International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 12 (2019), pp. 2826-2833

Radio Propagation Models Development for Lorawan in Suburban Area of Abidjan, Côte D'ivoire

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Abstract

LoRa network used for the Internet of Things (IoT) is increasingly being deployed in various environments to gather data. The accuracy of the radio propagation models for path loss prediction in this network is necessary in order to faithfully transmit data collected by the end-devices to the network server. In addition, the deployment of a radio network in complex environment such as a suburban environment is very difficult to perform. In this paper, we compare statistical measured data to those provided by some theoretical models for path loss prediction. And, we found that the statistical measured data are more closed to the path loss values predicted by Cost-231 Walfish Ikegami model, but not suitable for the complex suburban areas of Abidjan, Côte d'Ivoire. So, based on this model, we then developed an empirical radio propagation model for path loss prediction suitable for the environment of these areas.

Keyword head: IoT; Radio; LoRaWAN; antenna; attenuation

1. INTRODUCTION

New trend wireless technology is implemented to promote new objects and devices connection to internet. The tremendous growth of connecting various things to a wireless network and thus being able to remotely access them is starting to realise what is todays referred to as the Internet-of-Things (IoT). To achieve this goal, various techniques are used according to the use case. Low power wide area networks (LPWANs) are one of long-distance communication techniques. In fact, Long Range (LoRa) is an LPWAN technology designed for the IoT, known as LoRa Wide Area Network (LoRaWAN), and which has gained an important run-up in both industrial and research communities. LoRa uses chirp spread spectrum modulation to provide data with long battery life, very long communication distances, and a high node density.

LoRaWAN or LoRa network as a wireless network must propagate signals in the environment. And, we know that environments are characterized by complexity they present for the radio propagation. This complexity is the consequence of many high rise buildings and objects in the streets which produce reflection, diffraction and shadowing of the transmitted signals. This very often causes an important mitigation of electromagnetic wave power density when it propagates through space, called path loss. The estimation of the path loss is thus an important element of the link budget of a wireless communication system such as LoRaWAN. This is influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the antennas height and location.

Moreover, path loss prediction propagation models are experimental mathematical formulas for characterizing radio waves propagation as a function of the distance between the transmitter and receiver antennas. These models are designed based on a set of large data collected from specific environments. Radio propagation model determination is a very important parameter in network planning and studies of interference before starting a large deployment [1].

Therefore, from the perspective of future LoRa network deployment, we conduct a study in this paper. The main focus of this study is on a suitable radio propagation model for path loss prediction at 868 MHz in a suburban environment, specifically in the south areas of Abidjan, Côte d'Ivoire. A suitable propagation model for the south area cluster of Abidjan, will allow a proper LoRa network planning for the connected objects.

The rest of this paper is arranged as follows: section 2 explores existint radio propagation models for path loss prediction, and section 3 deals with the related works. Section 4 describes the study case and methodology, when section 5 presents the results and discussion. Finally, we end this paper with a conclusion in section 6.

2. RADIO PROPAGATION MODELS

It is with the advent of high-performance computers that many propagation models have been developed. Some models have been designed taking into account only limited number of environment parameters. They are essentially based on measurement campaign statistics in given environments; they

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are empirical or statistical models. To adapt these models to much more complex real environments, other important data must be taken into account. These adaptations led to the creation of new models called semi-empirical models. Some models based on the consideration of several parameters, use mathematical approaches to estimate the propagation channel. These models are the called exact or deterministic models.

We shortly present here some empirical and deterministic models relevant for our study case.

A. Empiric models

It is important to note that the first empirical model is the Okumura model proposed by Okumura in 1960. It was subsequently improved by Hata and took the name of Okumura-Hata in 1968. It is based on measurements made by Japanese Okumura in the Tokyo environment. Indeed, the Okumura-Hata model was put in equation in 1980 to be implemented with a computer tool. This model predicts the path loss based on frequencies range between 1500-2000 MHz with a base station antenna height between 30-200 m, and the mobile station antenna height between 1-10 m. This model adds a mitigation factor according to the urbanization degree. In the case of LoRa network, the mobile station is represented by objects that incorporate sensors, known as end-devices. Table 1 summarize the different application conditions for this model.

Table 1: Okumura-Hata model application conditions.

