Simulation-based Study of Interference Impact in ISM Bands in Smart Cities: Connected Traffic Light for Visually Impaired People Use-case

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Abstract: Wireless technologies operating in the unlicensed ISM (Industrial Scientific and Medical) bands are omnipresent. Indeed, with the expansion of the Internet of Things, plenty of applications are being developed on devices that use the 868.3 - 868.8 MHz ISM band. This expansion has an impact on existing technologies operating at the same frequencies. This paper focuses on the impact of IoT networks on a special use case deployed in smart cities which is the connected traffic light for visually impaired pedestrians. A connected traffic light is equipped with a radio receiver that operates at $868.3MHz$ frequency. It allows pedestrians to query the state of the traffic light using a handheld remote control. When the latter is pressed, a generated radio message will activate a sound beacon that tells the state of the traffic light. In some cases, when the traffic light is not optimally deployed or when it suffers from interference, the connection with the remote control cannot be established. In this paper, we investigate, using a detailed simulation analysis, the impact of interfering IoT devices and antenna types used on the receiver module of the traffic light on the quality of the radio links.

1 INTRODUCTION

The past decade has witnessed a large growth in the use of Low-Power Wide-Area (LPWA) technologies, which are low cost solutions providing long-range wireless communications. Long range sub-GHz band technologies such as LoRa, SigFox and IEEE 802.15.4 are getting increasingly popular for academic research and daily life applications (Saelens et al., 2019) (Augustin et al., 2016). This growth has a considerable impact on existing applications using the same unlicensed Industrial Scientific and Medical (ISM) bands. One such application is connected traffic lights for visually impaired people.

The use of ISM frequency bands is tightly regulated in European Union (EU) and it must confirm to Short Range Devices (SRDs) regulations. Even though these regulations are respected, sharing of the spectrum between technologies operating in free ISM Band raises serious problems, leading to a degradation of performance, dropping of packets, decreasing of the throughput and malfunctioning of the whole network. Interference could affect the security and the functionality of the network. Due to these reasons mentioned before, transmission of the modulated signal will be subjected to interference from the growing number of devices which can degrade Signal-To-Noise and Interference Ratio (SINR), leading to a greater Bit-Error-Rate BER or in most cases to packet loss.

NF-S32002/A1 protocol (Minaudier et al., 2006) is one of the technologies that comply to the SRDs ETSI standard since it operates at the band centered at $868.3MHz$. This protocol is used to help visually impaired people to communicate with connected pedestrian traffic lights in order to know its current state. Indeed, a visually impaired person will send a radio signal to the traffic light using a remote control. The traffic light will reply with an sound signal indicating its current state. This will help the person to know when it is safe to cross the street.

In this paper, we investigate the impact of ISM interference from technologies using the same frequency band as NF-S32002/A1, such as LoRa and Sigfox, on the traffic light receivers that are deployed in Clermont-Ferrand city center. Consequently, we use simulations to quantify the loss of the signals sent by pedestrians depending on the SINR as well as the bandwidth of the ISM interfering signal. We also study the improvements that the use of directional antennas on the traffic light receiver could bring to the radio link. We demonstrate that directional antennas increasing the resiliency of these receivers against

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ISM interference. We thus show that as the SINR situation improves by mitigating harmful interference the BER performance will be better. We also specify the threshold levels of SINR that should be respected to have low or zero packet loss. We do not propose any modifications to the existing communication standards, we focus on the added value of using a simulation study in order to give deployment guidelines of these wireless systems.

The remainder of this paper is organized as follows. Section II illustrates a brief overview of previous research about ISM interference of co-existing technologies. Section III presents the NF-S32002/A1 protocol. In Section IV we present HTZ simulator and describe the scenarios we used to assess the impact of ISM interference on connected traffic light. Simulation results are then presented in Section V. Finally, Section VI is dedicated for conclusions and perspectives. d.

