LORAWAN INDOOR PERFORMANCE ANALYSIS

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Abstract— Increasing demand on Internet of Things (IoT) requires specific communication technology to handle low-cost power consumption and coverage requirements. Several Low Power Wide Area Network (LPWAN) technologies emerged; however, Long Range Wide Area Networks (LoRaWAN) is the key technology to address these issues. LoRaWAN uses a unique LoRa modulation to provide long range data communication with low power consumption; this will lead LoRaWAN to be the key technology for IoT infrastructures. In this study, LoRaWAN performance is analysed with an experimental TestBed environment by considering communication range, data rates, packet losses and energy consumption for indoor usage. Obtained results are summarized and discussed possible future research directions

Keywords— LoRa, LoRaWAN, LPWAN

1. INTRODUCTION

LoRaWAN is a candidate to be a IoT communication infrastructure with key characteristic; Long Range, Ultra Low Power Operation, Low Cost, Scalability, and Quality of Service. There are several alternative LPWAN technologies such as Sigfox, Ingenu, Weightless in the market, however, LoRaWAN is the most promising one among these competitors. It has an open source driven community, quickly progressing coverage and technical features and able to operate using ISM bands makes LoRaWAN to be unique successor [1, 2]. Long Range (LoRa) technology is a physical layer radio signal modulation technology that aims to work on unlicensed bands (EU 868 MHz, US 433 MHz). Also, power consuming perspective LoRa is very energy efficient technology. Yet to cover IoT ecosystem LoRa needs a MAC layer technology which easy enough to developers to build products with and reliable enough to third party operators serve it as a service. LoRaWAN is the most promising technology to cover this gap which is also suggested by LoRa Alliance [2].

LoRaWAN is the mac layer for LoRa modulation and designed to fit general purpose IoT deployments. A very wide area of applications can employ LoRaWAN as their communication layer. Patient wellbeing being monitoring, security, agriculture and smart metering are a few suggested areas for this technology. Relatively wide bandwidth enables LoRaWAN to have wider area of applications [4,5,6]. The LoRa technology is occupied as physical layer of this protocol. LoRaWAN depends on start of stars topology for its network as the nodes directly and asynchronously connects gateways with LoRa layer and gateways connects central server with conventional Internet connection.
As the message reaches the central server it can reach the Internet as server forwards the message predetermined application server. This paper will be focusing on technical features and applications of LoRaWAN technology and performance analysis for indoor applications. The experimental results obtained from a self-developed TestBed environment which consists of LoRAWAN gateways (GW), nodes and a server. Analytical results are evaluated for future direction and possible research areas. Paper organized as follows, Section II introduces the LoRaWAN and Section III discusses related studies. TestBed environment and results are summarized in Section IV and Section V concludes the paper.

II. LORAWAN
This section briefly discusses the architecture, physical and mac layer of the LoRaWAN technology.

A. Architecture
LoRAWAN is an LPWAN technology which address to solve issues power consumption and communication range for IoT applications [2, 3]. Technology has designed to provide security and localization mechanism by default. It can be deployed as public or private networks for different use cases. As inspected the LoRAWAN networks consists of end nodes, gateways (GW) and data networks. LoRAWAN is a star of stars topology and GW are the links between nodes to data networks. GW-node communication carried out with FSK or LoRa modulation with different data rates and channels. Data network to GW communication is handled via standard Internet Protocol (IP). An overview of the LoRaWAN architecture is show in Figure 1.

![LoRaWAN architecture](image1)

**Fig. 1 LoRaWAN architecture**

B. LoRa: Physical Layer
LoRa modulation has ability to penetrate building easily and deliver encoded data to long distances [2]. The methods used in modulation are kept private. The interference prevention mechanisms are detailed in [2]. Also, analytical results show that communication range is up to 2 km for dense urban and indoor areas.