	Parameters [2]	**Values [2]**
Carrier frequency	f	1500 - 2000 MHz
Base Station antenna (BS) height	h_b	30 - 200 m
Mobile Station antenna (MS) height	h_m	1 - 20 m
BS-MS distance	d	1 - 20 km

The mathematical formula for calculating the path loss according to Okumura-Hata model is given by the equation below [2]:

$$P_{Loss} = 46.3 + 33.9\,log(f) - 13.82\,log(h_b) - ah_m + \left[44.9 - 6.55\,log(h_b)\right]log(d) + C_m \tag{1}$$

where, f represents the operating frequency in MHz ; d, the distance between the end-device and LoRa base station in km. h_b and h_m represent respectively antenna height above the ground in meters for the base station and end-device. The parameter C_m equals 0 dB specifically for both suburban and open environments. The quantity ah_m is expressed as below for suburban or rural areas:

$$ah_m = [1.1\log(f) - 0.7]h_m - [1.56\log(f) - 0.8] \tag{2}$$

Later, the European Scientific and Technical Committee adapted the Hata model to the European environment, it then takes the name of Cost-231 Walfich-Ikegami model. It is described as semi-empirical and was based on the theoretical work of Bertonie and Ikegami between 1988 and 1993. It can be used to predict the path loss during radio signals transmission in urban or semi-urban environment depending on the fact that there is line of sight (LOS) or no line of sight (NLOS) propagation [3]. The different application conditions of this model are indicate in table 2.

Table 2: Cost-231 Walfich-Ikegami model application conditions.

	Parameters [2]	**Values [2]**
Carrier frequency	f	800 - 2000 MHz
Base Station antenna (BS) height	h_b	4 - 50 m
Mobile Station antenna (MS) height	h_m	1 - 3 m
BS-MS distance	d	0.02 - 5 km

Cost-231 Walfich-Ikegami defines the path loss with existence of LOS in the street for large and medium-sized urban environments by the following formula [3]:

$$P_{Loss} = 42.64 + 26\log(d) + 20\log(f) \tag{3}$$

In the case of NLOS, the free space loss L_{fs} , the rooftop to street diffraction loss L_{rts}, and the multiple screen diffraction loss L_{msd} , are all combined to predict the total path loss. Therefore, the final expression of the path loss is mathematically described as follows [3]:

$$P_{Loss} = L_{fs} + L_{rts} + L_{msd} \tag{4}$$

The expression of the path loss due only to free space is defined as below:

$$L_{fs} = -32.45 + 20\log(d) + 20\log(f) \tag{5}$$

The diffraction loss from the rooftop to street is given by the following formula:

$$L_{rts} = -16.9 - 10\,log(w) + 10\,log(f) + 20\,log(h_r - h_m) + L_0 \tag{6}$$

The term w express width of the roads and h_r is the height of building. If, we consider the angle θ with respect to the direct radio path, the street orientation correction factor, L_o is given as the equation below [4]:

$$\begin{cases} -10 + 0.35\theta & for \quad 0° \langle \theta \langle 35° \\ 2.5 + 0.0755(\theta - 35) & for \quad 35° \langle \theta \langle 55° \\ 4 - 0.0114(\theta - 55) & for \quad 55° \langle \theta \langle 90° \end{cases} \tag{7}$$

As previously mentioned, the multiscreen loss represents diffraction loss from multiple obstacles and it is defined by the following mathematical expression:

$$L_{msd} = L_b + K_a + K_d\log(d) + K_f\log(f) - 9\log(s_b) \tag{8}$$

The terms L_b and K_a are respectively the correction factors of diffraction loss when the base station antenna is above and below the rooftops. And, the terms K_d and K_f represent the diffraction loss as a factor of the distance and frequency, and are determined in [5] as follows:

$$L_b = \begin{cases} -181\log(1+h_t-h_r) & h_t \langle h_r \\ 0 & h_t \langle h_r \end{cases} \quad (9)$$

$$K_a = \begin{cases} 54 & h_t \rangle h_r \\ 54-0.8(h_t-h_r) & h_t \langle h_r \quad and \quad d_{km} \geq 0.5km \\ 54-1.6(h_t-h_r) & d_{km} \langle 0.5km \end{cases} \quad (10)$$

$$K_d = \begin{cases} 18 & h_t \rangle h_r \\ 18-15(h_t-h_r)/h_r & h_t \leq h_r \end{cases} \quad (11)$$

$$K_f = -4 + \begin{cases} 0.7(f_{MHz}/925-1) & \text{for medium size city and suburban} \\ 1.5(f_{MHz}/925-1) & \text{for metropolitan centers} \end{cases} \quad (12)$$

A. Deterministic models

These models are particularly the models that use mathematical approaches to estimate the radio propagation channel. They remain theoretical models because their implementation is complex and difficult; they are therefore less used by operators. Some of them are given here.