2 STATE OF THE ART

Modulated signals will suffer from co-technology interference as well as inter-technology interference when operating in ISM bands. Inter-technology ISM interference is attributed to the co-existence of multiple technologies that use the same frequencies of the unlicensed shared ISM bands. To the best of our knowledge, this is the first paper that studies the interference between different long range wireless IoT systems and a short range wireless technology used by pedestrian traffic light receivers.

In (Lauridsen et al., 2017), authors in focused on determining if there is any interference which may impact deployment of Internet of things. Their focus was on LoRa and Sigfox technologies. Another article (Elshabrawy and Robert, 2018) studied the evaluation of BER performance of LoRa modulation when affected by different types of ISM interference. Also, authors quantified the loss of LoRa signal reception sensitivity as function of SINR.

Furthermore, (Lauridsen et al., 2019) presents performance evaluation of a narrow-band wireless Internet of Things technology operating in the 865-868 MHz band. They evaluate the impact of RFID on a narrow-band wireless Internet of Things technology by applying the measured in-band power as interference in a block error rate probability simulation. Their measurement results showed that deploying a wireless IoT technology in the 865-868 MHz band will suffer from areas blocked by interference due to the different transmit power and duty cycle restrictions in the European regulations.

In (Haxhibeqiri et al., 2018), authors showed the evaluation of the impact of other sub-one GHz technologies (SigFox, Z-Wave, IO Home Control) on LoRa technology. Their conclusion was that if the interference starts during the preamble time, losses can be as high as 28% in case of SigFox interference, while losses are reduced, or even tends to zero, if the interference starts by the end of the payload no matter the interfering technology. Also, spreading factor of LoRa technology is considered an effective technique in case of interference since results presented state that there is slightly high losses (5 to 10%) if SF=7 is used instead of SF=12 for the same cases.

In addition, different surveys (Zhang et al., 2018) talked about IoT technologies that share the same spectrum in license and unlicensed bands providing spectrum sharing solutions, interference models, interference schemes and disadvantages of sharing spectrum. In (Guo et al., 2012) they mentioned the mutual interference between different technologies that operates at 2.4 GHz ISM band and suggest ways to resolve interference. Moreover, in (Reynders et al., 2016) authors showed the impact on network performance when any of long range networks are deployed in the same area and discussed the main technologies LoRa and Sigfox. Their main work relied on the radio environment maps of interference and competing base stations that could be very useful to provide context information for these wireless networks. In (Mamadou Mamadou et al., 2020), authors present a survey on techniques in different technologies used in the 5G era that take into account coexistence with other technologies.

As a conclusion, we realized that there is a limited number of papers with specific focus on what may cause interference in the license-free ISM bands and how it may be harmful to short range devices operating in the same spectrum. Moreover, we did not find any studies that have been done on the performance of NF-S32002/A1 protocol which is published in 2014 as a new intelligent wireless transport communication system.

The added value of our paper, with regard to the state of the art, is to measure the signal activity and power levels of the transmission link established between remote-control transmitter and the pedestrian traffic light receivers. The results analysis are mainly focused on the SINR threshold level in case of IoT interfering nodes which are LoRa, Sigfox and Enocean which are typically spread all over in Clermont-Ferrand near the traffic light repeaters.

3 DESCRIPTION OF NF-S32002/A1 PROTOCOL

Traffic lights, in accordance with the decree of January 15, 2007 on application of decree no.2006-1658 of December 21, 2006 relating to the technical requirements for accessibility of roads and public spaces (French ministry of transportation and sea, 2007), include equipment allowing visually impaired people to know when it is possible for them to go through lanes. The associated R12 pedestrian signals must be supplemented by tactile or sound devices. These devices comply with NF-S32002/A1 standard (Leroux, 2009). They are considered as essential elements for optimal operation of pedestrian lights allowing the blind and visually impaired to cross the road knowing the state of the traffic light.

