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SHORT RANGE PROPAGATION MODEL FOR A VERY WIDEBAND DIRECTIVE CHANNEL AT 5.5 GHZ BAND

B. Taha Ahmed*, D. F. Campillo, and J. L. Masa Campos

Universidad Autónoma de Madrid, Escuela Politécnica Superior, Madrid 28049, Spain

Abstract—In this work, the propagation loss of three short range directive channels at 5.5 GHz is measured using different directive antennas and a Vector Network Analyzer (VNA). Results are given for a channel bandwidth of 300 MHz which will be the future channel bandwidth of IEEE 802.11 ac system. It has been noted that the multipath induced fading tends to have Normal Distribution at low distance between the transmitting and the reception antennas. At higher distances, it tends to have Normal distribution plus Rayleigh one. Channel Impulse response (CIR) is also measured indicating that the main contribution is due to the direct ray and the one reflected from the floor. The human being obstruction causes an extra propagation loss of 2 to 10 dB depending on its distance from the transmitting antenna.

1. INTRODUCTION

IEEE 802.11 ac systems will operate at the 5.5 GHz band with a frequency bandwidth per channel up to 160 MHz and 320 MHz in the near future. Thus it is important to study the indoor loses at this band.

The study of indoor propagation is of vital importance since it can be used in many applications, namely, indoor communications and localization [1–3]. In [4], a theoretical treatment of propagation in indoor environment has been given meanwhile in [5], a mode based approach for characterizing RF propagation in conduits has been given. Cut-off frequency of each mode of propagation has been obtained. In [6] indoor propagation loss at 2.4 GHz band has been

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* Corresponding author: Bazil Taha Ahmed (bazil.taha@uam.es).

presented. Studied zones are a closed corridor, an open corridor and a classroom. Results show that propagation loss deviation from the mean value can be presented by Gaussian distribution with $\sigma \approx 1\,\mathrm{dB}$ for all the cases. In [7] propagation losses are measured in different frequency bands (1, 2.4 and 5.8 GHz) within an arched cross section tunnels. Results show that fast fading could be represented by Rayleigh distribution. The used antennas were wideband horn antennas with a gain of 9.2 dBi at 2.4 GHz and 10.1 dBi at 5.8 GHz. In [8] propagation loss in narrow tunnels is presented. Measurements results at 374 MHz, 915 MHz, and 2400 MHz are given. Studied scenarios were unobstructed, line of site (LOS), Obstructed LOS, T-junction NLOS and L-bend NLOS. Results show that deviation from the mean value could be presented by Gaussian distribution. Antennas used at 2.4 GHz, have a gain of 6.5 dBi. In [9], different propagation models for coverage prediction of WiMAX microcellular and picocellular urban environments and for WiMAX indoor femtocells at 3.5 GHz are compared with experimental data. Results obtained for different urban and indoor environments show that statistical models are quite far from good agreement with experimental data while deterministic ray-tracing models provide appropriate prediction in all different complex analyzed environments. The modeling of new WLAN models for indoor and outdoor environments is presented in [10]. Based on the standard Opnet models for WLAN nodes, the propagation loss estimation for these two types of environment has been improved. Paper [11] describes and evaluates a new algorithm for the purpose of Indoor propagation prediction for centimetric waves. The approach shown in this paper started from formalism similar to the famous transmission line model approach in the frequency domain. In [12], the radio channel characterization of an underground mine at 2.4 GHz is investigated. Propagation loss as a function of the distance between the transmitter and the receiver has been presented. Delay spread has been also given. In [13], the propagation modes and the temporal variations along a lift shaft in UHF band have been given. Morever, propagation in corridors, as well as tunnels and urban street canyons has been studied in [14, 15].

In this paper, a model to characterize the indoor channel at 5.5 GHz frequency band in commonly found building scenarios is presented. Equations to describe path loss have been determined from the analysis of measurement results in each scenario. A 300 MHz bandwidth has been selected since it is the future bandwidth that can be used in the IEEE 802.11 ac system. This work also presents the Channel Impulse Response (CIR) of some scenarios and the obstruction loss due human beings between the transmitting and receiving antennas.

Our contribution is the study for the first time the propagation loss and the channel impulse response (CIR) of a very wideband directive channels at the 5.5 GHz band.

The rest of the paper is organized as follows. Section 2 presents the propagation model that can express the propagation loss. In Section 3, the measurement campaign details with its results are given. In Section 4, conclusions are drawn.

2. PROPAGATION MODEL

In indoor environment, propagation could be due to the direct ray and four reflection rays (reflection from side walls, ground and ceil). For a medium distance (higher than the width of the studied zone) between the transmitting antenna and the receiving one, multi reflection rays may are also exists. Thus, in general, indoor propagation cannot be represented by the Two Rays Model (direct ray and ground reflection one).

For a short distance between the transmitting and receiving antennas (d), the propagation loss for an indoor environment is given by:

$$L_p\,(\mathrm{dB}) = L_o + 10n_1 \log_{10}\left(\frac{d}{d_o}\right) + \xi_1, \tag{1}$$

where L_o is the propagation loss at the reference distance do (1 m in our case), n_1 the propagation exponent, and ξ_1 a random variable (Normal, Rayleigh or a combination of both) that represents the deviation from the mean value due to the multipath induced fading.

Sometimes, second mode of propagation exists due to the waveguide mode of propagation which is generated in narrow corridors (corridors with a width lower than the height). In this case, the propagation loss at a distance d higher than the breakpoint distance d_b can be written as:

$$L_p\,(\mathrm{dB}) = \begin{cases} L_o + 10n_1 \log_{10}(d_b) + \xi_1, & d \le d_b \\ L_1 + 10n_2 \log_{10}\left(\frac{d}{d_b}\right) + \xi_2, & d > d_b \end{cases}, \tag{2}$$

where L_1 is the propagation loss of the distance d_b at which the waveguide mode starts, n_2 the second propagation exponent usually lower than n_1 and ξ_2 a random variable (Normal, Rayleigh or a combination of both) that represents the deviation from the main value due to the multipath induced fading. In wide indoor environment, n_2 will be in general higher than 2 (3 to 4). Equation (2) represents the commonly known two slopes propagation model [16, 17].

The measurements deviation from the mean value is presented by the sum of M Normal (Gaussian) random variables N_m and the small scale fading is presented by a Rayleigh random variable (R) [11]. Thus, in the rest of the paper, we will present ξ_1 and ξ_2 as:

$$\xi_1, \xi_2 = \sum_{m=1}^{M} W_m N_m (\mu_m, \sigma_m) + W_{\text{Ray}} R \tag{3}$$

where

- W_m is the weight of the Normal (Gaussian) fading component m.
- μ_m is the mean value of the Normal (Gaussian) fading component m.
- σ_m is the standard deviation of the Normal (Gaussian) fading component m.
- W_{Ray} is the weight of the Rayleigh fading component m.

The sum of the weights of $M + 1$ fading components is 1, i.e.,

$$\sum_{m=1}^{M} W_m + W_{\text{Ray}} = 1 \tag{4}$$

3. MEASUREMENT CAMPAIGN

A Network Analyzer (6 GHz ZVL of Rohde & Schwarz) has been used to measure the propagation loss at the 5.5 GHz band. Calibration has been carried out with a 21 m cable. The gain of the two directional patch antennas used in the study has been measured with an error lower than 0.1 dB using the standard method (by comparison of received power between the measured antenna and a calibrated standard horn antenna). The propagation loss is the sum of the gain of the two antennas used in the measurements plus the reading of the network analyzer. It is believed that the measurement error is lower than 0.3 dB. The transmitted power in all the measurements was 10 dBm, with a receiver resolution bandwidth of 100 kHz, and the Rx antenna is separated from the Tx antenna (fix) from 1 to 19 m. Measurements have been carried out in different sites within the Escuela Politecnica Superior of the Universidad Autonoma de Madrid. To measure the Channel Impulse Response (CIR), the Vector Network Analyzer Agilent E5071C is used.

