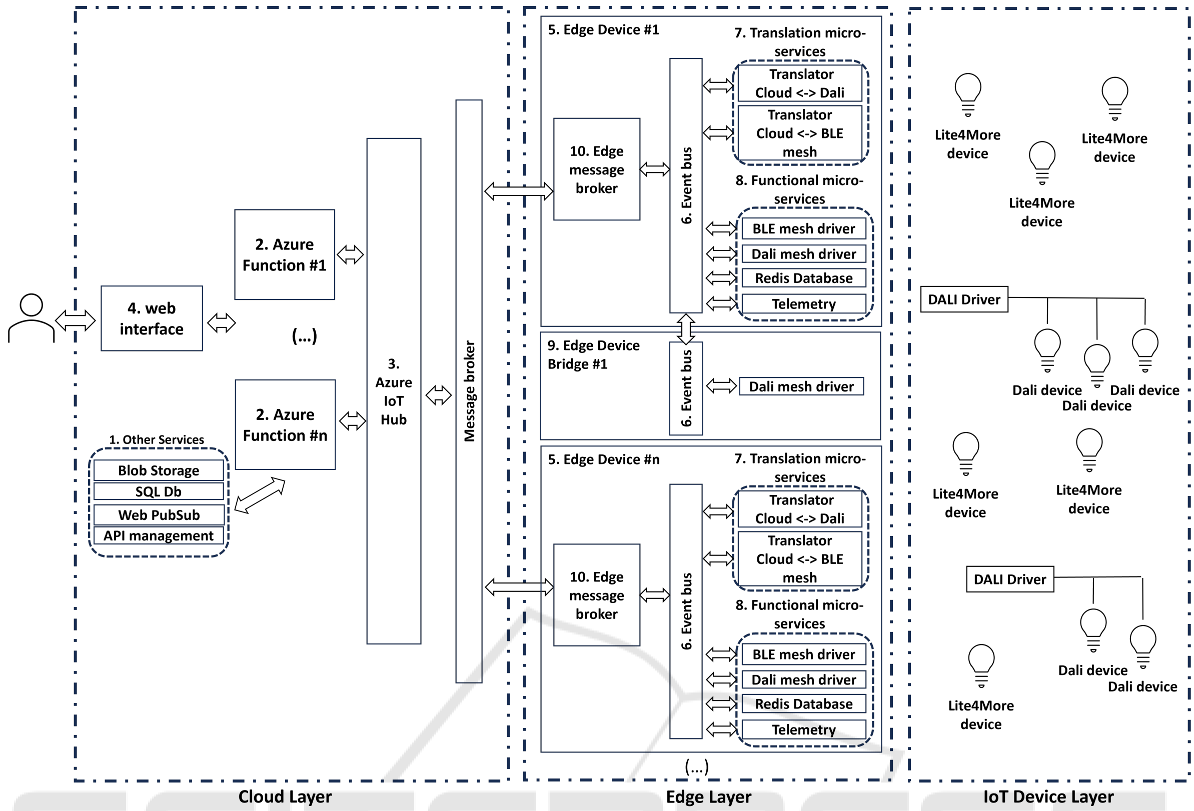

Figure 1: System architecture.

ture: luminaires, sensors, and actuators (e.g., light and dimmer switches). The Edge Layer serves as the interface between the lighting infrastructure and the components at the Cloud level.

The Cloud Layer builds on top of the Microsoft Azure Cloud platform (Microsoft, 2024). It comprises a set of services that control and manage the physical infrastructure and a web interface providing an interface between the user and the services. Using Azure API manager (cf. 1, Fig. 1), a REST API is provided as an interface for the web interface. For each action invoked with this API (e.g. scan for devices, add devices, light commissioning, etc.), an Azure function (cf. 2, Fig. 1) is triggered. These functions are a type of Function as a Service that executes Lite4More code in a server-less manner. They handle any events triggered by the Edge Devices, users or other services and run the logic required to commission, configure and plan the infrastructure. Another adopted service is the Azure Event Hubs, which provides queues to inject and consume messages that our system needs to forward between the different services and devices. A database service (cf. 1, Fig. 1) stores structured data, such as the system configurations and the information about the lighting infrastructure. The *blob storage* (cf. 1, Fig. 1) stores unstructured data, such as architectural blueprints. The Azure IoT Hub service (cf. 3, Fig. 1) provides the message broker that interfaces the Cloud services with the Edge Devices in the layer below. This service is crucial for synchronising the device data stored in the Cloud with its physical counterpart. When, for example, a user requests the system to provision a new luminaire (see section 3.2), the Azure function sends an identified action message to the closest Edge Device requesting the provision of such luminaire. Then, when the luminaire is provisioned, the Edge Device sends an identified action response, which is consumed by another Azure function that updates the network in the database. At the same time, another Cloud function is responsible for asynchronous notifications and sends an event to the web interface (cf. 4, Fig. 1) stating that the action was successful. These notifications are published by the Azure Web PubSub (cf. 1, Fig. 1), a WebSocket service allowing asynchronous messages to be published to our web interface.

