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On the Coexistence of LoRa and RF Power Transfer

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Abstract—**Wireless Power Transfer (WPT) is a promising technique of extending the battery lifetime of battery-powered end-devices (EDs) without getting physical contact between the power transmitter and the ED. At the same time, many of these devices use a long range radio technology to report data of their measurements. Both WPT transmitters and long range radio technologies for Internet of Things (IoT) devices, such as LoRa and Mioty, operate at the same Industrial, Scientific, and Medical (ISM) bands in the sub-GHz spectrum. This paper presents an interference analysis between the two technologies and provides evidences of substantial levels of interference around the US915 Central Frequency (CF) through a number of lab experiments. The results reveal that a number of conditions exist which allow collision-free transmissions (or a very low collision probability) when an ED is transmitting data and receiving energy at the same time.**

I. INTRODUCTION

LoRa constitutes one of the dominant IoT radio technologies which exhibits long distance and high penetration capabilities as well as remarkable resistance to interference. It is used in a wide range of applications such as in asset tracking in smart factories, smart agriculture, air pollution monitoring etc. [1].

IoT devices are usually powered by batteries which can provide limited operational lifetime. The battery replacement may be a hard task because the manpower cost of replacing the batteries may be high or the devices may be placed at inaccessible places. Thus, researchers and engineers are looking for more sustainable solutions to prolong as long as possible the ED battery lifetime or even provide solutions for battery-free applications [2]. Energy harvesting is a promising solution to replenish the energy capacity of the battery as it does not require physical contact between the power transmitting source and the IoT device. This is extremely helpful in many industrial applications because it enables energy replenishment without shutting down the IoT EDs themselves or the equipment that the IoT devices is monitoring.

Energy harvesting-enabled IoT EDs can convert part of the received signal power transmitted by ambient or dedicated sources to electricity. Depending on the transmitted power and the distance between the transmitting source and the receiver, a device can harvest from a few μW to several mW of power [3]. Examples of ambient sources of power are TV towers, cellular antennas, and WiFi access points. However, the amount of power a device can harvest from ambient sources is dramatically less compared to dedicated sources. In the latter case, dedicated power transmitters (PT) are used and placed at a short distance from IoT EDs. The transmission power is significantly higher and the directionality (i.e., high gain) of the transmitting antennas helps to provide many mWs of power to several meters of distance away from the PT.

In order to achieve long power transfer distances as well as to comply with the regional regulations, PT manufactures exploit sub-GHz ISM bands to transmit power. Because of the high transmission power (e.g., up to 3W in the US), any transmitting or receiving device in the range of the PT – operating at the same frequency – may experience considerably high levels of interference that can cause disruption in data communications.

The purpose of this paper is to give some theoretical insights about the co-existence of power and data transfer but mainly to experimentally assess the amount of interference on LoRa data communications and how destructive this interference can be. To do so, a series of lab experiments have been conducted using different distances between the PT and a transmitting LoRa ED, as well as different LoRa physical layer (PHY) settings. The results reveal that only transmissions with certain PHY settings and certain overlapping with the PT CF channels are affected.

The contributions of this paper are summarized as follows:

1) The theoretical conditions for interference-free power and data transfer are presented.
2) Experimental results are presented which clearly show the presence of interference at certain channels and LoRa PHY settings.

II. THE LORA RADIO TECHNOLOGY

LoRa is a proprietary spread spectrum modulation and long range radio technology currently owned by Semtech [4]. LoRa can achieve several kilometers of range with Line-of-Sight (LoS), while its wall penetration ability for indoor applications is also significant [5]. Its main feature is that it can trade data rate for sensitivity and, thus, achieve a longer range at the expense of a lower data rate. A PHY radio parameter, called Spreading Factor (SF), is employed to adjust the spread in the modulation which typically ranges from 7 to 12. Signals with higher SF values can be decoded with significantly lower sensitivity resulting in link budgets of over 150dB. However, the higher the SF, the lower the data rate. This means that for the same payload, the transmission time increases for higher SFs, so does the energy consumption. Apart from the SF, a series of other parameters can also affect the transmission time. These parameters are the channel bandwidth, the code rate (CR), the preamble size, and the cyclic redundancy check (CRC). The lower the channel bandwidth and the code rate, the higher the transmission time. A lower code rate gives better protection against external interference.

