

Sub-Gigahertz Inter-Technology Interference. How Harmful is it for LoRa?

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Abstract—Sub-one GHz technologies are getting utilized for different applications in home automation and smart cities, due to their long coverage range and support for large number of end devices. Due to different technologies used by different applications and device vendors, the impact of each technology on each other needs to be assessed in environments where multiple technology are used and most of the time they are coexisting with each other. In this paper, we show an inter-technology interference measurement setup for LoRa, Sigfox, Z-Wave and IO Home Control. In the setup, the packet transmissions are controllable in time and frequency, that makes it possible to test and evaluate various interference scenarios. From the designed and implemented setup, we evaluate the impact of the sub-GHz technologies (Sigfox, Z-wave, and IO Home Control) on LoRa. The results show that there is a significant loss (up to 20%) and a relatively lower loss (up to 12-15%) under Sigfox and Z-Wave or IO Home Control, respectively, when the interferer starts during the preamble and header time. Losses are practically zero if the interferer starts during the payload time.

Index Terms—LoRa, SigFox, IO Home Control, Z-Wave, interference measurements, interference.

I. INTRODUCTION

Sub-one GHz technologies are getting utilized for different applications in home automation and smart city domains. Their wide coverage zone makes them a potential candidate for applications (like smart cities), where end devices are far apart from the network. On the other hand, in home automation domain, sub-one GHz technologies are the preferred choice due to low penetration losses of the building materials [1]. With densification of applications and end devices from different vendors that use different technologies, problems caused by inter-technology interference increases.

From the vendor perspective, it is crucial to know the impact of one technology over the others before selecting the right technology for their products. On the other hand, if a technology is already deployed in an environment, it is beneficial for the developers to know what is the impact of the newly deployed technology on the already deployed one.

Different characteristics of each technology can be taken into account beforehand. LoRa technology is a wide spread spectrum technology, that has low receiver sensitivity (up to -140 dBm) which makes it possible to receive packets below noise floor. On the other hand, SigFox is a narrow band technology that concentrates the transmit power in a single narrow band, that decreases the possibility to get interfered from other coexisting technologies. Looking from the time

domain perspective, LoRa has a shorter on-air packet time compared to SigFox, but both of them have quite a long on-air packet time compared to other technologies due to low bit rates. This increases the chance for a packet to get interfered as the transmission time is long.

In order for different technologies to co-exists interference on one-another has to be assessed. In this paper, we assess the SigFox, Z-Wave and IO Home Control interference on LoRa. By means of a controllable setup, we do a set of measurements for different power differences between LoRa and the interferer technology as well as different time shifts between transmission of LoRa packet and the interferer packet. LoRa channels that are used are based on the operational channels of the interfering technology, being as near as possible with the LoRa channels. While for SigFox a TDnext RF module [2] was used, for the other two interfering technology emulated versions on Zolertia Remotes were used.

The rest of the paper is organized as follows: section II gives the related work in the interference measurements and sub-GHz spectrum occupancy while section III gives an insight to characteristics of the considered technologies (LoRa, SigFox, Z-Wave and IO Home Control). Section IV describes the measurement setup, methodology of measurements as well as the way how the technologies (Z-Wave and IO Home Control) were emulated, while section V shows measurement results. Finally, section VI concludes the paper.

II. RELATED WORK

There have been a number of studies that evaluate the impact of interference on LoRa performance, mostly being the result of self-interference and imperfection of spreading factor (SF) orthogonality.

In [3] differences between ultra-narrow band (UNB) and wide spread spectrum technologies in terms of range and resistance against interference are studied. By means of a network simulator authors in [3] show that the UNB networks cope well with wide spread spectrum network interference, while the reverse is valid for the vice-verse case. It means that in case of coexistence of LoRa and Sigfox, LoRa network will have higher losses due to SigFox interference, being up to 50% for LoRa end nodes at the cell edge. In [4] a performance comparison between different physical technologies (UNB, chirp spread spectrum (CSS) and Weightless) used in Internet of Things (IoT) is done. For LoRa self-interference, in case

of interference by the same spreading factor signal, the packet that is received with 6 dB higher signal strength will be received correctly. In addition, authors show the co-channel rejection for all combinations of spreading factors in case of LoRa. Considering the non-LoRa interference, LoRa can cope with a single-tone pulse interference if it is less than 5 dB (19.5 dB) above the desired signal for SF7 (SF12) [4].

