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Interference Measurements in the European 868 MHz ISM Band with Focus on LoRa and SigFox

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***Abstract*—In this measurement study the signal activity and power levels are measured in the European Industrial, Scientific, and Medical band 863-870 MHz in the city of Aalborg, Denmark. The target is to determine if there is any interference, which may impact deployment of Internet of Things devices. The focus is on the Low Power Wide Area technologies LoRa and SigFox.**

The measurements show that there is a 22-33 % probability of interfering signals above -105 dBm within the mandatory LoRa and SigFox 868.0-868.6 MHz band in a shopping area and a business park in downtown Aalborg, which thus limits the potential coverage and capacity of LoRa and SigFox. However, the probability of interference is less than 3 % in the three other measurement locations in Aalborg. Finally, a hospital and an industrial area are shown to experience high activity in the RFID subband 865-868 MHz, while the wireless audio band 863-865 MHz has less activity.

I. Introduction

The number of connected devices and sensors, constituting the Internet of Things (IoT), is increasing year by year, and wireless connectivity is a key enabler for continued growth. Cellular technologies such as GPRS and Narrowband-IoT [1] are designed to provide this service, but recently Low Power Wide Area (LPWA) technologies such as LoRa [2] and SigFox [3] have emerged. As opposed to the cellular technologies they operate in unlicensed bands, which reduces the deployment cost, but also means the spectrum must be shared with other technologies and devices according to spectrum regulations.

In Europe LoRa and SigFox will operate in the Industrial, Scientific, and Medical (ISM) 863-870 MHz band. This band allows wireless audio, Radio Frequency Identification (RFID), alarms, and general purpose devices to transmit provided that they obey duty cycle or Listen-Before-Talk rules [4], [5]. The multitude of devices is described in [6], which outlines subband usage within the 868 ISM band and the expected evolution in terms of number of devices. LoRa and SigFox rely on the duty cycle access method and thus the transmissions may be subject to interference from the growing number of devices, which can cause a degraded Signal-to-Noise-and-Interference Ratio (SINR) and in the worst case a lost packet. In order to evaluate the coverage and capacity of LoRa and SigFox it is thus of key importance to study the current signal activity and power levels in the European 868 MHz ISM band.

In previous work the authors of [7] study activities in the ISM bands of 169 MHz, 433 MHz, and 868 MHz in two German cities, but don't explain the scenario and what may cause the observed interference. In addition, the measurements were performed in September 2013 and thus with a lower number of transmitting devices as compared to today, according to [6]. 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 problematic to other devices. Examples include [8] where the authors measure received power for certain locations from 200 MHz to 3 GHz, and note that car keys generate noise in the 868 MHz band, while a car passing 5 m from the receiver may generate noise levels up to -95 dBm. In [9] it is studied how RFID deployment in 865-868 MHz may affect military telecommunication devices, while another study on RFID evaluates the potential effect on medical equipment [10]. Overall there are more papers focusing on the 2.4 GHz ISM band, which is also utilized by WiFi and Bluetooth, and one study of a specific noise source is [11] where the effect of a microwave oven, generating noise in the 2.4 GHz ISM band is studied with focus on LPWA networks. However, there is very little information available on 868 MHz ISM band interference for different scenarios such as urban, industrial and residential areas, and in addition the effect on LPWA networks is not considered.

