Aalborg Universitet

Feasibility of deploying wireless Internet of Things in the unlicensed European 865-868 MHz band

Lauridsen, Mads; Frederiksen, Frank; Rodriguez, Ignacio

Published in:
2019 IEEE Wireless Communications and Networking Conference (WCNC)

DOI (link to publication from Publisher):
10.1109/WCNC.2019.8886048

Publication date:
2019

Document Version
Accepted author manuscript, peer reviewed version

Link to publication from Aalborg University

Citation for published version (APA):
Lauridsen, M., Frederiksen, F., & Rodriguez, I. (2019). Feasibility of deploying wireless Internet of Things in the unlicensed European 865-868 MHz band. In *2019 IEEE Wireless Communications and Networking Conference (WCNC)* (pp. 1-5). Article 8886048 IEEE. https://doi.org/10.1109/WCNC.2019.8886048

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal -

Take down policy
If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.

Feasibility of deploying wireless Internet of Things in the unlicensed European 865-868 MHz band

Mads Lauridsen, Frank Frederiksen
Nokia Bell Labs
Aalborg, Denmark
{mads.lauridsen,frank.frederiksen}@nokia.com

Ignacio Rodriguez
Department of Electronic Systems
Aalborg University, Denmark
irl@es.aau.dk

Abstract—**The European Commission has made the unlicensed 865-868 MHz band available for deployment of wireless Internet of Things. The band is mainly used by RFID systems, but the current activity levels are unknown. In this paper, the in-band power levels are measured in five areas. The measurements show that RFID interrogators emit high-power single tone-like signals in four subbands, when active. Most signals are 0.4 s long, but it differs whether the subbands are used in a coordinated way or not. In some areas the RFID systems use a single subband about 80 % of the time, while in other areas two to three subbands are occupied simultaneously 65-80 % of the time.**

The measurements are used to evaluate the performance of a narrowband wireless Internet of Things technology, if it were to be deployed in the 865-868 MHz band. Specifically, the measurements serve as interference input in a calculation of error rate probability. If the least interfered subband is always selected for the wireless Internet of Things transmission the error rate is 0 % for desired signals up to -115 dBm, while if the subband with highest average interference is used, the error rate is up to 7.5 % and at least 25 % at -100 dBm and -120 dBm, respectively.

I. Introduction

The Internet of Things (IoT) is currently growing significantly, both in terms of use cases, deployed networks, and number of devices [1], [2]. A key enabler for the IoT is wireless connectivity between the nodes, being sensors or nodes, and the Internet, because it enables easy and flexible deployment in most locations. In June 2016, the 3rd Generation Partnership Project (3GPP) standardized the Narrowband IoT (NB-IoT) and enhanced Machine Type Communication (eMTC) to address the need for cellular IoT with long range and long device battery life time [3]. Currently operators worldwide are deploying the 3GPP IoT technologies, and according to the GSMA there are currently 66 commercial launches [2]. Thus operators need licensed spectrum, and even though NB-IoT and eMTC only require 180 kHz and 1.08 MHz, respectively [3], it may be a challenge to re-allocate the bandwidth from other systems. Therefore, one alternative option is to use unlicensed spectrum, as LoRa and Sigfox, which are the main competitors to 3GPP's IoT technologies in Europe, do [4]. Consequently, the MulteFire Alliance, which was formed in 2015 to enable operation of LTE-based technology in unlicensed bands [5], is currently evaluating whether the 3GPP IoT technologies can be deployed in unlicensed bands. Contrary to the 20 MHz LTE-like version of MulteFire 1.0.1 in 5 GHz [5], the Alliance is looking towards lower frequency bands, preferably < 1 GHz, to improve the coverage and reduce the outdoor-to-indoor penetration loss [6].

In Europe there are two options for < 1 GHz deployments; the 433.05-434.79 MHz and the 863-870 MHz unlicensed bands [7]. The usage of these bands is restricted in terms of transmit power and duty cycle. The latter defines the sum of transmission time a device may have within a window of one hour, e.g. 1 % corresponds to 36 s. Multiple wireless IoT technologies, such as LoRa and Sigfox, have selected the 868.0-868.6 MHz band as their mandatory band [4]. The reason is the good trade-off between bandwidth, a transmit power of up to 25 mW, and a duty cycle of 1 %. However, our previous measurement study [4], on the activity in this band, indicates that intra-band interference may make it challenging to utilize this band today, and even more challenging in the future, when more IoT devices are deployed [1]. Fortunately, the European Commission is aware of the issue and thus made new legislation that makes more < 1 GHz spectrum available with higher transmit power and lower duty cycle restrictions as compared to the 868.0-868.6 MHz band [8].

