Expanding IoT Connectivity by using 2.4 GHz LoRa Technology

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***Abstract*—With the increasing demand for IoT deployments, the traditional sub-GHz frequency bands are becoming congested, prompting the exploration of new communication mechanisms. This paper explores the potential of LoRa (Long Range) technology in the 2.4 GHz frequency band in the Low-Power Wide-Area Networks (LPWAN) domain, evaluating its application for Internet of Things (IoT) connectivity. The findings aim to contribute to existing knowledge by offering insights into network scalability and application potential. Moreover, our performance evaluation indicates that approximately from an area of 44 hectares we can cover 30% of the area with one receiver, that illustrating the potential of 2.4 GHz LoRa technology to enhance IoT connectivity despite the challenges posed by urban density and spectrum congestion. This study not only validates the effectiveness of LoRa technology in the 2.4 GHz frequency band but also highlights its potential to support a wider range of IoT applications through increased network scalability. In conclusion, 2.4 GHz LoRa can be considered viable for the growing needs of IoT deployments.**

Keywords—LoRa Technology, ISM Bands, LPWAN Networks, IoT Applications, Propagation Analysis

I. INTRODUCTION

Significant technological progress has led to key breakthroughs in human history connecting the first device to the Internet [1], seen as a breakthrough which is specific to the Internet of Things (IoT) concept. This revolutionary event of the first object connected to the internet set a precedent that indicated a new era of rapid advances in data transmission technology, paving the way for unprecedented global Internet interconnectivity of objects. The implications of this technological breakthrough have attracted increased attention in sectors such as healthcare [2], smart cities [3], commerce, and transport [4] .

Low-Power Wide-Area Network (LPWAN) technologies are a type of wide-area wireless telecommunications networks designed to enable long-distance communications at a low bit rate between devices. According to recent statistics [5], there are more than 1.2 billion LPWAN (Low-Power Wide-Area Network) devices in the world, with LoRa (Long Range) technology holding about 41% market share [5]. The popularity of LoRa can be attributed to its low power consumption, long transmission range and ease of integrating different sensors.

In this context, the expansion of LoRa technology into the 2.4 GHz frequency band emerges as a strategic solution, especially for applications requiring data transmission with low latency. LoRa on 2.4 GHz can operate on worldwide frequency channels, allowing for the global use of devices without the need to adjust for region-specific frequency bands, as is the case with sub-GHz LoRa technologies. The absence of duty-cycle limitations (e.g. 1 percent for the 868 MHz band) and the capability of higher data rates, enable applications that require low latency and high throughput, expanding the range of possible IoT applications.

The main contribution of this paper is related to the evaluation of propagation models and overall coverage abilities of the LoRa communication protocol within the 2.4 GHz ISM band in dense urban areas specific to the smart city paradigm. The 2.4 GHz ISM band is a widely used frequency range for various wireless communication technologies, including Wi-Fi and Bluetooth, due to its global availability and lack of licensing requirements. In the context of the 2.4 GHz band, LoRa on 2.4 GHz has the advantages of long communication distances and low power consumption over other data transmission technologies on this frequency. Unlike Bluetooth or BLE, which have a low power consumption and coverage of a few meters, insufficient to create a complex wireless sensor network, LoRa has a range of up to 500 meters in urban areas without line-of-sight and up to 1.7 km in the line-of-sight scenario [6].

To ensure a comprehensive analysis, this research paper is structured into several distinct sections, each addressing critical aspects of the study. Initially, Section II leads us into the technical overview of the 2.4 GHz LoRa technology, providing technical background and the theoretical support that informs our approach. Subsequently, Section III focuses on the hardware design of our proposed device, detailing the specific components and configurations used to facilitate the signal propagation study. Section IV presents an in-depth analysis of the simulation and measurements conducted to evaluate signal propagation characteristics of the 2.4 GHz ISM frequency band, offering insights into the performance and challenges encountered. Finally, Section V synthesizes the findings, drawing conclusions that highlight the implications of our research and suggesting potential avenues for future exploration in the domain of LoRa technology and its applications at the 2.4 GHz frequency band.