The first deterministic model that we would like mentioned in this paper, is the Friis model. It is used to determine the path loss due to free space in absence of any obstacle. This model cannot be used alone for prediction of a radio propagation channel path loss, because in reality free space does not really exist without any other conditions. One the other side, it is involved in all radio propagation channel predictions as previously seen in the paragraph concerning the empiric models. The path loss due to free space has the same expression as in equation (5).

The second model is ITU 256-14 model recommended by the International Telecommunication Union (ITU) in ITU-R Recommendation P.526-14 published in January 2018 [6]. This model is used to evaluate the diffraction loss for radio signal received at a given point. It can be applied for radio path with different types of obstacles having different shapes, and also used for a spherical terrestrial surface. A general guide in form of diagram for the model use has been developed to assess the diffraction loss in this recommendation.

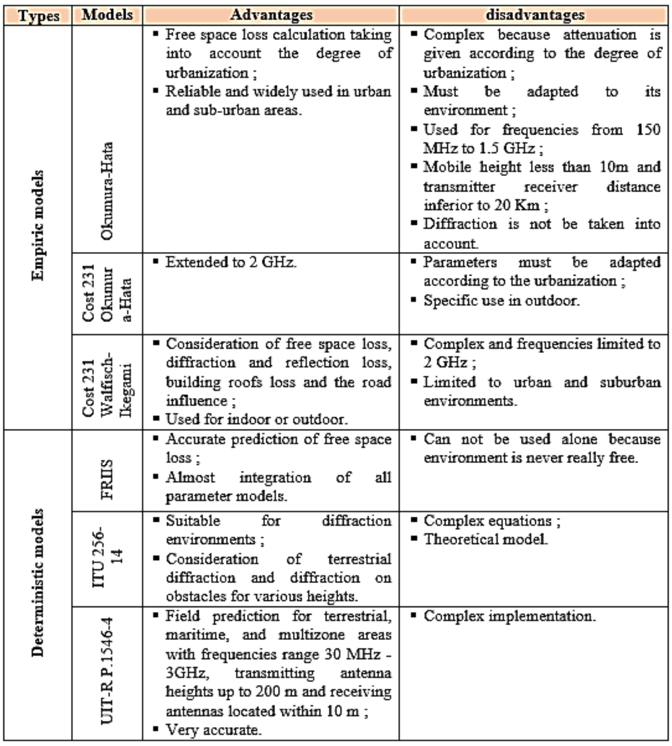
The last relevant deterministic radio propagation model lists for our work here, is the ITU-R P.1546-4 model which defines a point-to-area propagation prediction method for terrestrial services between 30-3000 MHz. The recommendation [6] establishes different curves quantifying the field E as a function of the radio path length and the model is applied for distance between 1-1000 km. For instance, the following formula defined by this recommendation allow the field E calculation for a mixed path (land-sea or vice-versa). Thus, the field E intensity is expressed by the formula below [6]:

$$E = \sum_i \frac{d_i}{d_{total}} \times E_i(d_{total}) \quad (13)$$

The term $E_i(d_{total})$ represents the field intensity for the radio path i considering the total length of all the combined paths into. The terms d_i and d_{total} are the radio path i length and total radio path length, respectively. The appendix 6 of this recommendation [7] leads to results similar to those induced by the Okumura-Hata model if the radio path length is less than or equal to 10 km, the mobile station height is equal to 1.5 m and the obstacle height closed to the receiving station antenna is equal to 15 m.

B. Models comparative table

Through the comparative table below, it is clear that there is no universal radio propagation model. Any model must be used or adapted for its environment. However, apart from proprietary models such as Ericsson models, the most used because of their reliability, appear to be the empirical models with consideration of moderate parameters number. Figure 1 indicates the advantages and disadvantages of all the previous radio propagation models mentioned.