In [5] impact of spreading factor orthogonality imperfection in interference is shown. The higher spreading factors (10 to 12) are more prone to get interfered by other spreading factors. As higher spreading factors will be used for far away end nodes to increase receiver sensitivity, they will be impacted by the near-far problem. However, by deploying multiple gateways the impact can be alleviated as different gateways experience different Signal-to-Interference Ratio (SIR) values [5].

In [6] the impact of interference between LoRa and IEEE 802.15.4g on each another is shown. Based on empirical measurement, for different power levels and different spreading factors, LoRa is shown to have high packet reception ratio (PRR) under IEEE 802.15.4g interference. Always for spreading factors higher than SF9 PRR is one, no matter the configuration of IEEE 802.15.4g channel usage or power level. In case of SF7 the PRR drops around 0.4 if IEEE 802.15.4 operates at channel 26.

In [7] authors study the effect of spreading factors of the transmitter and the interferer on the packet success ratio. By means of empirical measurements it is shown that higher SFs are more prone to get interfered than lower SFs due to higher time on air. On the other hand, when two signals are transmitted using the same SF, at least one of them can be captured with high probability (>80%) if it is 6 dB stronger. Moreover, it is shown that the LoRa modulated signals are interfered by Gaussian frequency shift keying (GFSK) modulated signals. In [8] LoRa communication performance in an industrial environment is shown.

III. INTRODUCTION TO CONSIDERED TECHNOLOGIES

In this section we will describe different characteristics of the considered technologies. We will cover characteristics such as: modulation techniques they use, channels, channel bandwidths, data rates etc.

A. LoRa

LoRa is wide spread spectrum based technology that represents each symbol of information by multiple chips. The number of chips per symbol is determined based on the spreading factor and it is 2^{SF} , where SF is the spreading factor used. The spreading factor can be from 7 to 12. By increasing the spreading factor the nominal data rate is decreased, as more chips are sent for single information symbol. However, this will increase the receiver sensitivity as well as the robustness against interference. E.g for SF12 the receiver sensitivity will be -137 dBm compared to -124 dBm for SF7 [9]. Table I shows the nominal data rates and receiver sensitivities per spreading factor. The forward error correction (FEC) codes are used to

TABLE I
NOMINAL DATA RATE AND RECEIVER SENSITIVITY FOR DIFFERENT SF.

SF	Bit rate [kbps]	Rx sensitivity [dBm]
12	0.25	-137
11	0.44	-135
10	0.98	-133
9	1.7	-130
8	3.1	-129
7	5.4	-124

detect and correct bit errors. Code rates from 4/5 to 1/2 are used. To be even more protective against burst noise, diagonal interleaving is used to spread the information symbols over time [10].

LoRa physical frame is composed by the preamble, physical header and the payload. The preamble is used to synchronize the receiver with the transmitter before actually starting to decode the data. The preamble starts with a programmable sequence of upchirps, that can be 6 to 65535 symbols long. The programmable part of the preamble is followed by two upchirps that encode the sync word and ends with 2.25 downchirps [9]. Physical header can be optional. If it is present in the packet it contains the information about the payload length and code rate of the payload. It is always protected by the FEC codes with code rate of 1/2 and has its own cyclic redundancy check (CRC) for header integrity checkup. The payload can be encoded with different code rate than header and can have an optional payload CRC.

In Europe, LoRa operates in the 863 - 870 MHz frequency band. It can operate in two sub-bands, one at 868 MHz that offers three 125 KHz LoRa channels and one at 867 MHz that offers five 125 kHz LoRa channels. Three channels at 868 MHz have center frequencies at 868.1 MHz, 868.3 MHz and 868.5 MHz.

B. Sigfox

SigFox is a proprietary technology and operates on different spectrum bands in Europe and in the US: 868MHz and 902MHz, respectively. It utilizes ultra-narrow bandwidth modulation scheme, which is also termed as Differential Phase Shift Keying (DPSK) in uplink and Gaussian Frequency Shift Keying (GFSK) in downlink. Due to the narrow band in the uplink, quite a large number of devices can communicate over a distance of 10 to 50 km. However, a downside is that it can only achieve up to 100bps data rate [11]. In addition to low data rate, there is also a regional regulation of 1% duty cycle [12]. Thus, the duty cycle limitation imposes a daily limit on a Sigfox device with a maximum 140 messages in uplink and 4 messages in downlink. The maximum payload in uplink and downlink is 12 bytes and 8 bytes, respectively.

