A Pressure and Temperature Wireless Sensing Network Communicating with LoRa Modulation

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***Abstract*—This paper focuses on applying Long Range (LoRa) technology to request pressure and temperature (P&T) sensors and retrieve their measurements over a wide range in the 2.4 GHz ISM band. We used the LoRa development kits (SX1280): one LoRa Master board and several LoRa Sensor boards (slaves), each interfacing with several individual P&T sensors. We study the quality and performance of this LoRa communication network by evaluating several setting parameters. Despite the strong ambient electromagnetic activity in the 2.4 GHz band, we successfully tested the data transmission. Various communicating ranges of this LoRa Sensing Network are studied for several scenarios depending on the spreading factor (SF) parameter.**

***Index Terms*—sensor network, communication, Long Range (LoRa) modulation, and Spreading factor parameter.**

I. Introduction

Low Power, Long Range wireless capabilities [1], [2] are needed to retrieve environmental and industrial monitoring data from remote, battery-driven sensors.

Long-range (LoRa) modulation offers significant advantages in wireless sensing networks, including extended range, low power consumption, robustness in challenging RF environments, scalability, adaptability, low infrastructure costs, and support for IoT applications. These advantages make LoRa modulation a popular choice for a broad class of wireless sensing and IoT deployments [3]–[5]. LoRa is a Chirp spread spectrum (CSS) modulation technique that can meet these requirements.

A CSS-based radio module was designed to operate in the 2.4 GHz frequency band [6], [7], whose advantages are: interference mitigation, global availability, data rates, antenna size, spectrum availability, compatibility, and ease of deployment, making it a compelling choice for many IoT applications.

This paper focuses on a Pressure and Temperature (P&T) wireless sensing network communicating with Long Range (LoRa) modulation. Thus, we interrogate several aeronautic sensors and send the measurement using LoRa modulation at a 2.4GHz frequency. We consider one LoRa Development Kit [8] to represent the LoRa Master board and several LoRa Sensor Node boards (slaves). Each LoRa Sensor Node board is connected to several aeronautic sensors using a Serial Peripheral Interface (SPI).

Therefore, the novelty of this paper lies in the evaluation of the pressure and temperature wireless sensing network communicating with LoRa modulation in the 2.4 GHz band.

The remainder of this paper is organized as follows: first, we describe the wireless sensing network model in section II. Then, we present the trade-off between range and data rate in section III. In section IV, we show the performance of this network in different scenarios. Finally, we conclude the paper in section V.

II. A LoRa System Model

We use LoRa development kits (SX1280 LoRa Transceiver [8]) representing the LoRa Master board and several LoRa Sensor Node boards (slaves) using LoRa modulation at a 2.4 GHz frequency. Each LoRa Sensor Node board is connected to several pressure and temperature (P&T) aeronautic sensors using a Serial Peripheral Interface (SPI). Thus, our LoRa system model can be represented as the following diagram in Figure 1.

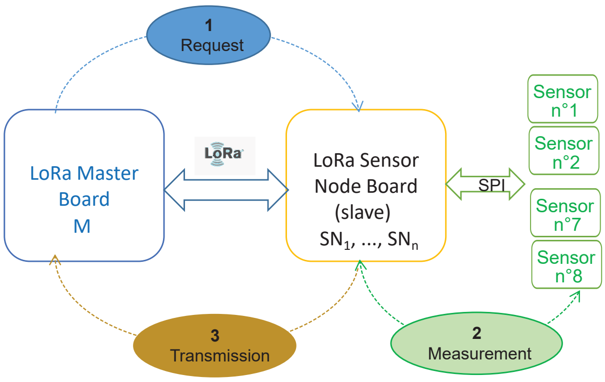

Fig. 1: A wireless sensing network communicating with LoRa modulation between a LoRa master board and a LoRa sensor node board

The pressure and temperature measurements should be done upon request from the LoRa Master board. In this work, we programmed the LoRa microcontroller, which drives the sensor board and a LoRa board to receive data and start a measurement acquisition of the pressure and temperature via the SPI interface and ultimately send it via a LoRa communication channel at a frequency of 2.4GHz. These operations should consume as little energy as possible. Different ranges of performance can be studied for several scenarios, such as different bandwidths, CR code, spreading factors, and environments.

In order to transmit the sensors' measurements from the LoRa master board (M) to each LoRa sensor node board $(SN_1, \ldots, SN_n), n \in \{1, \ldots, N\}$, we use the following steps:

1) Request: The sensor measurement should be done upon the master's request.

2) Measurement: We program the microcontrollers that drive the LoRa sensor node board to start a measurement acquisition of the sensors via the SPI interface.
3) Transmission: The LoRa master board receives data sent via LoRa communication at a 2.4GHz frequency from the LoRa sensor node board.

In the following, we will describe the LoRa modulation parameters to find the optimal trade-off between range and data rate based on the specific needs of low-power wireless communication.