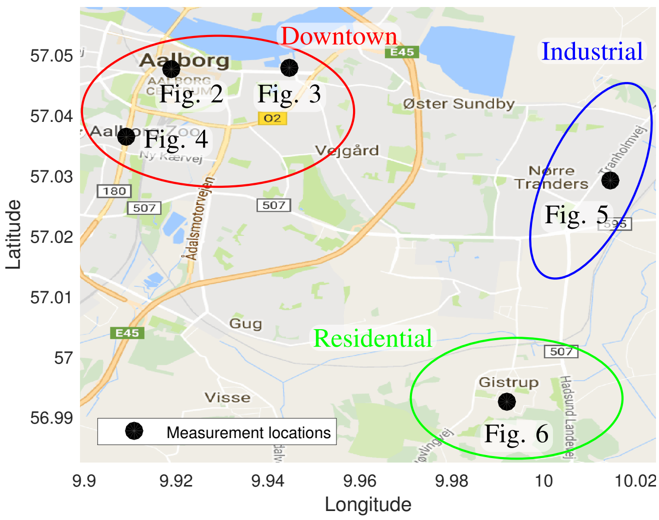

Fig. 1. The five measurement locations within Aalborg municipality.

The contribution of this paper is therefore to measure the 868 MHz ISM band signal activity and power levels in Aalborg in five distinct locations illustrated in figure 1; a *shopping area*, a *business park*, a *hospital complex*, an *industrial area*, and a *residential area*. The measurement analysis is specifically performed with focus on what the interference source may be

TABLE I
SUBBANDS AND THEIR APPLICATIONS IN THE EUROPEAN 868 MHZ ISM BAND. BASED ON [4], [5].

Category	Frequency [MHz]	Standardized application	Max ERP	Duty cycle	Potential devices
	863.00 - 870.00	Non-specific use	25 mW	0.1 % or LBT+AFA	For narrow- and wideband devices including spread spectrum techniques
Audio	863.00 - 865.00	Radio microphones	10 mW	None, see [4]	Microphones, wireless audio, and streaming
	864.80 - 865.00	Wireless audio	10 mW	None, see [5]	E.g. baby alarms and wireless headphones
RFID	865.00 - 868.00	RFID	2 W	None, see [12]	RFID readers and tags
Alarms etc.	868.00 - 868.60	Non-specific use	25 mW	1 % or LBT+AFA	Wireless-M, Z-Wave, IEEE 802.15.4 technologies, *LoRa*, *SigFox*
	868.60 - 868.70	Alarms	10 mW	1 %	Fire and intruder
	868.70 - 869.20	Non-specific use	25 mW	0.1 % or LBT+AFA	Industrial applications, wireless-M
	869.20 - 869.25	Social alarms	10 mW	0.1 %	Telecare (self/automatic triggered alarms)
	869.25 - 869.30	Alarms	10 mW	0.1 %	Fire and intruder
	869.30 - 869.40	Alarms	10 mW	1 %	Fire and intruder
	869.40 - 869.65	Non-specific use	500 mW	10 % or LBT+AFA	Industrial data links & communication devices, Wireless-M, *LoRa*, *SigFox*
	869.65 - 869.70	Alarms	25 mW	10 %	Fire and intruder
	869.70 - 870.00	Non-specific use	25 mW	1 % or LBT+AFA	Fire and intruder

and how the interference may affect LoRa and SigFox.

The paper is structured as follows; in section II the band under study and its spectrum usage regulation is described, in section III the measurement setup and scenario is presented, and in section IV the main results are presented together with a view on the probability of interference per location. Finally, we present a discussion and the conclusion in sections V and VI, respectively.

II. THE 868 MHZ ISM BAND AND ITS APPLICATIONS

There are multiple European ISM bands, which are defined by the European Union, more specifically the European Telecommunications Standards Institute (ETSI). In this work the focus is on the 863.0-870.0 MHz band, in short referred to as the 868 MHz ISM band.

The 868 MHz ISM band is a license-free spectrum, which can be utilized by almost any device as long as it obeys the spectrum use regulations. The usage is defined in terms of bandwidth, the Effective Radiated Power (ERP), and the spectrum access method, which for the 868 MHz ISM band relies on either duty cycling or Listen-Before-Talk (LBT) [4], [5]. The duty cycle is defined over 1 hour and describes the maximum accumulated time one device can occupy the specific channel, e.g. 1 % allows 36 s of transmission per hour. The LBT method enforces the transmitter to listen to the target channel for at least 5 ms before it initiates a transmission. The transmission may only start if the channel is found not to be occupied, and otherwise the transmitter has to wait. Furthermore, the LBT also enforces certain maximum transmit time limitations, which are 1 s for a single transmission and 4 s for a dialog or polling sequence. The total accumulated time of transmission may not exceed 100 s within 1 hour. The LBT devices can however apply Adaptive Frequency Agility (AFA), which enables the device to switch to a different channel and thus accumulate longer transmission times across channels. Finally, the LBT transmitter must also remain silent for at least 100 ms after a transmission.

