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Path Loss Characterization in an Indoor Laboratory Environment at 3.7 GHz in Line-Of-Sight Condition

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Abstract

The objective of this work is to propose experimental path loss propagation models for communication channels in indoor environments. In this sense, an experimental path loss characterization has been achieved, according to the measurements campaign carried out in a typical scenario of a university campus. These narrowband measurements were collected in the laboratory environment at 3.7 GHz in line-of-sight (LOS) condition. Also, these measurements were carried out at night to simulate stationary channel conditions. Thus, the results obtained show the values of the parameters of the close-in (CI) free space reference distance and floating-intercept (FI) path loss models, in terms of the transmitter and receiver separation distance. It should be noted that these values of the path loss models have been

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extracted applying linear regression techniques to the measured data. Also, these values agree with the path loss exponent values presented by other researchers in similar scenarios. The path loss behavior can be described with the implementation of these models. However, more measurement campaigns are needed to improve the understanding of propagation channel features, as well as to obtain better precision in the results obtained. This, in order to optimize the deployment and performance of next fifth-generation (5G) networks that combine indoor environments to offer their services and applications.

Keywords: 5G; channel characterization; channel measurements; channel models; indoor environments; path loss exponent.

Caracterización de las pérdidas de propagación en un entorno de laboratorio a 3.7 GHz en condición de línea de visión directa

Resumen

El objetivo de este trabajo es proponer modelos experimentales de las pérdidas de propagación para canales de comunicación en entornos *indoor*. Se ha efectuado una caracterización experimental de las pérdidas de propagación de acuerdo con la campaña de medidas llevada a cabo en un escenario típico de un campus universitario. Estas medidas fueron realizadas en un ambiente de laboratorio a 3.7 GHz en condiciones de línea de vista y con un enfoque de banda estrecha. Las mediciones se hicieron en la noche, simulando condiciones de estacionariedad del canal de comunicaciones. Los resultados obtenidos muestran los valores de los parámetros del modelo Close-In (CI) a una distancia de referencia en espacio libre, y del modelo Floating-Intercept (FI) en términos de la distancia de separación entre el transmisor y receptor. Se debe notar que dichos valores de los modelos de pérdidas de propagación se han extraído aplicando técnicas de regresión lineal a los datos medidos. Además, concuerdan con los valores del exponente de pérdidas de propagación presentados por otros investigadores en escenarios similares. Con la implementación de estos modelos se puede describir el comportamiento de las pérdidas de propagación en este tipo de entornos, sin embargo, es necesario hacer más campañas de medición para mejorar los conocimientos de las características

del canal de propagación. También, para obtener una mejor precisión en los resultados obtenidos, con el fin de optimizar el despliegue y desempeño de las futuras redes de quinta generación (5G), que combinen los entornos *indoor* para la prestación de sus servicios y aplicaciones.

Palabras clave: 5G; ambientes indoor; caracterización de canal; exponente de pérdidas de propagación; medidas de canal; modelos de canal.

Caracterização das perdas de propagação em um ambiente de laboratório de 3.7 GHz em condição de linha direta de visão

Resumo

O objetivo deste trabalho é propor modelos experimentais de perdas de propagação para canais de comunicação em ambientes internos. Uma caracterização experimental das perdas de propagação foi realizada de acordo com a campanha de medição realizada em um cenário típico de um campus universitário. Essas medições foram realizadas em um ambiente de laboratório de 3,7 GHz sob condições de linha de visão e com um foco de banda estreita. As medições foram feitas à noite, simulando as condições de estacionariedade do canal de comunicação. Os resultados obtidos mostram os valores dos parâmetros do modelo Close-In (CI) a uma distância de referência no espaço livre, e do modelo Floating-Intercept (FI) em termos da distância de separação entre o transmissor e o receptor. Deve-se notar que esses valores dos modelos de perda de propagação foram extraídos pela aplicação de técnicas de regressão linear aos dados medidos. Além disso, concordam com os valores do expoente de perda de propagação apresentados por outros pesquisadores em cenários semelhantes. Com a implementação desses modelos, pode-se descrever o comportamento das perdas de propagação neste tipo de ambiente, porém, é necessário realizar mais campanhas de medição para melhorar o conhecimento das características do canal de propagação. Também, obter maior precisão nos resultados obtidos, de forma a otimizar a implantação e desempenho das futuras redes de quinta geração (5G), que combinam ambientes internos para a prestação de seus serviços e aplicações.