In this paper, we examine the four 200 kHz subbands in the 865-868 MHz band, which has been made available for *non-specific short-range devices* [8]. We specifically analyze the feasibility of deploying narrowband (NB) wireless IoT. The new European legislation allows a transmit power of up to 500 mW in the four subbands and a duty cycle of 10 % for access points and 2.5 % for other devices [8]. These restrictions allow for a better link budget and higher activity factors than the regular 868.0-868.6 MHz band. The catch is that the four subbands originally were dedicated to Radio Frequency ID (RFID) interrogators (the tag readers) [9]. Since RFID tags are passive devices the interrogators are allowed to transmit with 2 W [7]. Therefore, there may be areas, where the RFID technology is deployed, with significant activity and power levels. In legacy EU legislation non-specific short-range devices are also allowed to use the 865-868 MHz band, but due to the 0.1 % duty cycle and 25 mW transmit power limitation [7], negligible activity and power levels are expected.

The contribution of this paper is to measure and quantify the operational status of the four RFID subbands in the 865-868 MHz band, and to evaluate the feasibility of deploying a NB wireless IoT technology in the band, through an estimation of the error rate probability. The measurements are performed in five areas in Aalborg, DK, and the error rate probability is simulated by applying the measurements as interference.

The paper is structured as follows; the next Section details the measurement methodology and setup, followed by the measurement results. Section IV contains the simulated error rate probability as a function of the measurements, which is followed by the discussion and conclusion.

II. Measurement Methodology & Setup

In this section the measurement methodology and setup is presented together with the post-processing procedures.

In order to measure and quantify the activity in the RFID subbands we have selected a measurement methodology, based on [4], where the in-band power, at selected areas, is logged for a certain period of time. The measurement is performed in the time-frequency domains to capture behavioral patterns over time and to understand the spectrum utilization.

The measurements were performed using a Rohde & Schwarz TSME radio network scanning connected to a Windows laptop running Rohde & Schwarz ROMES 18.01 software. The entire 865-868 MHz band was measured to capture the four RFID subcarriers centered at 865.7, 866.3, 866.9, and 867.5 MHz [7]. The radio network scanner was configured with a 5 kHz frequency resolution and a 100 Hz sampling rate in the time domain, and the measurement period was 10 minutes per area. This is sufficient to observe RFID patterns, which generally repeat every 0.5-5 s.

Five measurement areas were selected based on our knowledge/guess of potential RFID deployments in Aalborg.

- *industrial:* multiple factories in the area are expected to utilize RFID in the production,
- *hospital*: known to use RFID for tracking equipment such as beds and wheelchairs,
- *library*: applies RFID tags in books to manage loans and returns,
- *airport*: uses RFID for tracking suitcases
- *shopping*: multiple shops in the area are expected to utilize RFID for tracking goods and theft prevention

Note that the measurements are performed outdoors during daytime, and that we have no knowledge of the exact locations of the RFID interrogators and tags. This entails the distance between the RFID transmitter and the scanner is unknown.

In general, the RFID interrogators are only allowed to transmit, when they expect an RFID tag to be present [7]. Therefore, they may apply a specific ON-OFF pattern, which is interesting to observe and identify from the wireless IoT perspective, because it may allow such a technology to adapt to a subband, already occupied by RFID. In order to identify the time-domain patterns and evaluate the spectrum utilization the measurements are postprocessed using Matlab. First the four RFID subcarriers are identified by determining, which of the 5 kHz bins in the four subbands have the highest average power level. These bins are denoted as subbands in the remainder of the paper. Next, for identification of the ON periods a power threshold of -110 dBm is used. If the signal power exceeds the threshold an ON state is marked. The time domain

