Wi-Fi Interference Analyis for Scalable LoRa Communication

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***Abstract*—Internet-of-things are becoming an integral part of human life. By 2025, there would be 30.9 billion active connections in the world that sums to 3 active connections per person. In recent years, the use of LoRa tech has expanded enormously. A new chip was introduced by Semtech to provide wider range with lower power consumption in 2.4GHz. Moreover, the older generation boards used to work in sub-gigahertz frequency which differed region to region. Prior research has indicated that LoRa packets may suffer interference from Wi-Fi. In this paper, we are going to compare different frequencies available in 2.4GHz Wi-Fi channels to see how the communication is affected in different environments. Moreover, we will also test the ranging capabilities of the new chipset in the Urban environment. We plan to implement communication using Semtech's SX1280 chip and conduct experiments to evaluate its performance. Results show that LoRa can work efficiently while working simultaneously with Wi-Fi. The packet reception ratio achieved 95% while working in a 22 MHz Wi-Fi channel.**

I. Introduction

In Recent years, IoT's devices are becoming an important part of many industries such as Agricultural, Environmental, etc. LoRa is being used as a technology to communicate between large number of devices over a large area. LoRa powered devices can communicate over several kilometres without large amount of power consumption with capability to transmit at lower data rates.

Recently, Semtech has launched a new LoRa chip SX1280 which serves in 2.4Ghz band (which is same as Wi-Fi)as compared to the older generation boards that used to work in MHz (sub-GHz Frequencies). SX1280 can work and receive data with strict channel duty cycle limitation. The end-nodes using SX1280 can work with Bandwidth ranging 500kHz to 1600kHz. The new chipset also allows us to increase the range of communication by choosing different combinations of Spread Factor (SF). Moreover, 2.4Ghz can provide support for wider IoT applications in all the regions around the world.

Prior studies have been done using older generation boards about the ranging capabilities in LoRa. SX1280 has not yet been utilised to develop an experiment of point-to-point connection between the end node and the Gateway. The older generation boards didn't have the problem of Wi-Fi interference, but the new generation does encounter this problem.

In this paper, we developed a practical experiment around the SX1280 in an urban environment to check the ranging capabilities of the new chip and to analyse the interference from Wi-Fi while the communication takes place.

The contributions can be summarised as follows:

- We programmed the Sx1280 end nodes and gateway to work on different spread factors and frequencies to find out how open non-overlapping frequencies works when compared to the frequencies which lie inside the overlapping channels.
- We conducted an experiment using the SX1280 chip to find out the ranging capabilities of the new generation chip in an urban environment.
- We created an experiment in which we controlled the Wi-Fi interference and then introduced new Wi-Fi interference to find out how does the behaviour of the chip changes when interference is introduced
- We implemented the uplink and downlink communication between the end -nodes and the gateway with the use of Lora Wan Server. The communication used in this paper was point-to-point only.
- We propose an in-depth analysis of how the packet corruption and loss can be evaded with the help of certain strategies.

The rest of the paper is organised as stated below. Section II introduces the related work. Section III contain the details about the experiment conducted to collect data and identify the capabilities. Section IV presents the evaluation results. Section V concludes this paper.

II. Related Work

Before going into depth about how the experiment was designed, it's important to understand the history of LoRa, which is also known as Chirp Spectrum Spread (CSS) and is used in LoRa communication. Chip spread spectrum is a data encoding technology that employs linear frequency modulation chip pulses. A chirp is a periodic sinusoidal signal that increases or decreases in frequency over time. Lora's bandwidth in the 2.4GHz ISM band varies from 200kHz to 1600kHz. While prior generation boards had a frequency restriction of 500 kHz, which is nearly three times lower than the current 2.4GHz, newer generation boards have a frequency limit of 2.4GHz.