Palavras chave: 5G; ambientes internos; caracterização do canal; expoente de perda de propagação; medições de canal; modelos de canais.

I. INTRODUCTION

Fifth-generation (5G) technology significantly improves signal quality and service, providing the ability to support: volumes higher than 100 Mbps, with data rates reaching as high as 10 Gbps; communications in high user density instances, and low latency communications [1-3]. This means that 5G networks can be used to support communication for some special scenarios not supported by 4G networks [4]. The main feature of 5G networks is high bandwidth from hundreds of MHz to several GHz, which means that it can provide very high speeds, however, the higher frequency spread introduces severe path loss [5].

In every wireless communication system, several interacting items (reflectors and/or scatters) are present between the transmitter (Tx) and the receiver (Rx). As a result, multiple replicas of the Tx signal are received at the Rx antenna, which condition the performance of the channel capacity [6]. Therefore, one of the most important parameters to analyze the development of wireless communication systems is the path loss propagation. Moreover, the implementation of 5G networks depends on the accurate path loss channel characterization and modeling, to improve the coverage and to achieve the high transmission speed that this generation promises [7-8]. However, the propagation models require experimental measurements that include characteristics of an indoor or outdoor environment, where electromagnetic waves are propagated. The complexity of the environment determines the path loss parameters of the model. In addition, the 5G networks proper performance in indoor environments depends on the careful study of the communication channel behavior. The Federal Communications Commission (FCC) is taking action to make additional spectrum available for 5G services. The FCC concluded its first 5G spectrum auction last year with 28 GHz band and, this year, the FCC authorized full commercial deployment of the 3.5 GHz band. Moreover, the FCC categorized the bands as follows. High-band: 24 GHz, 28 GHz, 37 GHz, 39 GHz, and 47 GHz bands; mid-band: 2.5 GHz, 3.5 GHz, and 3.7-4.2 GHz bands, and low-band: 600 MHz, 800 MHz, and 900 MHz bands [9]. Then, the mid-band spectrum has become a purpose for 5G development, given its capacity characteristics and balanced coverage. Furthermore, the Radio Spectrum Policy Group (RSPG) considers the

3.4-3.8 GHz to be the main band apt for the initiation of 5G-based services in Europe [10]. It should be noted that mid-band could be potentially allocated for 5G applications. In fact, some studies have been done, and describe that the bands below 6 GHz work as the main access link for indoor communications, as well as how these will bring more than 600 MHz available for 5G deployment. [9], [11-12]. Also, the collection of measurements was done under line-of-sight (LOS) condition. The following explains the organization of this paper: Section II summarizes measurement configuration as well as the propagation environment, Section III shows path loss results, and Section IV provides the main conclusions of this work.

II. METHODOLOGY

A brief description of the methodology that has been used to acquire the data is made below, illustrating the equipment and parameters with which the channel sounder was configured. Additionally, the characteristics of the indoor laboratory scenario where the measurements have been carried out are described.

A. Measurements Configuration

A channel sounder was carried out in the frequency domain for narrowband propagation channel measurements to characterize the path loss, see Figure 1. This channel sounder was composed of a ZVA8 vector network analyzer (VNA) of R&S that was used to measure the received power level through the b_2 parameter at one of its ports; a continuous wave (CW) was transmitted at 3.7 GHz at the other ports with a transmission power of 0 dBm, in each Tx1-Tx8 position. The same antenna was used for both Tx and Rx purposes (model EM-6853), which were omnidirectional with a gain of 0 dB. In the Rx side, an amplifier with a gain of 20 dB was used. The Rx antenna was placed in the X-Y positioning system with a 6*6 uniform rectangular array (URA), with a separation distance for point to $\lambda/2$ close to 4.0 cm. In the VNA, the b_2 parameter was constantly measured by using traces of 1,001 test points, taking 8 traces for each array position, for a total of 2,304 traces from Tx1-Tx8, for an intermediated frequency (IF) filter equal to 100 Hz. It is important to note that the measurements were made at night to assure stationary

channel conditions. Table 1 shows the measurement system parameters used in this study.