III. Trade-off between range and data rate on LoRa modulation

The range of a LoRa communication is determined by its bandwidth, signal output power, and Spreading Factor (SF). In LoRa technology, the spreading factor is indeed defined as the logarithm, in base 2, of the number of chirps per symbol. Thus, there are 2^{SF} chirps in a symbol, and a symbol can effectively encode SF bits of information. SF then designates the number of devices per symbol, which varies between 7 and 12. Therefore, the spreading factor SF is given by:

$$SF = log_2(R_c/R_s) \tag{1}$$

where R_c is the throughput of the LoRa device and R_s is the throughput of the symbol. We can define the symbol rate R_s in symbols/second by :

$$R_s = \frac{1}{T_s} = \frac{BW}{2^{SF}}. \tag{2}$$

where T_s represents the symbol period (in seconds).

Finally, we define the chip rate R_c in chips/second as follows :

$$R_c = R_s * 2^{SF}. \tag{3}$$

The transmitted data signal is chipped at a higher data rate and then modulated onto the chirp signal. The modulation rate (in bits/second) is defined as follows :

$$R_b = SF * \frac{1}{(\frac{2^{SF}}{BW})} \tag{4}$$

where SF represents the spreading factor and BW denotes the modulation bandwidth (Hz).

In the following section, we will study the performance of this LoRa Sensing Network.

IV. Performance of the LoRa Sensing Network

In this section, we will investigate via numerical simulations from the measurements of the P&T sensors network, the impact of the SF on the Time on Air (ToA), the Received Signal Strength Indication (RSSI), and the Packet Error Rate (PER). All observations below have been verified via extensive experimental tests with generic parameters. We have selected only a few of the most illustrative and interesting scenarios to be depicted here. The quality and performance of the LoRa communication link have been studied and evaluated using several tuning parameters under difficult transmission conditions, such as through reinforced concrete walls or between floors of our building. In this section, we evaluate our LoRa communication of multiple pressure sensors [9].

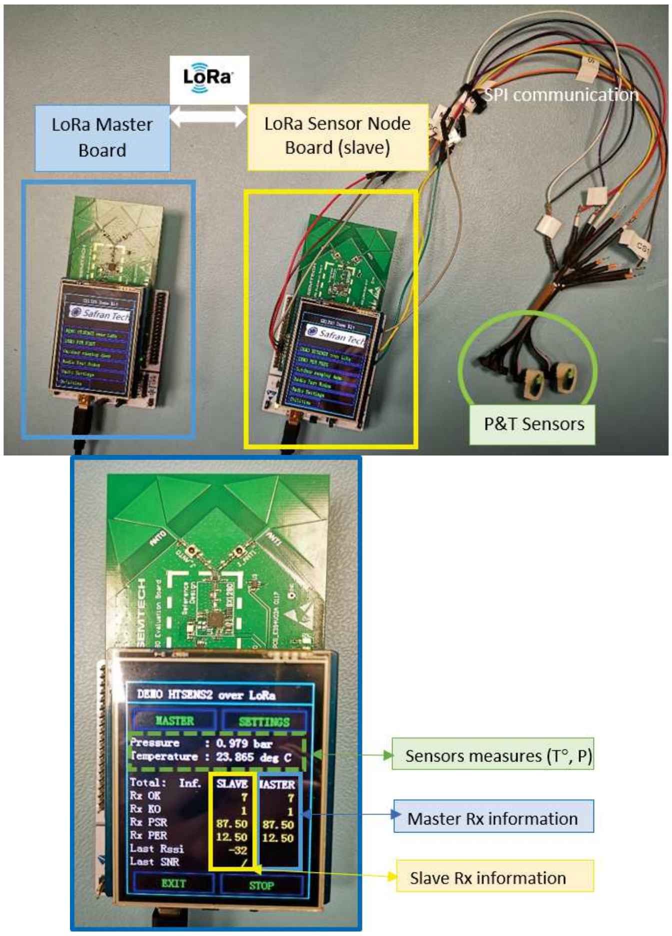

Fig. 2: (a) P&T Wireless Sensing Network based on a LoRa communication, (b) Performances displayed on the LoRa master board

A. The sensor data structure

The sensor data structure, containing the pressure and temperature data, is transmitted back by the LoRa slave board on every LoRa master board request. As the LoRa protocol is characterized by a low bit rate, the sensor data structure must be kept as simple as possible to reduce the ”Time-on-air (ToA)” and power consumption. The pressure and temperature (P&T) data pairs are retrieved by the LoRa slave board from multiple sensors, thanks to the SPI-wired bus.

The reason why higher SFs perform worse than lower SFs is partly related to the longer ToA of higher SFs.

The P&T LoRa exchange process is defined as follows:

1) On LoRa master board request, the payload is filled with an 8-bit mask,
2) On the receiver, the LoRa slave board initiates the P&T pairs retrieving process for each sensor selected by the mask,
3) The LoRa slave board replies by filling a payload with P&T pairs of each previously selected sensor.