The first studied scenario is represented by Figure 1(a) and a photograph of it is given by Figure 1(b). It consists of 5.65 m passage with a length of 55 m. Measurements have been carried out with

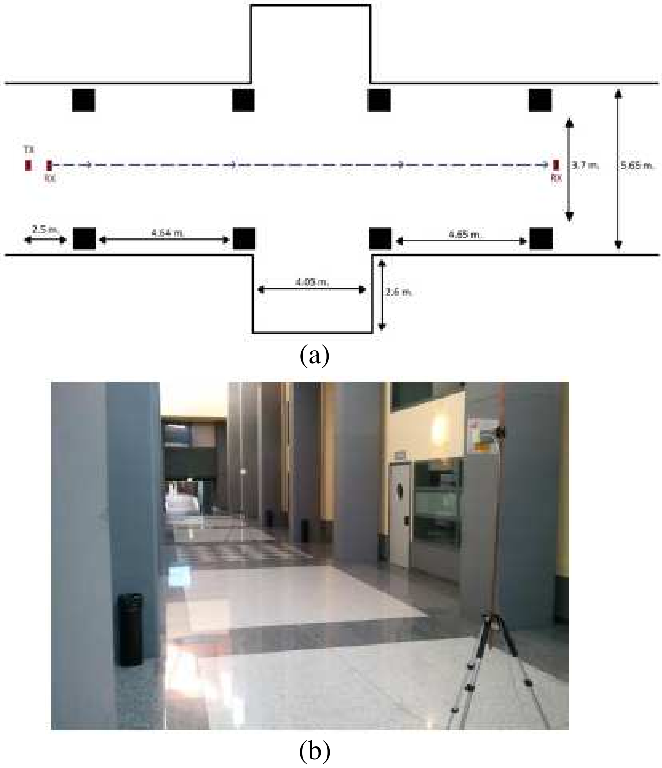


Figure 1. First studied scenario.

Table 1. Propagation parameters of the first case of scenario 1.

L_o (dB)	n_1	d_b (m)	L_1 (dB)	n_2
47.44	1.981	9	66.61	1.685

a maximum distance between the two antennas (transmitting and receiving one) of 19 m.

Figure 2 shows the propagation gain (loss) of the first case of this scenario using two antennas with a gain of 19 dB with vertical polarization.

Table 1 shows the propagation parameters of this case. (Please see Equation (2)).

It can be noticed that the propagation in first zone can be described by almost the free space model of propagation. Propagation in the second zone can be described by the waveguides modes of

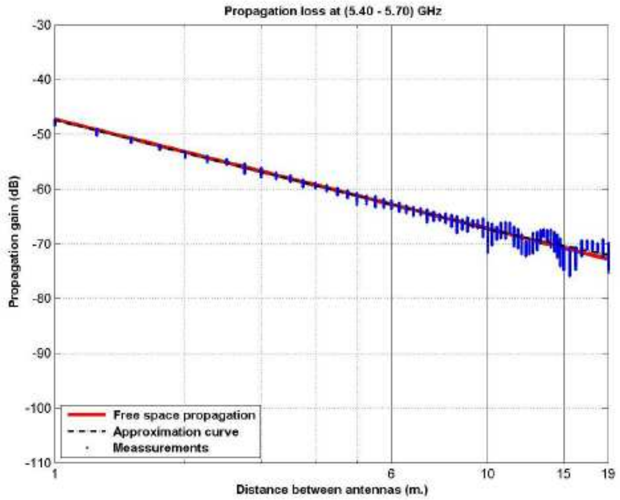


Figure 2. Propagation loss of the first case of scenario 1.

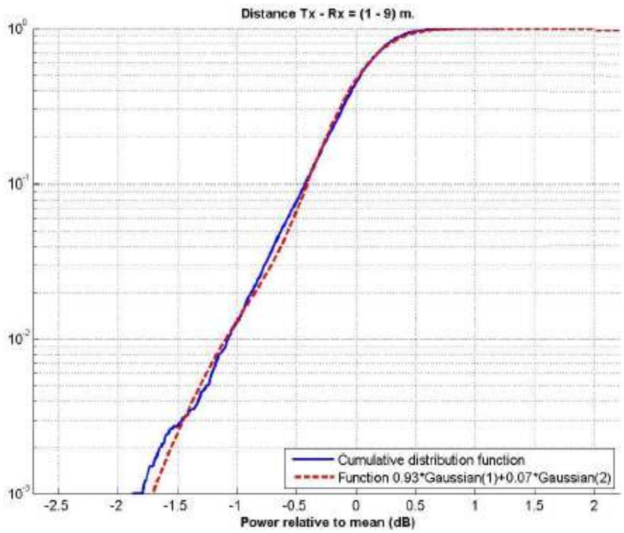


Figure 3. CDF of the multipath induced fading of the first zone of the first case of scenario 1.

propagation with a propagation exponent of 1.685. In the first zone, the main reasons of the measurements deviation from the mean value is due to the fact that the free space propagation loss is not constant at all the band and it increase with the increment of frequency within the channel bandwidth, that the antenna's gain is not constant at all the band, and due to the multipath emerging and arriving via the side lobes of both transmitting and receiving antennas.

Figure 3 presents the first zone (up to 9 m) Cumulative Distribution Function (CDF) of the measurements deviation from the

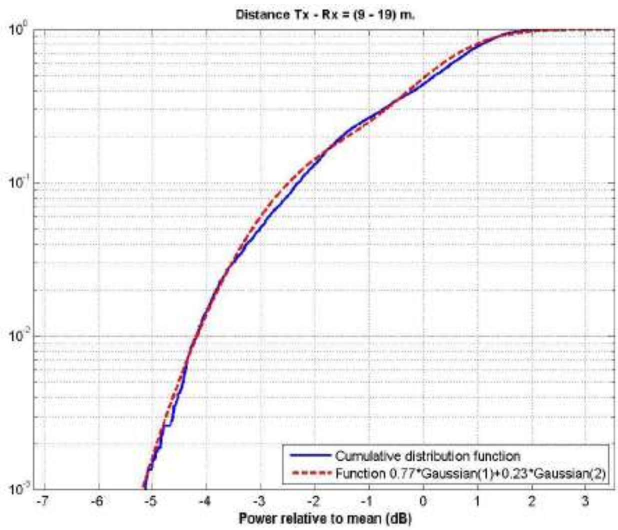


Figure 4. CDF of the multipath induced fading of the second zone of the first case of scenario 1.