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II. 2.4 GHz LoRa

Introducing a 2.4 GHz ISM band is a significant advancement in the efficiency of LoRa technology, by adapting LoRa to the 2.4 GHz band with an architecture based on Chirp Spread Spectrum (CSS). LoRa uses a patented digital spread spectrum modulation technique derived from CSS technology [7]. This modulation technique spreads the transmission over a wider bandwidth, which makes it more resistant to interference and noise and enables long-range communication compared to traditional modulation techniques used in the same frequency band. Initially, LoRa was defined in 868 MHz band in the EU, having parameters such as Spreading Factor (SF) that goes from SF 7 to SF 12. Bandwidth (BW) from 125 kHz, 250 kHz or 500 kHz, and Coding Rate 4:5, 4:6, 4:7, 4:8 has been preserved [7].

An important change in this domain is the introduction of additional Spreading Factors, SF5 and SF6, complementing the traditional range of SF7 through SF12. This expansion into lower SF is an enhancement in the technology's capability, particularly in optimizing the Time on Air (ToA) for message transmission. Incorporating SF5 and SF6 significantly reduces the ToA, achieving transmissions from 6.65 ms for SF5, with a bandwidth of 200 kHz and a payload of 5 bytes, and 11.73 ms for SF6 with a bandwidth of 200 kHz, and a payload of 5 bytes. This new configuration of spreading factors, facilitates package transmission efficiency and reducing the chance of collisions, especially over shorter distances [8]. Additionally, LoRa on 2.4 GHz has implemented Forward Error Correction (FEC), which helps to improve the transmission range and robustness of data transmission [9].

The table below provides a detailed analysis of the ToA across different transmission configurations, considering the Spreading Factor, Bandwidth, and varying payload sizes. This empirical data underscores the impact of these parameters on the efficiency of LoRa communication in the 2.4 GHz band [10].

TABLE I. TIME ON AIR FOR LORA 2.4 GHZ

Type of transmission	BW kHz	SF	Time on Air (ms)		
			5 bytes	105 bytes	255 Bytes
1	200	12	509.16	2530	5550
2	200	11	254.58	1360	3080
3	200	10	127.29	757.44	1720
4	200	9	76.24	429.13	971.06
5	200	8	38.12	246.07	561.15
6	200	7	19.06	145.09	334.13
7	200	6	11.73	90.50	208.65
8	200	5	6.65	58.64	137.41

This detailed examination of the ToA for various configurations of LoRa at 2.4 GHz, provides a clear insight into the potential for optimized communication strategies. By effectively leveraging the lower Spreading Factors, SF5 and SF6, it is possible to achieve significant improvements in transmission efficiency, contributing to the robustness and scalability of LoRa networks.

Another considerable improvement was the implementation of four new bandwidths, which allow higher data rates to be achievable due to the wider bandwidths of the channels in the 2.4 GHz frequency band. Bandwidths of 200 kHz, 400 kHz, 800 kHz, and 1600 kHz have been used to reach higher data rates. For a 200 kHz bandwidth, the rates range from 25.3 kbps at the lowest spreading factor to 476 bps at the highest. As the bandwidth increases to 400 kHz, 800 kHz, and 1600 kHz, the data rates also rise, achieving speeds up to 203 kbps at the lowest spreading factor with the highest bandwidth. Each subsequent bandwidth doubling approximately doubles the data rate across all spreading factors, demonstrating the impact of bandwidth and spreading factor settings on network throughput. These higher bandwidths are more important for WSNs, where a large amount of data can be transmitted with a little delay and no duty cycle regulation [9].

III. Performance Evaluation

Our research is structured to provide an in-depth perspective on the deployment and performance of LoRa technology within the Internet of Things (IoT) communications applications. A central area of interest is the coverage capabilities of LoRa sensors operating at 2.4 GHz, an issue of significant interest due to its implications for the range and reliability of IoT sensor networks. In addition, our study places particular emphasis on evaluating how these sensors perform under the pressure of high-density scenarios, a characteristic of 2.4 GHz ISM band-based technologies.

Fig. 1. Location of the receiver antenna in our test setup

The scenario we used for measurements was the Campus area of the Stefan cel Mare University of Suceava and its neighboring boundaries. It covered a surface of 43 hectares and had a high density of residential buildings, a high school, a hospital, and a commercial center in the close vicinity. The receiver and antenna have been placed on the 4th floor of the C building from the university campus, at about 10-meter height. As can be seen in Fig. 1, it is oriented towards the center of the neighborhood. The setup involves a point-to-point communication scenario.