Types	Models	Advantages	disadvantages
Empiric models	Okumura-Hata	▪ Free space loss calculation taking into account the degree of urbanization ; ▪ Reliable and widely used in urban and sub-urban areas.	▪ Complex because attenuation is given according to the degree of urbanization ; ▪ Must be adapted to its environment ; ▪ Used for frequencies from 150 MHz to 1.5 GHz ; ▪ Mobile height less than 10m and transmitter receiver distance inferior to 20 Km ; ▪ Diffraction is not be taken into account.
	Cost 231 Okumura-Hata	▪ Extended to 2 GHz.	▪ Parameters must be adapted according to the urbanization ; ▪ Specific use in outdoor.
	Cost 231 Walfisch-Ikegami	▪ Consideration of free space loss, diffraction and reflection loss, building roofs loss and the road influence ; ▪ Used for indoor or outdoor.	▪ Complex and frequencies limited to 2 GHz ; ▪ Limited to urban and suburban environments.
Deterministic models	FRIIS	▪ Accurate prediction of free space loss ; ▪ Almost integration of all parameter models.	▪ Can not be used alone because environment is never really free.
	ITU 256-14	▪ Suitable for diffraction environments ; ▪ Consideration of terrestrial diffraction and diffraction on obstacles for various heights.	▪ Complex equations ; ▪ Theoretical model.
	UIT-R P.1546-4	▪ Field prediction for terrestrial, maritime, and multizone areas with frequencies range 30 MHz - 3GHz, transmitting antenna heights up to 200 m and receiving antennas located within 10 m ; ▪ Very accurate.	▪ Complex implementation.

Figure 1: Comparative table of propagation models.

3. RELATED WORKS

The essential aspect in the planning and optimization of wireless network is to find a radio propagation model adapted to the specific environment. Radio propagation models are widely used for network planning, especially for network expansion or deployment such as; data collection networks, mobile network services. To determine the characteristics of an adequate radio propagation channel, the propagation models real state and calibration ought to be tested. Many radio propagation models exist in the scientific literature [8-12], for example. These models have been calibrated, optimized and used in a variety of environments. Others many published works have widely used propagation models to demonstrate the feasibility of radio coverage. In [13], Mardeni and Priya presented an optimized COST-231 Hata model for path loss prediction in suburban and open urban environments for frequency range between 2360-2390 MHz. Medeisis and Kajackas [14] in their paper, deal with a radio propagation model in urban and rural areas of Lutiania at 160, 450, 900 and 1800 MHz bands, and the main focus of their paper contribution was to improve the Okumura model for these environments. Some authors have been particularly interested in using the least-square method to calibrate or determine the radio propagation models. We have for instance, Allam Mousa, Yousef Dama and All [15] in Palestine focused their work on an ‘‘Optimizing Outdoor Propagation Model Based on Measurements for Multiple RF Cell’’. Chen, Y.H. and Hsieh, KL [16] deal with ‘‘A Dual Least-Square Approach to Tuning Optimal Propagation Model for existing 3G Radio Network’’ in Thaiwan. And, MingjingYang and Al [17] in China worked on ‘‘A Linear Least Square Method of Propagating Model Tuning for 3G Radio Network Planning’’.

4. STUDY CASE AND METHODOLOGY

A. Presentation of LoRa WAN radio interface

In general, LoRa designates the physical layer (PHY) that defines the radio link between the end-devices and the gateways while LoRaWAN defines the MAC layer (i.e.: the communication protocol), and the network architecture [18]. The architecture of this long-range network is in star topology, formed of a large number of nodes (transmitters) and some gateways (receivers). The function of the gateway can simply be described as a packet forwarder. The key function of the network server is to interpret the data sent by the end-devices, but also to handle the functionality of LoRaWAN and the global management of the network. The network server also keeps track of information regarding each individual end-device in the network in order to help optimise the routing of traffic to them.