![LoRaWAN layers](image2)

**Fig. 2 LoRaWAN layers.**
LoRa is very sensitive to noise and supports up to 27 dB network power. LoRa has better performance when compared Frequency Hopping Interfering Signal techniques. The modulation can tolerate interference mechanism of arbitrary power levels for up to 30% of the symbol length with less than 6 dB sensitivity degradation [2,3]. Spreading factors (SP) are key variables to ensure quality of service. When use of lower SP range is very limited but data rate is very high and time on air is low. The higher SP factors extend the range but limits the Quality of Service. From SF 6 to SF12 is available orthogonally which means different networks can speak simultaneously on same frequencies without collision. This brings LoRa two advantages even if LoRa employs little bit more wider frequency band. This area can be used with 8 orthogonal communication layers. Another advantage of the modulation is to give reliability against interfering signals [3].

C. LoRaWAN: MAC Layer

LoRaWAN is a MAC layer protocol which regulates the medium access for end-devices with multiple frequencies. It is an open standard developed and maintained by LoRa Alliance. MAC layer defines tree main access categories (A, B and C) for power usage strategies. Protocol controls uplink communication in order to avoid unnecessary messaging the protocol relies on hope that any message transmitted from an end-device would catch at a gateway. The messages caught forwarded to backend server and mac layer solving done in there. Acknowledge messages possible trough receives windows but ACK system was not the main concern at the design of this protocol.

<table>
<thead>
<tr>
<th>Class</th>
<th>Battery Consumption</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Most Energy Efficient</td>
<td>Must Be Supported All End-Nodes. DL after Transmission</td>
</tr>
<tr>
<td>B</td>
<td>Efficient with Controlled Down Link (DL)</td>
<td>Slotted Communication Synchronized with Beacon Frames</td>
</tr>
<tr>
<td>C</td>
<td>Least Efficient</td>
<td>Devices Listen Continuously. DL without Latency</td>
</tr>
</tbody>
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An Adaptive Data Rate (ADR) mechanism is used to control data transfer rates between nodes-to-gateways depending on the distance from 0.3 kbps to 50 kbps. Each end device can be optimized with ADR schemes independently. Table 1, summarizes three different classes supported by the protocol. A class devices are only listening network after transmits message. Two receive period comes after a delay. If the server couldn’t act within these periods receive window closes until next transmission. All devices must implement device class functionality. Class A is the most efficient protocol. B type devices listens network periodically. These listening periods synchronized with network beacons. If network beacon could not receive within two hours device drops to A type protocol until beacon received in next try. C type devices listens the network continuously until it needs to transmit messages. These devices would be energy hungry and suggested to use with continuous energy supply. LoRaWAN layers are briefly illustrated in Figure 2.

III. RELATED WORK

There are several studies about LoRaWAN with different aspects; this section will highlight most important studies about the technology. Mahmoud et al. [7] introduces a detailed evaluation of IoT technologies with different aspects have been discussed and compared. The most important aspect of the study is that, energy consumption comparison for variety of chips are evaluated and results are summarized. Also, study aims to create a TestBed environment in order to evaluate LoRaWAN technology. The TestBed consists a gateway with 9 nodes in a building distributed in different floors. Several measurements conducted with nodes containing sensors and multi metric evaluation has conducted. An array of metrics such as data rate, time to wait, measured and analysed. Another general-purpose survey about IoT communication technologies presented by [8], which covers WiFi, Bluetooth, Zigbee, 6lowpan, wimax, zwave, NB-IoT, and LoRaWAN. Vocal explanations of these technologies were made in the article. Possible areas of use mentioned and discussed. Study interests with drawing an outline of IoT universe in terms of wireless communication. To do this it benchmarks all technologies available technologies in terms of energy, network, security and capacity.