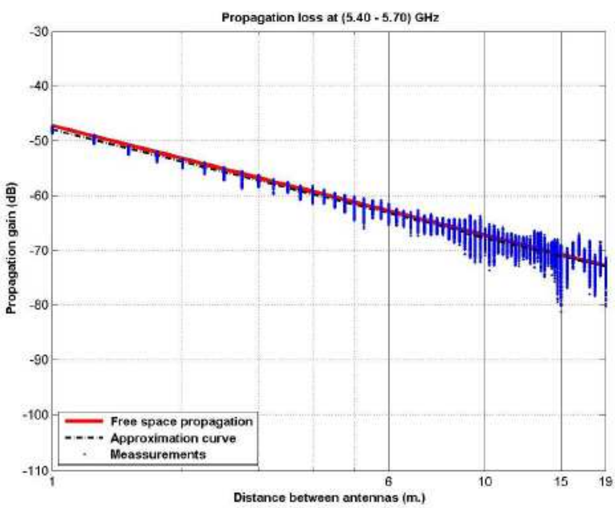


Figure 5. Propagation loss of the second case of scenario 1.

mean value given as the sum of two Normal (Gaussian) functions. Due to the antenna's high gains, the measurements deviation from the mean value has a Gaussian distribution with low value of σ.

Figure 4 presents the second zone (distance $> 9\,\mathrm{m}$) Cumulative Distribution Function (CDF) of the measurements deviation from the mean value given as the sum of two Normal (Gaussian) functions. Due to the higher distance between the transmitting and receiving antennas and thus higher contribution of the multipath, the measurements deviation from the mean value has a Gaussian distribution with higher value of σ compared with the first zone.

The multipath induced fading for the two measurement zone is given by:

Zone 1	Normal 1 — Weight = 93%, $\mu = 0.05\,\mathrm{dB}$, $\sigma = 0.3\,\mathrm{dB}$ Normal 2 — Weight = 7%, $\mu = -0.50\,\mathrm{dB}$, $\sigma = 0.55\,\mathrm{dB}$
Zone 2	Normal 1 — Weight = 77%, $\mu = 0.4\,\mathrm{dB}$, $\sigma = 0.9\,\mathrm{dB}$ Normal 2 — Weight = 23%, $\mu = -2.3\,\mathrm{dB}$, $\sigma = 1.1\,\mathrm{dB}$

Figure 5 shows the propagation gain (loss) of the second case of this scenario using a transmitting antenna with a gain of 19 dB and a receiving one with a gain of 8 dB with vertical polarization.

Table 2 shows the propagation parameters of this case.

It can be noticed that the propagation in first zone can be described by almost the free space model of propagation. Propagation in the second zone can be described by almost the waveguides modes of propagation with a propagation exponent of 1.875.

The multipath induced fading for the two measurement zone is given by:

Zone 1	Normal 1 — Weight = 85%, $\mu = 0.2\,\mathrm{dB}$, $\sigma = 0.6\,\mathrm{dB}$ Normal 2 — Weight = 15%, $\mu = -0.8\,\mathrm{dB}$, $\sigma = 0.8\,\mathrm{dB}$
Zone 2	Normal 1 — Weight = 69%, $\mu = 0.2\,\mathrm{dB}$, $\sigma = 1.3\,\mathrm{dB}$ Normal 2 — Weight = 30%, $\mu = -1.0\,\mathrm{dB}$, $\sigma = 2.2\,\mathrm{dB}$ Rayleigh — Weight = 1%.

Here the measurements deviation from the mean value has a higher value of σ compared with the first case of this scenario. This is due to the lower value of the antenna's gain and therefore higher contribution of the multipath.

Figure 6 shows the propagation gain (loss) of the third case of this scenario using a transmitting antenna with a gain of 11 dB and a receiving one with a gain of 8 dB with vertical polarization.

Table 2. Propagation parameters of the second case of scenario 1.

L_o (dB)	n_1	d_b (m)	L_1 (dB)	n_2
47.94	1.965	9	66.95	1.875

Table 3. Propagation parameters of the third case of scenario 1.

L_o (dB)	n_1	d_b (m)	L_1 (dB)	n_2
47.65	1.966	9	63.12	1.966

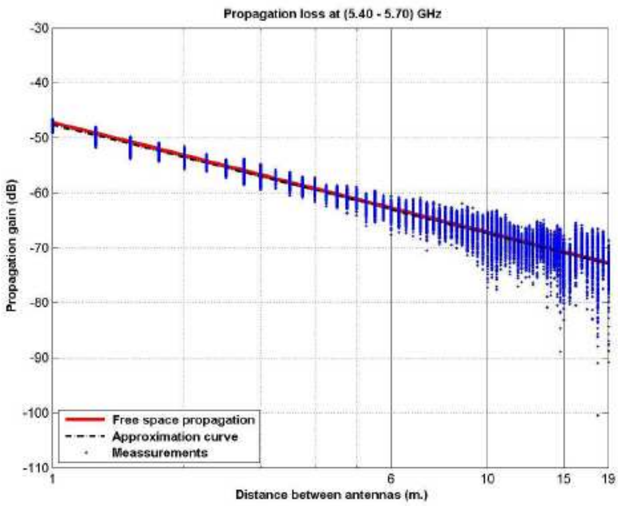


Figure 6. Propagation loss of the third case of scenario 1.

Table 3 shows the propagation parameters of this case.

It can be noticed that the propagation in first and the second zones can be described by almost the free space model of propagation with n_2 of 1.966. Comparing n_2 of the three studied case, it can be noticed that n_2 has the minimum value when the antennas have the maximum value of the gain.

Figure 7 presents the first zone (up to 9 m) Cumulative Distribution Function (CDF) of the measurements deviation from the mean value given as the sum of two Normal (Gaussian) functions.

Figure 8 presents the second zone (distance > 9 m) Cumulative Distribution Function (CDF) of the measurements deviation from the mean value given as the sum of two Normal (Gaussian) functions and a Rayleigh one.

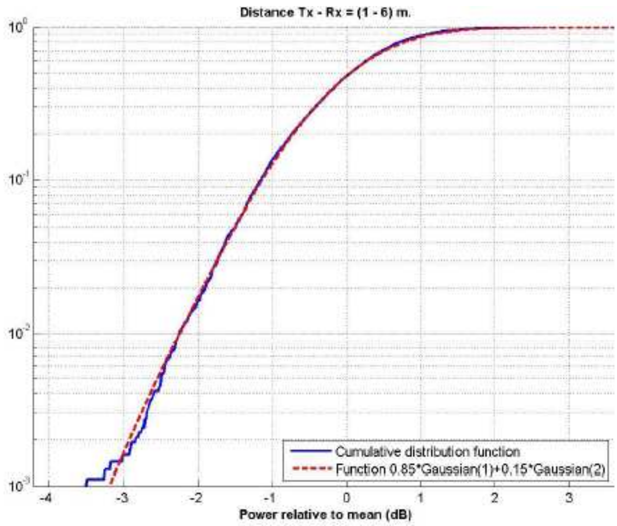


Figure 7. CDF of the multipath induced fading of the first zone of the third case of scenario 1.