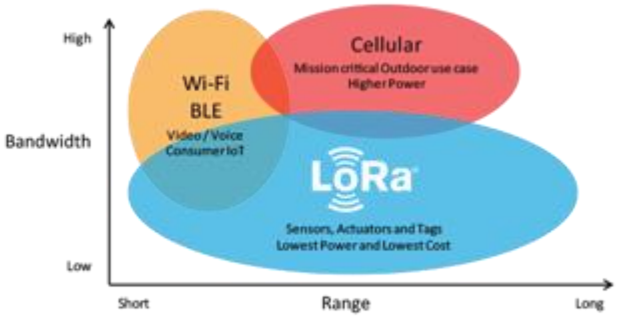


Figure 1. Lora Comparison with Cellular and Wi-Fi network

Modulation of the LoRa chirp is done with the help of Bandwidth B and Spread Factor S , and the LoRa symbol is modulated on the basis of combination of the Bandwidth and Spread Factor. These two factors are then used to demodulate the message when received by the gateway.

LoRa can function in six different spread factors ranging from 7 to 12, and these spread factors are responsible for the computation of Signal Sensitivity levels and time on air for the packets that are being transferred through the network.

Below table shows you the calculation of maximum sensitivity level on different spread factors according to the Bandwidth 812.5kHz and payload size of 23.

Bandwidth	Receiver Sensitivity[dBm]					
	SF7	SF8	SF9	SF10	SF11	SF12
203	-115	-118	-121	-124	-127	-130
406	-113	-116	-119	-122	-125	-128
812	-112	-115	-117	-120	-123	-126
1625	-106	-109	-111	-114	-117	-120

Table 1 Maximum Sensitivity level Over Different Spread Factor

Value	Description
rssiSync	RSSI value latched upon the detection of the sync address. Actual signal power is $-(\mathbf{rssiSync})/2$ (dBm)
snr	Estimation of SNR on last packet received. In two's compliment format multiplied by 4. Actual SNR is $(\mathbf{snr})/4$ (dB) If the SNR ≤ 0, RSSI_{packet, real} = RSSI_{packet,measured} – SNR_{measured}

Figure 2: Calculation of Rssi and Lsnr

Certain factors, such as the Received Signal Strength Indication (rssi), which is the signal power in milliwatts, can obstruct the demodulation process. According to the datasheet for the SX1280, the sensitivity of the received signal can go as low as -132 dBm, which can be used to communicate with the end node but is still a weak signal. The necessary rate should be between -30dBm and -132dBm. Furthermore, if the Signal to Noise Ratio exceeds -20 dBm, the packet may be corrupted. It is preferable to have a positive signal to noise ratio, which signifies that the communication is taking place above the noise floor, which is made up of all the interference.

In this study, we'll look at how Wi-Fi affects the variables mentioned above. This has been researched, but only in simulation. Furthermore, when compared to the simulation findings, practical results and application have been seen to differ. When compared to the simulation generated, this study will give a better comparison of how the actual circumstance influences communication. Furthermore, the testing of a large number of frequencies has never been done previously; frequencies are employed both inside and outside the 802.11b 2.4Ghz ISM band, which is widely used by contemporary Wi-Fi.

Furthermore, because there are few resources accessible over the datasheet, this paper will give documentation of the basis on how to programme the end-nodes and Gateway in the most effective manner. There will also be a lot of new information that is either not stated in the datasheet or is really difficult to find. Consequently, because they will spend less time on these factors, this work could be used to help speed up future research endeavours.

III. Methodology

Design

In this section, we discuss how the experiment was conducted. The experiment was conducted using SX1280Z3DSFGW1 (*Figure 3*) 2.4GHz gateway which can connect over 1000 end -nodes and has 4 different channels out of which 3 are dedicated RX channels and 1 is dedicated TX channel. The gateway is a half-duplex mode operation that means it can either receive or transmit at a point of time. The Gateway can be configured to work on different spread factors with single-data rate (SF7 ~ SF12 / 812.5 kHz). The limitation of using this gateway is that it can work only to receive data over 812kHz Bandwidth.

End-nodes were developed using Semtech SX1280ED1ZHP (*Figure 4*) which is a worldwide interoperable hardware which works on 2.4Ghz ISM band. The LoRa head is programmed with the help of Semtech's NUCLEO-L073RZ – STM32 Nucleo-64 board. The end-node can be programmed to work on 3 different frequencies as well but it'll take turns to transmit data over each frequency.

Figure 3

Figure 4

A. Specific Frequency

802.11b Wi-Fi channels were utilised during the whole process. As per Figure 5 and 6, Frequencies were identified to test the Wi-Fi Interference in different environments.