The 868 MHz ISM band is split into 3 bands, each targeting a specific device category as given in table I. The lower band (863-865 MHz) is designated wireless audio, the middle band (865-868 MHz) is designated RFID devices, and the upper band (868-870 MHz) is designated alarms, but has also started to see usage for more general types of communication [6]. Each of the bands is split into multiple subbands, which have different spectrum regulations as listed in table I. Note there are specific subband channel spacing requirements, which are not listed in the table. Refer to [4], [5] for further details.

The RFID band (865-868 MHz) is a special case of the ISM band and defined in further detail in [12]. The ETSI standard defines four 200 kHz wide high power channels, spaced with 600 kHz and starting in 865.7 MHz. The maximum ERP of such a channel is 2 W for an antenna having a maximum beamwidth of 90 degrees, while it is lower for larger antenna beamwidths. The high power channels are utilized by the interrogators, which are able to activate any adjacent RFID tag and read the data the tag contains. The RFID tags are then able to respond in the spectrum in between the four high power channels, but is only allowed to transmit with -20 dBm. The interrogator can transmit continuously up to 4 s before it must remain silent in the channel for at least 100 ms. However, similar to the AFA functionality of LBT it can switch to another channel instead of stopping the transmission.

As indicated in the final column of table I each subband may be utilized by different types of equipment. The British Office of Communication have published a report [6], which provides details on the different applications and equipment types and their expected growth rates. However, many other devices have appeared for the subbands with *non-specific use*. The LoRa and SigFox Low Power Wide Area technologies are targeting to utilize the 868.0-868.6 MHz band for uplink and potentially the 869.4-869.65 MHz for downlink due to the 0.5 W transmit power. However, they may also utilize other parts of the 868 MHz ISM band if needed. Besides LoRa and SigFox, the Personal Area Network physical layer standard IEEE 802.15.4

[13] allows technologies such as ZigBee and WirelessHART to utilize the 868.0-868.6 MHz channel. Other short range technologies, which utilize this channel include the home-automation technology Z-Wave [14] and Wireless-M [15]. The latter technology can be used for remote meter reading and is also targeting other *non-specific use* subbands as indicated in table I. One example is the 868.7-869.2 MHz channel, which besides Wireless-M is utilized by certain industrial applications [16]. As mentioned previously the 869.4-869.65 MHz band allows ERP up to 0.5 W and therefore LoRa, SigFox, and Wireless-M all target it in addition to various industrial applications and communication devices [17].

III. Measurement Methodology

The purpose of this work is to examine the signals, if any, in the 868 MHz band. According to table I the band is composed of many smaller subbands, which accommodate various applications and thus traffic patterns. In order to capture as many of these different patterns as possible, even at low received power levels, the Rohde & Schwarz TSMW radio network scanner with Romes 4.82 software was applied. The scanner was set to measure from 863 MHz to 870 MHz using 7 kHz bins and 200 ms sampling time. The total measurement time per location was two hours to capture at least two periods of the duty cycle, which is specified over one hour [5]. The scanner comes with a calibrated, omni-directional antenna and has a sensitivity of approximately -115 dB in the $870\,\text{MHz} - 863\,\text{MHz} = 7\,\text{MHz}$ bandwidth [18]. Finally, a van with DC-to-AC converter was used to supply the scanner and the laptop recording the measurements, while the antenna was mounted on the van's roof.