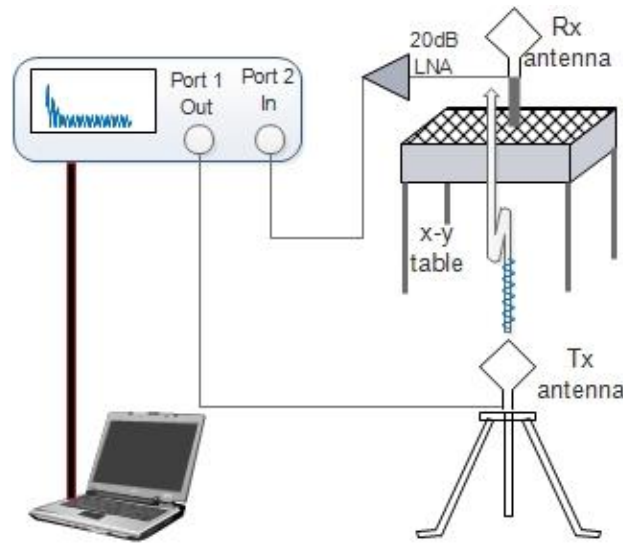


Fig. 1. Channel sounder.

Table 1. Measurement system parameters.

Parameter	Value
VNA IF bandwidth	100 Hz
VNA center frequency	3.7 GHz
Frequency points for trace	1001
VNA output power	0 dBm
Tx antenna height	1.07 m
Rx antenna height	1.78 m
Tx-Rx antenna gain	0 dB

B. Measurement Environment

The measurements collection was done in an indoor location: a telecommunications laboratory at the Pedagogical and Technological University of Colombia. Figure 2 shows the location layout with the following characteristics: length 8.2 m x 7.2 m and height 2.7 m, exposed brick walls, concrete ceiling, ceramic floor, and a lighting system with 9 double fluorescent tube lamps. Additionally, there is an embedded video beam in the ceiling of the laboratory center. The transmitters were located at a height of 1.07 m from the floor level, and the receiving antenna at a height of 1.78 m.

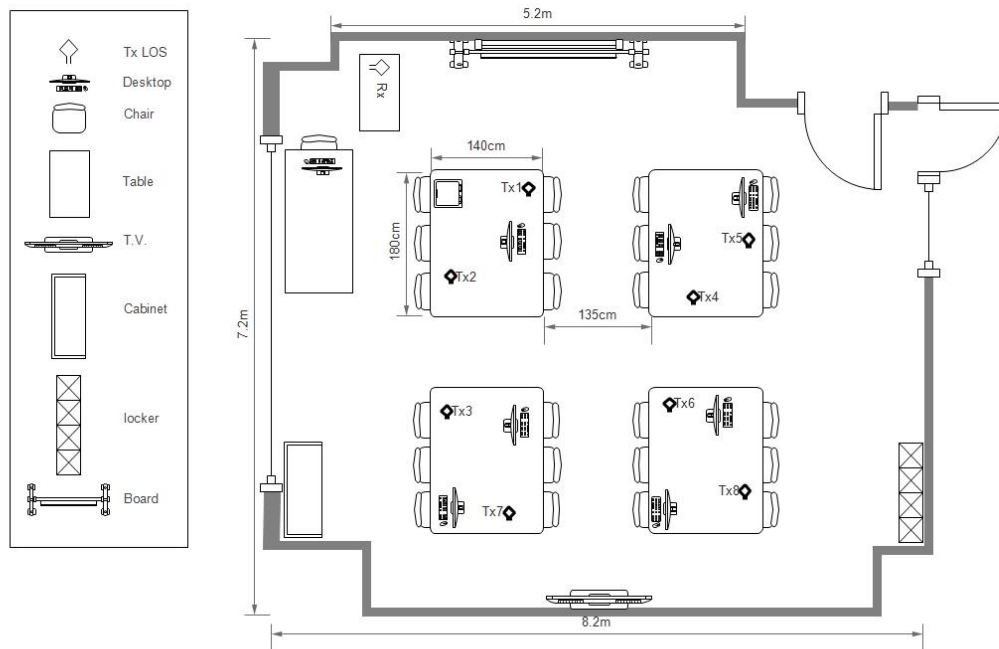


Fig. 2. Top view of the indoor laboratory environment.