LoRa operates at the license-free sub-GHz (or recently at 2.4GHz) radio frequency bands (e.g., EU868, US915) where a number of restrictions are imposed by regional authorities. In most regions, the transmission power cannot exceed 25mW

(14dBm) or 50mW (17dBm) Effective Isotropic Radiated Power (EIRP) [6]. Moreover, duty cycle restrictions impose a total transmission time of up to 36 or 360 seconds in an hour depending on the radio band in the spectrum. In some regions, a channel hopping mechanism is also required for successive transmissions.

III. RELATED WORK

RF-energy harvesting networks have been extensively studied from different aspects. For a complete literature review the reader can refer to [7] and [8]. The performance determinants that affect an RF-power transfer system are also presented [9]. Despite the recent advances and the high research effort around WPT, its effect on the most commonly used IoT radio technology operating at the same ISM frequency is not yet studied.

Many works in the literature deal with the circuit design and their main challenge is to improve the RF-to-DC efficiency of the harvesting devices. Recently proposed implementations achieve a maximum efficiency of 80-85% which however rapidly falls below 5-10% as the receiver moves away from the source [10]. However, despite the current low conversion efficiency of RF-energy harvesting units, there is still much room for improvement using better materials and new MAC layer protocols [11]. Such an approach is recently proposed by Cuozzo et al. [12]. The authors proposed a communication protocol and architecture based on LoRa operating at 2.4 GHz for the monitoring of industrial machines. The authors present an approach which jointly uses frequency and Time Division Multiple Access (TDMA). A scheduler is also employed to manage the communication and recharging phases depending on the tasks assigned to the EDs.

A series of studies also focused on throughput fairness and scheduling problems. The scope of these articles is to provide solutions to efficiently schedule the access to the medium in order to meet specific QoS criteria, like throughput, delay and packet loss [13, 14, 15]. These works are related and can be benefited from our results since they also consider a number of dedicated transmitters to periodically replenish the battery of IoT devices.

On the other hand, LoRa susceptibility to interference has also been extensively studied, however, this has mainly been done from the intra-LoRa network perspective [16]. Interference coming from non-LoRa sources has been barely explored. More specifically, Orfanidis et al. [17] investigated interference caused by IEEE802.15.4g transmissions. It is shown via experiments that due to the nature of the two different modulations (LoRa and GFSK), the effect of the GFSK transmissions on the LoRa performance is not high. It is revealed that the lower the SF, the higher the effect of interference for transmissions at overlapping EU868 channels. Goursaud et al. [18] also discovered that non-LoRa interference comprising of tone pulses less than 5 dB above the desired signal for SF7 (and less than 19.5 dB for SF12) with a code rate of 4/6, is not a problem.

IV. THEORETICAL INTERFERENCE ANALYSIS & RESULTS

The examined interference scenario is presented in Fig. 1. The scenario consists of a data transmitting LoRa ED, a PT placed up to a few meters away from the ED, and a receiving LoRa ED (or a gateway) placed up to several hundreds of meters away from the ED. It is assumed that the ED antenna is entirely in the beam range of the PT.

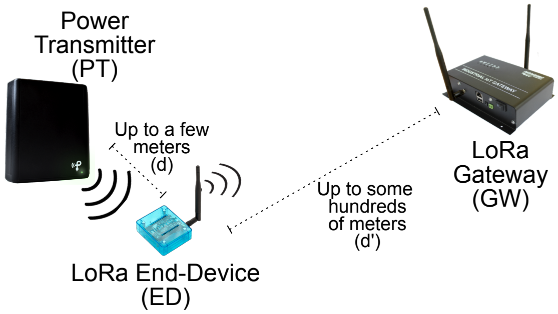

Fig. 1. Experimental setup scenario consisting of a power transmitter (PT), a LoRa end-device (ED), and a LoRa receiver (gateway - GW). We want to measure the interference that the power emission of the PT may cause on the data transmissions from the ED to the GW.

In order to successfully deliver a data packet to the LoRa receiver, the received power at the transmitting ED coming from the PT should not destruct the transmitted LoRa packet. Thus, the received power should not exceed a certain threshold which depends on the data transmission power and the LoRa interference immunity expressed with I. Assuming a free-space path-loss model, the following expression holds:

$$P_{tx}^{LoRa} + G_{tx}^{LoRa} - L_{tx}^{LoRa} > P_{rx}^{d} - I, \tag{1}$$

where P_{tx}^{LoRa} is the transmitted power of the ED, G_{tx}^{LoRa} is the antenna gain of the ED, L_{tx}^{LoRa} is the power loss, and P_{rx}^{d} is the power the ED receives from the PT at distance d.