The measurements were performed at five distinct locations within Aalborg, which has approximately 125k inhabitants, during normal working hours in weekdays. The locations are illustrated in figure 1. The three downtown measurements were made in a *shopping area* with shopping streets and 3-5 storey apartment buildings, a *business park* with office buildings and 3-5 storey apartment buildings, and a *hospital complex* with multiple, large hospital buildings and some single family houses. The *industrial area* in figure 1 consists of industrial production facilities and office buildings, while the *residential area* is a suburb of Aalborg with single-family houses. All measurements were performed while parked in a parking lot or at the roadside, that is at street level.

Besides examining the overall signal activity and power levels in the 868 MHz ISM band at each location, the measurements in the 868.0-868.6 MHz and 869.4-869.65 MHz channels, targeted by LoRa and SigFox, are post-processed sample by sample. The goal is to determine the probability of samples (200 ms x 7 kHz) being above a -105 dBm threshold, which is 10 dB above the scanner's sensitivity as suggested by [7]. Such high power samples will affect the LoRa and SigFox systems' performance because the SINR is degraded. The LoRa technology applies spread spectrum modulation to spread the interference across the receive bandwidth [2], while SigFox utilizes frequency hopping by transmitting the same

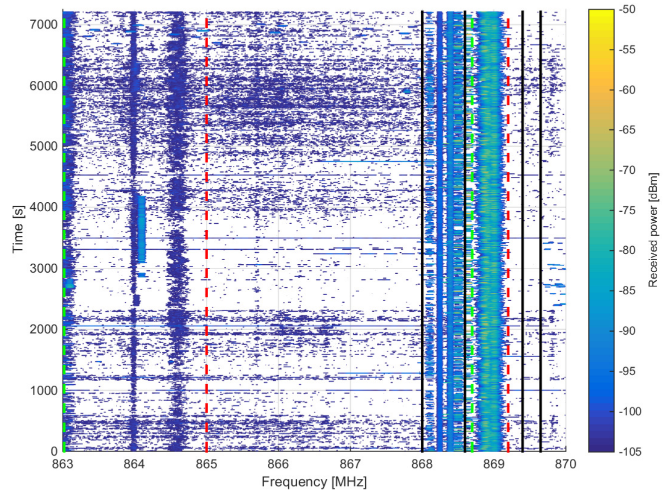

Fig. 2. Measurement in the *shopping area*. The area is in downtown Aalborg and consists of shopping streets and 3-5 storey apartment buildings.

packet on three separate channels [3]. Independently of the interference mitigation mechanism it is interesting to determine the probability of high power samples in the measurements, and this result is provided after the main measurement results in the next section. In addition, the power level distribution is provided for the 868.0-868.6 MHz band based on normalized histograms for each measurement location.

IV. Measurement Results

The measurements and related observations per location are given in this section, followed by the view on interference probability and power level distributions.

Figure 2 shows the measurement result from the *shopping area* in downtown Aalborg. The result is examined subband by subband according to table I and marked with a dashed red line at the lower frequency bound and a dashed green line at the upper frequency bound. The two channels, which are of particular interest to LoRa and SigFox are marked with black lines. The first observation is the activity in the audio band of 863-865 MHz. This band is not duty cycle restricted and thus nearly continuous activity is observed. The next band with high activity is the mandatory LoRa and SigFox 868.0-868.6 MHz band. The measurement show two almost continuous signals centered at 868.25 MHz and 868.4 MHz with -97 dBm and -93 dBm power levels, respectively. Since the band is restricted to a 1 % duty cycle or use of LBT with a maximum continuous transmission time of 1 s and accumulated time of 100 s in one hour, there are either some devices which seem to be violating the regulations or a large number of devices each transmitting frequently. According to table I the signals may originate from Wireless-M meter reading or home automation systems. In addition to the two main signals there is also quite high activity levels in the rest of the 868.0-868.6 MHz band and therefore LoRa and SigFox will experience significant interference in this area of the city. The final band with activity in the *shopping area* is