There are approximately 5000 sound beacons published in France by Okeenea according to the ministry of ecological transition of France. The R12 signals, commonly called “pedestrian” figures, are made up of two bright silhouettes, one moving for green, and the other motionless for red. They must include a device allowing blind or visually impaired people to know the periods when the crossing is allowed. This device can be tactile or based on sound. When equipping their pedestrian lights, many cities provide remote controls free of charge to residents who need them. Messages are emitted by these specific devices, which operate permanently, semi-permanently, by manual activation or by remote control activation. These tactile or sound devices are always associated with an R12 signal. For example, when the devices send a tactile message, it is characterized by the emission of a vibrating or rotating movement over a suitable surface for the duration of the signal green R12 associated. Today, the touch is abandoned in favor of sound, which responds much better to the expectations of users. Technical characteristics of repeater devices sound of R12 signals are specified in standard NF-S32002/A1.

The EO-Evasion NF-S32002/A1 remote control is an essential complement to all sound accessibility equipment. It enables all sound devices intended for the visually impaired to be triggered: pedestrian lights, sound beacons, posts, passenger information terminals, etc. These devices meet accessibility standards and, by transforming visual information into sound, improve the mobility and safety. The EO-Evasion universal remote control is therefore an essential tool for a visually impaired person, just like the white cane or guide dogs.

NF-S32002/A1 standard is implemented on the traffic light repeater devices using the radio frequency $868.3 MHz$. This standard puts an end to prejudicial situation for users, since the pedestrian had to have up to three remote controls on them to be able to activate all the lights. After upgrading the remote-control standard one remote control can activate all sound beacons both for safety of pedestrians crossing and orientation around and inside the buildings.

If the sound repeater device is activated by a remote control, it must be able to receive an order which transmission characteristics are described in this next paragraph. This activation is called Interoperability Transmission Link. It should be noted, however, that this mode of activation is not exclusive; other means of transmission may be added to it. For example, the devices may have several other radio activation. The general characteristics must comply with the RTTE 1999/5/EC directive and the harmonized standards: ETSI EN 300 220-1, ETSI EN 301489-3, and ETSI EN 300 220-2 (ETSI, 2019).

The transmission frequency must be centered on $868.3 MHz$, the signal will be transmitted in amplitude modulation at a power less than or equal to 25 mW. When the pedestrian presses the button of the remote-control, an RF signal is transmitted with amplitude modulation (ASK) more specifically with On-Off shift keying (OOK) which is also similar to binary shift keying BPSK from the point of view of channel occupancy. This Remote control is one of the SRDs that obey to duty cycle limitations and a maximum transmission power equal to 14 dBm. The code message that is sent through the RF signal consists of two parts: a header and a code of 24 bits. In fact, there is no MAC layer or a medium access technique or even a data link layer. Whenever the person press the button, an RF signal is transmitted by the physical layer. The bandwidth used in this technology varies between 100 and 300 kHz according to the manufacturer of the remote-control device, and the transmission rate or the bit-rate varies between 2 and 32 kbps (Report ITU-R SM.2153-2,). NF-S32002/A1 standard is designed to operate in France. Nevertheless, the outcome of the study presented in this paper can be applied to other protocols that operate at the 865-868 MHz frequency band.

4 SIMULATION AND EVALUATION RESULTS

All the presented results are done using a simulator tool from the manufacturer ATDI which is HTZ communications. The main functions of this simulator helped us calculate interference levels by using all the required tools to make full analysis of outdoor and indoor coverage by signal penetration, loss calculation and point to point network analysis. Based on a real city map, HTZ is able to provide precise signal propagation impact on the received signal strength taking into account various types of automatically detected obstacles in the map.