P_{rx}^{d} can be expressed as the received power (in dBm) according to the Friis equation:

$$P_{rx}^{d} = P_{tx}^{PT} + G_{tx}^{PT} + G_{rx}^{LoRa} + 20\log_{10}\frac{\lambda}{4\pi d}, \tag{2}$$

where P_{tx}^{PT} is the transmit power of the PT, G_{tx}^{PT} is the antenna gain of the PT, G_{rx}^{LoRa} is the antenna gain of the ED, and λ is the signal wavelength.

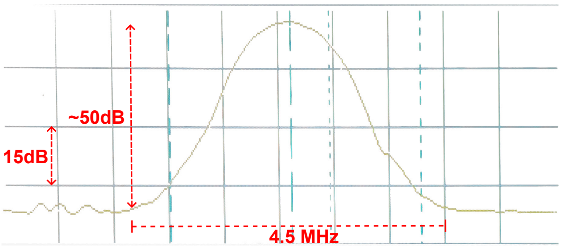

Fig. 2. Received power distribution in the 915MHz ISM band measured on a spectrum analyzer at 30cm distance from the PT. An edited spectrum analyzer screen is shown with X=frequency in MHz and Y=received power in dB.

According to experiments conducted in the lab using a spectrum analyzer (see Fig. 2), the power distribution over the occupied bandwidth shows only one generated signal. The PT uses the Direct Sequence Spread Spectrum (DSSS) modulation for power emission. As it was expected, the power peaks at the central frequency (915MHz) while it rapidly weakens as we move away from that frequency. Some sub-signals appear in sub-frequencies sideways of the main signal which however are very weak. It must be mentioned that the peak received power at 30cm away from the PT is still much higher than the manufacturer's EIRP transmission power reported value (34.77dBm) because of the high gain of the receive antennas used in these particular experiments.

Assuming a wide-sense stationary random process, in order to calculate the power at different sub-frequencies, the Power Spectral Density (PSD) is required. PSD can be calculated computing the Fourier transform of the correlation function once all signal properties are known [19]. Alternatively, PSD can be measured using special equipment such a signal analyzer. Because not all the properties of the signal were known, to estimate the received power at different sub-frequencies of the received signal, the received signal was split into sub-frequencies and each of those sub-frequency bandwidth was multiplied with the experimentally measured PSD value. The Federal Communications Commission's value was used for this purpose[1]. The generated points were fitted into an exponential function of the form $\alpha e^{-\beta \pi x^2}$, where α and β are fixed coefficients.

Given the fundamentals presented in the previous paragraphs, interference may exist when the received power at a distance d from the PT exceeds the transmitted power of the LoRa device for a certain frequency channel c_i. Thus, it is important to know the received power coming from the PT for the given LoRa transmission channel c_i which can be calculated combining Eq. (2) and (3), while the presence of interference can be tested by Eq. (1).

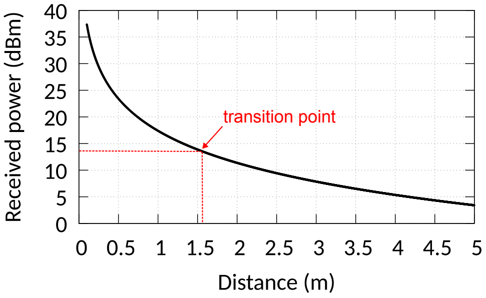

Fig. 3. Theoretical received power at the LoRa ED at the CF.

Fig. 3 presents the theoretically received power emitted by the PT towards the LoRa ED for distances between 10 and 500cm. The setup settings presented in Table I were used. The result reveals that the received power at a distance of approximately 1.6m away from the ED becomes equal to the transmission power of the LoRa ED (including some minor antenna gain). This means that there is a transition point beyond which there is no interference since condition of Eq. (1) holds. We must mention that this result does not take into account the LoRa immunity I but it refers only to the received power.

Similarly to the previous figure, Fig. 4 illustrates the theoretical received power as a function of the PT transmitted power at all the range of frequencies and 3 different distances. The LoRa transmission is also shown for comparison. LoRa transmission bandwidth is exaggeratedly widened for presentation purposes. It can be observed that LoRa transmissions are not fully covered by the power signal at the full range of frequencies. Moreover, at a distance of 2 meters, the LoRa transmission already exhibits a higher power than the received power from the PT, even though this is just a theoretical indication and does not practically guarantee that there will be no interference or data loss.

