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LoRaWAN Downlink Power Quality Evaluation for 3D Environments

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Abstract. The exponential growth of the number of mobile devices has improved the development of technologies adapted to the new environmental requirements, Low Power Wide Area Networks have become an essential area of study and investigation due to its diverse types of applications, including the IoT (Internet-of-Things) environments, sensors monitoring, medical applications, etc. There are some tools for the analysis of the implementation of this technology that helps to identify its advantages and disadvantages within its implementation parameters. This paper presents a downlink power quality evaluation of the received signal in a 3D environment using the LoRaWAN parameters. Two propagation models log-distance and Okumura-Hata are included to measure the outage probability.

Keywords: LPWAN, LoRaWAN, 3D environment, network evaluation.

1 Introduction

Low Power Wide Area Networks (LPWAN) are an important type of wireless communications that has been growing up in the last few years due to its applications and advantages. This network technology offers an improvement on the covered area (10 to 40 km in rural areas and 1 to 5 km in urban areas), also its easy scalability at a low cost [1, 2].

Several companies are working with LPWAN networks such as the Institute of Electrical and Electronics Engineers (IEEE), the European Telecommunication Standards Institute (ETSI), 3rd Generation Partnership Project (3GPP), the Internet Engineering Task Force (IETF), and LoRa Alliance. These companies developed their standards. SigFox, LoRaWAN, and NB-IoT, offering efficient solutions to connect multiple smart devices [3, 4]. In a previous paper was presented an outage probability analysis for a 3D environment for some technologies.

This paper improves that analysis for LPWAN networks, using the requirements and parameters of the LoRaWAN technology created by LoRa Alliance [5].

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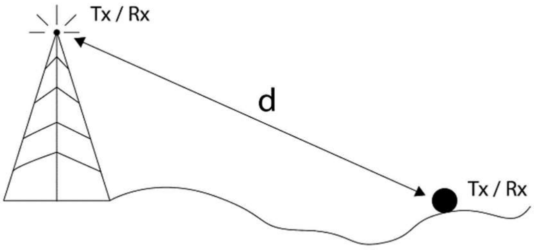

Fig.1. Scheme of the distance between the antenna and the end device.

When a network is being analyzed there are some affectations that must be included, one of those is the propagation losses that are generated in the wireless environment and it is caused by the distance of the devices, the antenna height, the devices height, and some other environment interferences.

This could be done by using some mathematical models that represent these affectations. Most of the LoRaWAN networks simulation tools, such as LoRaSIM uses the log-distance propagation model, but this is a bad approximation for a wide area analysis because it becomes inaccurate at long distances, a more realistic model for these kinds of networks is the Okumura-Hata model which is analyzed further in this paper [6].

This work is structured as follows. Second section presents the mathematical model of our system. Third section includes the simulation set-up and results, and finally in the last section is presented the conclusions.

2 Mathematical Model

In our simulation the coexistence of mobile and fixed end devices with a defined and undefined trajectory is analyzed. Inside the simulation the coexistence of mobile and fixed end devices is analyzed. Mobile devices movement is set on randomly in all three axes X, Y and Z. The analysis implies the received power evaluation considering the shadowing effects, distance losses using the log-distance and Okumura-Hata models, antenna gain (as a function of the user position) and 3D end devices distribution. The received power is expressed in the equation (1):

$$P_{RxM} = \frac{P_{Tx} \cdot G_{Tx} \cdot G_{Rx}}{d^{\mu}} \cdot 10^{\frac{\zeta}{10}}, \tag{1}$$

where P_{tx} is the transmission power, G_{Tx} and G_{Rx} are the antenna gains for the transmitter and the receiver respectively, d is the distance between the antenna and the end device, μ is the propagation losses exponent and ζ is the characteristic Gaussian random variable of the log-normal distribution which models the shadowing effects as shown in Fig. 1.

The transmitted antenna gain is considered as a parabolic function which depends on the angle $\phi_{l,n}$ between the end device and the antenna, this function is expressed in equation (2):

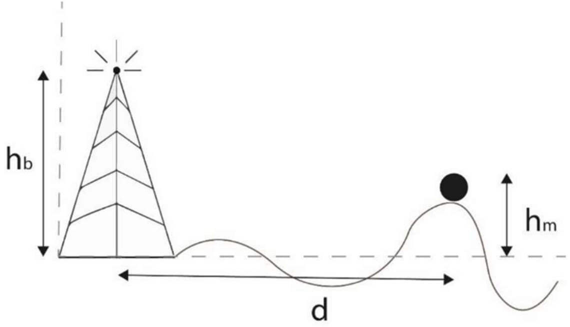

Fig.2. Illustration of the parameters used in the Okumura-Hata model.

Table 1. Maximum and minimum values for Okumura-Hata parameters.