C. Z-Wave

Z-Wave is a ITU-T G.9959 standard [13] based low-power wireless technology that is used in home automation for connecting different sensors. ITU-T G.9959 specifies a list of

radio frequency (RF) profiles that each node has to comply to, depending on the region of operation. The RF profile is a combination of center frequencies and data rates. Three different data rates are supported 9.6 Kbps (R1), 40 Kbps (R2) and 100 Kbps (R3). Z-Wave operates at ISM bands, respectively at 868.40 MHz and 869.85 MHz band in Europe and 908.42 MHz and 916 MHz in the US.

Physical layer employs frequency shift keying (FSK) for the RF profiles R1 and R2 and Gaussian frequency shift keying (GFSK) for R3, respectively, as modulation techniques. Different coding schemes are used, Manchester encoding for R1 and non-return to zero (NRZ) encoding for R2 and R3. Receiver sensitivity typically is below -104 dBm, while coverage can go up to 100 m in the line of sight communication or up to 30 m in an indoor home environment.

The physical layer frame format of a Z-Wave transmission is composed of a variable length preamble sequence, 1 byte start of frame delimiter, variable length of physical layer payload and in case of R1 profile 1 byte of end-of-frame delimiter. The preamble sequence is a variable byte sequence of the binary pattern "01010101" [13] that allows receiver to obtain symbol synchronization. The maximal physical layer payload is 64 bytes.

D. IO Home Control

Another technology that operates in sub-one GHz band is IO Home Control. It operates at 868 MHz ISM band using one of three channels centered at 868.25, 868.95, 869.85 MHz. It uses FSK or GFSK as modulation techniques with an data rate of 38.4 Kbps [14].

IV. MEASUREMENT SETUP AND METHODOLOGY

The interference has different impacts based on the power strength of the interferer, the time how long the interference happens and the time when the interference started referring to the main transmission. We created a measurement setup where all of these three parameters can be controlled that can be used for any interference testing scenarios. The setup consists of a microcontroller that manages the time of transmissions of the devices (technologies) under test. Both devices are connected to two different controllable attenuators. After attenuating the signals coming from the devices (emulating the power level difference accordingly), both signals are combined and are sent to the receiver of the technology that is being tested, in our case LoRa receiver. All devices (transmitters and the receiver) are located inside the RF shielded boxes, in order to have no impact from any outsider transmitter and to have full control on introduced interference. In Figure 1 measurement setup schematic is shown. The Qosmotec boxes were used as RF shielded boxes. The attenuation box was of type PAH-6000/80-2 [15] with eight input/output ports with maximal insertion losses of 14 dB. The splitter/combiner box was from MTS Systemtechnik with eight paths with maximal insertion losses of 6 dB [16].

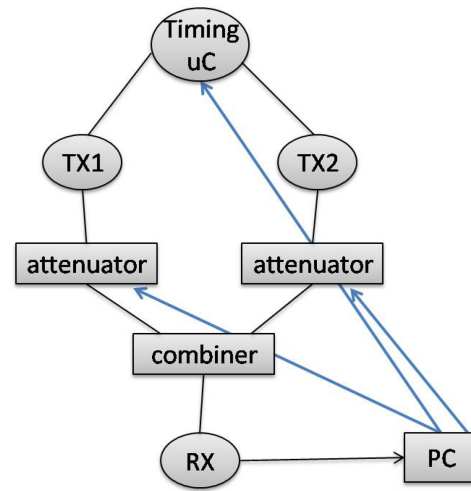


Fig. 1. Controllable measurement setup schematic.

A. Methodology

In typical home deployment setup end devices are not far apart from the gateway that is installed inside the house. So, compared to interfering technology that is already deployed in the neighborhood, the signal power of the main transmission always will be higher at the receiver side. In the reverse case, when both technologies are co-located and the interferer transmitter is nearer to the receiver than the main transmitter, the main transmitter can end up in lower received power than the interferer in the received side. To emulate these two scenarios we will test for two different power levels: when the interferer has 10 dB lower signal strength than the main transmission in the receiver side and when interferer is 10 dB higher. In our case the main transmission will be LoRa transmission while the other technologies will be the interferers. We set the received signal strength for LoRa at -65 dBm, while the interferer signal strength at the receiver will be +10 dB and -10 dB, respectively, compared to LoRa signal. This is achieved by adjusting the attenuation levels of the tunable attenuators. In Table II LoRa settings used for the measurements are shown. Channel centered at 868.1 MHz was used for the measurements under SigFox interference while channel centered at 868.3 MHz was used for measurements under Z-Wave and IO Home Control interference, in order to test the worst case scenario.