In this paper, our basic analysis is to interpret the performance of NF-S32002/A1 protocol that is located in Clermont-Ferrand specifically in traffic light receivers. We have done different interference scenarios to test the received signal quality by interpreting the level of SINR which is the main output of the simulation in addition to the Received Signal Strength Indication (RSSI) which describes the received power level. Each scenario differs from the other by the random distribution of the interfering IoT nodes (LoRa, Sigfox, and En-Ocean) that are located near the traffic light receiver. These simulations describe a real deployment case located in Clermont-Ferrand city. HTZ uses the satellite cartographic maps that have the same projection of map layers including all objects built in the city such us the buildings, streets, the civil surroundings, and every object placed in the area where the traffic lights are located and the scenario takes place. This simulator has a specific tool that takes into consideration the real environment parameters that could affect the signal propagation and penetration, such as obstacles, type of buildings, material permittivity and conductivity, etc. All of these essential tools of the simulator provide a deterministic propagation model that is used into any phase of simulation. This deterministic model includes calculates the generation of propagation losses due to (diffraction, absorption, ducting, reflections) attenuation. Before any simulation, the configuration settings for the base stations and their distributed subscribers must be configured according to the global standards. In this case, traffic light receiver is configured as a base station in order to receive RF signal from the remote-control handled by pedestrians.

In the real deployment, the traffic lights are equipped with omni-directional antenna pattern of a standard gain for SRDs approximately equals to 2.15 dBi. We mainly show the benefits of using a directional antenna in this kind of use cases where the covered zone of the receiver is more or less well identified and situated in a known direction. Thus, all the results are evaluated according to these two antenna patterns in order to compare the impact of interference on the traffic light receiver. Both antennas have the same gain, only the directivity changes. In the case of directional antenna, the directivity would protect the receiver from interference coming from nodes positioned outside the covered zone. For a given user at a specific position in the coverage of the main lobe, the received power for both antennas would be the same. Figure 1 shows the horizontal (on the left in red) and vertical (on the right in blue) patterns of omnidirectional and directional antennas that we used in our simulation scenarios.

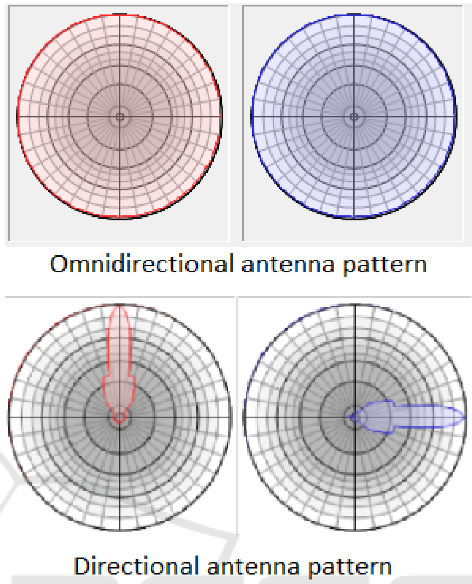

Figure 1: Omnidirectional vs Directional antenna patterns.

The different interference cases that we simulated are the following:

- Scenario 1: the position of the pedestrian is at a typical distance of 25 meters from the traffic light where the interfering nodes and their base stations are distributed randomly in this area. The number of the interfering nodes varies from 25 nodes to 150 nodes.
- Scenario 2: we located the pedestrian at a variable distance from 5 meters to 30 meters from the traffic light receiver. The interfering nodes are generated according to two different densities, 1 node per square meter, and 1 node per 10 square meters.
- Scenario 3: the pedestrian is in front the traffic light receiver at a minimum distance of 5 meters. A single IoT interfering node is placed at 5 meters also from the traffic light. The distance of the interfering node is increased to reach 15 meters from the traffic light.
- Scenario 4: The last interference case describes the case where a large number of indoor IoT subscribers situated inside smart buildings that are located at 10 to 20 meters from the traffic light receiver.

4.1 Scenario 1

We added subscribers around the position of traffic lights with a number varying between 25 and 150 nodes. Then, we assigned an omni-directional antenna as a pattern of the receiver and extracted the needed results to interpret the propagation results. The comparison is done by fixing the pedestrian at the same location but changing the relative IoT nodes. The relative interfering nodes can be wireless sensors placed in parked cars, buildings, people handling such devices, alarms or any vehicle crossing by the street. Second step was to change the pattern to directional one with the same relative positions of all IoT nodes.