Parameter	Symbol	Minimum value	Maximum value
Frequency	f	150 MHz	1500 MHz
Antenna height	h_b	30 m	200 m
Device height	h_m	1 m	10 m

$$G_{tx}(\phi_{l,n}) = \begin{cases} 1 - \frac{(1-q}{(\frac{\pi}{3})^2} \cdot \phi_{l,n}^2 \; si \; |\phi_{l,n} \leq \sqrt{\frac{1-p}{1-q}\frac{\pi}{3}} \\ \\ p \qquad si \; \phi_{l,n} > \sqrt{\frac{1-p}{1-q}\frac{\pi}{3}} \end{cases}, \tag{2}$$

where q represents the gain level of the antenna at a 60^o sector and p is the mean normalized gain of the side lobes [7].

In this simulation it has been evaluated the probability of the received power to be higher than the threshold given by the sensibility to guarantee the recovery of the signal and the link quality. This probability is given by the equation (3):

$$P(P_{rxM} > P_{min}) = \int_{P_{min}}^{\infty} f_{P-rxM}(x)dx \; . \tag{3}$$

Solving equation (3), we have the equation (4):

$$P(P_{rxM} > P_{min}) = \frac{1}{\sqrt{2\pi}} \int_{\frac{P_{min}-m_p}{\sigma_P}}^{\infty} e^{-\frac{u^2}{2}} du = Q(\frac{P_{min} - m_P}{\sigma_P}) \; , \tag{4}$$

where, $m_P = 10log(\frac{P_{tx}G_{tx}G_{rx}}{d^{\mu}}) + m_\zeta$
$\sigma_P^2 = E\{P_{rxM}dB^2\} - E^2\{P_{rxM}dB\} = \sigma_\zeta$.

The Okumura-Hata is based on empirical data that could be used to model the mobile propagation signals on rural and urban areas as a function of correction factor, the antenna height, end devices height, and the frequency [8]. The equation (7) describes the behavior of the Maximum Path Loss (MPL):

$$MPL_{dB} = A + B \cdot log(d) + C, \tag{5}$$

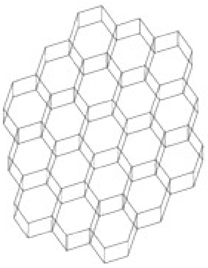

Fig.3. Hexagonal cells region.

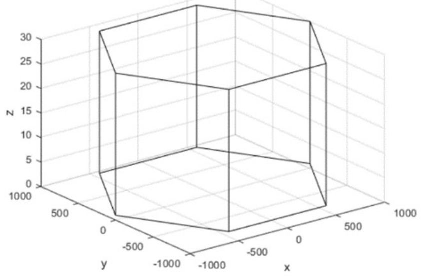

Fig. 4. Simulation 3D environment.

where, A, B, and C is described as follows:

$$A = 69.55 + 26.16log(f_c) - 13.82log(h_b) - a(h_m)$$

$$B = 44.9 - 6.55log(h_b)$$

$$C = 0.$$

C depends on the chosen environment, in this case, for metropolitan areas, f_c represents the central frequency given in MHz, *d* represents the distance in kilometers, h_b represents the antenna height or gateway in meters, h_m is the mobile height in meters and $a(h_m)$ is a function that represents the correction factor due to the antenna height and depends on the frequency of the communication, this function is given by the equation (6) [9]:

$$a(h_m) = \begin{cases} 8.29(log(1.54h_m)^2) - 1.1 \quad para\ f_c \leq 200MHz \\ 3.2(log(11.75h_m)^2) - 4.97\ para\ f_c \geq 400MHz. \end{cases} \tag{6}$$

The Fig. 2 shows graphically the parameters used to calculate the values of the Okumura-Hata model.

In the Table 1 are shown the maximum and minimum parameters that could be analyzed using Okumura - Hata model. Due it values, LoRaWAN Network could be analyzed with this model.

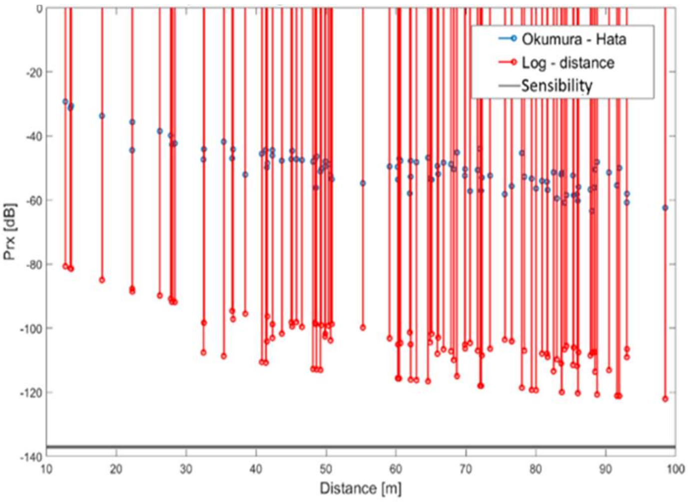

Fig.6. Received power for Log-Distance and Okumura-Hata for mobile users in a 100 meters radius.