As it was shown in [17], interference has different impact on different LoRa packet parts. If the interference happens during the preamble it prevents the receiver to detect the packet. If it happens during the header time it makes the packet to be decoded wrongly due to wrong payload length, while if it happens during the payload the impact might be lower due to FEC code usage and diagonal interleaving. Based on this, different time shifts for the interferer after the start of the main transmission were used. The interference was started during the preamble time (time shifts of 8 ms for SF7 and 150 ms for SF12), during the header time (time shifts of 17 ms for SF7

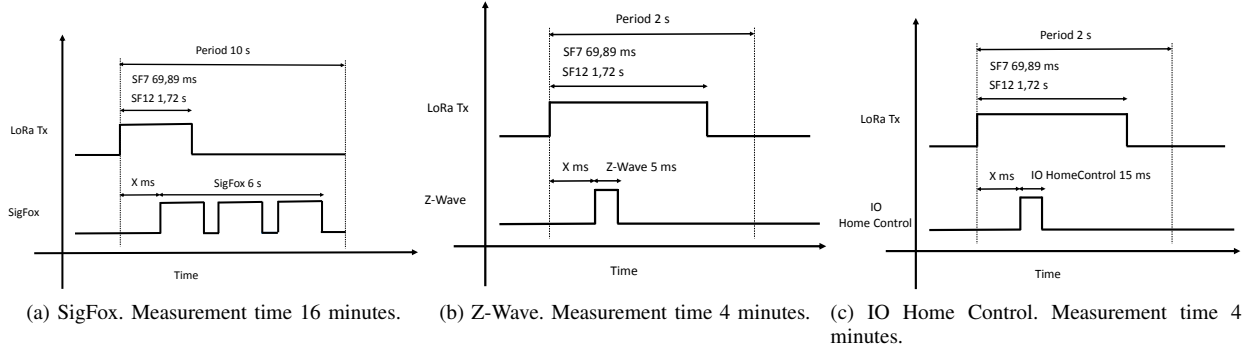


Fig. 2. Different time shifts for different measurements. In case of SF7 $X = \{8, 17, 30, 55\}$ ms and in case of SF12 $X = \{150, 500, 1000, 1500\}$ ms.

TABLE II
LORA SETTING FOR MEASUREMENTS.

Parameter	LoRa settings
Channels	868.1, 868.3 MHz
Bandwidth	125 KHz
Data Rate	5.4 Kbps (SF=7) and 183.11 bps (SF12)
Tx Power	14 dBm
Payload length	17 bytes
Time on air	69.89 ms (SF7) 1.72 s (SF12)
Physical header	Explicit
Preamble time	12.54 ms (SF7) 401.4 ms (SF12)
Header time	21.54 ms (SF7) 605.4 ms (SF12)
Symbol time	1.02 ms (SF7) 32.77 ms (SF12)

and 500 ms for SF12) and during the payload time (30 and 55 ms for SF7 and 1 and 1.5 s for SF12). The measurement period is shown for each technology in Figure 2.

In case of SigFox interference testing, due to long transmission time, the measurement period was longer implying the need for longer measurements for each case. The measurement time in SigFox interference case was 16 minutes while for the other two technologies it was 4 minutes per measurement. This allowed to collect around 100 packets per measurement that were enough to draw statistics in terms of percentage of packets lost and received with wrong payload CRC. For each interfering technology there were in total 16 different measurements, for each combination of 4 time shifts, 2 different power levels and 2 different spreading factors.

B. Technology emulation

As we did not have the Z-Wave and IO Home Control end nodes we emulated the packet transmission using Zolertia Remote [18]. The Zolertia Remotes use the CC1200 chip from Texas Instruments for sub-GHz communication and can support modulations that are used for Z-Wave and IO Home Control, GFSK and 2-FSK, respectively. It has a programmable bandwidth from 12.5 kHz to 1600 kHz offering data rates in the range 1.2kbps to 1250kbps. They are flashed with the Time Annotated Instruction Set Computer (TAISC)

framework [19] based on the Contiki operating system. This setup runs a custom program to transmit emulated Z-Wave/IO Home Control packets as soon as one of the input pins of the Zolertia is toggled. In case of Z-Wave, the RF profile R3 was emulated as only that profile interferes with the LoRa channel at 868.3 MHz center frequency.