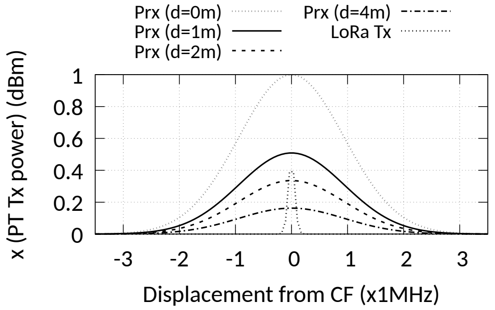

Fig. 4. LoRa ED theoretical received power (Prx) at 0, 1, 2, and 4m distance away from the PT and different frequencies as an expression of the PT transmitted power. For example, "1" means 1MHz away from the CF (CF=915MHz).

V. EXPERIMENTAL EVIDENCE OF INTERFERENCE

A set of experiments were conducted in order to assess the effect of power emission on the LoRa performance and confirm the theoretical findings. The experimental setup and the results are presented in the following paragraphs.

The experiments were conducted in a large open room using off-the-shelf commonly used hardware. The setup consisted of a PT located at different distances away from a LoRa ED with LoS and without any obstacles being at a distance of 2m range. A LoRa gateway was placed in another room without LoS. The TX91501b Powercast transmitter[2] was used for the emission of power which can generate 3W EIRP with 65 degrees of Half Power Beam Width using a 8.3dBi antenna. Pycom Lopy4 LoRa devices equipped with typical 2dBi antennas were used for data transmissions (both ED and gateway) operating at the US915 ISM spectrum[3]. The transmitting ED was always in the beam range of the PT. The experiments were repeated for several PT positions, all available SFs, and 2 CRs. 50 instances per scenario were generated and the average results are presented. The packet delivery ratio (PDR) was employed to measure an eventual destructive effect of the PT interference on LoRa transmissions. No significant difference between those 50 runs was noticed which makes the quality of the results very consistent. The experimental parameters are summarized in Table I.

Fig. 5 presents the experimental results for 4 different distances and CR=4/5 (default LoRa value). As it can be observed, there is a significant level of interference which sometimes completely destructs data communications. It seems that lower SFs suffer more even though lower SF transmission exhibit lower transmission times. This is a result which coincides with the findings of [17]. It also reveals that higher SFs have better immunity to external DSSS interference. Moreover, only frequencies very close to the PT CF seem to suffer (i.e., 914.7, 915.0, and 915.3 MHz) while the rest of the frequencies exhibit

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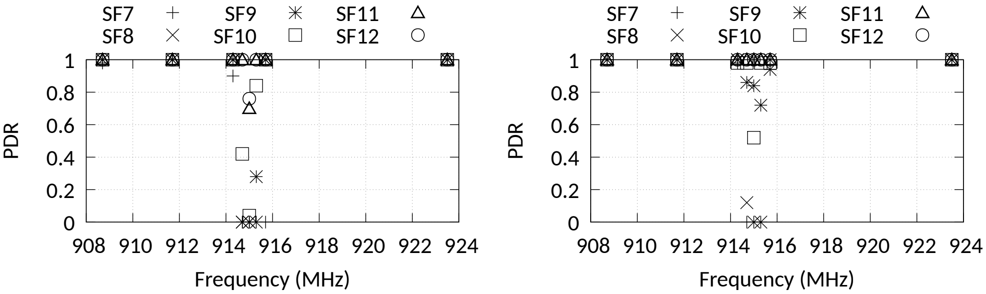
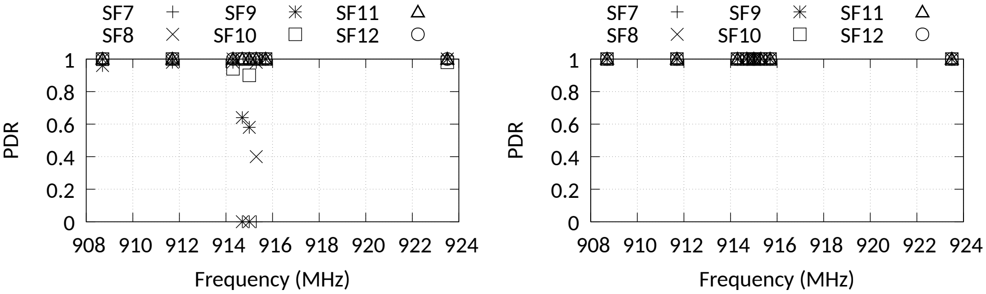
[1] https://fccid.io/YESTX91501B/Test-Report/Test-report-ES2174-1-Final-Report-pdf-4048541.pdf

