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A Museum Artefact Monitoring Testbed using LoRaWAN

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***Abstract*—This paper presents a long range wide area network (LoRaWAN) testbed for environmental monitoring of artefacts within a museum storage facility. The goal is to identify the optimum feasible wireless technology for this application by studying eight different wireless technologies. A testbed network was deployed inside a 5600 m^2 concrete building to validate the performance of the candidate wireless technologies by way of measurements. In addition, a LoRaWAN scalability approach was also used to simulate the packet delivery ratio for a 500 node network. The wireless communication performance of LoRaWAN was shown to offer the most optimal solution for wireless communication for museum artefact monitoring application.**

***Index Terms*—Artefact monitoring, BLE mesh, LoRaWAN, NB-IoT, museum, NFC, PDR, RFID, SigFox, WiFi, Zigbee.**

I. INTRODUCTION

In museums, the vast majority of artefacts (up to 90 %) are deposited in dedicated storage areas [1], representing large facilities with thousands of storage crates. These storage crates are essential for the protection of the museum artefacts from light, mechanical damage and dust, to prevention of deterioration of the housed objects. It is not uncommon, that some of these enclosures are shelved for over 20 years without being moved. Depending on the variety of materials (like paper-based, canvas or acrylics in paintings and modern art, metals, etc.), those objects often require specific temperature and relative humidity (RH) storage condition, in which they can be protected best from material degradation [2]. At the same time, the material's varying moisture contents or emission of degradation products are able to create unfavorable microclimate in these closed containers that can accelerate the natural ageing in itself. This may be caused by temperature changes or adverse surrounding (indoor) climates, connected with impermeability of the enclosures.

Since most of medium and small-sized institutions are unable to afford expensive heating, ventilation, and air conditioning (HVAC) systems for the mentioned areas, the monitoring of the crate's inner environment is a useful tool to control microclimate and its altering nature. In [3], [4], [5], [6], museum artefact monitoring solution are presented using wireless sensor and the Internet of Things (IoT) technologies. The selection of a suitable wireless technology for stored artefact monitoring is vital mainly because the museum storage areas are often located in old buildings with high signal attenuation.

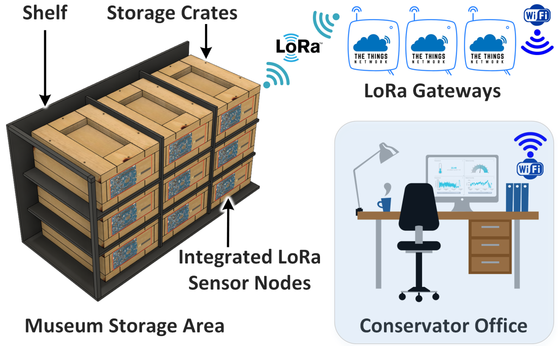

Fig. 1. Illustration of stored museum artifact monitoring using LoRaWAN.

Building structures for historical buildings may include thick walls that attenuate more high-frequency radio signals (e.g., 2.45 GHz) compared to lower frequencies (sub-GHz), and this results in a decrease in the wireless communication range [7]. Similarly, artefacts owned by museums are stored in the basement areas, and some museums are located in remote areas where the cellular network may be unavailable or have a poor connection [8]. Likewise, artefacts can be located in large quantities that are housed in wooden crates and that are placed in areas with limited real-estate. Wireless monitoring of microclimate parameters of individual storage crate at regular intervals may create wireless signal congestion, which can decrease the packet delivery ratio (PDR) [9].

This paper presents the development of LoRaWAN testbed for environmental monitoring of artefacts within a museum storage facility. Experimental and simulation results of a LoRaWAN, show that this technology is feasible for the museum artefact monitoring application. Fig. 1 illustrates a typical museum artefact monitoring scenario where a LoRaWAN-enabled wireless node is integrated into each storage crate which sends environmental sensed data to a LoRa gateway(s). The gateway(s) then forwards these data packets to a LoRa network server through the Internet (i.e., The Things Network). Finally, the conservator can access and analyze the sensed environmental data through via the web for the purpose of artefact preventive conservation.