The hardware aspect of our study on LoRa technology at the 2.4 GHz frequency is composed of two devices that we've designed and built: a receiver and a transceiver, presented in Fig.2. Both devices are constructed using the *e28-2g4m12s* chip produced by Ebyte [11]. The chip is known for its full compatibility with the SX1280 LoRa 2.4 GHz specification, whose sensitivity has reached -132 dBm with a gain of up to +12.5 dBm[9]. For the receiver antenna, we use an omnidirectional antenna with a gain of 8 dBi, and for the transceiver, we use a smaller omnidirectional antenna with a gain of 2 dBi. We integrated the transmitter with the SIM28ML [12] module into our system for location data acquisition. The SIM28ML is a compact GPS receiver module, with high sensitivity, low power consumption, and rapid positioning features, making it an ideal choice for IoT applications requiring precise location tracking. By introducing the 2.4 GHz LoRa module capability, the ability to retrieve GPS data via the SIM28ML module provides a robust platform for testing and validating performance improvements in 2.4 GHz LoRa technology.

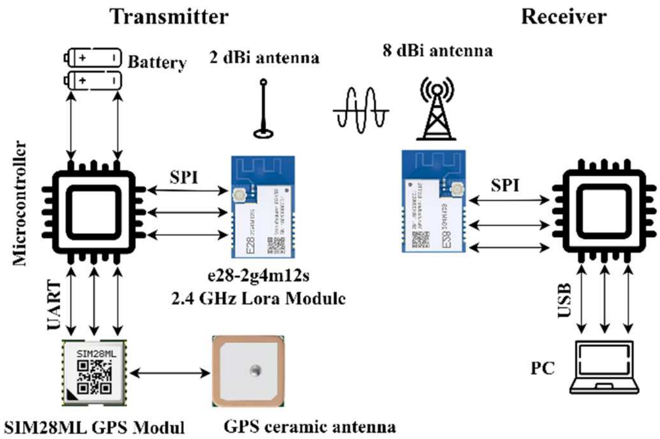

Fig. 2. Receiver and transmitter used in proposal.

To fully assess the coverage capabilities of the LoRa communication, we define a mixed testing scenario, with measurements taken at street level, covering the points presented in Fig.3, using number of packets received as performance metrics.

The transmitter node sends the location of the device every second, which means that measurements have been taken for every SF, resulting in eight rounds of collected data points. By covering these points, we can ensure that the data has been transmitted and verify that the receiver can cover all transmission points. Thus, each SF is sampled and considered.

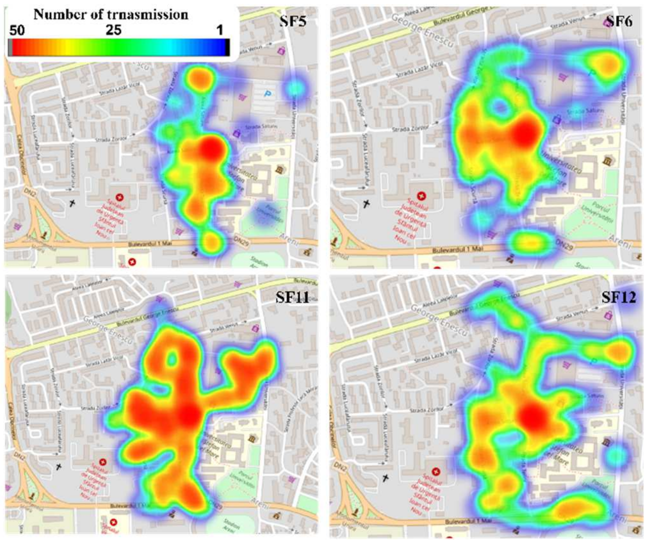

Fig. 2. Heatmaps of successful data transmissions

All measurement results are shown in Table II, where the number of packets received, the number of packets received that had errors and could not be read, and the number of packets received successfully are shown for each SF**.**

Experimental measurements evaluate the effectiveness of LoRa communications in an urban environment by varying spreading factors and analyzing the impact on packet reception and error rates.

TABLE II. TIME ON AIR FOR LORA 2.4 GHz

	SF5	SF6	SF7	SF8	SF9	SF10	SF11	SF12
Packets received	425	560	460	1012	1669	1438	1128	1014
Packets error	351	306	1344	807	1177	787	530	484
TOTAL packets	776	866	1804	1819	2346	2225	1658	1198

Higher SFs generally resulted in more packets being received (indicating better range), but also came with higher error rates, which is a trade-off in LoRa networks. Figure 4 shows an increasing trend in the number of packets for SF8, SF9 and SF10, while the total number of packets is decreasing for the other spreading factors. It can also be seen that as the transmission time increases, the number of successfully demodulated packets decreases, meaning a larger number of packets that could not physically be received.