[2] https://www.powercastco.com/products/powercaster-transmitter/

[3] https://www.thethingsnetwork.org/docs/lorawan/frequency-plans

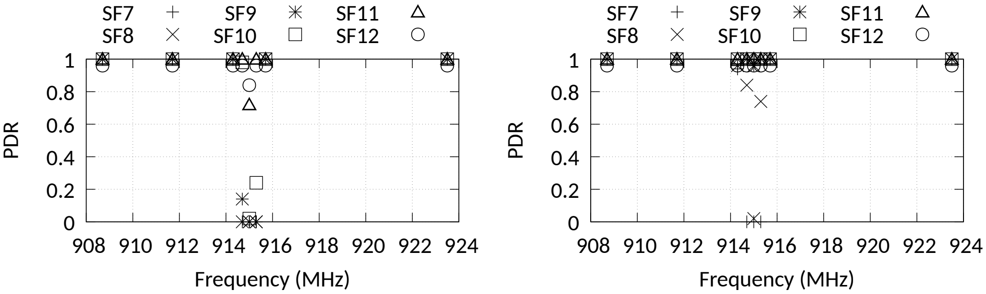


(a) 30cm (b) 60cm

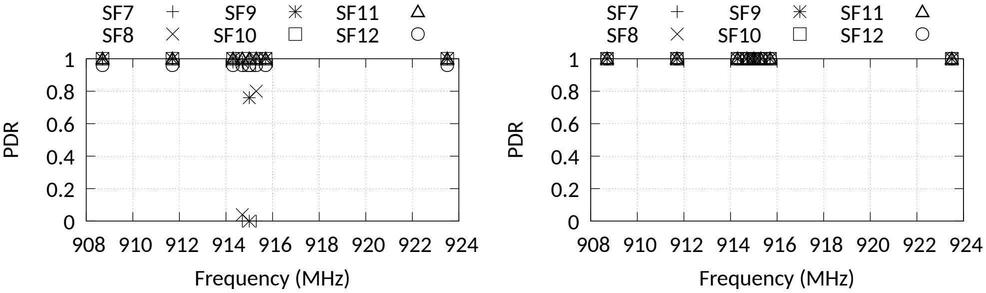


(c) 90cm (d) 200cm

Fig. 5. [Code rate = 4/5] Packet delivery ratio for different frequency channels, Spreading Factors, and distances between the PT and the LoRa transmitter.



(a) 30cm (b) 60cm



(c) 90cm (d) 200cm

Fig. 6. [Code rate = 4/5] Packet delivery ratio for different frequency channels, Spreading Factors, and distances between the PT and the LoRa transmitter.

100% delivery ratio. No interference was detected in the 2m distance scenario. These two results confirm the theoretical findings presented in the previous section.

The experiments were repeated for the lowest possible code rate and the results are presented in Fig. 6. This lower code rate enables a higher error correction in data transmissions. The results reveal that the lower CR does not significantly improve the performance. In some cases, there is an up to 20-25% higher delivery ratio, however, lower SFs are still heavily affected by the power emission close to the CF.

VI. CONCLUSIONS & FUTURE WORK

In this paper, the effect of power transfer on the LoRa data transmissions was studied. Theoretical conditions were presented and a series of lab experiments were conducted to get more useful details of the resulted interference. The experimental results confirm – up to some extent – the theoretical findings. Besides, some very interesting results regarding the immunity of higher LoRa SFs were discovered. The lower SFs suffer a

TABLE I
EVALUATION PARAMETERS

Parameter	Value
End-devices	1+1
Spreading Factors	7 – 12
Channel bandwidth	125 kHz
Preamble symbols	8
Coding Rate	4/5 and 4/8
Uplink channels	8 in US915 ISM
Receiver sensitivities	Typical Semtech SX1276
Data Tx power	14 dBm
Power Tx power	34.77 dBm EIRP
LoRa antenna gain	<2dBi
PT antenna gain	8.3dBi
Antenna losses	0
Payload size	16 Bytes
Fit-function coefficients	$\alpha = 1$, $\beta = 0.18$
PSD peak	7.07 dBm

lot more especially for channels around the power transmitter central frequency. These results might be useful for researchers and engineers who design power harvesting solutions for IoT applications.

In the future, we are planning to extend this work testing the interference level at the received LoRa end-device but also implement a protocol which follows a channel hopping scheme without selecting interference-affected frequencies.

VII. ACKNOWLEDGEMENTS

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