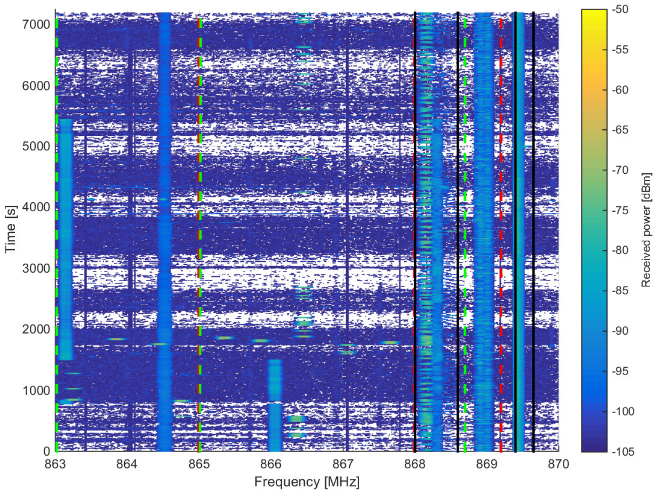

Fig. 3. Measurement in the *business park*. The area is in downtown Aalborg and consist of office buildings and 3-5 storey apartment buildings.

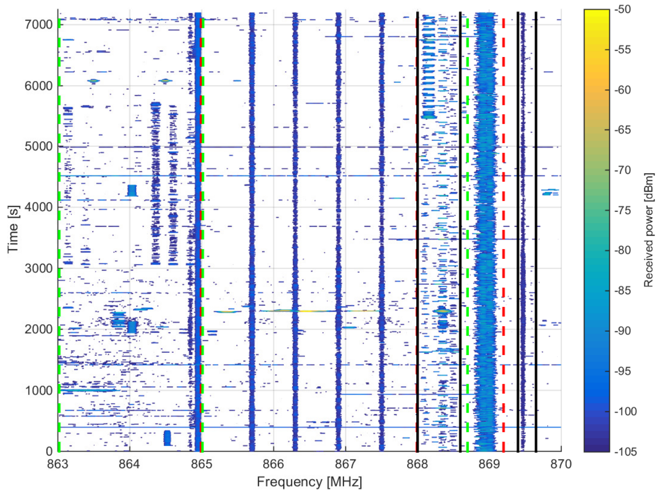

Fig. 4. Measurement in the *hospital complex*. The area is in downtown Aalborg and consists of multiple hospital buildings and single-family houses.

the 868.7-869.2 MHz band that despite its 0.1 % duty cycle restriction shows an almost continuous transmission with signals stronger than −70 dBm. From a LoRa and SigFox perspective the potential downlink band 869.4-869.65 MHz seems not to be utilized in this area.

The next measurement result, illustrated in figure 3, from downtown Aalborg was performed in the *business park*. Similar to the previous observation there is activity in the non-duty cycled audio band below 865 MHz. The 868.0-868.6 band is again shown to be highly occupied, containing a signal with 5 s periodic behavior with power levels above -75 dBm and another weaker periodic signal. Similar to the previous measurement the 868.7-869.2 MHz band is occupied, probably by the same source, and in addition the band 869.4-869.65 MHz contains a strong continuous signal of approximately -80 dBm which may prevent efficient LoRa and SigFox downlink operation. The signal may originate from Wireless-M meter interrogation and updates or industrial data links in the offices, see table I. Note that the general noise level in the entire 868 MHz ISM band in this location is above -105 dBm during most of the measurement time.