The Edge Layer comprises multiple Edge Devices that connect the distinct lighting infrastructure with the Cloud. The architecture of the Edge Device (cf.

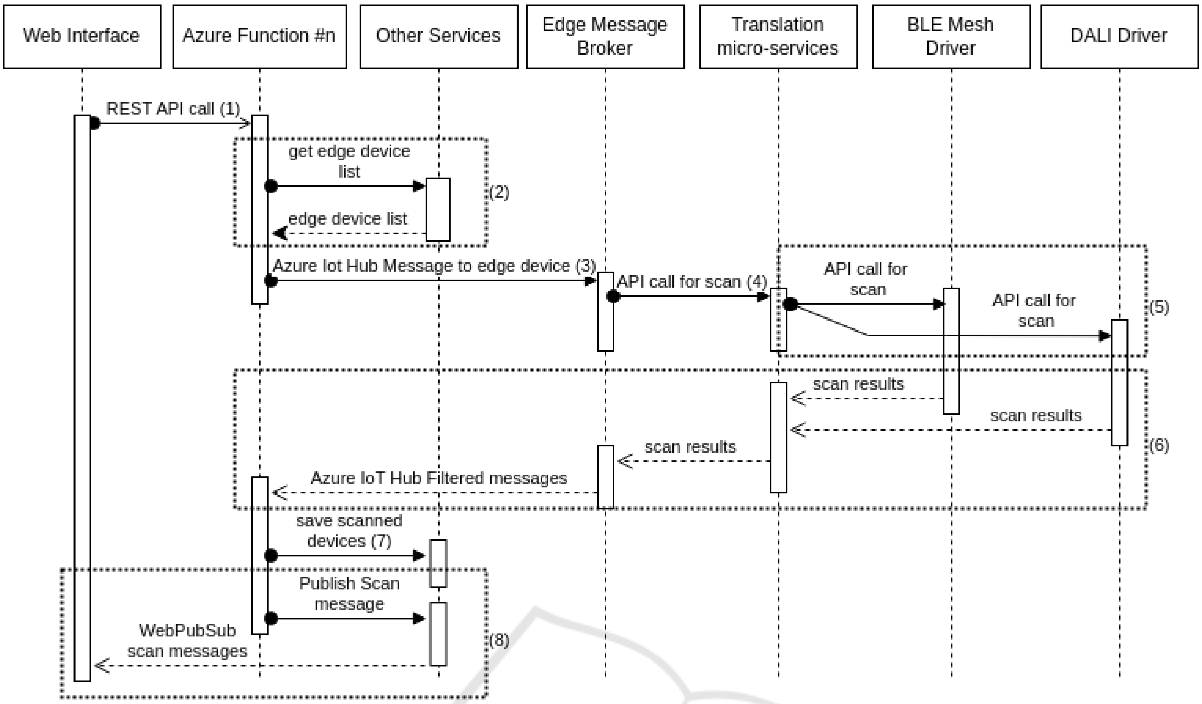

Figure 2: Sequence diagram for scan operation.

5, Fig. 1) is based on microservices that communicate with each other through an event bus (cf. 6, Fig. 1). Those microservices can be classified into translation (cf. 7, Fig. 1) and functional (cf. 8, Fig. 1). Translation microservices are responsible for translating Cloud events into events understandable by the functional microservices and vice-versa, decoupling the latter's interface from the interface on the Cloud. The functional microservices are typically used to perform some type of functional computation (cf. 8, Fig. 1), namely: the Redis Database stores a local configuration of the nearby IoT Device layer; the Telemetry module bypasses the Edge message broker to send large amounts of data (e.g. sensor data) back to the Cloud; and the protocol drivers, currently BLE Mesh or DALI, communicate directly with the target devices in the IoT Device Layer. The different microservices in an Edge Device communicate using a single event bus based on the Dapr (Dapr, 2023). This bus can also be shared with other devices, called Edge Device bridges, a type of Edge Device without a connection to the Cloud (cf. 9, Fig. 1). The Dapr event bus allows Edge Device bridges to use full-featured Edge Devices as a relay to the Cloud. To achieve this, each full-featured Edge Device has an Edge message broker (cf. 10, Fig. 1) to receive and send messages from and to the Cloud. Based on microservices, this architecture allows us to easily extend Lite4More to other lighting infrastructure protocols beyond BLE Mesh and DALI.

