URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

Path Loss Analysis for the IoT Applications in the Urban and Indoor Environments

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Abstract

The Internet of Things (IoT) networks concept implies their presence in a various and untypical locations, usually with a disturbed radio signals propagation. In the presented paper an investigation of an additional path loss observed in an underground environment was described. The proposed measurement locations correspond to the operation areas of rapidly growing narrowband IoT (NB-IoT) networks, the ones using the Long Term Evolution (LTE) network resources. During the measurement campaign the received signal power (RSP) in an *outdoor-to-indoor* (OUT2IN) and *outdoor-to-outdoor* radio link was measured. After analysis of the measurement results obtained in the building floors and in a basement, it was possible to derive an assessment of the observed additional 11.4 dB – 18.3 dB attenuation of the RSP in the *outdoor-to-basement* communication regarding the typical signal reception on a building floor (OUT2IN).

1 Introduction

The IoT (Internet of Things) networks has noticed a rapid growth in their popularity for the last few years. The interest of companies or national institutions gained the standardization process and influenced the development of the narrowband IoT (NB-IoT) networks. The CAT-B1 was initially introduced in the Rel. 13 of the 3GPP standard, while CAT-NB2 in the Rel. 14. The radio link is based on the 200 kHz width channel, e.g. the Long Term Evolution (LTE) resource blocks, Global System for Mobile Communications (GSM) channels or arranged unused frequency resources of these systems. The NB signals are formed as the 15 subcarriers of the Orthogonal Frequency-Division Multiplexing (OFDM), where their placement on the frequency resources can be adapted by the service provider. The NB1/NB2-IoT networks can be widely used as a critical infrastructure, including the national energetic security, telemetric networks or emergency communication. In the standardization documents also a CAT-M1/M2 communication variant offering more resources, pointed on more complicated services, is described [1-5].

The special application of the CAT-NB1/NB2 or CAT-M1/M2 implies the untypical environment of network locations taking into account the radio signal propagation conditions. As an example, a low floor of the buildings can be pointed, especially the basements where the telemetric systems using the CAT-NB1/NB2 are usually installed. Thus, involves the need of investigating the *outdoor-to-indoor* (OUT2IN) propagation conditions in the time-changing radio channel.

2 Related Works

The growing popularity of the IoT networks can be observed in the scientific and commercial areas. In many publications the NB-IoT network placement in the indoor environment is widely investigated and thus the channel modeling analysis of the OUT2IN or strictly indoor communication, in terms of the frequencies in Ultra High Frequency (UHF) / Super High Frequency (SHF) bands assigned for cellular systems, is investigated [6, 7]. The research studies are focused on extending the applicability of the 3GPP and ITU-R models [1-3]. The goal is to gather the radio channel characteristic for the wideband signal emitted by a cellular base station and received inside the building. Results of the investigations presented by various research groups [6, 7] show that the propagation environment changes have the key influence on the received signal power (RSP) of the cellular systems in the OUT2IN communication. In addition, the noticed change in the RSP is similar for different building floors. In the full-indoor networks, the path loss introduced by the structure of the building is much more noticeable on the different floors which complicates the placement of the nodes [8].

In some publications the untypical environments for radio communication are also taken into account. As an example, the Internet of Underground Things (IoUT) can be pointed. In these types of networks, the communicating devices (in general the nodes) are buried in the ground or mounted just under the ground level. The IoUT network application can mostly be seen in the precision agriculture or canal monitoring [9]. Thus, when the nodes are located close to each other, the additional attenuation introduced by the ground reduces the communication range to tens or single hundreds of meters.

Previously mentioned research examples, focused on the IoT networks, point the most popular regions of interest. There is still a need for performing further research on the radio link based on the LTE network used for narrowband control and telemetric communication. Even in a dense and small urban area, characterized by a large number of the closely located eNodeBs (E-UTRAN, Node B), there is a possibility of losing the connection or observe a degradation of the service quality if the node will be mounted in a basement or underground building level. Thus, it was decided to investigate the difference in the OFDM LTE RSP for the OUT2IN radio link, if the receiver is located on a building's floor or in the basement, with comparison to the signal power recorded outside, in the neighborhood of the building under consideration.