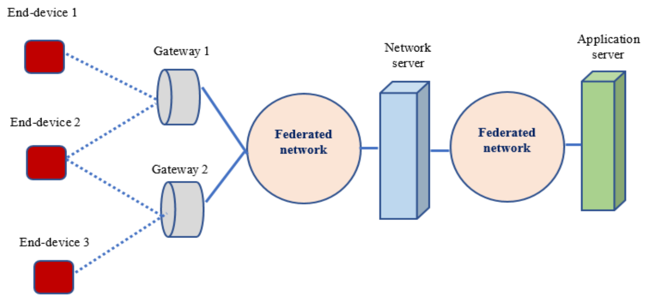


Figure 2: LoRaWAN Architecture

In the LoRa network, sensors are the main part of the data collection network and carry out data measurements that they transmit via radio interface at regular time intervals to the gateways. Data are then transmitted to a network server where they are selected and classified. The server also manages gateways and data rates to optimize sensor batteries in the network. In fact, data collected by end-nodes are gathered at an application server level for their exploitation. Thus, users have the possibility to analyse data (data post-processing) through this application server and the system security is strengthened at this level.

This architecture brings many benefits for our application domain: long rang, large network capacity dues to a star network topology, long battery life of end-nodes, and end-nodes are less complex in term of implementation. The frequency bands and associated parameters are given in the table 4 below. This table shows the different channels that can be used by LoRa network in Industrial Scientific and Medical (ISM) unlicensed band around 868 MHz. We can also observe in this table the restrictions such as transmitted power and cyclic ratio that must be respected for signal transmission in this frequency band. LoRa modulation has three important parameters. The first parameter is the spreading factor (SF) whose value is defined from 5 to 12 and two signals with different SF are orthogonal. The second parameter is the chirp bandwidth (W) that can take the different following values: 125 kHz, 250 kHz or 500 kHz. The third one is the coding rate (CR) corresponding to a data transmitted code protection with the different following values 4/5, 4/6, 4/7 and 4/8.

Table 3: LoRaWAN specifications for Europe.

Channel (MHz) [19]	**Bandwidth (Khz) [19]**	**EIRP (dBm) [19]**	**Cyclic ratio [19]**	**Throughput (Kbps) [19]**
868.1	125	14	≤ 1	0.3 - 5 Kbps
868.3	125	14	≤ 1	0.3 - 5 Kbps
868.5	125	14	≤ 1	0.3 - 5 Kbps

ESATIC is an Information and Communication Technologies (ICT) college in Abidjan, Côte d’Ivoire. Since 2018, ESATIC has integrated IoT into its training modules, particularly in the Master course. This desire is part of the political vision of ivorian Digital Economy and Post Ministry in order to promote this new technology in all sectors of the country. For this purpose, ESATIC, a ICT college under the authority of this department, acquired a LoRa base station having one gateway associated with one antenna for an experimental stage with a view to deploy this technology for connected objects in a mayor part of the country. Roughly speaking, ESATIC's experimental LoRa network, in addition to this one gateway, includes an application server and sensors for humidity, temperature, carbon dioxide (CO2), carbon monoxide (CO), and dust particles. ESATIC's LoRa Gateway (Outdoor LoRa V2.1**)** showed by figure 2, uses Semtech's LoRaWAN technology to provide a low-power and long-range wireless connection. It operates in the ISM 868 band and can support connectivity roughly equal to 20,000 objects in a wide range for IoT applications. The LoRaWAN specifications are defined by the LoRa Alliance. With a transmitting power of 20 dBm, the LoRa base station can theoretically reach a range of 20 Km.

Figure 3: ESATIC LoRa base station

The table 4 below shows the technical characteristics of the Outdoor LoRa V2.1 Gateway:

Table 4: LoRa base station technical characteristics.

	Parameter	Values	Unit
Power	P_e	20	dBm
Frequency band	ISM 868	868-870	MHz
Channel spacing	CS	20	KHz
Antenna gain	G_e	8	dBi
Antenna height	h_{1b}	8	m
RG223 cable Loss (1m)	L_{ecab}	0.22	dB
SMA-F connector Loss	L_{econ}	0.8	dB

B. *Description of the environment*

The radio radiated power levels are measured in Abidjan southern area environment, composed in particular of the areas of Treichville, Marcory, Koumassi and Port-Bouët. Their population density is moderate, and each of these areas can be assimilated to a suburban agglomeration with medium-sized buildings. One of their common features, is the existence of an industrial or port zone. After surveys, we have summarized in the following table 5 the common environment features of these areas:

Table 5: Measurement environment features

	Parameter	Values
Building average height (Ground + 2 floors)	H_{roof}	10,5 m
Roads average width	W	10 m
Average distance between buildings	d_i	50 m
Average road traffic per minute	T_v	20 Vehicles
Population average density /km^2	P_D	1400
Pedestrians average number / 100m	P	6

Figure 4 shows the different southern areas of Abidjan, and these radio propagation environment considered for measurements and simulations is NLOS since there is no direct visibility between the LoRaWAN end-device and ESATIC LoRaWAN base station antenna in the measured locations.