The lighting infrastructure lies at the IoT Device Layer. This lighting infrastructure consists of luminaires, sensors, actuators (such as light switches and dimming switches) and sometimes a combination of these. These devices can be divided into two categories: Lite4More devices, which are based on Nordic nRF52840 microcontroller (Nordic Semiconductors, 2019), use BLE as communication technology and have a set of sensors that provide relevant data for the commissioning procedure; and the classic devices, which use well-established communication technologies that do not account for IoT scope and are the standard in the lighting industry, such as DALI devices. The DALI devices are integrated into the Lite4More scope through the DALI microservices running on the Edge Device. Currently, the lighting infrastructure only supports BLE and DALI devices, but other communication protocols can be easily added by including new functional microservices responsible for communicating with them in the Edge Devices.

The sequence diagram in Figure 2 resumes the interactions with the different elements of the architecture described above. Figure 2 showcases the scan request, which prompts the Edge Devices within the installation to search for BLE Mesh and DALI-compatible devices. We use this example, but the flow of information is similar in all the requests. The

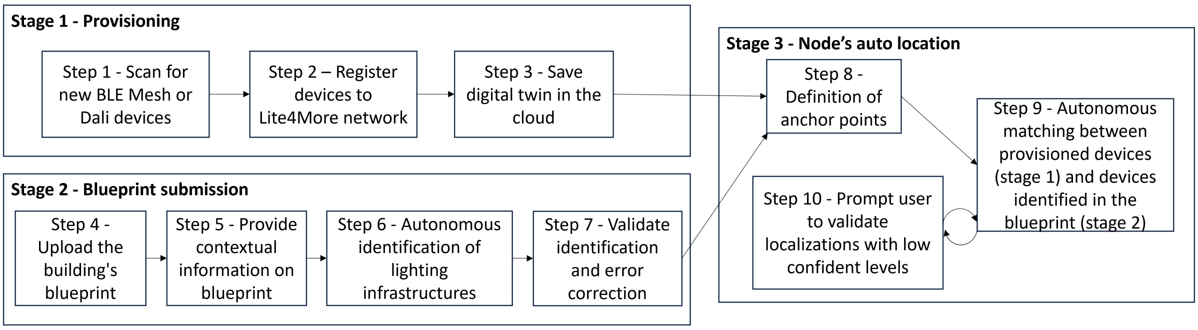

Figure 3: Overview of commissioning stages.

main difference resides in the ”Azure Function” used, the services of the set ”Other Services” provided by the Cloud, and the ”Translation micro-services” used. These macro elements provide a set of different services and functions that respond to each performed request.

In Figure 2, the web interface will perform a scan request to the Cloud through the exposed ”REST API” (cf. 1, Figure 2). This triggers an ”Azure Function” that will get the list of available Edge devices from the ”SQL Database” (one of the services available in the set of ”Other Services” in the Cloud) and identify which Edge device it needs to forward the request to (cf 2, Figure 2). An ”Azure IoT Hub Message” is sent to that Edge device (cf 3, Figure 2). The Edge device receives such a message in the ”Edge Message Broker”, which will convert it into the scan API call (cf. 4, Figure 2). This call is consumed by all ”Translation micro-services”, which will call the respective driver modules to perform the scan (cf. 5, Figure 2). From here, the scan results are propagated backwards until the ”Edge Message Broker”. They are then filtered in the ”Azure IoT Hub”, triggering an ”Azure Function” that will save the scanned devices (cf. 7, Figure 2) and publish the information to the ”Web Interface” (cf. 8, Figure 2) through the ”Web PubSub” socket (service available in the set of ”Other Services” in the Cloud).

3.2 Commissioning Procedure

Figure 3 provides an overview of the three stages of the Lite4More commissioning procedure. ”Stage 1 - provisioning” and ”Stage 2 - blueprint submission” do not depend on each other's outputs, so they can be run concurrently. ”Stage 3 - node's auto-localisation” can only be run after the conclusion of the other two. In the commissioning procedure, we assume that the lighting infrastructure and the remaining Lite4More system are already installed and ready to be configured.

In Stage 1, technicians incorporate lighting devices into the Lite4More network. Utilising a web interface, they initiate a scanning process for both BLE Mesh and DALI devices (Step 1). This directive prompts the Edge Devices to scan for BLE Mesh and DALI-compatible devices during installation. After scanning, Lite4More automatically registers the identified devices to its network (Step 2) and stores them in a Cloud-based database (Step 3).