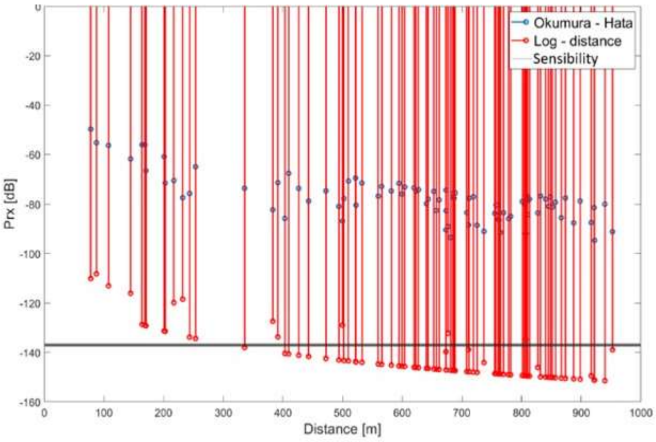

Fig.7. Received power for Log-Distance and Okumura-Hata for mobile users in a 1000 meters radius.

2.1 LoRaWAN Network

For a LoRaWAN simulation some parameters must be considered such as the frequency and bandwidth which depends on the unlicensed Industrial, Scientific and Medical (ISM) bands regulations for different areas, in US the accepted frequency is from 902 MHz to 928 MHz and the bandwidth is 125 kHz or 250 kHz, the spreading factor that defines the number of bits that could be transmitted on each symbol that could take values from 7 to 12, number of preambles that are used for the synchronization of the signal, the payload, the power of the transmitted signal and the sensibility that defines the minimum power level that could be received successfully.

Table 2. Maximum and minimum values for Okumura-Hata parameters.

Parameter	**Value**
Number of users	10-1000
Radius	100 - 1000 m
Frequency	902 MHz
Spreading Factor	12
Bandwidth	125 kHz
Transmission power	25.1mW / 14dB
Sensibility	1.98e-14W

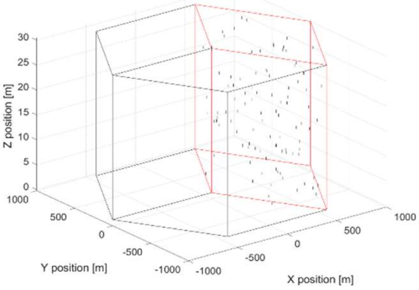

Fig.5. 3D environment for 100 users inside a radius of 1 km.

3 Simulation Set-Up

3.1 Simulation Scenario

For the simulation scenario we used the model developed in a previous paper which consider an environment divided in microcellular cells modeled as hexagonal prisms as shown in Fig. 3 [5].

The simulation occurs in a single cell with an adjustable radius, frequency, antenna height and device height. Considering a 120 degrees sectorization remarked in red color. This sector matches with the antenna propagation pattern placed in the center of the cell (black dot); this scenario is shown in Fig. 4 [5].

Once the simulation environment was set, several experiments were run, all of them using the mathematical model presented before. The value of the different parameters used are shown in the Table 2.

4 Results

The Fig. 5 represent the 3D environment with 100 users, the relation between mobile and fix users was randomly chosen within a radius of 1 km.

A comparison between both path loss models (Okumura-Hata in blue and log-distance in red) was done using different ratios, in the Fig. 6 is shown the behavior of

Table 3. Results for LoRaWAN using log-distance model.

Users	**Events**	**Ratio [m]**	**Mean Prx [W]**	**Outage probability**
10	1000	100	1.16e-9	1.9%
50	1000	100	4.93e-9	1.1%
100	1000	100	3.10e-8	2.5%
1000	1000	100	3.26e-7	1.9%
100	1000	200	8.20e-10	41.1%
100	1000	400	4.48e-12	82.3%
100	1000	500	3.16e-10	89.7%
100	1000	1000	1.54e-13	97.7%

Table 4. Results for LoRaWAN using Okumura-Hata model.

Users	**Events**	**Ratio [m]**	**Mean Prx [W]**	**Outage probability**
10	1000	100	4.70e-21	0%
50	1000	100	1.79e-19	0%
1000	1000	100	1.92e-20	0.01%
100	1000	200	6.24e-22	1%
100	1000	400	1.43e-23	9%
100	1000	500	2.66e-24	22%
100	1000	1000	2.31e-24	46%

both models at a 100 meters ratio, the black line represents the sensitivity of the system, in this case the result of both models is above the minimum power, therefore the signal will be correctly received.

If the ratio grown the outage probability for both models grown as well, for the log-distance model if the ratio is bigger than 300 meters the losses will be greater than the sensibility, in the Okumura-Hata model the losses at 300 meters are approximately 80 dB which is further from the sensibility (137 dB) as shown in Fig. 7.

The analysis which includes the log-distance and the Okumura-Hata models is presented in Table 3 for the log-distance and in the Table 4 for the Okumura-Hata. These results shown that the Okumura-Hata model works better for long distances.

5 Conclusions

We have observed for the log-distance that the outage probability increases over the 40% when the distance is greater than 200 meters which means that is not a reliable technology for long distances, considering that LoRaWAN was created for LPWAN technologies which its name represent wide areas log-distance is not a model that represents its behavior, the opposite occurs with Okumura-Hata which outage probability at the same distance (200 meters) is 1%, therefore in the study of LPWAN networks should be used the Okumura-Hata model.

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