Figure 4: Abidjan south areas

C. *Data collection process*

Data collection process is obviously base on ESATIC's LoRa base station previously described. So the main purpose of this process is to develop a radio propagation model for a LoRa network in southern areas of Abidjan through the collected data. The method used here, consists of measuring power levels radiated by this base station, calculating the received power average level at different points of Abidjan southern area and determining the attenuation induced by the environment. Indeed, the power level measuring device here, is the Aronia spectran HF60105. It is fit to measure power and electromagnetic field levels for frequencies from 10 MHz to 10 GHz. In addition, it can measure the signal power levels of different technologies such as GSM, UMTS, LTE, LoRa etc. The technical parameters used for this device as receiver during the measurements are showed in the table 6 below:

Table 6: Aronia Spectran HF60105 parameters

	Parameter	Values	Units
HyperLOG 60100 antenna Gain	G_r	4.9	dBi
RG 316U Flexible Cable loss	L_{rcab}	-1	dB
SMA connector loss	L_{rcon}	0.3	dB
Receiving antenna height	h_{2m}	2	m
Antenna factor	F	24.18	dB
Antenna weight	M	250	g

The measurements are performed in the ISM 868 unlicensed band in which our base station receives and radiates its signals. This band is used for applications such as IoT and is subdivided into sub-bands and channels from 868 to 870 MHz. The measurement chain consists of one HF60105 spectran, one laptop on which the MCS Analyzer application has been installed to record data, one GPS to record the geographical coordinates of the different measurement points, one multimeter used in thermometer mode to pick up the temperature, and one clock to record the measurement time. All the equipments used for the measurements are showed in the following figure 5.

(a) Aronia Spectran HF60105.

(b) All the equipments used.

Figure 5: Equipments used for measurements

Firstable, we realized three outdoor series of measurements, two series in rainy weather and one serie in clear weather. For the two outdoor measurement series during rainy weather, one was performed around 5 mm/h of rain intensity average and the other around 12 mm/h. All the measurement series were realised in the month of April 2019 at 30° Celsius average temperature during clear weather, and in June 2019 during the rainy weather.

The operating mode was as follow, at each measurement point, we take several thousand samples of the power level with the measuring device. At the same time, we also record the temperature, the geographic coordinates point and time of the measurement. However, it important to precise that in our case the time and the temperature are not really relevant. This is explain by the fact that here the measurements were performed at ground-level and we have the high frequencies. So the measurements cannot be influenced by time and temperature.

D. *Experimental results*

Having implemented the aforementioned method on radio data measurements, we obtained the different curves of figure 5. On the curves showed in figure 5, we can notice that the rain has a negative effect on the waves radiated by our LoRa base station.