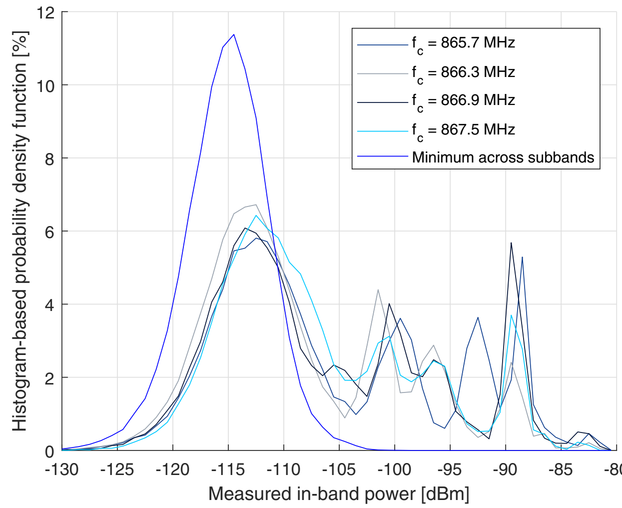


Fig. 1: Probability Density Function for the measured in-band power in the industrial area.

figures in Section III are filtered using a moving average Finite Impulse Response filter with window length 10, effectively being a 100 ms averaging filter. Furthermore, the probability density function (PDF) is determined, using a histogram-based count, per subband for each of the five areas. In addition, the minimum in-band power across the four RFID subbands is determined time-sample by time-sample. This corresponds to the statistical lower bound, which can be achieved by perfect selection diversity in a coordinated deployment.

III. Measurement Results

This section contains the measurement results of the RFID interrogators' activity in the time-frequency domains.

If a NB wireless IoT technology were to be deployed in the four RFID subbands, a key metric is the in-band interference, because it impacts how the systems can coexist. Fig. 1 shows the PDF for the measured in-band power levels in the industrial area, as an example. The background noise floor is centered at -113 dBm. The signal powers of the four detected subbands; 865.7, 866.3, 866.9, and 867.5 MHz, are measured to be distributed between -80 dBm and -105 dBm in the 10 minutes period. The reasons for the variations are the applied ON-OFF patterns, and the (probably) distributed location of each RFID interrogator. As previously mentioned, we have no prior knowledge of the deployment, but the PDFs are as expected. To examine the PDF differences, the 50 %-tile and 99 %-tile are collected in Table I. In general, the 99 %-tile, being a peak power estimate, is within $\sim$5 dB across the subbands and at least -100 dBm per area, except for the shopping area, where the difference between the subbands exceeds 10 dB. The 50 %-tile is -105 dBm to -115 dBm, and is fairly constant across the subbands in each area. The similar observations in the five areas serve as a generalization of the study, making it applicable in other areas, subject to RFID activity, as well.

In addition to the in-band power PDF level, it is important to examine the distribution in the frequency domain. Fig. 2 is an example of the in-band power spectrum in the industrial area. Note that the frequency axis is centered at the four

TABLE I: Measured in-band power levels across subbands and areas for the 50 %-tile and 99 %-tile. Values are in dBm.

	Frequency	Industrial	Hospital	Library	Airport	Shopping
99 %-tile	865.7 MHz	-85.1	-100.8	-97.5	-101.4	-92.6
	866.3 MHz	-86.5	-100.5	-94.1	-99.9	-98.5
	866.9 MHz	-83.9	-99.0	-94.1	-97.6	-88.5
	867.5 MHz	-87.7	-102.5	-99.8	-100.6	-101.1
50 %-tile	865.7 MHz	-109.1	-115.2	-107.4	-113.9	-113.0
	866.3 MHz	-110.1	-115.0	-105.8	-113.9	-112.9
	866.9 MHz	-109.2	-115.0	-105.3	-113.9	-111.6
	867.5 MHz	-109.7	-115.5	-110.3	-113.8	-114.0

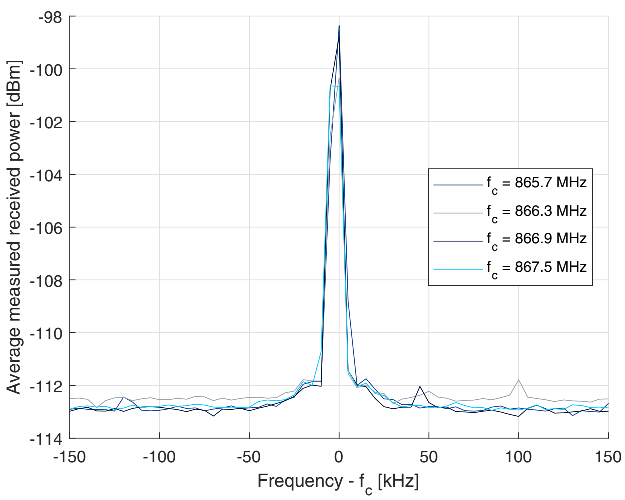


Fig. 2: Industrial area power spectrum (normalized frequency).