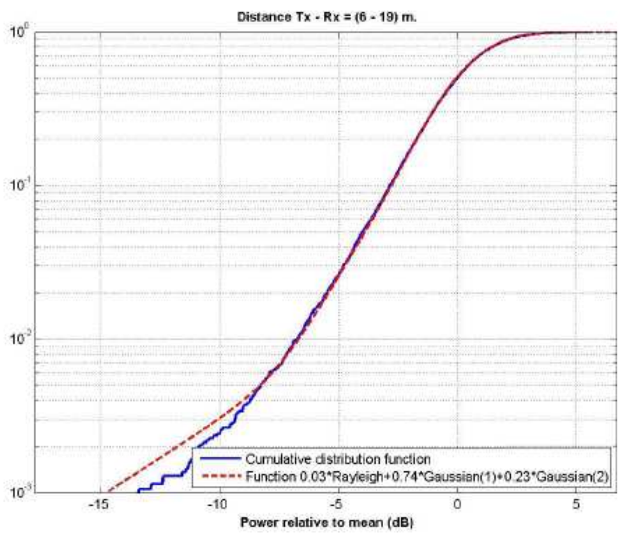


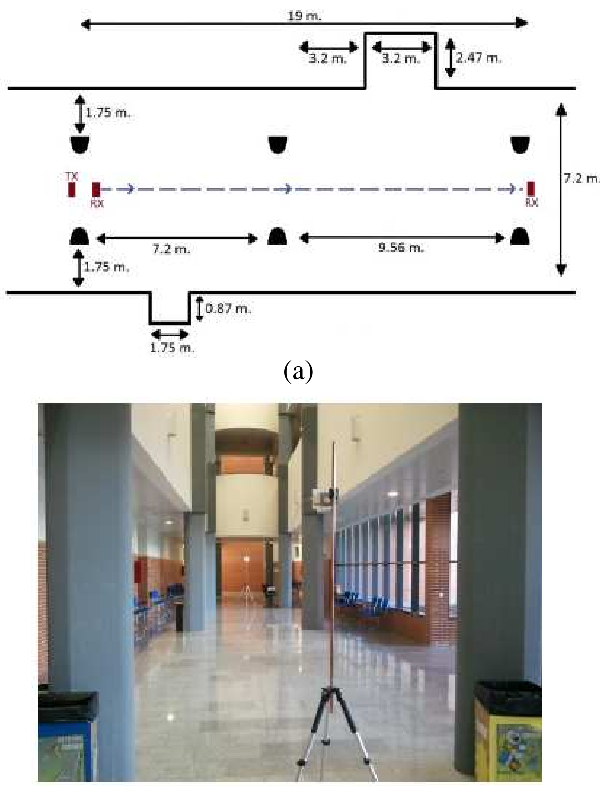
Figure 8. CDF of the multipath induced fading of the second zone of the third case of scenario 1.

The multipath induced fading for the two measurement zone is given by:

Zone 1	Normal 1 — Weight = 85%, $\mu = 0.12\,\mathrm{dB}$, $\sigma = 0.85\,\mathrm{dB}$ Normal 2 — Weight = 15%, $\mu = -0.45\,\mathrm{dB}$, $\sigma = 1.10\,\mathrm{dB}$
Zone 2	Normal 1 — Weight = 74%, $\mu = 0.25\,\mathrm{dB}$, $\sigma = 1.6\,\mathrm{dB}$ Normal 2 — Weight = 23%, $\mu = -1.30\,\mathrm{dB}$, $\sigma = 2.5\,\mathrm{dB}$ Rayleigh — Weight = 3%

In this case, the measurements deviation from the mean value has a higher value of σ compared with the first and the second case of this scenario. This is due to the lower value of the antenna's gain and therefore higher contribution of the multipath.

The second studied scenario is represented by Figure 9(a) and a photograph of it is given by Figure 9(b). It consists of 5.75 m



(a)

(b)

Figure 9. Second studied scenario.

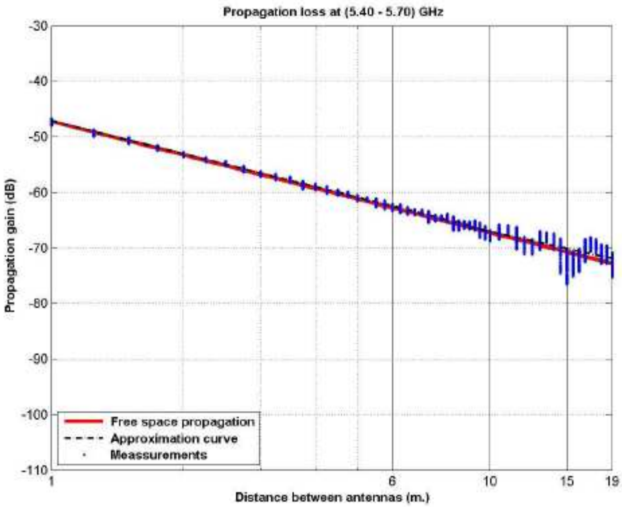


Figure 10. Propagation loss of the first case of scenario 2.

passage with a length of 60 m. Measurements have been carried out with a maximum distance between the two antennas (transmitting and receiving one) of 19 m.

Figure 10 shows the propagation gain (loss) of the first case of this scenario using two antennas with a gain of 19 dB with vertical polarization.

Table 4 shows the propagation parameters of this case.

It can be noticed that the propagation in first zone can be described by almost the free space model of propagation. Propagation in the second zone can be described by the waveguides modes of propagation with a propagation exponent of 1.784.

The multipath induced fading for the two measurement zone is given by:

Zone 1	Normal 1 — Weight = 93%, $\mu = 0.05$ dB, $\sigma = 0.30$ dB
	Normal 2 — Weight = 7%, $\mu = -0.10$ dB, $\sigma = 0.64$ dB
Zone 2	Normal 1 — Weight = 85%, $\mu = 0.2$ dB, $\sigma = 1.2$ dB
	Normal 2 — Weight = 15%, $\mu = -2.5$ dB, $\sigma = 1.6$ dB

Figure 11 shows the propagation gain (loss) of the second case of this scenario using a transmitting antenna with a gain of 19 dB and a receiving one with a gain of 8 dB with vertical polarization.

Table 5 shows the propagation parameters of this case.

Table 4. Propagation parameters of the first case of scenario 2.

L_o (dB)	n_1	d_b (m)	L_1 (dB)	n_2
47.13	1.973	9	66.27	1.784

Table 5. Propagation parameters of the second case of scenario 2.

L_o (dB)	n_1	d_b (m)	L_1 (dB)	n_2
47.89	1.987	9	67.03	1.707

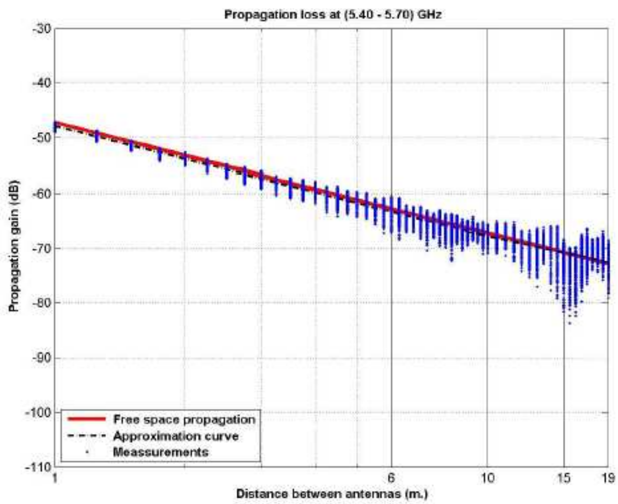


Figure 11. Propagation loss of the second case of scenario 2.

The multipath induced fading for the two measurement zone is given by:

Zone 1	Normal 1 — Weight = 85%, $\mu = 0.2\,\text{dB}$, $\sigma = 0.9\,\text{dB}$ Normal 2 — Weight = 15%, $\mu = -0.5\,\text{dB}$, $\sigma = 1.6\,\text{dB}$
Zone 2	Normal 1 — Weight = 70%, $\mu = 0.2\,\text{dB}$, $\sigma = 1.3\,\text{dB}$ Normal 2 — Weight = 30%, $\mu = -1.3\,\text{dB}$, $\sigma = 3.3\,\text{dB}$

Here the measurements deviation from the mean value has a higher value of σ compared with the first case of this scenario. This is due to the lower value of the antenna's gain and therefore higher contribution of the multipath.