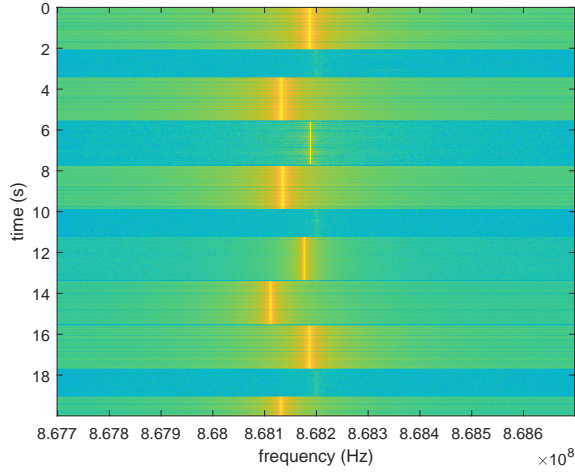
Differently from Z-Wave and IO Home Control case, in SigFox case we used an TDnext RF module to transmit uplink SigFox packets [2]. TD1207R devices offers a receiver sensitivity of -126dBm and an output power of +16dBm, which makes these devices compatible with the SigfoxTM network. The TD1207R radios are not possible to be triggered via microcontroller (as it is required in our setup) but they can be operated via AT commands (triggered by a computer). As precise timing of transmission is required, the TD1207R is triggered by AT commands that are generated by a Zolertia Remote [18], while the Zolertia itself is triggered by the microcontroller. The SigFox module was configured to operate on randomly allocated SigFox channels.

The time and frequency illustration of the technologies is shown in Figure 3. It is seen from the spectrograms that Sigfox (Figure 3a) has the longest time-on-air compared to the shortest just some ms for Z-Wave (Figure 3c).

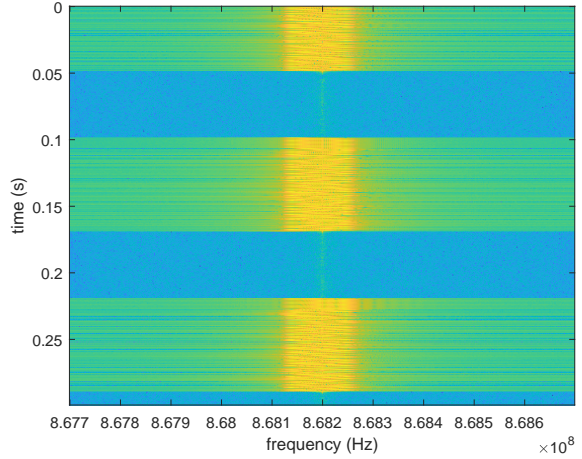
V. RESULTS

This section will detail the achieved results for the interference impact of other sub-GHz technologies in LoRa.

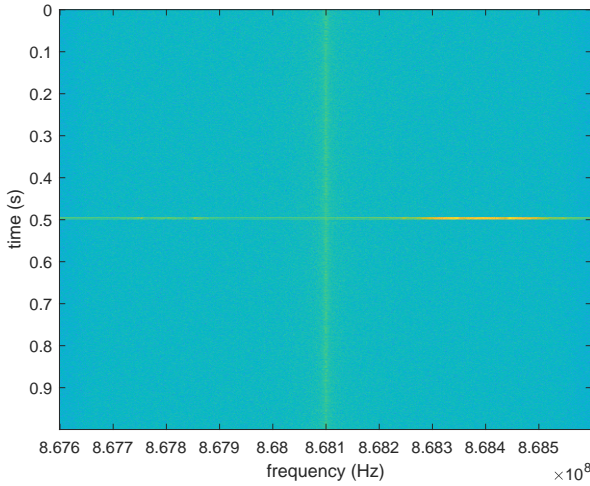
Results when LoRa uses SF7 are given in Table III. The most severe interference is when it happens during the preamble time (time shift of 8ms). This is from the fact that due to interference the receiver can not get synchronized with the transmitter by losing the preamble start, making thus impossible for the LoRa receiver to start receiving the packet. For the time shift of 17 ms (when interference starts during the header time) losses are less compared to the preamble time shift but higher than in payload. As during the measurements explicit physical headers for LoRa were being used, if the header CRC is wrong the receiver will stop receiving the packet. This will cause the packet to be lost even if the interference is short and happens only during the header time. This is the case with Z-Wave interference when the interfering