subbands' frequencies and that the power is averaged over time. The figure shows that the RFID interrogator utilizes a narrowband signal, which on average is 15 dB stronger than the sideband. According to regulations [7] the bandwidth is up to 200 kHz, but the RFID system is built to concentrate the power in a continuous wave [9]. The observations from the industrial area are similar to the four other areas, except for the library, where side-lobes approximately 10 dB weaker than the main signal were observed at $+/-20$ kHz.

Given the time-domain restrictions for the RFID devices (and other technologies), it is important to examine the measured subband utilization as a function of time. Fig. 3 contains two snapshots of the measured in-band power over time for the industrial area and the hospital. The industrial area (Fig. 3a) seems to run one or more uncoordinated deployments, in the sense that the ON periods of each subband overlaps with other subbands' ON periods, e.g. at 196 s. This also entails that some parts of the measurement have limited activity, e.g. at 188 s. On the contrary, the hospital deployment (Fig. 3b) seems strongly coordinated, because the subbands are ON in a round-robin fashion with a duty cycle of $\sim$25 %.

The probability of overlapping subbands is quantified per area in Table II. A subband is defined to be ON if the measured power exceeds the threshold defined in Section II. Subbands are compared time-sample by time-sample to evaluate whether their ON periods overlap. In addition to the industrial area, the airport is observed to have an uncoordinated deployment, where the probability of experiencing two or three simultaneously occupied subbands is about 80 % combined. The shopping area seems coordinated, like the hospital area, because the probability of observing one active subband exceeds 80 %. In general, it is rare (<10 %) that all four subbands are active simultaneously.

TABLE II: Number of simultaneously occupied subbands. The threshold for activity is -110 dBm, defined in Section II.

# subbands	0	1	2	3	4
Industrial	0.2 %	26.3 %	45.4 %	20.8 %	7.3 %
Hospital	17.8 %	76.6 %	5.1 %	0.5 %	0 %
Library	2.8 %	51.9 %	39.7 %	5.3 %	0.4 %
Airport	0.6 %	11.1 %	41.9 %	38.3 %	8.1 %
Shopping	1.7 %	81.9 %	10.2 %	4.1 %	2 %

Since the subbands are not continuously used, see Table II, the ON-OFF pattern is key. If another system is able to track/learn the pattern it may adapt its transmissions to vacant time slots on the subbands. Fig. 4 shows the cumulative distribution function for the ON periods in the shopping area (solid lines), estimated using the power threshold and the moving average filter described in Section II. About 65 % of the samples have an ON period of 0.4 s. This is also the case for 60-80 % of the samples from the hospital and library areas, while the airport statistics are less clear, but with all ON periods below 1 s. In the industrial area (dashed lines in Fig. 4), periods of 1.5, 3, and 4 s comprise the majority.

IV. Simulated Error Rate Probability

Having quantified the in-band power levels and the time-frequency utilization of the four subbands in the five areas, the potential impact on a NB wireless IoT technology operating in this unlicensed 865-868 MHz band is evaluated next.