Figure 12 shows the propagation gain (loss) of the third case of this scenario using a transmitting antenna with a gain of 11 dB and a receiving one with a gain of 8 dB with vertical polarization.

Table 6 shows the propagation parameters of this case.

Figure 13 presents the first zone (up to 9 m) Cumulative

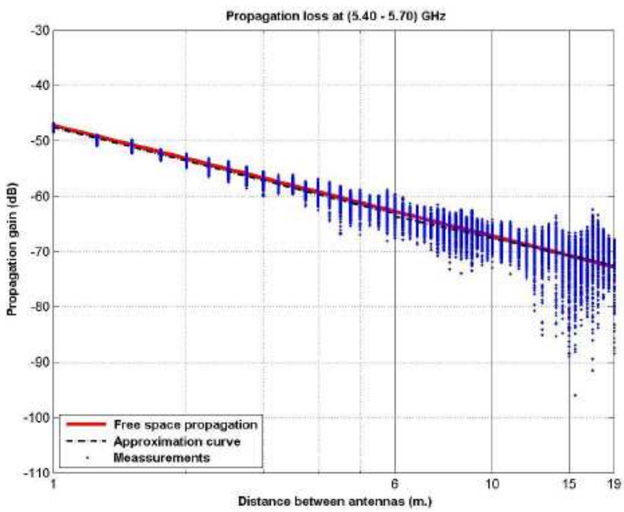


Figure 12. Propagation loss of the third case of scenario 2.

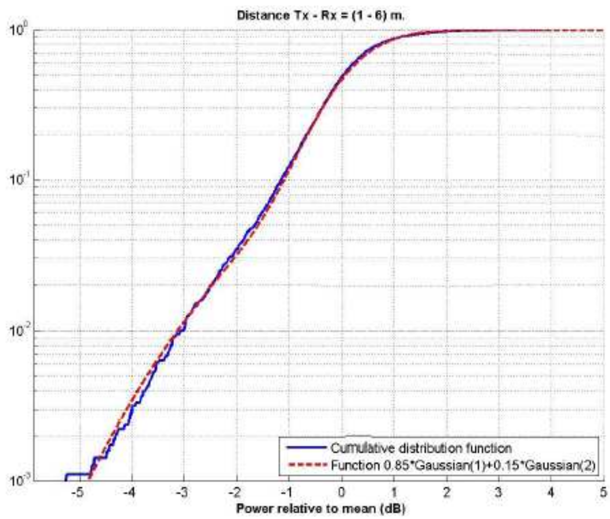


Figure 13. CDF of the multipath induced fading of the first zone of the third case of scenario 1.

Distribution Function (CDF) of the measurements deviation from the mean value is given as the sum of two Normal (Gaussian) functions. Figure 14 presents the second zone (distance > 9 m) Cumulative Distribution Function (CDF) of the measurements deviation from the mean value is given as the sum of two Normal (Gaussian) functions and a Rayleigh one.

The multipath induced fading for the two measurement zone is given by:

Zone 1	Normal 1 — Weight = 85%, $\mu = 0.12$ dB, $\sigma = 0.75$ dB Normal 2 — Weight = 15%, $\mu = -0.50$ dB, $\sigma = 1.75$ dB
Zone 2	Normal 1 — Weight = 70%, $\mu = 0.25$ dB, $\sigma = 1.6$ dB Normal 2 — Weight = 23%, $\mu = -1.30$ dB, $\sigma = 3.3$ dB Rayleigh — Weight = 7%

In this case, the measurements deviation from the mean value has a higher value of σ compared with the first case of this scenario and little bit higher value of σ compared with the second case of this scenario. This is due to the lower value of the antenna's gain and therefore higher contribution of the multipath.

The third studied scenario is represented by Figure 15(a) and a photograph of it is given by Figure 15(b). It consists of 2.5 m

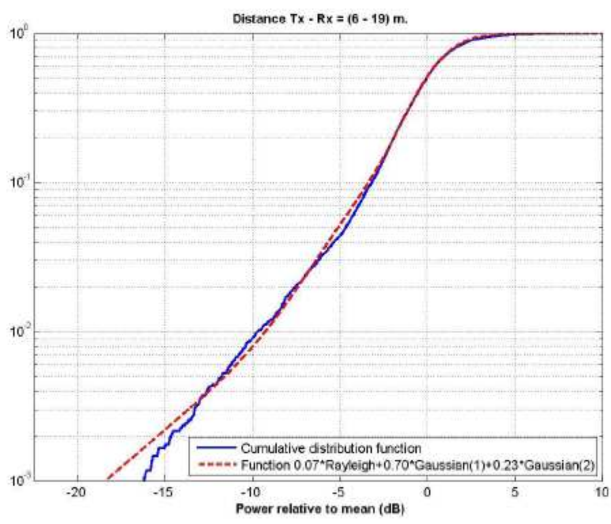
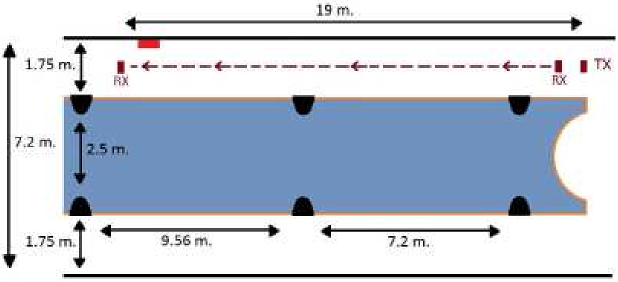


Figure 14. CDF of the multipath induced fading of the second zone of the third case of scenario 1.

Table 6. Propagation parameters of the third case of scenario 2.

L_o (dB)	n_1	d_b (m)	L_1 (dB)	n_2
47.57	2.011	6	63.69	1.772



(a)

(b)

Figure 15. Third studied scenario.

passage open from one side with a length of 60 m. Measurements have been carried out with a maximum distance between the two antennas (transmitting and receiving one) of 19 m.

Figure 16 shows the propagation gain (loss) of the first case of this scenario using two antennas with a gain of 19 dB with vertical polarization.

Table 7 shows the propagation parameters of this case.

It can be noticed that the propagation in first zone can be described by almost the free space model of propagation. Propagation in the second zone can be described by the waveguides modes of propagation with a propagation exponent of 0.814.

Figure 17 presents the first zone (up to 9 m) Cumulative Distribution Function (CDF) of the measurements deviation from the mean value is given by one Normal (Gaussian) function. Figure 18 presents the second zone (distance > 9 m) Cumulative Distribution

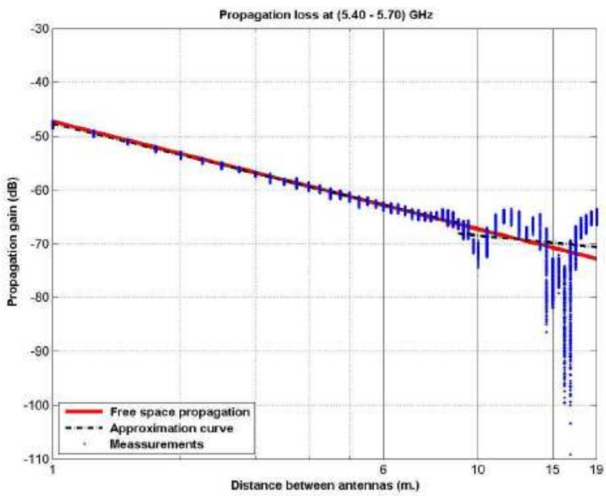


Figure 16. Propagation loss of the first case of scenario 3.