According to digital communications calculations of the target SINR for NF S32002/A1 protocol, the SINR objective to ensure a successful reception of the modulated signal with a minimum sensitivity of the receiver (-105 dBm) must be equal or higher than 14 dB. Figure 2 represents the first simulation results. We can realize that SINR value is higher for a directional antenna (SINR = 20dB and SINR = 4dB respectively) when the number of interfering nodes is equal to 25 IoT subscribers. As the number of nodes increases from 25 to 50, the interference level of directional antenna achieves the target SINR but it decreases to reach 15dB while the omni-directional one did not reach the objective SINR and its value reaches -16 dB with 150 IoT subscribers where the directional gives an acceptable value SINR = 10 dB. This means directional antenna equipped at the sound beacons enhances the signal quality between TX/RX and provides a good tuning for the power received.

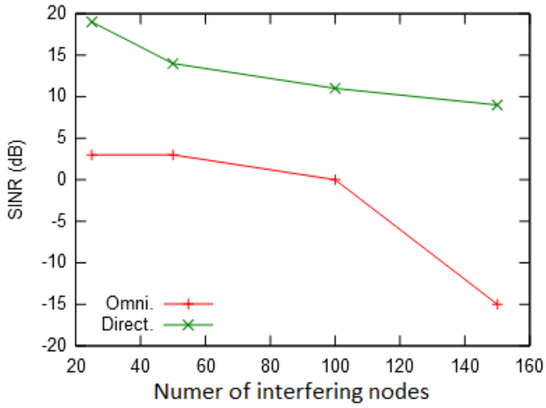

Figure 2: Scenario 1: SINR level with increasing number of interfering nodes.

4.2 Scenario 2

The results in this scenario are divided into two parts. In each case we have different distribution of IoT nodes with respect to city area. High density scenario refers to spreading 1 node per square meter. Low density scenario refers to spreading 1 node per 10 square meters. In this simulation, the distance between the transmitter and the receiver (pedestrian and traffic light respectively) varies from 5 meters to 30 meters. Figure 3 shows the values of SINR for high density scenario with 50 interfering nodes. SINR values for an omni-directional antenna starts with a value of 17.94 dB till it reaches 5.44 dB at 30 meters. As for the directional antenna, SINR level starts at 32.06 dB and drops to 16.91 dB at 30 meters. Hence, using a directional antenna helps achieve target SINR levels (above 14 dB), whereas this level is not achieved with omni-directional antennas for a distance above 10 meters.

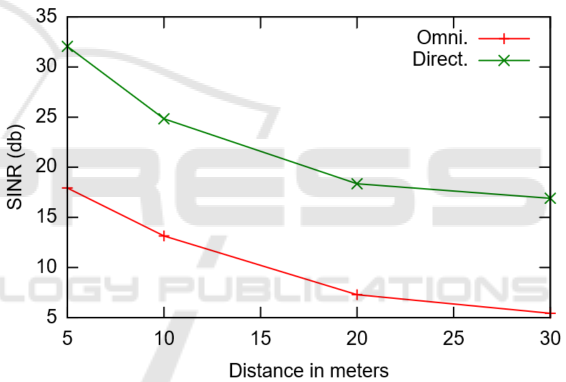

Figure 3: Scenario 2: SINR level with 50 interfering nodes deployed at high density.

With low density scenario, 112 IoT interfering nodes are spread one in 10 square meters. Simulation results in are shown in Figure 4. SINR levels vary from 30 dB to 18 dB when the distance increases from 5 meters to 30 meters respectively. On the other hand, with an omni-directional antenna, SINR levels decrease from 14 dB to 4 dB as the distance between TX/RX reached 30 meter.