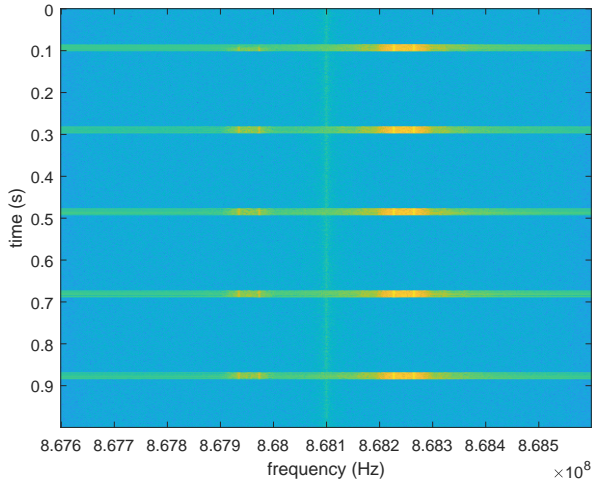
(a) Sigfox



(b) LoRA - SF7



(c) Z-Wave



(d) IO Home Control

Fig. 3. Non-overlap transmission of sigfox, LoRA - SF7, zwave, and iohome.

time is not longer than 5 ms. Comparing between different technologies, SigFox causes the highest packet losses for LoRa due to its long burst transmission even though it uses narrow bands. This will make impossible for LoRa to recover as the interference is longer than the LoRa packet itself. In case of Z-Wave and IO Home Control interference time is shorter (5 ms and 15 ms, respectively). That has practically no impact if it starts during the payload time as it can be recovered by using FEC codes in LoRa.

Considering the usage of SF12 the results are shown in Table IV. In general, for each measurement case losses are lower than when SF7 was used. This is due to lower receiver sensitivity for SF12 as well as the ability to receive packets in lower SNR threshold, -22 dB, compared to -7.5 dB for SF7 [9]. Even for SF12 the losses based on different technologies and different time shifts does not make any exception compared to SF7 case. The most problematic technology is SigFox as

TABLE III
PERCENTAGES OF PACKET LOSSES FOR DIFFERENT INTERFERING TECHNOLOGIES, DIFFERENT POWER LEVELS AND DIFFERENT TIME SHIFTS. LORA IS CONFIGURED TO USE SF7

Interfering tech - Time shifts	8 ms	17 ms	30 ms	55 ms
SigFox -10 dB	15%	16%	14%	9%
SigFox +10 dB	28%	18.80%	14%	12%
Z-Wave -10 dB	16%	3%	0%	0%
Z-Wave +10 dB	17%	1.80%	2%	0%
IOHomeControl -10 dB	12.3%	1.50%	0%	0%
IOHomeControl +10 dB	12.8%	2.6%	0.5%	0%

it has the highest impact on LoRa packet losses compared to other technologies. Regarding different time shifts, even in this case, the most severe case is when interference starts during the preamble time.

TABLE IV
PERCENTAGES OF PACKET LOSSES FOR DIFFERENT INTERFERING TECHNOLOGIES, DIFFERENT POWER LEVELS AND DIFFERENT TIME SHIFTS. LORA IS CONFIGURED TO USE SF12

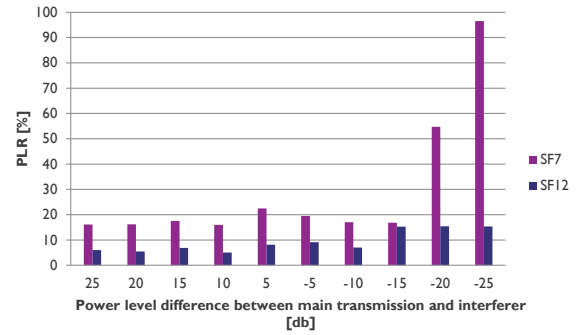
Interfering tech - Time shifts	150 ms	400 ms	1 s	1.5 s
SigFox -10 dB	14%	7.35%	12%	6%
SigFox +10 dB	20%	20%	14%	8%
Z-Wave -10 dB	5%	2%	0%	0%
Z-Wave +10 dB	7%	2.00%	0%	0%
IOHomeControl -10 dB	7.2%	1.50%	0%	0%
IOHomeControl +10 dB	12.4%	1%	0%	0%

As it is shown in Tables III and IV the worst case scenario in terms of time shifts is when the interferer starts during the preamble time. However, the impact of power level is not straight forward noticeable. For this we do a set of measurements only for time shifts when the interferer starts during preamble time, but adjusting the received signal level difference between LoRa transmission and interferer.