The following image shows the overlapping and non-overlapping frequencies in the license free 2.4Ghz band which is used by modern Wi-Fi.

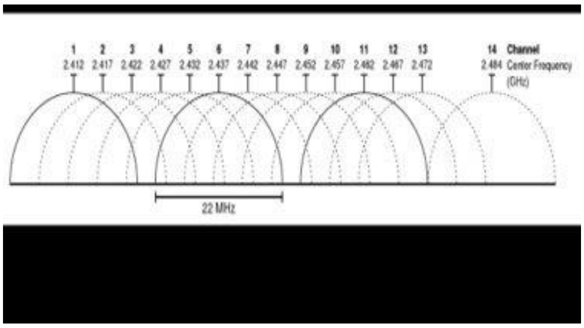


Figure 5 802.11b 2.4GHz Wi-Fi spectrum

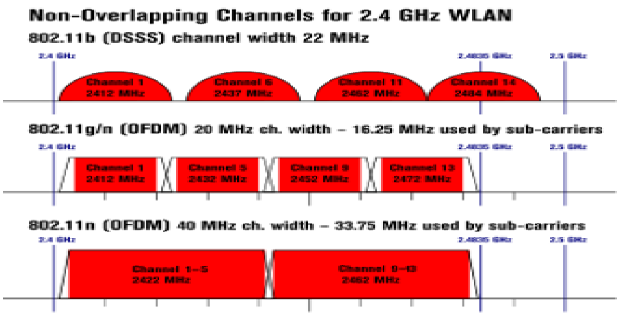


Figure 6 Non-Overlapping Wi-Fi Channels

According to the above diagrams, few frequencies that lie inside and few that lie outside the active 2.4GHz channels were used in order to test functionality in different environments with different amounts of interference.

B. Testing Locations

The locations were chosen based on the intensity of interference; Figure x was in the heart of the city and Figure x was near the Brisbane River..

Testing Location 2

Testing location 1

The third location testing was done near the river where the Self-generated Wi-Fi interference was introduced to compare the results as presented in the Figure x

Testing Location Image 1

C. Testing

The testing was done over three different spread factors which are as follows: S.F 7, 10 and 12. These spread factors were chosen on the basis of ranging capabilities. As we know from table 1,as the spread factor increases, the range of LoRa connection doubles and the sensitivity and the time in air increases.

D. Data Collection

After the deployment of nodes and gateway, the packets containing a payload of 23 were sent from the end nodes in different parts of the experiment as discussed below.

Multiple nodes working on different frequencies and one gateway

This part of the experiment was carried out in location 1 where three nodes working on different frequencies and spread factors were deployed in many places and packets were sent to the gateway. The experiments were conducted in three cycles, with the spread factor changing every cycle while the frequencies remained constant..

Single Node working on Multiple Frequencies and One Gateway

In this part of the test, the end nodes were working on 3 different frequencies and the spread factors were changed at every location to check the ranging capabilities of different spread factors.

One Node One Location with Self Introduced Wi-Fi Interference

During this round of the testing, the node was operating on two different frequencies, one with and the other without self-generated Wi-Fi interference. The frequencies were chosen based on the channels used by the recently introduced Wi-Fi.
In this case, it was channel 1. Furthermore, the second frequency was chosen to avoid Wi-Fi interference by operating in a non-overlapping Wi-Fi channel.
For all the cases above, the packets were continuously sent and then analysed to check the throughput, rssi (receiver signal strength indicator) and Lsnr (LoRa signal to noise ratio). The packets were sent over time in the presence of non-controllable interferences which includes building, river, Wi-Fi, etc.

E. Data Analysis

In this part, the data was analysed to find out how the LoRa nodes performed in different factors when the location and configuration differs. The results for same is as presented below:

1. Range: The ranging capabilities were analysed with the help of throughput to test how many packets were received and how many were lost in different locations. The analysis was done based on Spread factors and frequencies.
2. Throughput: Different frequencies were checked to see how successful they were in delivering data in form of packets without the packet being corrupted.
3. Rssi: Rssi: rssi was used to compare how the signal intensity among different frequencies behaved in the presence of various variables.
4. Lsnr: The signal-to-noise ratio (Lsnr) was examined to determine if communication occurs above or below the noise floor (level of Interference).