4.3 Scenario 3

The results in this scenario show the high impact of one individual IoT interfere located near the traffic light while a pedestrian is trying to activate the sound beacon of the traffic light standing 5 meters away. In this simulation we moved the interfering node gradually. Figure 5 shows the variation of SINR values with respect to the increasing distance between the

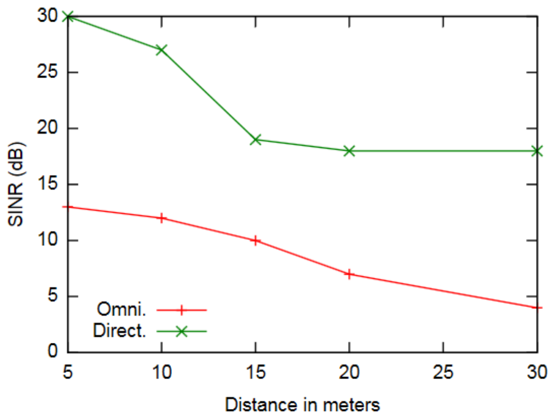

Figure 4: Scenario 2: SINR level with 112 interfering nodes with density 1/10.

interfering node and the traffic light. When the interfering node is at 5 meters, the values of SINR are -7 dB and -26 dB for directional and omni-directional antenna respectively. This shows the unsuccessful activation of NF S32002 protocol due to high interference level from the IoT interfered but still has a lower impact when a directional antenna is used on the receiver. In addition to that, notice that SINR increases to achieve a target value SINR of 15 dB when the distance was 10 meters and remains constant as the distance increases to 15 meters. On the other hand, SINR did not reach the target value in omni-directional case and remains below the required value in all distance sections.

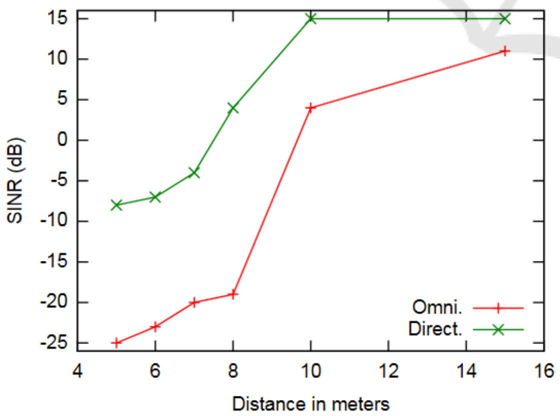

Figure 5: Scenario 3: SINR level with 1 inteferer node.

4.4 Scenario 4

This interference case describes the absence of interferes in the street close to the traffic light receiver but we generated a large number of indoor IoT subscribers inside the buildings that are close by. The pedestrian is at a fixed minimum distance in-front of the traffic light (5 meters). HTZ Communication simulator supports powerful tools that allows us to generate indoor subscribers placed in specific floors in the buildings, or any place in the clutter of the map like roofs of buildings, roads, forests, etc. The objective here is to determine the impact of a smart building equipped with many IoT devices sharing the spectrum of 868MHz band at the same time when a pedestrian crossing the road. Figure 6 shows the google hybrid map with the distribution of indoor subscribers. Results of SINR are also represented in the graph showing the difference of values according to the pattern of antenna used.

Results showed, in case of omni-directional pattern used on the receiver, that the SINR value was -1.55 dB which is way under the threshold values while the directional antenna achieved an SINR of 24.5 dB. This simulation explains the influence on the interference level due to these indoor distributed IoT sensors in buildings that lead to increase the propagation losses. This is of course a worst case scenario study, but the rational behind it is that in the near future more and more buildings will be equipped with wireless IoT objects.

Overall, results of SINR levels show the need to use directional antennas to mitigate interference from IoT devices. Bare in mind that using directional antennas will reduce the coverage area of the traffic light receiver. This is why a careful deployment and positioning of these receivers should be done taking into consideration pre-deployment simulation results for better estimation. We argue that in this paper we showed how using a realistic radio systems and signal propagation simulator helps better estimate possible interference levels when deploying wireless communication systems.