III. MEASUREMENT RESULTS

The term channel modeling, which is also known as channel characterization, depicts the approaches, models, and channel measurements performed to comprehend how the propagation channel harms and distorts the transmitted signal that propagates through it in an specific environment [6]. In this sense, this work is analyzed by path loss propagation in an indoor laboratory environment using the floating-intercept (FI) path loss model, which channel standardization and some others works have supported [13-15]. The path loss (in dB) defined through this model is given by equation (1).

$$PL^{FI}(d) = \beta + 10\alpha \log_{10}(d) + \chi_{\sigma}^{FI}, \quad (1)$$

Where χ_{σ}^{FI} is referred to in literature as the shadow factor (SF), that is modeled as a zero-mean Gaussian random variable in logarithmic units; β is the floating offset parameter in dB; α is the path loss exponent (PLE), associated to the characteristics of the propagation environment; d is the Tx-Rx separation distance, and the

standard deviation σ is used to describe the statistical variation about the distant-dependent mean path loss [16]. The close-in (CI) free space reference distance path loss model is also reinforced in literature [14-15], [17]. In the CI model, the path loss is given according to equation (2).

$$PL^{CI}(d) = FSPL(f_c, 1 m) + 10n\log_{10}(d) + \chi_{\sigma}^{CI}, \quad (2)$$

$FSPL(f_c, 1 m)$ being the free space path loss (FSPL) for a Tx-Rx separation distance, equaling 1 m at frequency f_c in GHz (43.81 dB at 3.7 GHz); n is PLE and is calculated through $FSPL(f_c, 1 m) = 10\log_{10}(4\pi f_c/c_0)^2$, where c_0 is the speed of light, and χ_{σ}^{CI} is the SF term. The path loss model parameters were created from the measured data through the minimum-mean-square-error (MMSE) approach. The path loss that fits the results for the FI and CI models is shown in Figure 3. The measured path loss (denoted by dot marker in blue color), and the mean value of the path loss (denoted by square marker in red color) in relation to the Tx-Rx separation distances are depicted in Figure 3.

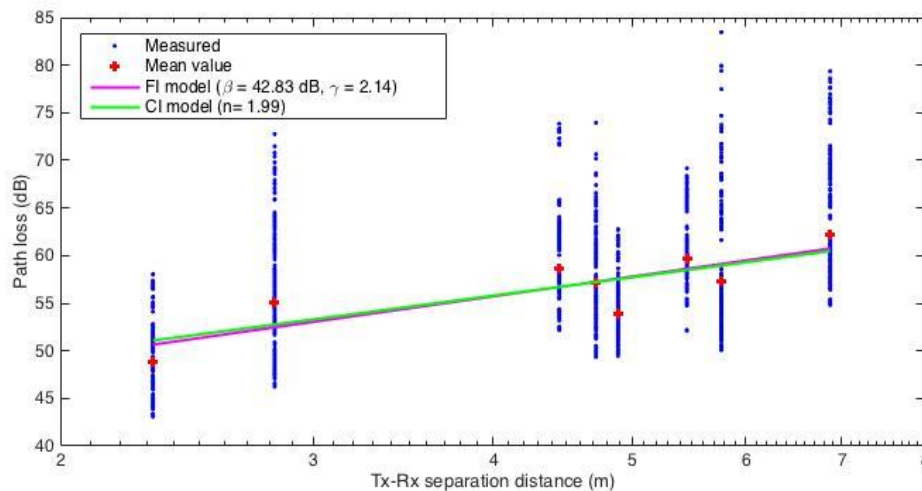


Fig. 3. CI and FI path loss models in relation to the Tx-Rx separation distance at 3.7 GHz for LOS condition.

Considering the FI model, a mean value of 42.83 has been obtained for the β parameter, with a 95% confidence interval from 41.90 dB to 43.76 dB; whereas a mean value of 2.14 has been obtained for the α parameter, with a 95% confidence

interval from 2.00 to 2.28. For the CI model, the mean path loss exponent derived is 1.99, with a 95% confidence interval from 1.96 to 2.03. Regarding the SF, the values derived from the two models are very close, 5.11 dB and 5.12 dB for the FI and the CI model, respectively. The mean values of both models and their 95% confidence interval are summarized in Table 2 for FI model and CI model.

Table 2. FI and CI path loss models parameters in LOS condition.

Model	$\beta(\beta_{95\%})$	$\alpha(\alpha_{95\%})$	$\sigma(\text{dB})$
FI	42.83 (41.90-43.76)	2.14 (2.00-2.28)	5.11
Model	$FSPL(f_c, 1\text{ m})$	$n(n_{95\%})$	$\sigma(\text{dB})$
CI	43.81	1.99 (1.96-2.03)	5.12

It is worth noting that the path loss exponent values derived in this study are less than the values described by Sreedevi et al. [18], where path loss exponents of 2.74 and 2.9 were measured at 3.4 GHz and 5.2 GHz, respectively. Nonetheless, higher values have been shown by [19], where the path loss exponents from 1.51 to 1.69 were measured at 3.6 GHz. These differences can be explained because of the specific qualifications of the scenario and propagation conditions.