IV. Results and Evaluation

In this section, We evaluate and discuss the results obtained after analysing the collected data while performing the experiment. Later, we analyse the working of different configurations and compare the results of different factors with other parameters. Finally, we investigate the LoRa coexistence with Wi-Fi.

A. Throughput:

The throughput ratio of packets sent, and packets received amongst the three different frequencies and spread factors is shown in Table 2. The throughput is reduced as the range increases. There are many other factors which lead to the reduced throughput interference from Wi-Fi and buildings as the first testing was done in the city.

ThroughPut

Cycle 1

Frequencies	Spread Factor	Node	Packets Sent	Packets Received	Percentage
2479	12	1	35	33	94.28
2403	12	2	40	35	87.5
2425	12	3	38	37	97.36

Cycle 2

Frequencies	Spread Factor	Node	Packets Sent	Packets Received	Percentage
2412	10	1	52	40	76.92
2403	12	2	41	35	85.36
2451	10	3	60	38	63.33

Cycle 3

Frequencies	Spread Factor	Node	Packets Sent	Packets Received	Percentage
2439	7	1	59	35	59.32
2403	12	2	41	28	68.29
2463	7	3	65	30	46.15

Table 2 Through Put over three different frequencies

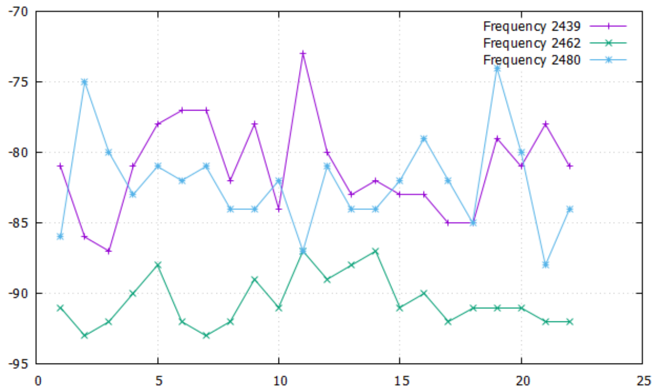
As you can see from the table, the received percentage is ranging between 87-97 % in spread factor 12 and the remaining packets were lost were due to no clear line of sight between the Gateway and end nodes. This remains constant in all the three nodes which are sending packets of data.
As shown in the table, the received packets ranges from 87 to 97 percent in spread factor 12, while the remaining packets were lost due to lack of a clear line of sight between the Gateway and the end nodes. This remains constant across all three nodes that are sending data packets.

B. Rssi (Received Signal Strength Indication)

This is the signal power in milliwatts which is measured in dBm. This depicts how well the gateway can listen to the sender which in this case are the end nodes. The closer rssi is to 0, better the signal.

In Sx1280 the -30dBm is considered as the best signal strength and -120 dBm is considered to be weak.

Following Graph 1 shows the rssi in different Frequencies used in the testing area 2:

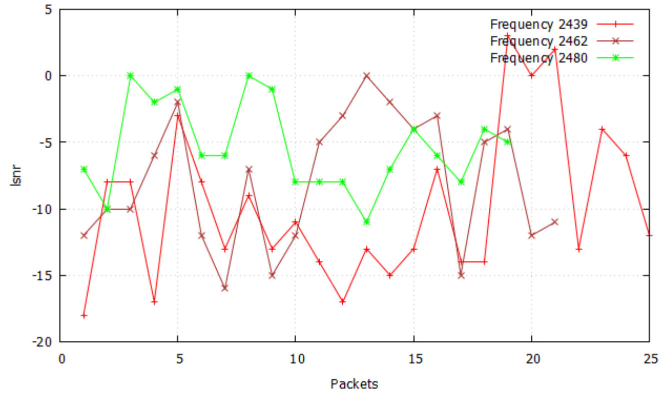


Graph: 1

As shown in above diagram, 3 frequencies **2439, 2462, 2480** depicts how the rssi varies when location of the transmitting node changes. In the above diagram, the location of the node is changing every 5 packets.