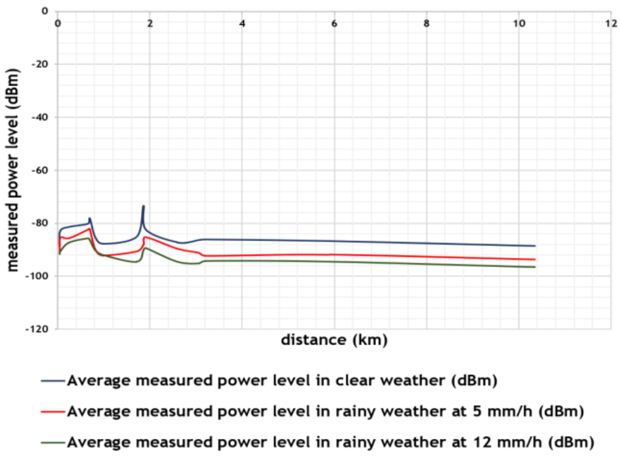


Figure 6: Variation of receiving power at different measurement points

The rain intensity brought an average attenuation around -4.73 dB for the outdoor measurement at 5 mm/h of rain intensity average, and around -7.54 dB for outdoor measurement during the rainy weather for an average rain intensity of 12 mm/h. Obviously, we can see that the power loss is more important when measurements are done in the case of rainy weather at 12 mm/h of rain intensity average. Therefore, for the rest of our work, we used the worst conditions in order to get reliable results at any time. So, we are going to base the development of our radio propagation model for path loss prediction in the Abidjan southern areas, on experimental results obtained during the outdoor measurements in rainy weather at 12 mm/h of rain intensity average.

E. *Development of an adapted model*

First, it important to start exploring the existing models with a view to find an existing adequate model for our case. Thus, if we consider the heights of the base station antenna and the receiver, the operating frequency band, we can argue that the Cost 231 Walfish Ikegami model is suitable for deploying the LoRa network in our environment. However, when observing the coverage distance of our base station, we can see that it is far from the reference distance given for the application conditions of this propagation model.

With the previous observation in mind, it is imperative to develop an adapted model for our environment type if we want to optimize the deployment of the LoRa network in the southern areas of Abidjan. Our NLOS environment is roughly equivalent to what is relatively illustrated by the following figure 7.

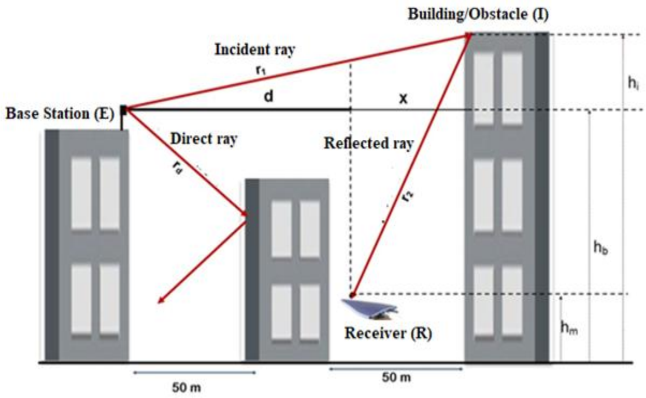


Figure 7: Suburban environment of Abidjan southern illustration

Due to the dispersion of the obstacles around the measuring point (50 m at most) and considering the base station height relatively to the buildings, the reflection is more important than the refraction. Indeed, even when an incident ray diffracts on a building roof or wall, it ended up reflecting on another building. Under these conditions, we also note that the reflection angles are small. So base on these conditions and from Cost 231 Walfish Ikegami model, we define a new model more adapted to environment southern Abidjan. The loss caused by the wave path and its reflections can thus be summarized in the following equations giving our particular model, called here ESATIC model:

$$P_{Loss} = AEL_1 + AEL_2 + L_r \tag{14}$$

The terms AEL_1 and AEL_1 represent the path losses due to the free spaces for the electromagnetic rays r_1 and r_2, respectively, and these terms are determined by the following mathematical representation :

$$\begin{cases} AEL_1 = 27.56 - \log(f) - 10\log\left[(d+x)^2 + \Delta h_b{}^2\right] \\ AEL_2 = 27.56 - \log(f) - 10\log\left[x^2 + \Delta h_m{}^2\right] \end{cases} \tag{15}$$

By adding the two terms and putting d^2 into factor, we finally obtain:

$$P_{Loss} = 55.12 - 40\log(f) - 20\log(d) + G_{dif} + L_r \tag{16}$$

where :

$$G_{dif} = -10\log\left[\left(\left(1+\frac{x}{d}\right)^2 + \left(\frac{\Delta h_b}{d}\right)^2\right) \times \left(x^2 + \Delta h_m^2\right)\right] \tag{17}$$

The expression G_{dif} represents the loss due to buildings diffraction around the receiver. Its positive value here, shows that there is an addition of different electromagnetic rays at this measurement point and therefore, the buildings layout probably forms a channel for the radio wave guidance. The point of measurement is most likely less than 50 m ($x \leq 50\,m$) and reflects the radio wave. We precise that a simulation according different values of x, allow us to find the average loss of building diffraction which is around 32.45 dB (see figure 8). The term L_r is assimilated to a corrective factor, and its different values are given below:

$$L_r = \begin{cases} -82dB & \text{for} \quad d\langle 0.24km \\ -56dB & \text{for} \quad 0.24\langle d\langle 1km \\ -48dB & \text{for} \quad 1km\langle d\langle 3.5km \\ -40dB & \text{for} \quad d\rangle 3.5km \end{cases} \tag{18}$$

The values of L_r consequencely represent the extent of the propagation channel effects. Figure 7 shows the loss G_{dif} of obstacle diffraction variations around the receiving point at different values of x.