The final measurement in downtown Aalborg was performed in the *hospital complex*. The results are illustrated in figure 4 and activity in the audio band is again noted, especially in the narrow 864.8-865 MHz band defined by [5]. The hospital is known to utilize RFID for tracking of medical equipment, beds, and other objects that are moved within the complex, and this is also evident from the measurement, which shows high activity in the four interrogator subbands of the 865-868 MHz RFID band. The 868.0-868.6 MHz band is much less occupied as compared to the other downtown measurement locations, and the transmitting devices seem to respect the duty cycle restrictions. For example one or more devices start transmitting after 5500 s, and it/they follow a pattern of 5-7 messages with 5 s interarrival time every 100 s. Similar to the previous locations, activity is observed in the 868.7-869.2 MHz band, and the strong signal is expected to be from the same source. This may also be the case for the weak signal in the 869.4-869.65 MHz band.

The next measurement was performed in the *industrial area* east of downtown Aalborg as indicated in figure 1. As expected, the industry applies RFID for tracking of goods and equipment, and therefore activity is observed at the four interrogator carriers of the RFID band 865-868 MHz. The 868.0-868.6 MHz band has periodic activity on three specific carriers; 868.2 MHz, 868.35 MHz, and 868.5 MHz, but the power levels rarely exceed -100 dBm. One signal source may be the industrial WirelessHART technology using IEEE 802.15.4. Combined with the low periodicity, LoRa and SigFox should be able to operate in this area with a limited number of collisions. Again a very strong and almost continuous signal is observed in the 868.7-869.2 MHz band and if it is the same source it may be located somewhere between the *industrial area* and the *business park*, because the latter measurement, shown in figure 3 also showed high received power. Note that the potential downlink LoRa and SigFox band 869.4-869.65 MHz is virtually empty.

The final measurement was performed in the *residential area*. In the first 1300 seconds of the measurement a signal exceeding -70 dBm is observed in the audio band 864.8-865 MHz, and this could be an alarm placed in a baby carriage outside a house. It is interesting to note that there is quite a lot of activity in the 868.0-868.6 MHz band in this area, and it may be due to IEEE 802.15.4 home automation technologies and Wireless-M meter reading according to table I. However, the low power and periodicity should not be a significant issue for LoRa and SigFox operations and in addition the downlink band 869.4-869.65 MHz is not occupied. The *residential area* is the first measurement location where activity in the 869.7-870.0 MHz band is observed, but it is highly sporadic.

The two hour measurements at each of the five locations have shown that the bands of interest for LoRa and SigFox have very different levels of activity. Table II provides the probability of experiencing a signal above -105 dBm per

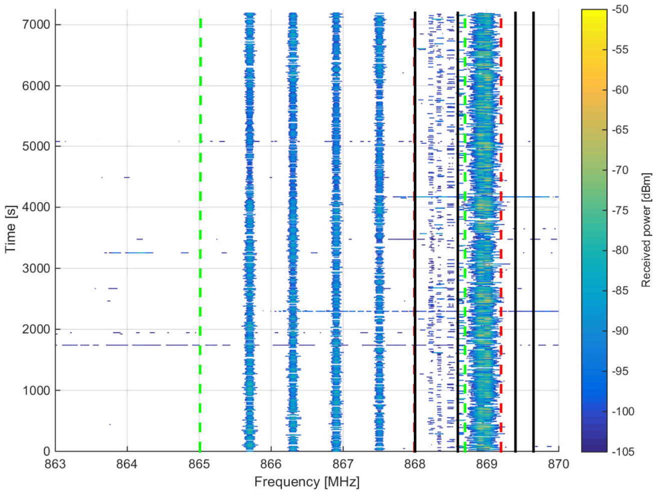

Fig. 5. Measurement in the *industrial area*. The area consists of industrial production facilities and office buildings.