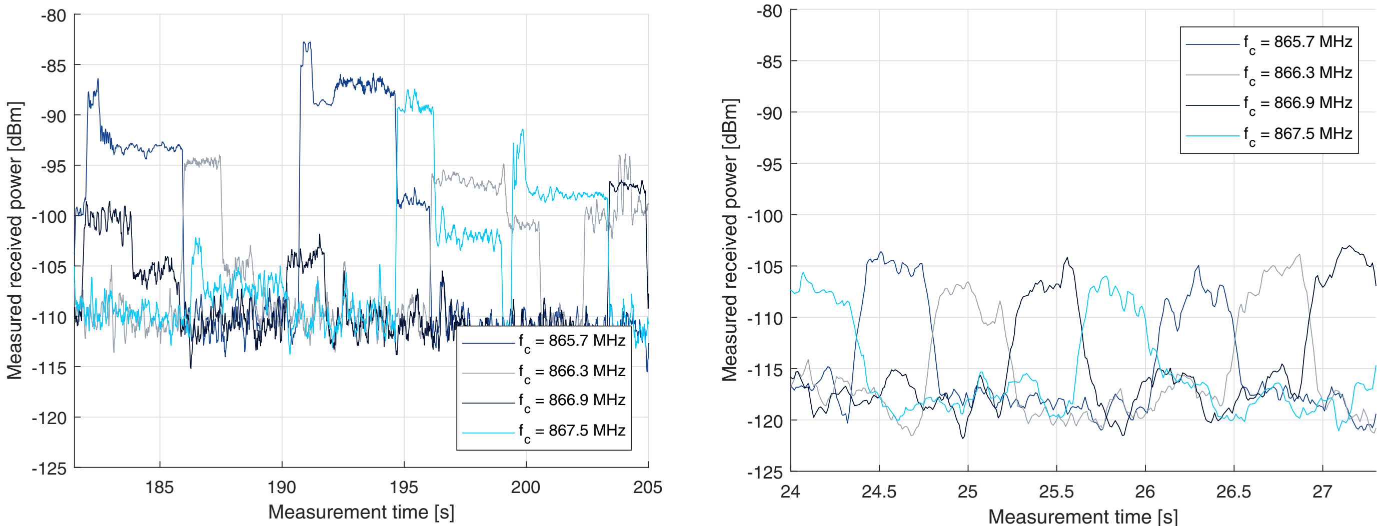
The target is to simulate the block error rate (BLER) probability, for the five areas, as a function of the desired signal power (S) of a given NB wireless IoT technology under study, using the measured in-band power as interference (I). The NB wireless IoT technology is expected to use robust modulation and coding. Therefore, the starting point is the mapping curve from signal-to-interference-plus-noise-ratio (SINR) to BLER for a Quadrature Phase Shift Keying (QPSK) modulation with code rate 1/3, illustrated in Fig. 5. Note the mapping curve allows the BLER to reach 0 % for high SINRs.

The interference PDF I is based on the following schemes:

- *minimum across subbands*: minimum in-band power across the subbands (see Fig. 1), corresponding to perfect selection diversity and thus the **best case** deployment.
- *worst subband*: the single subband with the highest average in-band power, corresponding to a non-frequency hopping one-subband-only deployment i.e. **worst case**.

The noise power N is defined as the thermal noise in a 5 kHz band ($=-137$ dBm), because this was the scanner's measurement resolution, see Section II, and because the wireless IoT technology is assumed to be NB like the measured RFID.

The SINR is calculated by combining the interference PDF and noise power with a specific desired signal level. The resulting SINR PDF is compared with the mapping curve in



(a) Industrial area.

(b) Hospital.

Fig. 3: Time traces with coordinated and uncoordinated RFID deployments. The plots are filtered according to Section II.

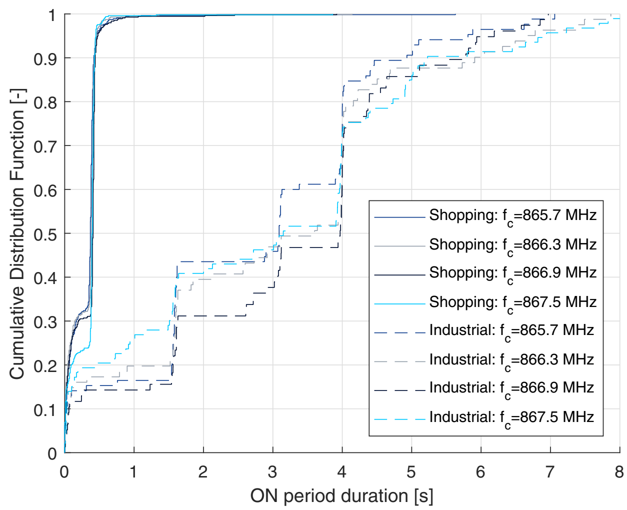


Fig. 4: Estimated ON periods for the shopping and industrial areas, using the power threshold and filter of Section II.