The mean and dispersion values of the path loss exponent in relation to the Tx-Rx distance for all Tx positions are depicted in Figure 4. In these boxplots the path loss is analyzed by intervals of Tx-Rx distance, where the red line represents median values, and the sides of the box represent the 25th and 75th percentiles. The values derived from Figure 4 are summarized in Table 3.

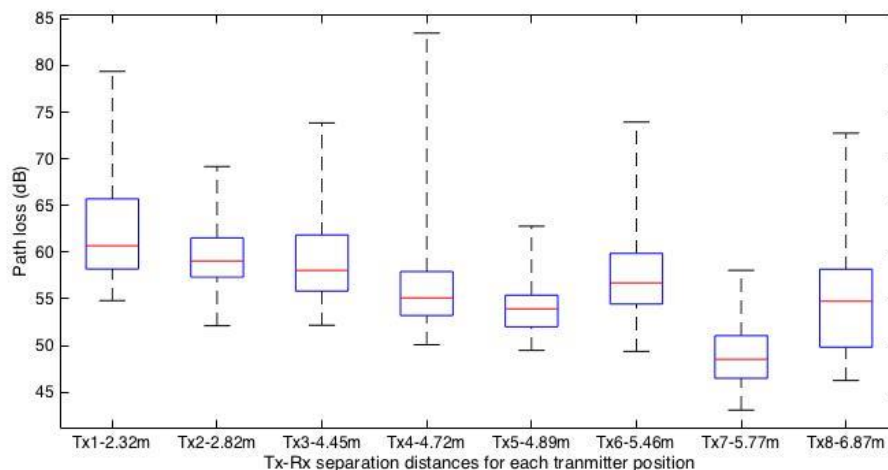


Fig. 4. Boxplots of the path loss as a function of the Tx-Rx separation distances.

Table 3. Statistical path loss at 3.7 GHz in LOS condition.

Value	Tx1	Tx2	Tx3	Tx4	Tx5	Tx6	Tx7	Tx8
25th percentile	58.2	57.3	55.8	53.2	52.0	54.4	46.5	49.8
50th percentile (median)	60.7	59.1	58.0	55.1	53.9	56.7	48.5	54.7
75th percentile	65.7	61.5	61.9	57.9	55.4	59.9	51.1	58.2

IV. DISCUSSION AND CONCLUSIONS

A narrowband measurement campaign has been carried out in a laboratory scenario at a 3.7 GHz band, taking a total of eight locations for the transmitter in line-of-sight (LOS) condition to analyze the received signal performance caused by the multipath effect, time-dispersion, as well as how it affects the path loss in the indoor environments.

The floating-intercept (FI) and close-in (CI) path loss models parameters and their 95% confidence interval have been obtained out of the measured data through the minimum-mean-square-error (MMSE) approach. For instance, a mean value of 2.14 has been obtained for the α parameter in the case of FI model, and for CI model a mean value equal to 1.99 has derived for the n parameter. These results agree with values obtained by some researchers in indoor environments at mid-band frequencies.

This study helps to inform better on path loss propagation in indoor environments. In fact, it is required to continue making measurements in this frequency band, due to the initiative of international organizations, such as the Federal Communications Commission (FCC), to use the mid-band for fifth-generation (5G) applications. Therefore, the results described in this document may be used to make progress in the design and deployment of coming 5G networks in these scenarios.

AUTHOR'S CONTRIBUTION

Sandy-Enrique Avella-Cely: Methodology, Validation, Formal analysis, Investigation.

Juan-Carlos Muñoz-Perez: Methodology, Validation, Formal analysis, Investigation.

Herman-Antonio Fernandez-Gonzalez: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Supervision, Writing—original draft, Writing—review & editing.

Lorenzo Rubio-Arjona: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Supervision, Writing—original draft, Writing—review & editing.

Juan-De-Ribera Reig-Pascual: Conceptualization, Methodology, Formal analysis, Investigation.

Vicent-Miguel Rodrigo-Peñarrocha: Conceptualization, Methodology, Formal analysis, Investigation.

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