3 Measurement Campaign

Collecting the data from a cellular network in many cases is one of the most common method of gathering signals from the real propagation channel. Unfortunately, in some regions investigation of the narrowband LTE for IoT is impossible due to their incomplete implementation. Such a situation can be currently observed in the area of Gdansk University of Technology regarding the NB-IoT cat. NB1/NB2. There are no cellular networks being compliant with the mentioned standards, only some tests are realized by the providers (in other region of the country).

Taking into consideration previously mentioned circumstances, it was decided to analyze the LTE800 and LTE1800 signals, to asset the ability of operation of a real device functioning in an indoor IoT network. As the Polish 4G networks are not transmitting NB1/NB2 signals the measurements were taken in wideband LTE channels. This assumption does not affect the applicability of the conducted measurements and analysis, because the main goal is to capture the scale of the additional attenuation of the signal in a basement environment with respect to the typical OUT2IN conditions.

As a source of the sounding signal the LTE OFDM signals with a center frequency of 803.5 MHz and 1832.4 MHz, with a bandwidth of 5 MHz and 15 MHz respectively, were selected. The signals were emitted by one eNodeB located 250 m away from the measurement location (The Faculty of Electronic, Telecommunications and Informatics, Gdansk University of Technology). The placement of the measurement locations is presented in the Figure 1a, 1b.

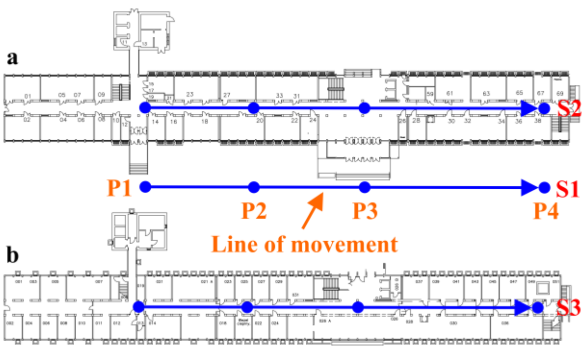

Figure 1. Placement of the measurement points outside (a) and inside the building (a – corridor , b – basement).

The blue dots represent the stationary measurement points and the blue arrows represent the direction of movement in a dynamic scenarios. The measurements were conducted in the ground floor, basement and in front of the building as a reference location.

The campaign was divided into 6 scenarios (Si, where i represent the scenario number), grouped into two main series, a dynamic (S1, S2, S3) and stationary (S4, S5, S6). In the scenarios S1-S3 the receiver was placed on a trolley that was moved with a constant speed 0.25 mps from the P1 to the P4 point. In the other scenarios, i.e. S4-S6, the stationary measurements were done in points marked in the Figure 1a and 1b. In total, the signals were received in 12 stationary points and along three paths with a length of 75 m. It must be noted that each scenario was performed twice, recording the signals in the LTE800 and LTE1800 frequency band.

Additionally, in the indoor environment the measurements were conducted on other floors (OUT2IN scenario), each with the similar structure and room arrangement as the ground floor. After the preliminary statistical analysis, it occurred that the values of the RSP in a ground floor can be treated as a representative for the other ones, with a statistical parameters in a range values presented in the Table 1 and 2. Analogical results and conclusions were pointed out in [8].

To collect the measurement data a mobile stand consisting of the spectrum analyzer Anritsu MS2724B, PC computer and an antenna Cobham OA2-0.3-10.0V were used. All the components were placed on a trolley. The receiving antenna, with an omnidirectional characteristic, was mounted at a 1.5 m height above the floor level.

The samples of the RSP were obtained from the spectrum analyzer using the developed PC software. During the measurements over 64000 RSP values were collected for all considered scenarios, with a 100 ms interval between the measurements.

4 Obtained Results

The analysis of the RSP datasets was mainly focused on determining the empirical Cumulative Distribution Functions (CDFs) as a metric to assess the collected data. Additionally, the mean value μ_j [dBm] of the RSP and its standard deviation σ_j [dB] were determined, where j represents the analyzed band. It is worth noting that the noise level during the measurements was at a -115 dBm level.