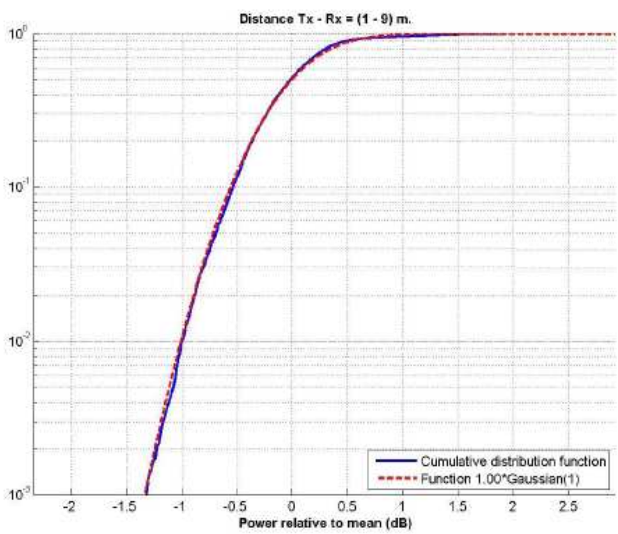


Figure 17. CDF of the multipath induced fading of the first zone of the first case of scenario 3.

Function (CDF) of the measurements deviation from the mean value is given as the sum of two Normal (Gaussian) functions and a Rayleigh component.

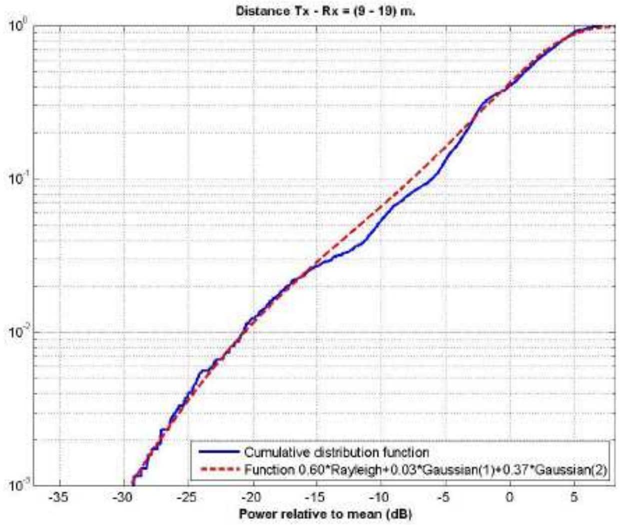


Figure 18. CDF of the multipath induced fading of the second zone of the first case of scenario 3.

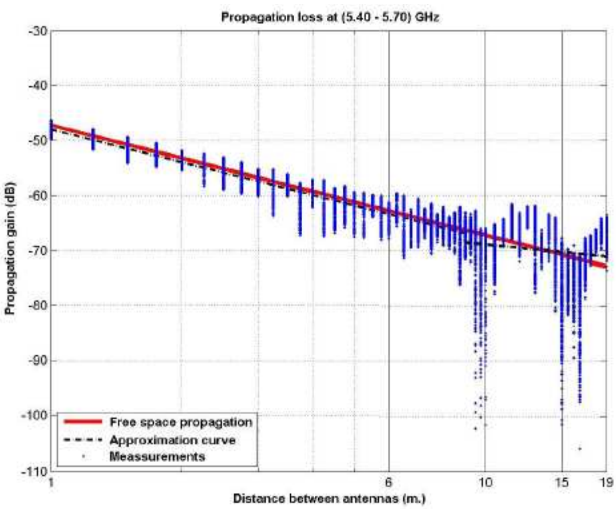


Figure 19. Propagation loss of the second case of scenario 3.

Table 7. Propagation parameters of the first case of scenario 3.

L_o (dB)	n_1	d_b (m)	L_1 (dB)	n_2
47.73	1.926	9	68.05	0.814

Table 8. Propagation parameters of the second case of scenario 3.

L_o (dB)	n_1	d_b (m)	L_1 (dB)	n_2
48.03	1.978	9	68.57	0.780

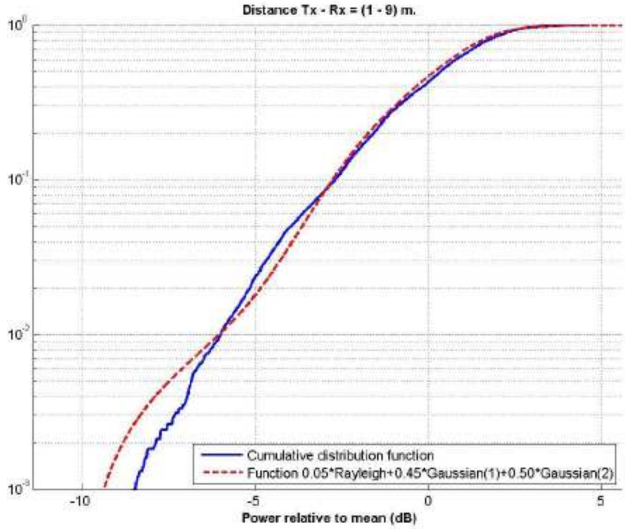


Figure 20. CDF of the multipath induced fading of the first zone of the second case of scenario 3.

The multipath induced fading for the two measurement zone is given by:

Zone 1	Normal 1 — Weight = 100%, $\mu = 0.0$ dB, $\sigma = 0.43$ dB
Zone 2	Normal 1 — Weight = 3%, $\mu = -15.0$ dB, $\sigma = 7.0$ dB Normal 2 — Weight = 37%, $\mu = 4.0$ dB, $\sigma = 2.2$ dB Rayleigh — Weight = 60%

In zone 2, the multipath contribution is high due to the low value of the passage width. Thus gives arise to a multipath induced fading with higher Rayleigh component in comparison with the two previously

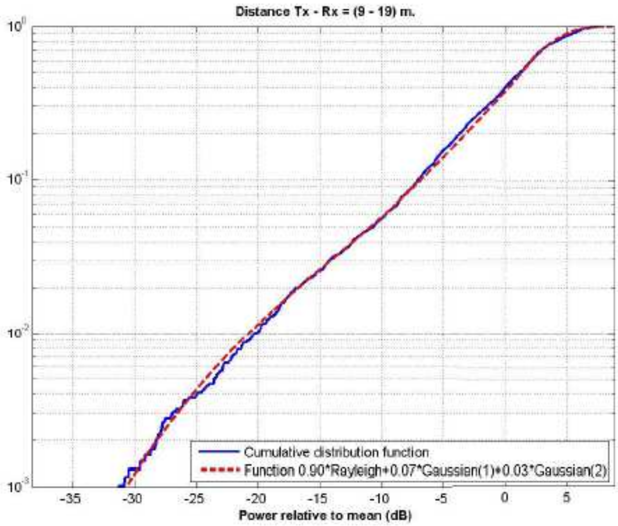


Figure 21. CDF of the multipath induced fading of the second zone of the second case of scenario 3.

studied cases.

Figure 19 shows the propagation gain (loss) of the second case of this scenario using a transmitting antenna with a gain of 19 dB and a receiving one with a gain of 8 dB with vertical polarization.