In [9], the author focuses on physical layers of the most popular three LPWAN technologies; LoRaWAN, Sigfox and Weightless. The paper has very good descriptions of UNB and CSS along with RPMA as they are underlying technologies of these protocols. An important part of this paper the interference sensitivity of LoRa demonstrated. In the technology comparison and summary table author introduces ten variables to consider while evaluating these technologies. Also in [10] OnRamp Wireless, Sigfox and LoRaWAN are evaluated. The LoRaWAN criticized with its on air activation mechanism. The mechanism seen as security vulnerability. Another criticism is that LoRaWAN technology lacks CRC field in downlink messages. That would lower quality and reliability of downlink communication. In the study [1], LPWAN challenges Long Range, Ultra low power operation; Low Cost, Scalability, and quality of service requirements are presented. It is worth mention here the paper explains the ultra-low power operation is achieved with right topology, duty cycle, light weight mac layer and offloading complexity from end devices. The low cost requirement is achieved by reducing hardware complexity, minimizing infrastructure and using unlicensed bands.
Paper inspects Sigfox, LoRaWAN, Ingenu and Telensa as exemplary LPWAN technologies. These technologies compared for their mac layers, data rates, security measures, and QoS features. Another topic in the paper is Standards and Alliances. IEEE, ETSI, 3GPP, IETF, LoRa Alliance, WEIGHTLESS-SIG and DASH7 Alliance mentioned as rival alliances competing to fulfil LPWAN infrastructure. Lastly the authors examine LPWAN Challenges such as SLA support, Supplier ecosystem, licensing, deployment status, and longevity and give exemplary table to demonstrate how technologies studied faces these challenges. In [15], author compares LoRaWAN with Wi-Fi multi-interface communication module. The real TestBed experiments are conducted in 6, 15, 20 km distance. At these ranges RSSI and data rate tests are handled. The test site is in shore of a gulf this ensures antenatal line of sight. The results show that Wi-Fi data rates are higher than LoRa but it depends on lower energy consumption. The study can be extended with urban area tests, sending real data instead mockups and measuring energy consumptions. In [12], author covers Machine to Machine (M2M) LTE technologies for all IoT applications. It is mentioned IoT requirements, IoT applications and possible economic value of all IoT landscape. In technological landscape section Sigfox, LoRa, IoT, NB LTE-M, LTE-M, EC-GSM, and 5G technologies are compared and some of their features are mentioned. The paper mostly concerns about NB LTE-M (rel 13) and LTE-M (rel 12/13). The most important claim in the paper is that it is possible to reach energy efficiency of native IoT LPWAN technologies such as LoRa and Sigfox. To do this in Discontinuous Reception (DRX) periods are extended in the Rel-13. Other measure that is taken is that UE receive bandwidths are reduced as well. This gives technology chance to reduce dBm and give another energy efficiency leverage. Even if it is still a proposed technology given LTE-M technologies seems to be promising LPWAN technology of near future. Along with advantage of already build infrastructure it can overcome disadvantage of entering market very late.

Sigfox and LoRaWAN are the two important LPWAN technologies gathered research and industrial attentions. Authors of [13], compares these two technologies with detailed explanations of Sigfox and its work logic. The most important part of the article is that it contains one of the rare experimental works on Sigfox and experimental study on Sigfox makes this study valuable. A tested is prepared with a gateway and signal measuring device installed at an altitude of 770 meters in Dublin city. Here, 25 km distance measurements were made available and Power Spectral drawings and tables with SNR and RSSI Delay were obtained. Although the urban areas are included in the coverage calculations, the experiments done in suburban area, thus the accuracy of the coverage maps provided by the coverage area and the TLS are doubtful. It is possible that this work can be improved with measures to be made in urban area and with results to be obtained without TLS. The proposed technology LoRa Fabian [14] would be an alternative for LoRaWAN in restricted use cases for example extreme environments such as underground mines and highly uninhabited areas. This could be possible with its multi hoop technology and extended range. In other areas such as urban and suburban cites other criteria would get into the equalization such as density and node life time. LoRaWAN would be the better alternative in those areas. In [15] author proposes another LoRAWAN alternative technology. Author firstly evaluates LoRa technology capacity and then offers a new mac protocol for LoRa. LoRaBlink. LoRaBlink is not interoperable with LoRaWAN this protocol must be considered as a rival technology of LoRAWAN. LoRaBlink is a protocol that is all nodes also act as receiver and relay. The multi hop architecture gives LoRaBlink range advantage. In the paper a theoretical sample simulation time schedule is given in order to explain the mechanism better. An experimental deployment is also given as part of technology evaluation. The authors claim that LoRaBlink is not an energy optimized protocol this could severely affect its implementation scenarios. Even though the protocol is not much energy efficient as in extreme scenarios creating a harvester supported node probably will be cheaper than adding new gateway to network thus protocol has some promise. Another importance study is that even though it is not interoperable with LoRAWAN it could strengthen arguments of multihop support in LoRaWAN [16]. Most of the studies compare existing or alternative solutions; also, authors try to find alternative MAC layer implementations to boost technology. This study will evaluate LoRaWAN for indoor usage with analytical results.