In the following, we will consider four locations (L1, L2, L3, L4) representing respectively 10m, 20m, 30m, and 50m of distance between the LoRa master board and the LoRa sensor node board.

B. Impact of Received Signal Strength Indication (RSSI)

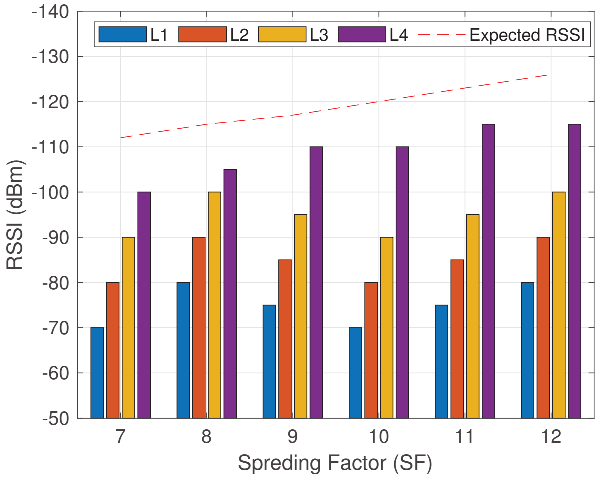

Fig. 3: Minimum RSSI (in dBm) for SF=7 to 12 at different locations (L1, L2, L3, L4)

Received Signal Strength Indication (RSSI) plays a crucial role in LoRa communication systems, impacting various aspects of system performance and reliability.

To test the overall capability of the LoRa radio receiver to demodulate sensor data from a received signal, we analyze the received packets in terms of their RSSI values. These values are compared to the Semtech SX1280 LoRa receiver theoretical sensitivity (expected RSSI) specified for various BWs and SF settings [8].

Figure 3 shows the minimum RSSI measured at L1, L2, L3, and L4 locations. As the number of obstructions and distance to the LoRa master board increases, the RSSI values decrease. This trend is observed for all SF values. Theoretically, one would expect the minimum RSSI for received packets to decrease as the SF value increases. We can remark that lower SF values offer higher data rates and reduced transmission times but may be less resilient to noise, interference, and fading, especially in challenging propagation environments.

C. Impact of Packet Error Rate (PER)

The Packet Error Rate (PER) in a LoRa communication system significantly affects system performance, reliability, and overall network efficiency. PER directly affects the reliability of data transmission. A high PER indicates a higher likelihood of packet loss or corruption during transmission. This can lead to incomplete or inaccurate data delivery, impacting the reliability of the communication link.

Figure 4 shows that higher SF values generally result in lower PER. Higher SF values provide better resistance to noise and interference but also lead to lower data rates and increased airtime, which can reduce overall network capacity and throughput. Lower SF values offer higher data rates and reduced transmission times but may be more susceptible to noise, interference, and fading, resulting in higher PER under adverse conditions.

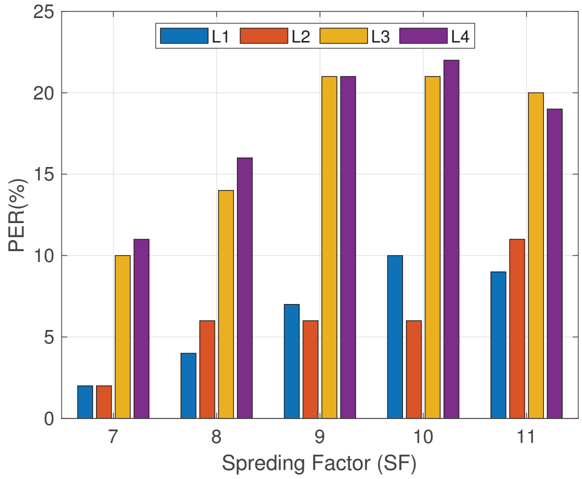

Fig. 4: Packet Error Rate (PER) for SF=7 to 12 at different locations (L1,L2, L3, L4)

V. Conclusion

In this paper, we have focused on the Long Range (LoRa) technology to interrogate pressure and temperature sensors and send the measurements at the 2.4 GHz frequency band. We used two LoRa Development Kits: the first kit as the LoRa Master board and the other as the LoRa Sensor board (slave). The LoRa Sensor board is connected through a microcontroller to sensor nodes. The quality and performance of the LoRa communication link were studied and evaluated using several setting parameters. Data transmission could be achieved despite the ambient strong electromagnetic activity in the 2.4 GHz band (e.g. Wi-Fi, Bluetooth). Lower SF values offer higher data rates and reduced transmission times but may be less resilient to noise, interference, and fading, especially in challenging RF environments. A high SF is easily decodable, resulting in a high Time on Air (ToA), lower PER, and lower minimum RSSI. A lower SF, therefore, results in a higher PER and a higher minimum RSSI. Further work will describe a new method for maximizing the wireless sensing network's throughput communicating with Long Range (LoRa) modulation.

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