In Stage 2, technicians upload the building's blueprint to Lite4More using its web interface (step 4). After the upload, they provide additional contextual information, such as the blueprint's scale and lighting legend (step 5). When all the contextual information is provided, a computer vision algorithm identifies the lighting infrastructure on the blueprint and estimates the distance between identified objects (step 6). In the end, the technicians use the web interface to verify the algorithm's output and fix identification errors (step 7).

In Stage 3, the technicians use the web interface to run a localisation algorithm based on RSSI and luminance values that match provisioned devices to the identified objects in the blueprint (step 8). The algorithm requires the technician to set at least one anchor point (match one provisioned luminaire with a point in the blueprint) from which all the other luminaires are matched in the blueprint (step 9). The procedures use a human-in-the-loop approach in which, depending on the confidence level of the localisation, the technician is asked via the web interface to validate the luminaires with low confidence levels or select another anchor to continue the localisation procedures (step 10). A more detailed explanation of such algorithm is found on (Barandas et al., 2024).

Even though the provisioning still requires the presence of a technician onsite, it is important to note that such presence is only required to identify the anchor points and validate luminary localisation with a low confidence level. These are specific and well-known locations, so there is no need for the technician to scan all the physical infrastructure. The procedure can be completed with a quick visit to the installation site rather than weeks or even months, as is the case of the current procedure identified in the state of the art.

After commissioning, the technician is invited to create groups of luminaires and scenes (sets of predefined settings). The system can also suggest groups and scenes based on the location of the luminaires and existing groups and scenes.

In conclusion, except for the definition of the anchor points and validation of localisations with low confidence levels, all the steps of the commissioning procedure can be performed remotely with the support of the web interface.

3.3 Lessons Learned

The current version of Lite4More allowed us to draw some conclusions about the technological decisions that were made for the solutions. The most relevant is using Microsoft Azure for the Cloud and BLE for the luminaire communication.

Microsoft Azure is a powerful tool for developing IoT solutions for the Cloud with seamless integration with the Edge, but the efficient selection and combination of some of their products is not straightforward. When using Microsoft Azure for complex solutions composed of several of their products, it is crucial to have good knowledge about Azure and always contact technical support in case of doubt or inefficient/slow execution of code.

Regarding BLE, we started setting up a testbed in an office to evaluate Lite4More developments. This setup is currently composed of a Raspberry Pi 4 that plays the role of an Edge Device and 86 luminaires distributed through open spaces and small rooms spanning 705 square meters. Initial tests indicate that BLE mesh network parameters such as the number of relays, the transmission power, the time to live, and the number of Edge Devices influence, as expected, the message delivery success rate and response time. Such success rate and response time are intrinsically connected to the provisioning success rate and duration. This indicates that we will need to tune the BLE parameters to the installation under-provisioning. We need to perform a structured evaluation and characterisation of the provisioning procedures to define an adequate network configuration according to a set of installation topologies. Additionally, to deal with possible network failures in the provisioning, we need to implement a scheme that monitors node provisioning success and enables retries in case of failure.

4 CONCLUSION

In this paper, we presented Lite4More architecture, a hardware and software solution that targets the autonomous commissioning of lighting systems, which, to the best of our knowledge, is the first proposal in that direction. Lite4More reduces the commissioning time by guiding the technician along the commissioning procedure and reducing on-site work. To achieve this, it comprises a set of serverless functions running in the Cloud, which integrate multiple lighting infrastructures connected via Edge devices running local storage, communication and translation services. For the lighting system, we propose using a BLE-based device with backward compatibility with DALI, composed of sensors that provide relevant data for the commissioning procedure. The proposed solution aims to be highly scalable and easily adapted to new lighting system communication protocols and installation requirements.

The current status of the solution allowed us to validate some of our technological decisions, namely the use of Microsoft Azure for the Cloud and BLE mesh for the lighting system communication. However, this is not without some challenges, namely the efficient selection, integration and setup of all the services provided by Microsoft Azure and the tuning of the BLE mesh network parameters to guarantee low response time and high success rate on message transmission, which relate with the successful provision of the lighting system.

The next steps for Lite4More are to perform a structured evaluation and characterization of the provisioning procedures in an office environment to understand clearly how the BLE mesh network will influence it. In the second stage of the evaluation, we will evaluate the system in other environments (office, warehouse, etc.) to fully characterize how BLE influences the provisioning in different installation topologies and, with this, prepare a set of pre-configurations for the BLE network according to different installation topologies. The roadmap also includes the evaluation of the other stages of our commissioning procedure, namely blueprint submission and node autolocalization.

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