The CDFs for both frequency bands are grouped in the Figure 2. For the outdoor S1 scenario in the 90 % cases the RSP does not exceed -30.3 dBm and -39.4 dBm for LTE800 and LTE1800 respectively, what gives a difference equal to approximately 9 dB. In the indoor environment (the S2 scenario) the values of the RSP dropped to -55.1 dBm and -67.1 dBm (12 dB of difference) for 90 % of cases. The highest attenuation of the LTE signal, as expected, can be observed in the basement environment. During the S3 scenario for the 90 % of cases the RSP reaches -63.4 dBm and -79.5 dBm respectively. This gives a 15.2 dB difference between the received signal in analyzed bands and moreover, the observed attenuation in the S3 scenario is 8.3 dB and 12.4 dB higher than in the S2.

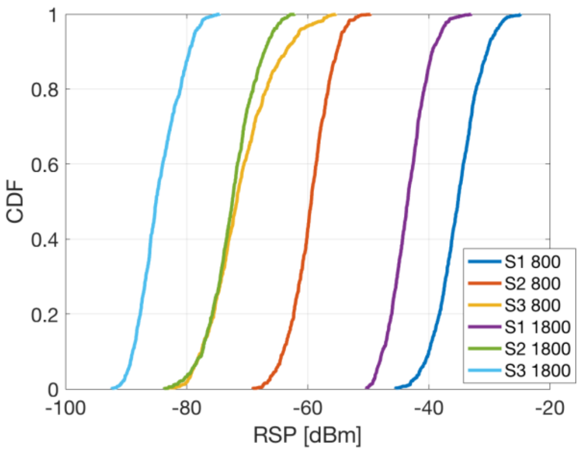

Figure 2. The empirical CDF of the RSP in the LTE800 and LTE1800 bands, S1-S3 scenarios.

The mean values of the RSP and the standard deviations for scenarios S1-S3 realized for both investigated frequency bands are presented in the Table 1.

Table 1. Mean value and standard deviation of the RSP in the S1-S3 scenarios.

Scenario	μ_{800} [dBm]	σ_{800} [dB]	μ_{1800} [dBm]	σ_{1800} [dB]
S1	-34.8	3.7	-43.2	3.2
S2	-59.3	3.3	-72.2	3.9
S3	-70.7	5.4	-84.4	3.5

The difference between the mean RSP in the indoor conditions with respect to the outdoor reaches 24.5 dB to 29 dB (for LTE800 and LTE1800 respectively), with additional attenuation of approximately 11.4 dB and 12.2 dB when the signal was received in the basement. It can be noticed, that the σ_{800} for the S3 scenario is the highest for the analyzed dynamic scenarios. It leads to a conclusion that during the movement, in some regions of the basement corridor, the signal propagating by the stairway could be received.

In the second part of the measurement campaign the signals were recorded in 4 points (P1 – P4) in the three scenarios regarding the measurement location – outdoor, indoor and basement (S4, S5, S6). The determined μ_j and σ_j for both frequency bands are presented in the Table 2. With respect to the values presented in the Table 1 (dynamic scenarios) a smaller standard deviation can be observed in all static measurement points, except the P3 point in S5 scenario. This situation is probably caused by the people movement inside the building. It must be mentioned that during all measurement no obstacles or moving people occurred in the proximity of the receiving antenna, but in general people were present in the building.

Table 2. Mean value and standard deviation of the RSP in the S4-S6 scenarios.