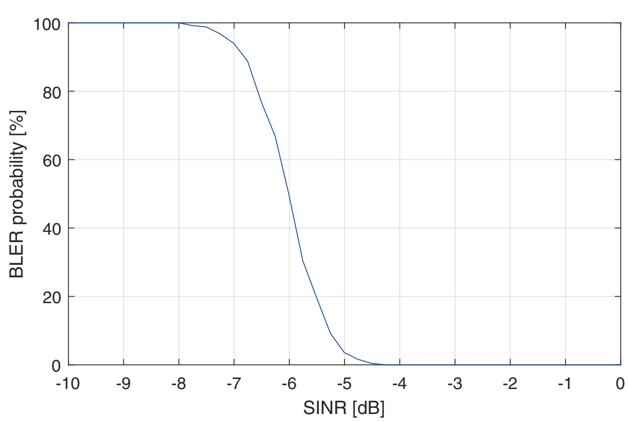


Fig. 5: Link level simulation of the block error rate for QPSK using code rate 1/3 as a function of SINR.

Fig. 5 to estimate the BLER for the desired signal level. We use the instantaneous signal level, without fast fading, instead of a distance between transmitter and receiver, because the signal level allows the reader to map the BLER estimate to any area and distance using any propagation model. The range $S = -90 : -120\,\text{dBm}$ corresponds to what a device may experience in urban non-line-of-sight outdoor and light to deep indoor conditions i.e. similar to the measurement areas.

The estimated BLER probability per area is shown in Fig. 6. If the envisioned wireless IoT technology is able to track the activity of the four subbands and utilize the free subband, i.e. selection diversity, the results show that the BLER probability is $\sim$0 % for $S > -115\,\text{dBm}$ for any deployment. At $S = -120\,\text{dBm}$ the industrial and airport areas experience about 8 % BLER. In case the wireless IoT technology utilizes the subband with the highest interference level, i.e. the *worst subband*, the BLER levels increase significantly. At $S = -100\,\text{dBm}$ the BLER is 7.5 % and 1 % for the industrial and library areas, while at $S = -110\,\text{dBm}$ the BLER has risen to 27 %, 15 %, 6.5 %, 6.5 %, and 1 % for the industrial, airport, library, shopping, and hospital areas. At $S = -120\,\text{dBm}$ all areas experience at least 25 % BLER. Note that for the range of S the signal-to-noise-ratio is in the range 17-47 dB, thus the scenarios in Fig. 5 are interference limited.

V. Discussion

The simulated BLER performance demonstrated a major difference between the *minimum across subbands* and the one-time selection of the *worst subband*. At signal levels $\leq -110\,\text{dBm}$ the BLER is 20-50 % higher for the *worst subband*, while in better signal conditions some areas will experience 5-10 % BLER when using the *worst subband* and 0 % when continuously selecting the least interfered subband.

Therefore, it is worth considering whether a wireless IoT technology, deployed in this newly available band, can adapt to the existing RFID systems' transmissions. The measurements have shown that only 1-2 subbands are occupied simultaneously in most areas and therefore it may be a good approach to apply co-existence methods, e.g. Listen-Before-Talk. However,

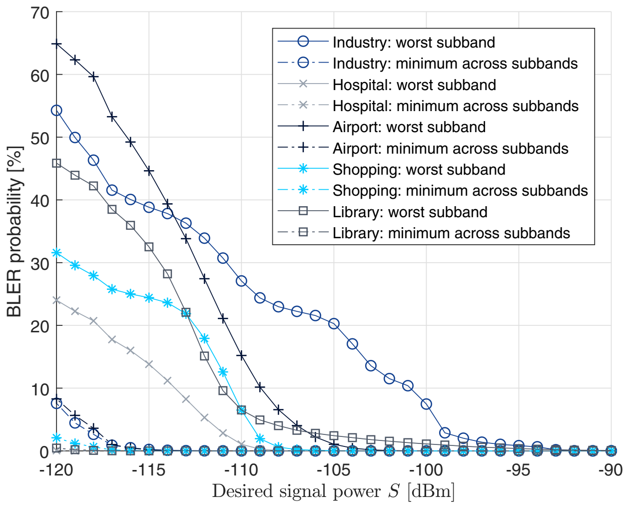


Fig. 6: BLER per area for the two interference schemes.

the interference conditions at transmitter and receiver side will be quite different due to the expected large coverage areas. If the receiver was able to track and learn the transmission patterns of any nearby RFID systems and report it to the IoT network it might be useful for adapting the transmission to free time-frequency slots, but due to clock-drift in both the RFID and IoT systems it may not be a long-term solution. Thus, we suggest that IoT operators during deployment perform careful interference measurements in areas that are estimated to be subject to use of RFID. Furthermore, the measurements demonstrated the RFID systems concentrate the signal power in a narrow band ≤ 10 kHz. Thus, to minimize the interference impact a wireless IoT technology could utilize wideband spread spectrum, like LoRa [4], or avoid using the spectrum centered around the four RFID subcarriers.