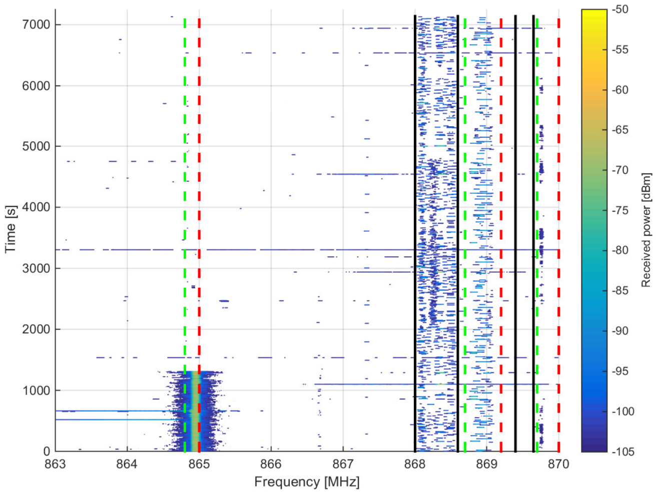

Fig. 6. Measurement in the *residential area*. The area is a suburb to Aalborg and consists of single-family houses.

location and band. The probability p is calculated as:

$$p = \frac{\sum_{i=1}^{N} \chi(R(i))}{N} \text{ where } \chi(R) = \begin{cases} 1 \text{ if } R > -105\,\text{dBm} \\ 0 \text{ if } R \leq -105\,\text{dBm} \end{cases} \quad (1)$$

and R is the received power samples (7 kHz x 200 ms) and N is the total number of samples. The *shopping area* and *business park* measurement locations in downtown Aalborg, illustrated in figures 2 and 3 were observed to have almost continuous, high power signals in the 868.0-868.6 MHz band and this is reflected in probabilities of 22-33 %. In addition, the potential downlink band 869.4-869.65 MHz also has an interference probability of almost 60 % in the *business park*. The *hospital complex*, *industrial area* and *residential area* all reported periodic activity in the 868.0-868.6 MHz band, but the probabilities are in the order 1-3 %.

Figure 7 illustrates the received power level probability density function (PDF) for the five measurement locations. The probabilities are calculated for the 868.0-868.6 MHz band, and

TABLE II
INTERFERENCE PROBABILITIES FOR SELECTED CHANNELS. MODELED FOR SAMPLES STRONGER THAN -105 DBM.

Location	**Figure**	**868.0-868.6 MHz**	**869.4-869.65 MHz**
Shopping area	2	33.7 %	0.9 %
Business park	3	22.8 %	58.2 %
Hospital complex	4	2.6 %	6.3 %
Industrial area	5	1.0 %	0 %
Residential area	6	2.3 %	0.1 %

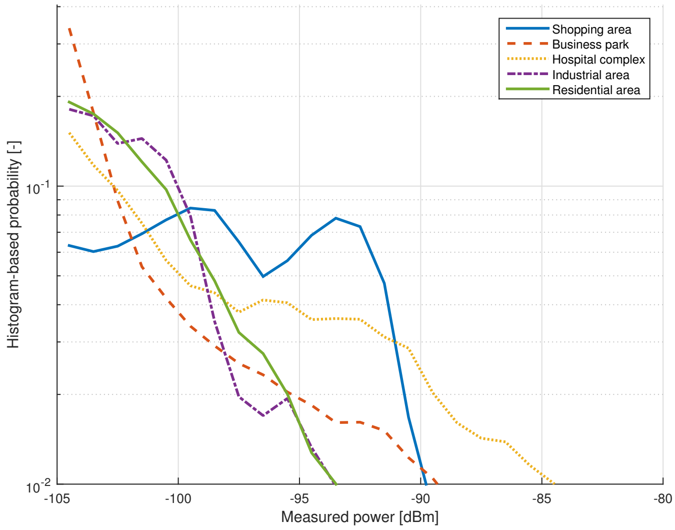

Fig. 7. Received power level probability density function based on a normalized histogram of the measurements in the 868.0-868.6 MHz band.

when comparing with the results in table II it is interesting to note that the power level PDF for the *business park*, which has 23 % probability of occurrence, is fast decaying as compared to the *shopping area*. The latter location has two peaks at 7-8 % that are stronger than -100 dBm and may therefore impose significant interference towards LoRa and SigFox. The *industrial area* and the *residential area* have similar power level PDFs and less than 2 % probability of powers stronger than -95 dBm. Finally, the power level PDF of the *hospital complex* is observed to have a long tail and therefore signals of -85 dBm to -100 dBm may be observed with 1-5 % probability.