Table 8 shows the propagation parameters of this case.

Figure 20 presents the first zone (up to 9 m) Cumulative Distribution Function (CDF) of the measurements deviation from the mean value is given as the sum of two Normal (Gaussian) functions and a Rayleigh component. Figure 21 presents the second zone (distance > 9 m) Cumulative Distribution Function (CDF) of the measurements deviation from the mean value is given as the sum of two Normal (Gaussian) functions and a Rayleigh one.

The multipath induced fading for the two measurement zone is given by:

Zone 1	Normal 1 — Weight = 45%, $\mu = 1.2$ dB, $\sigma = 1.1$ dB Normal 2 — Weight = 50%, $\mu = -1.0$ dB, $\sigma = 1.7$ dB Rayleigh — Weight = 5%
Zone 2	Normal 1 — Weight = 7%, $\mu = 2.0$ dB, $\sigma = 1.0$ dB Normal 2 — Weight = 3%, $\mu = -15.0$ dB, $\sigma = 8.0$ dB Rayleigh — Weight = 90%

In zone 1, the Rayleigh induced multipath fading contribution is higher than the first case of this scenario due to the lower values of the antenna's gain.

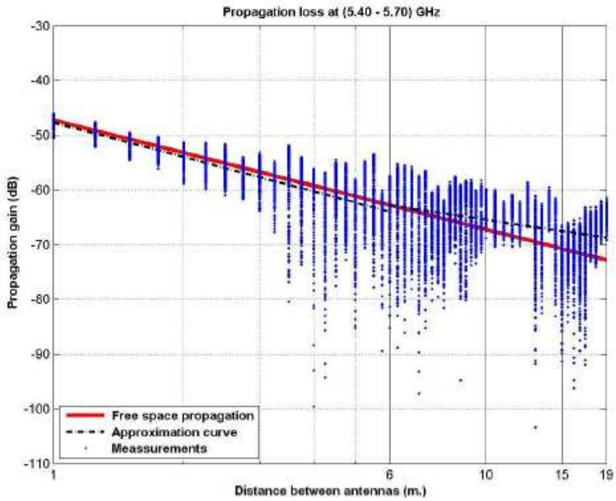


Figure 22. Propagation loss of the third case of scenario 3.

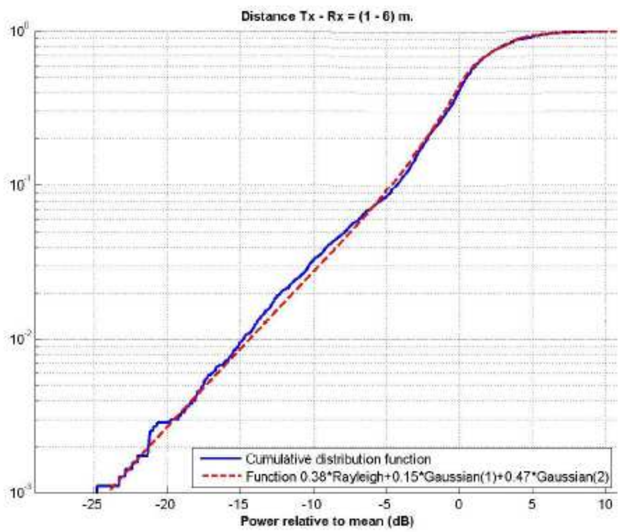


Figure 23. CDF of the multipath induced fading of the first zone of the third case of scenario 3.

Table 9. Propagation parameters of the third case of scenario 3.

L_o (dB)	n_1	d_b (m)	L_1 (dB)	n_2
47.74	2.092	9	62.84	1.181

Figure 22 shows the propagation gain (loss) of the third case of this scenario using a transmitting antenna with a gain of 11 dB and a receiving one with a gain of 8 dB with vertical polarization.

Table 9 shows the propagation parameters of this case.

Figure 23 presents the first zone (up to 9 m) Cumulative Distribution Function (CDF) of the measurements deviation from the mean value is given as the sum of two Normal (Gaussian) functions and a Rayleigh component. Figure 24 presents the second zone (distance > 9 m) Cumulative Distribution Function (CDF) of the measurements deviation from the mean value is given as the sum of two Normal (Gaussian) functions and a Rayleigh one.

The multipath induced fading for the two measurement zone is given by:

Zone 1	Normal 1 — Weight = 15%, $\mu = 0.0$ dB, $\sigma = 0.85$ dB Normal 2 — Weight = 47%, $\mu = 1.7$ dB, $\sigma = 3.00$ dB Rayleigh — Weight = 38%
Zone 2	Normal 1 — Weight = 23%, $\mu = 4.0$ dB, $\sigma = 1.9$ dB Normal 2 — Weight = 15%, $\mu = -3.0$ dB, $\sigma = 5.0$ dB Rayleigh — Weight = 62%

In zone 1, the Rayleigh induced multipath fading contribution is higher than the first and second cases of this scenario due to the lower values of the antenna's gain.

Comparing the results of this scenario with those of the first and second ones, it can noticed that the second propagation exponent n_2 is in general lower than 1.5 while it is generally higher than 1.5 for the first and the second scenarios. Also it can be noticed that for the second part of the measurement zone, the deviation from the mean value has a higher contribution of Rayleigh component.

Figure 25 represents the Channel Impulse response of the first case of scenario 1 for at 6 and 16 m. It can be noticed that the delayed signals have a very small contribution (lower than -30 dB). The time delay of the first peak (at 6 m distance) is 21 nsec (20 nsec due to propagation and 1 nsec due to the feeding systems of the two antennas). The time delay of the first peak (at 16 m distance) is 54.3 nsec (53.3 nsec

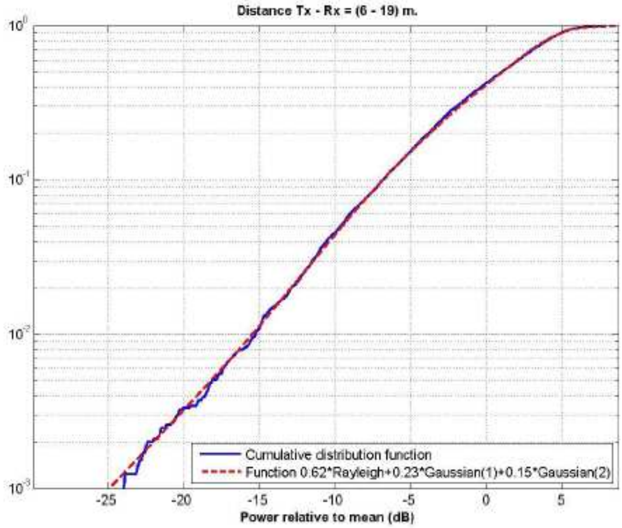


Figure 24. CDF of the multipath induced fading of the second zone of the third case of scenario 3.

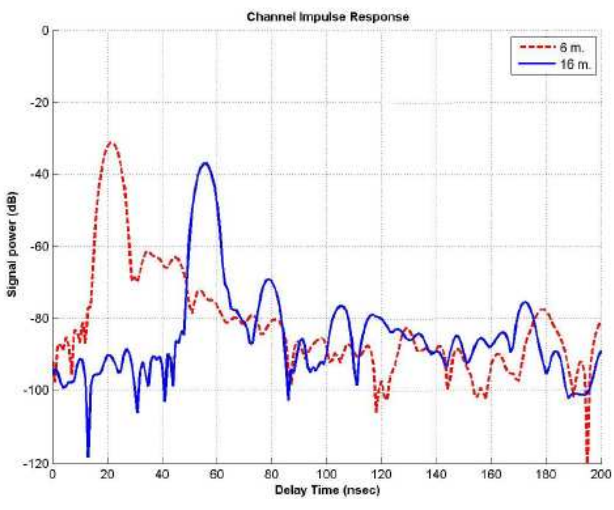


Figure 25. CIR of the first case of scenario 1.

due to propagation and 1 nsec due to the feeding systems of the two antennas). In both cases the first lobe is due to the direct ray and the one reflected from the floor.