II. CHOOSING A SUITABLE WIRELESS TECHNOLOGY

In [10], [11], [12] comprehensive reviews of various wireless technologies have been reported. To select a suitable wireless technology for museum artefact monitoring application, the analysis of several key wireless performance parameters is required. These parameters include power consumption during data transmission, reception and during sleep mode, indoor wireless communication range as well as the data rate.

Table I presents a comparison of the above technical parameters for the eight wireless technologies listed. Narrowband Internet of Things (NB-IoT) is a low power wide area network (LPWAN) technology with a wireless communications range of approximately 1 km typically with a data rate of 200 kbps [12]. However, an NB-IoT radio transceiver requires a peak DC current of approximately 300 mA during transmission and 5 μA current in sleep mode [11]. In addition, a network subscription (€ 0.02/MB) [13] and the dependency on cellular coverage makes NB-IoT difficult to be employed for this application. SigFox is an another LPWAN technology developed for low-power and low bitrate applications, which requires a peak DC current of 22 mA during transmission and 0.7 μA in sleep mode [14]. However, because of a low data rate of 0.1 kbps, SigFox requires 2.08 seconds of air-time to transmit a payload of 12 bytes. Because of the increasing number of sensor devices, this increased air-time may lead to an increased packet error rate (PER) [9]. ZigBee and WiFi are short to medium-range wireless technologies with high data rate of 250 kbps and 600 Mbps, respectively [11]. As shown in table 1, Zigbee and Wi-Fi technologies have low communication range as well as they consume more power during transmission when compared to other LPWAN technologies, such as LoRa. Therefore, Zigbee and Wi-Fi are not suitable for the intended application. On the other hand, ultra-high frequency radio-frequency identification (UHF RFID) and near field communication (NFC) technologies operate in battery-free and battery-assisted power mode and consume a low DC current of respectively 350 μA [15] and 330 μA [16]. However, as shown in Table I, the communication range of both UHF RFID and NFC technologies is low and, therefore, additional infrastructure cost is required for an autonomous sensor data collection.

LoRaWAN is another LPWAN radio technology that enables long-range communication while consuming a low DC current of 32 mA [11]. LoRaWAN has an acceptable data rate for this type of application. In addition, the user does not have to subscribe to third-party network providers like NB-IoT, and several years of battery lifetime can be achieved. Similarly, BLE also meets data rate and power consumption requirements. However, the communication range of BLE is typically less than 20 m in indoors [19], thus, multiple relay nodes are required especially when the node deployment involves a wide coverage, or when the BLE gateway is located far from the storage crates. Nevertheless, some performance test results of LoRaWAN and BLE technologies are performed.

TABLE I
COMPARISON OF WIRELESS TECHNOLOGY TECHNICAL PARAMETERS.

Wireless Technology	**Range (m)**	**Data Rate (kbps)**	**Sleep Current (μA)**	**Tx Current (mA)**	**Ref.**
NB-IoT	10000	200	5	300	[10], [11]
SigFox	10000	0.1	0.7	22	[11], [14]
LoRaWAN	5000	50	1	32	[10], [11]
ZigBee	100	250	0.9	46	[11], [17]
WiFi	250	600k	4	229	[11], [18]
BLE	20	1000	0.97	6.40	[19], [20]
UHF RFID	15	640	0.7	0.350	[15], [21]
NFC	0.045	848	1.3	0.330	[16], [22]

III. DEVELOPMENT OF TESTBED NETWORK

A LoRaWAN testbed network, BLE mesh server, and the client node were developed for the purpose of performance comparison (see Fig. 2). The implemented LoRaWAN testbed network comprises 3-sensor nodes and 4 gateways (TTN-GW-868). One of the LoRa sensor nodes was developed using a commercial evaluation kit (L072Z-LRWAN1) and sensors expansion board (X-NUCLEO-IKS01A2). Further, this LoRa sensor node was connected to a commercial 868 MHz whip antenna [23]. Also, two commercial LoRa devices (Dragino LHT65) were used for performance analysis. All LoRa sensor nodes transmitted data with the adaptive data rate feature on (to automatically select the least energy consuming settings). Similarly, to develop BLE client and server node, commercial evaluation kit of BLE (nRF52840-DK) was used.