In future measurements, it would be beneficial to collect more samples to improve the statistical significance and observe the interference pattern over a full day. In addition, it is not clear whether one or more RFID systems were observed at each measurement area. For example, the time-wise overlap in Fig. 3a may be due to either multiple RFID systems or one system with handshake and/or acknowledgment procedures. In terms of the absolute interference level and the impact on the BLER performance this is irrelevant, but it makes the characterization complicated. Furthermore, the selected power threshold of -110 dBm, which is used to identify ON periods, has an impact on the characterization. For example, Fig. 3b clearly shows round-robin based subband utilization i.e. 100 % of the time only one out of four RFID subband is active, but using the power threshold the number is 80 %.

Finally, it is important to note that we selected areas where RFID deployments were expected to be. In areas without RFID the new 865-868 MHz band will be an excellent choice for wireless IoT, because it allows higher transmit power and duty cycle both at the access point and the device [8]. However, in the future the band may be used by a multitude of wireless IoT technologies, and become as occupied as the currently used IoT subbands of the unlicensed 863-870 MHz band [4].

VI. Conclusion

The unlicensed European 865-868 MHz RFID band has been opened to wireless Internet of Things technologies, allowing higher transmit power and duty cycle than the generally employed 868.0-868.6 MHz band.

In this paper, in-band power measurements are performed in five outdoor areas to characterize the RFID-originated interference towards a potential wireless Internet of Things deployment. The measurements show high-power signals of -85 dBm to -100 dBm in the four RFID interrogator subbands. Each RFID signal resembles a single tone, having the power concentrated in < 10 kHz. From a time-domain perspective, most deployments utilize a signal of 0.4 s duration to activate the RFID tags. Two of the deployments are observed to be uncoordinated in the sense that two or more subbands are active simultaneously 65-80 % of the time. We also observed highly coordinated deployments, where only one out of four subbands is occupied about 80 % of the time.

We evaluate the impact of RFID on a narrowband wireless Internet of Things technology, by applying the measured in-band power as interference in a block error rate probability simulation. Using a QPSK code rate 1/3 modulation, we observe that if the wireless Internet of Things technology can always select the subband with the least interference the error probability is 0 % for desired signal levels up to -115 dBm. However, if the subband, with highest average interference level, is selected the error probability can be up to 7.5 % at -100 dBm and at least 25 % in any area at -120 dBm. The worst case performance is achieved in areas with long transmissions and uncoordinated subbands, which also makes adapting to the interference difficult.

The measurements show that deploying a wireless Internet of Things technology in the 865-868 MHz band entails that there will be areas blocked by interference, at least in single subbands, due to the different transmit power and duty cycle restrictions in the European regulation.

References

[1] Cisco, "The Zettabyte Era: Trends and Analysis," White paper, June 2017.
[2] GSM Association, "Commercial launches," https://www.gsma.com/iot/mobile-iot-commercial-launches/, accessed Oct. 2018.
[3] A. Rico-Alvarino *et al.*, "An overview of 3GPP enhancements on machine to machine communications," *IEEE Communications Magazine*, vol. 54, no. 6, pp. 14–21, June 2016.
[4] M. Lauridsen, B. Vejlgaard, I. Kovacs, H. Nguyen, and P. Mogensen, "Interference Measurements in the European 868 MHz ISM Band with Focus on LoRa and SigFox," in *IEEE Wireless Communication and Networks Conference*, 3 2017.
[5] MulteFire Alliance, "https://www.multefire.org," Accessed Oct. 2018.
[6] I. Rodriguez, H. C. Nguyen, I. Z. Kovács, T. B. Sørensen, and P. Mogensen, "An Empirical Outdoor-to-Indoor Path Loss Model From Below 6 GHz to cm-Wave Frequency Bands," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 1329–1332, 2017.
[7] Electronic Communications Committee, "ERC Recommendation 70-03," May 22, 2018.
[8] European Commission, "Legislation L214," *Official Journal of the European Union*, vol. 60, Aug. 2017.
[9] International Organization for Standardization, "ISO/IEC 18000-6:2013 Information technology - Radio frequency identification for item management - Part 6: Parameters for air interface communications at 860 MHz to 960 MHz General," 3rd edition, 2018.