Scenario	Point number	μ_{800} [dBm]	σ_{800} [dB]	μ_{1800} [dBm]	σ_{1800} [dB]
S4	P1	-33.9	2.4	-46.7	1.4
S4	P2	-31.0	2.3	-43.1	1.8
S4	P3	-30.3	2.0	-36.6	2.6
S4	P4	-34.8	2.1	-42.7	1.7
S5	P1	-59.9	2.2	-71.5	1.9
S5	P2	-56.7	2.4	-67.6	1.5
S5	P3	-62.2	3.0	-73.7	5.1
S5	P4	-55.1	1.9	-68.4	2.3
S6	P1	-74.5	2.0	-89.8	1.2
S6	P2	-68.8	2.3	-85.9	1.3
S6	P3	-72.5	2.3	-84.4	1.9
S6	P4	-70.1	2.2	-82.8	2.3

In addition to the analysis presented in the Table 2 for data collected in the P1 measurement point the CDFs were determined for both frequency bands and they are presented in the Figure 3. For the outdoor S4 scenario in 90 % of the cases the RSP does not exceed -30.4 dBm and -44.8 dBm for LTE800 and LTE1800 respectively, what gives a difference equal to 14.4 dB. In the S5 the RSP is equal to -57.4 dBm and -69.3 dBm (11.9 dB of difference), for 90 % of cases. In the S6 scenario for 90 % of the cases the recorded RSP reached -72.1 dBm and -88.4 dBm respectively, what gives a 16.3 dB difference. In total, the standard deviation of the determined difference values does not exceed 5.4 dB regarding the dynamic measurements.

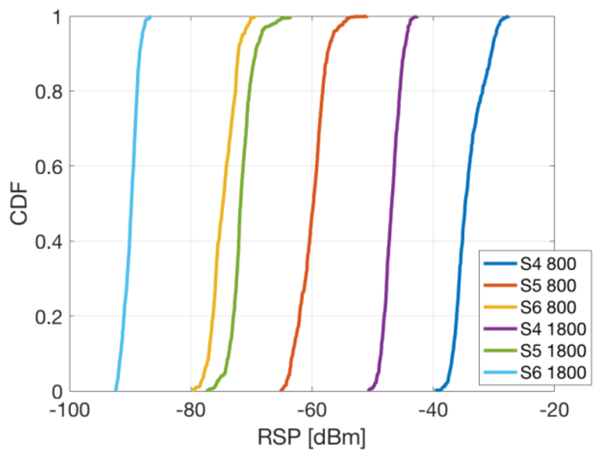

Figure 3. The empirical CDF of the RSP in the LTE800 and LTE1800 bands, S4-S6 scenarios in the P1 measurement point.

After analysis of the probability distribution of the RSP for other stationary measurement points the presented CDFs can be treated as the representative ones regarding the noticed difference of less than 2 dB of the RSP in the 90 % cases for other sets.

Investigating the presented results, a clear assessment on the scale of additional attenuation introduced in the channel during the OUT2IN communication can be done, during signal reception in the basement or on a different floor. As expected, the dissimilarity of the stationary measurements (S4-S6) with respect to the dynamic (S1-S3) scenarios is visible in the mean values and the standard deviations. The σ_j values presented in the Table 1 and 2 confirm the stationary character of the radio channel during the measurements, which includes only mean path loss and large-scale fading components [10].

5 Summary

In the article the influence of the underground indoor environment on the reception of the radio signals is presented. By using the developed measurement stand signals of the LTE800 and LTE1800 network were collected in a various conditions, i.e. outdoor and indoor ones. The results of the performed analysis showed that in the underground level (in the basement) a significant additional attenuation of the received signal can be observed (up to 11.4 dB – 12.2 dB in dynamic and 14.6 dB – 18.3 dB in static measurements).

The performed research studies show the scale of additional signal attenuation in the radio channel that must be taken into consideration during the design and development of the NB-IoT networks in indoor environment. Regarding the standard [1-3], the IoT devices can cope with harsh propagation conditions and reach a 164 dB maximum coupling loss or link budget, and the -141 dBm receiver sensitivity. Nevertheless, an environment in which the signal is received with a power less that -95 dBm is treated as poor within the quality assumptions [8]. It also must be pointed that RSP in the narrowband NB1/NB2 channel will be smaller than the RSP in the analyzed wideband LTE channel. In the future, further measurements and research of the radio channel will be performed in other underground levels of buildings, also including the underground car parks to propose a detailed model of the OUT2IN radio link.

6 Acknowledgements

This work was supported under ministry subsidy for research for Gdansk University of Technology.

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