V. DISCUSSION

The measurement results have shown a very diverse utilization of the 868 MHz ISM band in Aalborg. In the *shopping area* and *business park* the general interference level is high and there is a number of devices, which transmit in the 868.0-868.6 MHz band with 22-33 % probability. This may be a significant issue, when considering a deployment of LoRa and/or SigFox to support the Internet of Things in downtown Aalborg, especially when taking into account the probability of collision due to transmissions from other SigFox and LoRa devices. However, the measurements have also showed that the *hospital complex*, *industrial area*, and *residential area* have activity levels below 5 % within the band of interest. In addition, the potential downlink band 869.4-869.65 MHz is virtually unused except for the *business park*. This is a bit surprising since this bands allow for ERP of 0.5 W and 10 % duty cycle, and it should thus be a good candidate for long range or deep indoor transmissions.

In future work we target to quantify how the observed interference affects the coverage and capacity of LoRa and SigFox [19]. This initial measurement study has shown that the interference is present in certain locations, but the sampling resolution in time and frequency is not sufficient to propose an accurate interference model. Therefore a first next step will be repetition of the measurements at selected locations, but focused on the 868.0-868.6 MHz band with a granularity that matches the LoRa and SigFox channel bandwidths and message durations. In addition, the measurements must be performed for a longer period to determine whether there is a correlation with the time of day, as reported by [7]. Finally, it is important to adjust the scanner to obtain higher sensitivity that better matches the capability of LoRa and SigFox devices. Narrowing the scanner bandwidth from the current 7 MHz to 600 kHz will yield a significant improvement in this direction.

When developing an accurate interference model based on new measurements in Aalborg it is important to consider the model's applicability. The current measurements were performed outdoor, but many devices may be indoor experiencing a different propagation environment, antenna height and pattern. Furthermore, the LoRa and SigFox technologies are strongly uplink centered and therefore it may be more important to model the interference at the potential base station location. Aalborg University have LoRa and SigFox base stations and devices available and it is thus possible to perform received power and interference measurements at both ends.

VI. Conclusion

This measurement study has shown that there is significant activity in the 868 MHz Industrial, Scientific, and Medical band in the European city Aalborg with 125k inhabitants. The Low Power Wide Area technologies LoRa and SigFox, which are targeting to facilitate the wireless Internet of Things, may be strongly affected in terms of coverage and capacity, because the measured activity degrades the Signal-to-Interference-Ratio and may even block access to the target channel.

The measurements were performed in five distinct locations; a shopping area, a business park, a hospital complex, an industrial area, and a residential area. The received power was measured in the 863-870 MHz unlicensed band using a Rohde & Schwarz radio network scanner for two hours during normal working hours. The mandatory LoRa and SigFox 868.0-868.6 MHz band was shown to be occupied by signals stronger than -105 dBm with a probability of 22-33 % for the shopping area and business park, while having less than 3 % probability of interfering signals in the industrial and residential areas. The measurements also show that the potential downlink band 869.4-869.65 MHz is only used in the business park, where the probability of a signal however exceeds 55 %.

The 863-865 MHz audio band is not duty cycle restricted and in four out of five locations a continuous high power signal was observed, making it infeasible for deployment of Lora and SigFox. As expected the industrial and hospital areas employ RFID for tracking of goods and equipment and thus the band 865-868 MHz is occupied by strong RFID interrogator signals, which may prevent LoRa and SigFox deployment. However, the subbands between the four interrogator carriers may be applicable since the carrier spacing is 600 kHz.

The planned future work is a more detailed measurement in the 868.0-868.6 MHz band in order to model the interference. An accurate model will enable an analysis of the ISM band interference effect on LoRa and SigFox coverage and capacity.

Acknowledgment

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