IV. EXPERIMENTAL RESULTS

LoRaWAN analysis for Health Care Systems is already addressed in the early work [17]. In this study, a realistic hospital environment and medical data transmission scenario is tested and analyzed. To be able to establish an experimental lab environment we developed a TestBed with a gateway using IC880a board integrated to Raspberry Pi3 as illustrated in Figure 3a. The GW is fully support LoRaWAN protocol and operate over 3 simultaneous channels. TestBed nodes have RN2483 chipset which is connected to the Raspberry Pi3 board [18]. A node setup is seen in Figure 3b.

Experimental scenarios are planned as follows; the gateway is positioned at office rooms in the roof of the building and tests are made over several floors of the building and different locations. Test building has thick walls and glass panels that separates open areas and contains mixed material that effects RF signal propagation. All experiments are made the same building through 4 floors with different node deployments scenarios. An overview of the floor plan and GW deployments are presented in Figure 4.
In the study, we performed experiments for two different configurations; frame transmission airtime and packet loss ratios. First configuration is planned for all spreading factor (SP) with 4/5 coding factor at 125 kHz bandwidth. This configuration is experimented 10 different times with the same payloads. 10-50 bytes long data packets are generated and transmitted from the end-node through the gateway. The protocol has 14 bytes long overhead so, total frame size is 24 bytes for a 10 bytes long payload. All tests are performed using a single channel in a non-noisy environment with measured 10 ± 1 SNR (with 95% confidential interval).
If it is inspected, obtained results for frame transmission airtimes in Figure 5 show, transmission time increases significantly when SF increases even for small payloads. Node to GW real time data transmission for large payloads cannot be applicable for critical applications. It is necessary to process and summarize data on nodes to reduce frame tx times.

![LoRaWAN Frame Transmission Airtime (4/5 Factor, 125 kHz BW)](image)

**Figure 5: LoRaWAN frame transmission airtime**

Successful data transmission is the key function of the wireless communication, for this reason, in the several packet transmissions made and successful deliveries are measured from the GW. Each experiment 50 packets send and received rates are recorded for 10 different experiments. Average results are show in Figure 6a, as a natural result GW-node distance affects the successful packet delivery strictly. Also, materials used in floors (walls, desks, glasses ...etc.) affect the propagation of the signal. Figure 6b, presents RSSI signal levels received from the GW for successfully frame reception. Also, packet loss and RSSI values have a common pattern which validates protocol communication.

![Packet Loss Ratios](image)

**a. Packet Loss Ratio**

![RSSI Results](image)

**b. RSSI Results**

As seen, from the graphs packet loss ratio is higher even same floor of the building. There is an unexpected drop for packet loss ratio at Floor 2, the reason is node placement which was located on emergency exit having covered full of walls. It is possible to reduce loss ratio by using multiple GW with distinct locations of the building. LoRaWAN can be used for many applications however, it is necessary and also an open topic of optimization.

**V. CONCLUSIONS**

There are several Low Power Wide Area Network (LPWAN) technologies available, however, LoRaWAN is becoming a de facto IoT communication standard because of its open nature and works on unlicensed spectrum. In this study, it is evaluated for indoor communication performance by variety of experiments over the custom TestBed lab. Gathered results prove that LoRaWAN can be used for indoor applications even a single GW can cover whole building. However, there are open research areas for LoRaWAN networks to be optimized based on the use cases. For the future work, we plan to work on GW caching algorithms to optimize network performance of the LoRaWAN networks for indoor e-Health applications.
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