C. Lsnr (LoRa Signal to Noise Ratio)

Lora Signal to Noise ratio is the ratio between the received power signal and the noise floor power level. The Graph 2shows how the lsnr behaves at different locations in different frequencies with different levels of interference.



Graph 2: LSNR over different Frequencies

As shown by the graph in testing location 2, there was least amount of inference from Wi-Fi and buildings as most of the locations were around the river except the first and the last ones. So, you can see that the Lsnr was mostly near 0 during the testing except in the beginning and the ending. Furthermore, we know that when lsnr is positive, the communication is working over the noise floor and hence it's more effective.

D. Signal Power

According to the SX1280 datasheet, the signal power recovered by the gateway when the packet is received is not the true signal power if the lsnr of the packet is negative (-ve)

The Negative Lsnr indicates that the rssi must be reduced by the negative lsnr in order to obtain the real signal strength.

Wi-Fi Analysis

The third experiment which was performed while introducing self-controlled Wi-Fi interference produced the following results.

The two frequencies which were used while this experiment was performed were **2412 and 2450.**

Following 2 Figures show the level of interference before and after Wi-Fi was introduced in testing environment.

Figure 7 Without Wi-Fi Interference

Figure 8 With Wi-Fi Interference

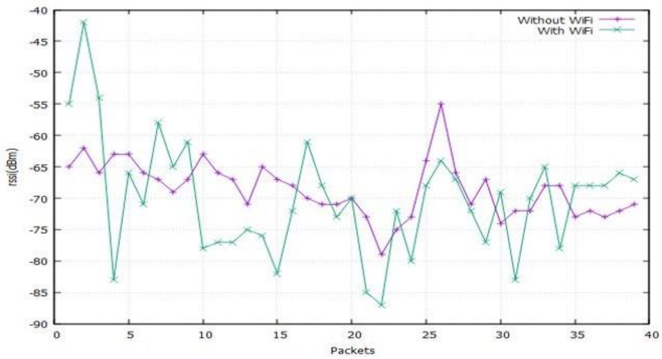
The results of two distinct situations are shown below with the help of comparison of the change in Rssi and Lsnr while being at the same location.

Frequency 2412

This frequency lies inside the Channel 1 on which self-introduced Wi-Fi was working

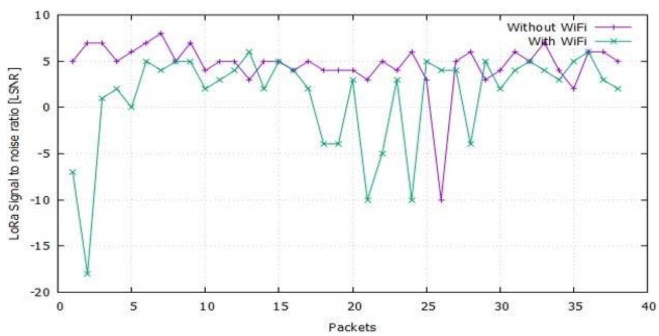
Without WIFI Interference

The below Graph 3 shows how the rssi behaves when there is an introduction of interference in the environment.



Graph 3 Rssi with Wi-Fi and Wi-Fi Interference

When no Wi-Fi interference was observed in the area, the rssi was quite consistent, ranging from (-75 to -65) in frequency 2412.
However, when we introduced the interference, the rssi began to move across the graph from -40 to -87.
This indicates that even when only one Wi-Fi interference is added, the receiver signal strength suffers significantly.



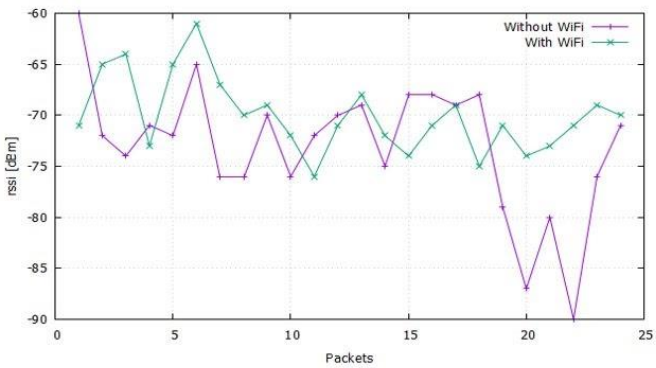
Graph 4 LSNR with and without Wi-Fi interference

Graph x shows how LoRa signal to noise ratio changes due to introduction of Wi-Fi. As you can see Noise was almost negligible and remained constant between +5 to +10 with one or two interruptions as the test was conducted inside a public park near university campus.