5 CONCLUSION AND PERSPECTIVES

Wireless technologies are being used in many applications in our everyday life. A big part of the wireless technologies used by these applications use unlicensed ISM bands for data transmission. With the limited resources in the ISM band, this creates cases of interference that might render the application non-operational due to data loss. In this paper, we focused on the specific use case of connected pedestrian traffic lights. These traffic lights are used to help the visually impaired to be aware of the state of the traffic light. Pedestrians use a remote control that operates at the 868MHz ISM band in order to communicate with the

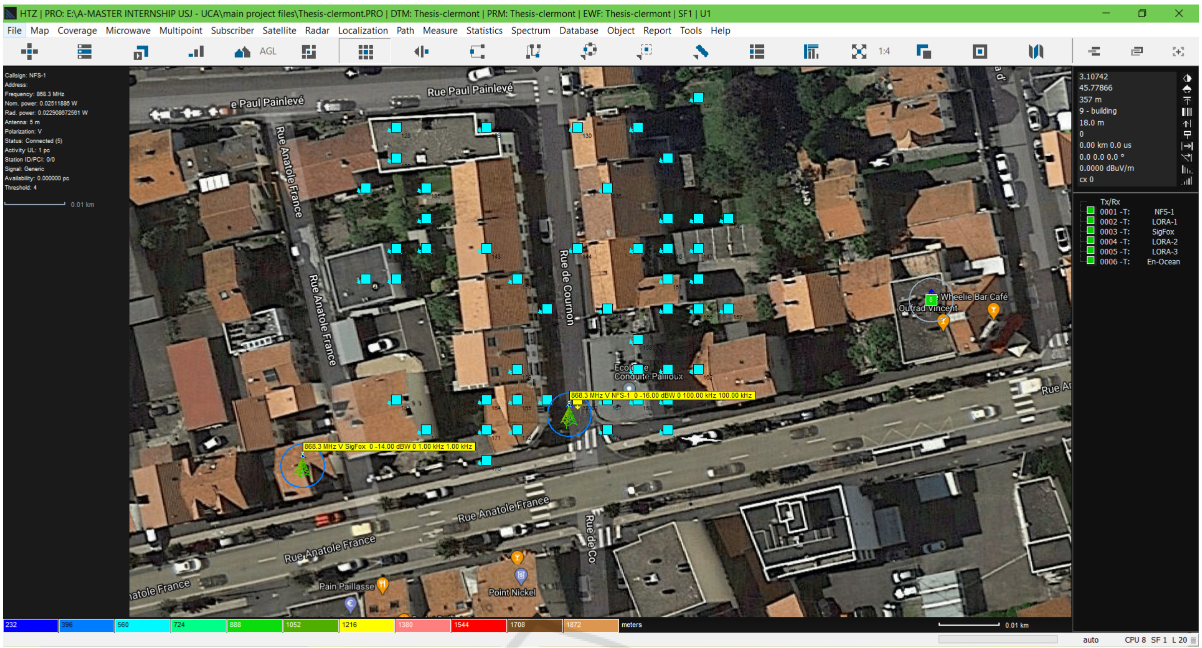

Figure 6: Screenshot of HTZ simulator showing the placement of IoT nodes inside the buildings near the traffic light.

traffic light.

We studied the impact of interference in the 868MHz band on these traffic light receivers using a state of the art RF simulator called HTZ. We presented many scenarios where possible interference might occur due to the presence of near by IoT wireless devices using technologies such as LoRa, SigFox or En-Ocean. We emphasized on the importance of using a directional antenna on the traffic receiver in order to enhance the SINR level and resist against interference. The downside of using a directional antenna might lead to limited covered, thus, it is very important to carefully adjust the position of antennas and their direction.

In our future studies, we will troubleshoot some connected traffic lights deployed in Clermont-Ferrand city. Some of these traffic lights do not respond reliably to remote controls. We will analyse the deployment of these specific traffic lights and compare the RF measurements to what we obtained in our simulations in order to propose adequate solutions.

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