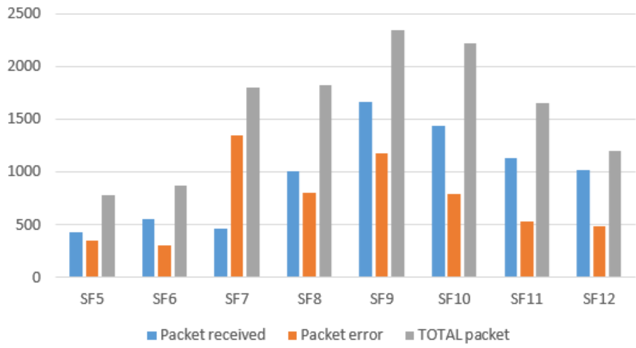

Fig. 3. Ratio of potential packet and received packet.

Observations derived from GPS information encapsulated in LoRa packets, together with an understanding of the predetermined transmission path, showed that packet loss correlates predominantly with increasing distance between the transmission source and the receiving endpoint. Fig.3 shows us the maximum distances at which the 2.4 GHz LoRa transmitter could successfully achieve, also the furthest point at which a successful transmission was achieved was 443 m. In addition, crowded areas of buildings were also identified as contributing factors to packet losses.

IV. PERFORMANCE EVALUATION AND RESULTS

Section IV dives into an analysis of simulations and empirical measurements to assess the signal propagation characteristics unique to the 2.4 GHz frequency band. This part of the study provides valuable insights into the performance dynamics and identifies potential challenges inherent in deploying LoRa technology within this frequency band. To get a better understanding of the LoRa propagation mechanism within the 2.4 GHz frequency band, the field measurements were compared with an empirical analysis using specialized simulation software. To achieve this, we employed a ray-tracing [13], [14] technique model facilitated by MATLAB.

The simulation parameters regarding the ray tracing model, corresponds closely with the LoRa 2.4 GHz specifications, specifically, we set the receiver parameters to comply with the physical implementation mentioned in the previous section: antenna height at 10 meters for the RX component and a maximum receiver sensitivity of -130 dBm, corresponding to the higher SF of the module as per the SX1280 module specifications. The transmitter simulated power is 150 mW, based on the Semtech SX1280 module specifications, and an antenna height of 1.5 m. The scenario configures a ray-traced propagation model that incorporates a limitation to two reflections and one diffraction, to get a good approximation of the propagation model, while maintaining the computational costs of the simulation to a minimum. The 3D map used for the simulation environment model was provided the OpenStreetMap service [15], ensuring that the ray-tracing model accurately simulates the 3d environment.

As a result of the simulation, we have obtained a coverage map of the target environment, where all the key points are selected compared to the receiver location, in Fig. 5. One may observe how TX nodes from the selected points transmit to the RX receiver and see the coverage pattern. We validated the measured data provided in Fig. 3 with the simulated ones.

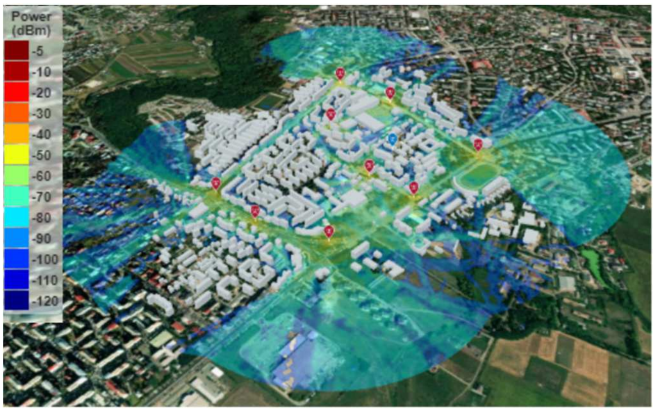

Fig. 4. Transmitters coverage area evaluation.

Conclusion

In conclusion, this study demonstrates the viability and potential benefits of leveraging LoRa technology within the 2.4 GHz spectrum for IoT applications. Exploring the 2.4 GHz band, a departure from the traditional sub-GHz frequencies, reveals a promising avenue for enhancing IoT connectivity regarding performance and scalability. Additionally, the introduction of new spreading factors and bandwidth specific to the 2.4 GHz frequency band, has demonstrated significant improvements in data transmission efficiency and robustness. This advancement is particularly relevant in urban environments, where the demand for IoT services is continuously growing, necessitating technologies that can provide reliable communication even in dense and complex settings.

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