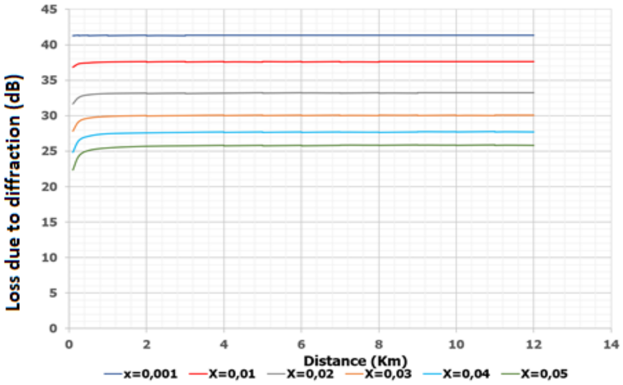


Figure 8: Diffraction variations around the receiver

F. *Simulation results*

Our propagation model prediction accuracy in this study, is assessed using statistical analysis of the collected data. The performance evaluation is based here on the comparison between data obtained from our model simulation or estimated power level and those collected from signal power measurements or measured power level. We call back again that the measured power levels used for this assessment are those collected in rainy weather at 12 mm/h of rain intensity.

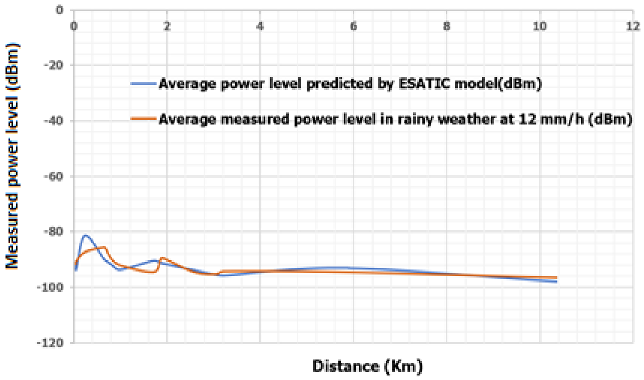


Figure 9: Comparative curves of estimated and measured power levels

In fact, the results of the comparison between the estimated and the measured power levels will determine the validity of our ESATIC model for the LoRa network deployment in 868 MHz relatively to Abidjan south environment.

Figure 9 shows the estimated power levels of ESATIC model and the statistical measured power levels collected in rainy weather comparative curves for Abidjan suburban areas. Our ESATIC model (curve in brown) gave the close prediction results when compared with what was obtained from statistical measurements (curve in blue) for LoRaWAN 868 MHz. Although there were small differences between values obtained from the two curves around 0.5 km and 1.5 km, we noticed that ESATIC model can validly give a good prediction results for our suburban radio propagation environments.

The previous analysis therefore validates the results given by ESATIC model and it is right to say that this model is adapted to path loss prediction for LoRaWAN 868 MHz planning in Abidjan suburban environment of the southern areas.

5. CONCLUSION

This paper deals with the development of an efficient radio propagation model on LoRa network in 868 MHz for Abidjan suburban areas environment. It turns out that standard radio propagation models such as Okumura Hata and Cost-231 Walfish Ikegami are not suitable, so it is important to optimize these models to obtain similar models but representing the propagation environment considered here. The LoRaWAN technology, which combines reliability and long range, requires a good radio propagation path loss prediction. So, after an experimental study, we deduce that the new model developed through our work on the basis of Cost-231 Walfish Ikegami model is more accurate and suitable radio propagation path loss prediction model for LoRaWAN 868 MHz radio network deployment in the suburban areas in Abidjan and in all others suburban areas of Côte d'Ivoire.

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