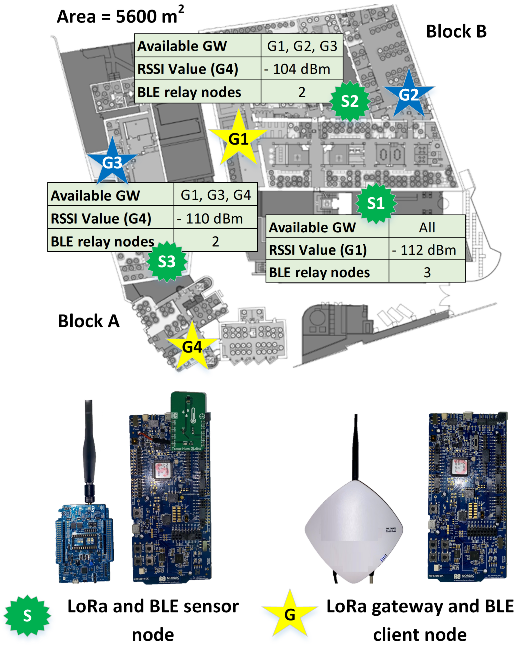

Fig. 2. Indoor wireless communication facilities of LoRaWAN and BLE.

IV. RESULTS & DISCUSSION

For the indoor wireless communication test, the LoRaWAN testbed network and the BLE nodes were deployed in one of the Tyndall National Institute's building (see Fig. 2). This building is divided into two blocks: Block A (old construction and thick walls) and Block B (modern style construction). As shown in Fig. 2, the LoRa gateway and BLE client node were set up at location G1 in Block B. The LoRa sensor node (evaluation kit-based) was placed at locations S1 and S2. The LoRa Received Signal Strength Indicator (RSSI) metrics recorded at location G1 were -112 dBm and -104 dBm for location S1 and S2, respectively, showing the high attenuation level of the environment. Similarly, to transmit data from S1 and S2 to G1, BLE required 3 and 2 relay nodes, respectively. A similar performance test was conducted in Block A. The LoRa gateway and the BLE client node were set up at location G4. A LoRa RSSI value of -110 dBm was measured at the gateway location G4 from the sensor location S3. For BLE, 2 relay nodes were required to transmit data from S3 to G4. Therefore, even though BLE presented a high PDR [24], it requires additional infrastructure which increases the overall deployment cost. In this particular deployment, the increase in cost is about 200% given that a BLE relay node (e.g., nRF52840-DK) costs approximately € 41 [25]. Furthermore, if a high number of BLE end-devices are placed in the storage area, the additional battery replacement cost is significant, since the collected traffic must travel via the relay nodes, which must constantly be in active mode. In contrast, the LoRaWAN nodes presented a very low energy consumption during the entire duration of the experiment. In order to evaluate the experimental configuration (i.e., range, path-loss characteristics) with a larger number of nodes, a series of simulations utilizing the LoRaWAN-SIM simulator were performed [26]. 100 to 500 nodes were used and each node was capable of sending 1 confirmed packet every 20 minutes for 1 day. The packets were received by 4 gateways which were placed far from the 30 m^2 storage area. The results are depicted in Fig. 3, showing a very high PDR (>0.995) even for a high number of devices.

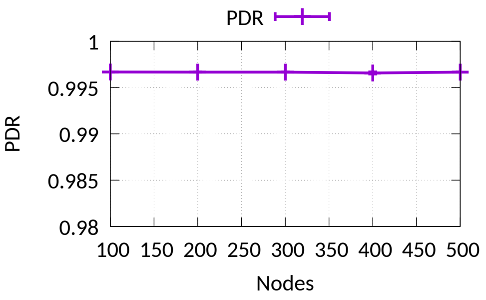

Fig. 3. LoRaWAN Packet Delivery Ratio for 100 to 500 nodes.

V. CONCLUSIONS

This paper presented the development and assessment of a LoRaWAN testbed for museum artefact monitoring. The main conclusion of this study is that LoRaWAN is the most suitable candidate for a museum artefact monitoring application for numerouos reasons. LoRaWAN provides a cost-effective solution with low infrastructure costs, a high network reliability (PDR > 0.995) and an energy consumption of less than 105 mW. Future work will focus on sensor node hardware development, battery lifetime analysis, and a real-world deployment in a museum storage area.

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