Figure 26 represents the Channel Impulse response of the third

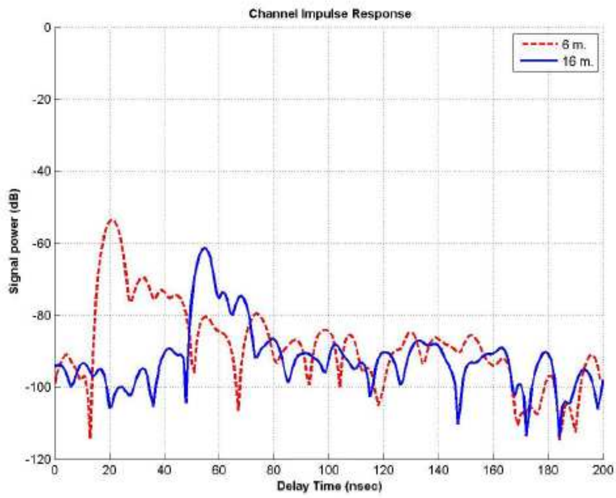


Figure 26. CIR of the third case of scenario 1.

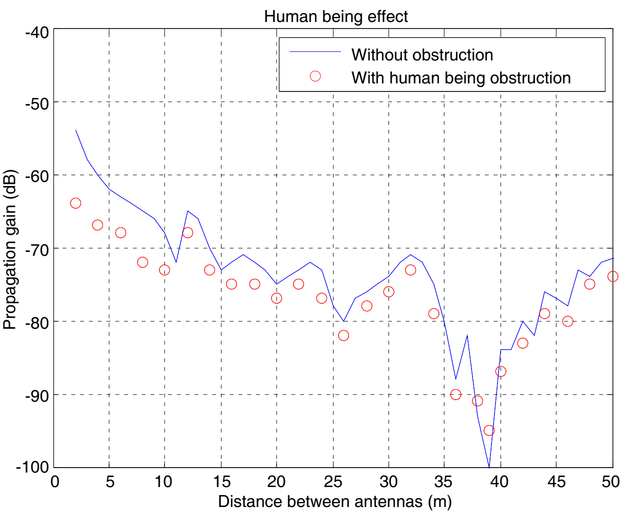


Figure 27. Human being effect on the propagation loss.

case of scenario 1 for at 6 and 16 m. It can be noticed that the delayed signals have a higher contribution than the previously case.

The effect of the human shadowing due to non-directive channel has been studied in [18] and [19]. Here we present further result dealing with human shadowing due within directive channel. First of all measurement of the propagation loss up to 52 m have been carried out using R&S RF generator SMB 100A as a transmitter and the Anritsu spectrum analyzer MS2717B as a receiver. Then, the human being effect is got measuring in some point the new propagation loss with the human being within the line between the transmitting and the receiving antenna. The difference between the two measurements presents the human being shadowing. Figure 27 presents the effect of the human being (1.8 m height and 90 kg weight) obstruction with an operating frequency is 5.6 GHz with antenna's height of 1.3 m and a gain of 19 dB. The human being was always in the midway between the transmitting antenna and the receiving one. It can be noticed that it has an effect of 6 to 10 dB when it is near to the transmitting antenna (lower than 10 m of distance). At higher distance the effect is to reduce the received signal by only (1 dB to 3 dB) or even to increase the received signal in the minimum point at a distance of 39 m.

4. CONCLUSIONS

In this work, the propagation loss of three short range directive channels (two of them are narrow corridors with two lateral walls and one narrow corridor with only one lateral wall) at 5.5 GHz (used for the IEEE 802.11 ac systems) is measured using different directive antennas and a channel bandwidth of 300 MHz. After that, the propagation loss mean value has been found and defined using the two slope propagation loss model. The multipath induced fading has been approximated using one or two Gaussian component and one Rayleigh component when it is applicable. It has been noted that the multipath induced fading tends to have Normal Distribution with one or two components at low distance between the transmitting and the reception antennas. At higher distances, it tends to have Normal distribution components plus Rayleigh one. Channel Impulse response (CIR) is also measured indicating that the main contribution is due to the direct ray and the one reflected from the floor. Using the CIR it was possible to note that each one of the directive antennas has a delay time of almost 0.5 nsec due to the feeding system. The human being obstruction causes in general an extra propagation loss of 2 to 10 dB depending on its distance from the transmitting and receiving antennas.

APPENDIX A.

Figures A1 and A2 plot the probability density Function of two possible combinations of two Gaussian distribution functions plus a Rayleigh one. This shows the high capability of our propagation model to

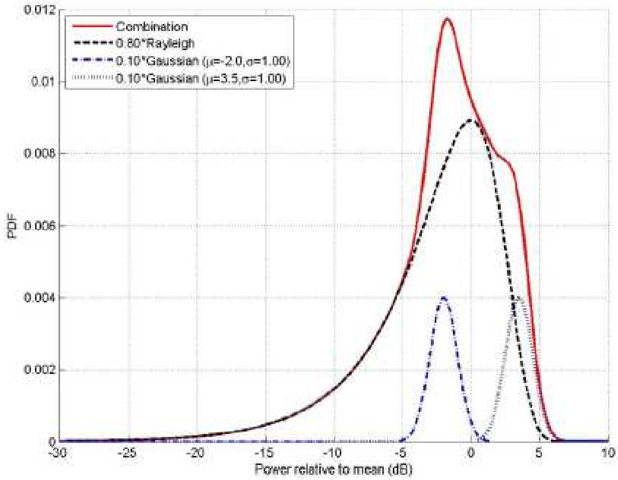


Figure A1. First PDF of two Gaussian distributions and a Rayleigh one.

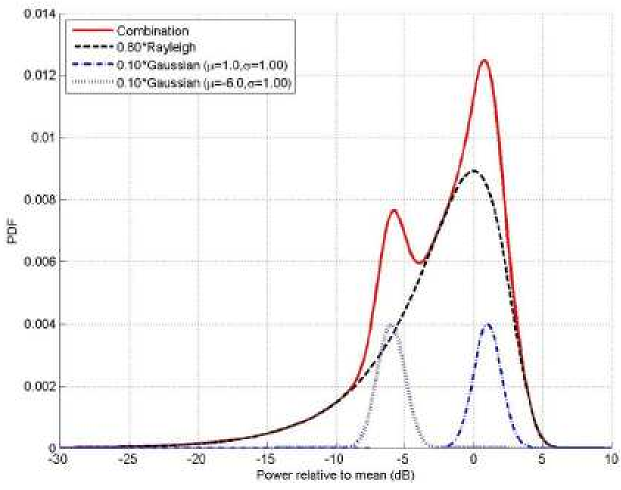


Figure A2. Second PDF of two Gaussian distributions and a Rayleigh one.

represents an infinite number of possible PDF of the multipath induced fading. It is believed that a combination of four Gaussian distribution functions with one Rayleigh component can almost fits the all possible multipath induced fading profiles.

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