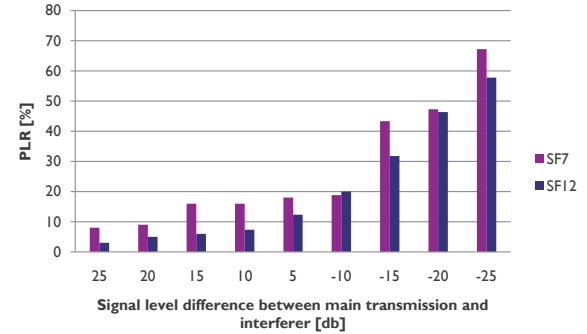
The packet loss ratio for Z-Wave interferer case is shown in Figure 4a. It is seen that if LoRa signal will be lower than 20 dB compared to Z-Wave signal, the packet loss will be higher than 50%, reaching 96% for -25 dB difference in case of SF7. On the other hand, for SF12 even for difference of -25 dB in signal level packet losses are still only 15%. This comes due to the higher sensitivity of SF12 that is able to receive signals even at SNR level of -22 dB. In case when LoRa signal is much stronger than Z-Wave, the losses are around 6% for SF12 and higher for SF7 (up to 16%). These residual losses are due to the fact that the power level of the Z-Wave is fixed at -65 dBm that impacts LoRa receiver. We would expect lower impact if the Z-Wave power level is lower, e.g. at -80 to -100 dBm.

Sigfox interferer case is shown in Figure 4b. When LoRa signal is lower than 20 dB compared to SigFox signal, the packet losses increase fast and can be as high as 67% for SF7 at -25 dB signal difference. By increasing the Sigfox signal level at the receiver site, the packet loss ratio is increased faster than when the interferer was Z-Wave emulated transmitter. However, in this case the differences between using SF7 and SF12 are not that big as in case of Z-Wave. This comes as result of long Sigfox transmission that will impact even SF12 long packet transmission during the whole packet time as in case of SF7.

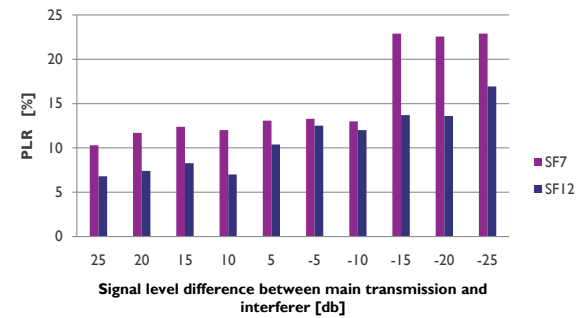
IO Home Control interferer case is shown in Figure 4c. For LoRa signal 20 dB lower than IO Home Control signal at the receiver side the packet loss will be around 22% for SF7 and 14% for SF12. The differences between SFs come as result of the different receiver sensitivities and ability to receive packets even under noise level. On the other hand, when LoRa is more than 20 dB stronger than IO Home Control interferer the losses are less than 10% for both SFs.



(a) Z-Wave interferer



(b) Sigfox interferer



(c) IO Home Control interferer

Fig. 4. Packet loss ratio for different received signal levels between LoRa and interferer signal when the interferer starts during the preamble time.

VI. CONCLUSIONS AND FUTURE WORK

In this paper we describe a controllable measurement setup for interference testing between different technologies. Further, we perform interference measurements to evaluate the impact of other sub-one GHz technologies (SigFox, Z-Wave, IO Home Control) in LoRa. Based on the results it is shown that if the interference starts during the preamble time, losses can be as high as 28% in case of SigFox interference. Losses are reduced, becoming zero, if the interference starts by the end of the payload, no matter the interfering technology. A slightly higher losses (+5 to +10%) are recorded when SF7 is used instead of SF12 for the same cases.

Using the same setup future measurement can be done for different power levels as well encountering more transmitters at the same time.

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