Further, when self-generated interruptions were introduced, the snr reduced drastically and reached almost -20.Later, it recovered for a while, but was falling continuously during the further testing.

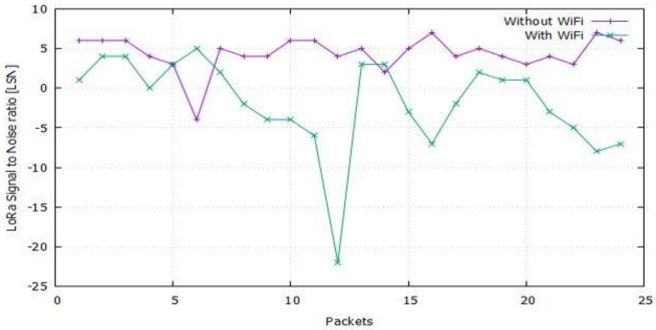
Frequency 2450

This frequency lies outside all the channels utilised by 2.4GHz 802.11b.



Graph 5: Rssi with and without Wi-Fi Interference

The above graph provides information about the frequency 2450 being utilised for LoRa communication with and without Wi-Fi Interference.
According to the graph above, even when Wi-Fi interference is added, the rssi is not significantly affected and acts relatively similar to the non-interference situation.
The rssi stays in the same range except for packets 20-23, where we can control all the factors, but it eventually catches up in the same range again.



Graph 6: LSNR with and without Wi-Fi Interference

Thus, we can conclude after analysing the graph x that the Lsnr also follows the same track as the rss. It hardly goes -ve and stays similar to lsnr without Wi-Fi interference.

Ranging capabilities

During my study of the experiment, the ranging capabilities of SX1280 chip is 1.2 km at the highest for SF 7 and beyond which the packets are lost.

To get higher ranging capability, clear line of sight is also important. During the first testing, clear line of sight between the node and the gateway played a significant part in generating higher throughput.

Strategies to counter Wi-Fi Interference

1. Frequency Modulation: Frequency modulation plays a vital part in communication by reducing the amount of interference in the transmission by employing frequencies that do not lie inside the Wi-Fi channels.
2. The only issue is determining which channel the Wi-Fi is using.
3. Spatial Separation: The second option would be to avoid the location of Wi-Fi terminal's while setting up the LoRa communication.
4. However, during the testing procedure, we under the impression that we did not have control over this aspect while designing the experiment.
5. Low Bandwidth: As we know Wi-Fi consumes high bandwidth, so, avoiding the utilization of a lot of bandwidth while transmitting the data over LoRa can be seen as a extremely effective technique to counter Interference from Wi-Fi

Other testing

Downlink communication was not achieved in the preceding experiment as there are certain parameters that are must be met without which point to point downlink communication is not possible. Furthermore, server (LORAWAN) is an integral part of downlink communication where the nodes are identified and recorded, data is maintained, and the frequency is manipulated on which the nodes are transmitting but that requires Server as the part of the communication. Therefore, point to point communication without a server still remains under investigation.

CONCLUSION

In this article, we built an experiment around the SX1280 board to allow LoRa and Wi-Fi to cohabit. The results indicate that LoRa communication is viable while decreasing Wi-Fi interference by employing particular Frequency Separation and Low Bandwidth methods. The rssi and snr findings show that by selecting a specific frequency that is outside of the Wi-Fi channel, reception may be enhanced. Many strategies were also addressed in order to avoid or eliminate Wi-Fi interference in communication. Future work can go in a variety of areas. First, the operation of point-to-point downlink communication between the gateway and nodes remains unresolved. Second, optimize the network further while keeping the other LoRa settings in mind. Furthermore, LoRa communication may be made more effective by using LiFi to cohabit alongside Wi-Fi.

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