Wireless Personal Communications 84.2 (2015): 1089 – 1118

DOI: http://dx.doi.org/10.1007/s11277-015-2677-7

Effect of Antenna´s gain, polarization and channel bandwidth on short range directive channel propagation loss in indoor environment at 5.6 GHz band

BAZIL TAHA AHMED, bazil.taha@uam.es

Escuela Politécnica Superior

Universidad Autónoma de Madrid

Abstract: Propagation loss models for indoor environment are presented. The directive channel propagation loss in indoor environment at a frequency band of 5.6 GHz with a channel bandwidth of 300 MHz and 20 MHz is measured using both vertical and horizontal polarizations. Sets of directive panel antennas are used in the measurements. RF signal generator and a spectrum analyzer are used in the measurement campaign. It is found that propagation loss is sensitive to the scenario configuration. It is noticed that the propagation loss can be modelled by two slopes propagation model giving a rise to two propagation zones. It is noticed that the first zone of propagation is almost free space propagation zone. In general, the second zone has a higher deviation from the mean value of propagation loss.

Keywords: Directive channel, propagation loss, Gaussian distribution, Rayleigh distribution

1- INTRODUCTION

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 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 $\sigma \approx 1$

dB for all the cases. In [7] propagation losses have been measured in different frequency bands (1, 2.4 and 5.8 GHz) within an arched cross section tunnels. Results have shown 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 has been 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. Moreover, propagation in corridors, as well as tunnels and urban street canyons has been studied in [14, 15]. In [14], the radio wave propagation from an indoor hall to a corridor was studied by analyzing the results from a multi-link MIMO channel sounding measurement. The results showed that despite NLOS conditions, the dominant propagation mechanisms comprised direct path through the wall and specular reflections. In [15], the different propagation mechanisms associated with the lift shaft have been studied in detail. Analysis of the measurement results verified the presence of electromagnetic waves being guided along the lift shaft. The guiding effect of the lift shaft has been an important propagation mechanism. In [16], the propagation loss for indoor scenarios has been given at 5.5 GHz band where antennas with different gains have been used in the propagation loss measurements.

In this paper, a model to characterize the indoor directive channel at 5.6 GHz frequency band is presented. Equations to describe path loss have been determined from the analysis of measurement results of the studied scenario.

2- PROPAGATION MODEL

In open zones, the two ray propagation model (the direct ray and the surface reflected ray) is used to calculate the propagation loss. The 2-Ray ground reflected model may be thought as a special case of multi-slope model with break point at critical distance with slope 20 dB/ decade before the critical distance and slope of 40 dB/ decade after the critical distance.

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 represented by the single slope propagation model given by:

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

, where L_o is the propagation loss at the reference distance do (1 m in our case), n_1 is the propagation exponent, and ξ_1 is a random variable (Gaussian (G), Rayleigh (R) or a combination of both) that represents the deviation from the mean value [16].

For a higher distance between the transmitting antenna and the receiving one, a second propagation exponent n_2 is observed, thus the propagation loss will be presented by the two slope model. The change from n_1 to n_2 occurs at the break point at a distance R_b. Thus, the propagation loss can be written as:

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

, where L_1 is the propagation loss of the distance R_b at which the propagation exponent changes to n_2, n_2 is the second propagation and ξ_2 is a random variable (Gaussian, Rayleigh or a combination of both) that represents the deviation from the main value [16]. The propagation exponent n_2 could have a value higher or lower than 2 depending on the studied scenario.

The random variables ξ_1 and ξ_2 can be presented by:

$$\xi_{1,2}=\sum_{n=1}^{N} W_{G,n} \quad G_n(\mu,\sigma)+W_R \; R \quad (3)$$

Where

- $W_{G,n}$ is the weight of the Gaussian component n
- W_R is the weight of the Rayleigh component

3- MEASUREMENT EQUIPIMENTS

RF generator (R&S SMB 100A) has been used as a transmitter and the spectrum analyzer (Anritsu Ms2717B) as a receiver to measure the propagation loss at the 5.6 GHz band. Calibration has been carried out with cables each one with a length of 2.5 m. Three sets of directional panel antennas have been used in the measurements. 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). 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 20 m. Measurements are carried out with an antenna height of 1.4 m for each one of the transmitting and receiving antennas. Measurements have been carried out within the Escuela Politecnica Superior of the Universidad Autonoma de Madrid. Fig. 1 illustrates the measurement system set up.

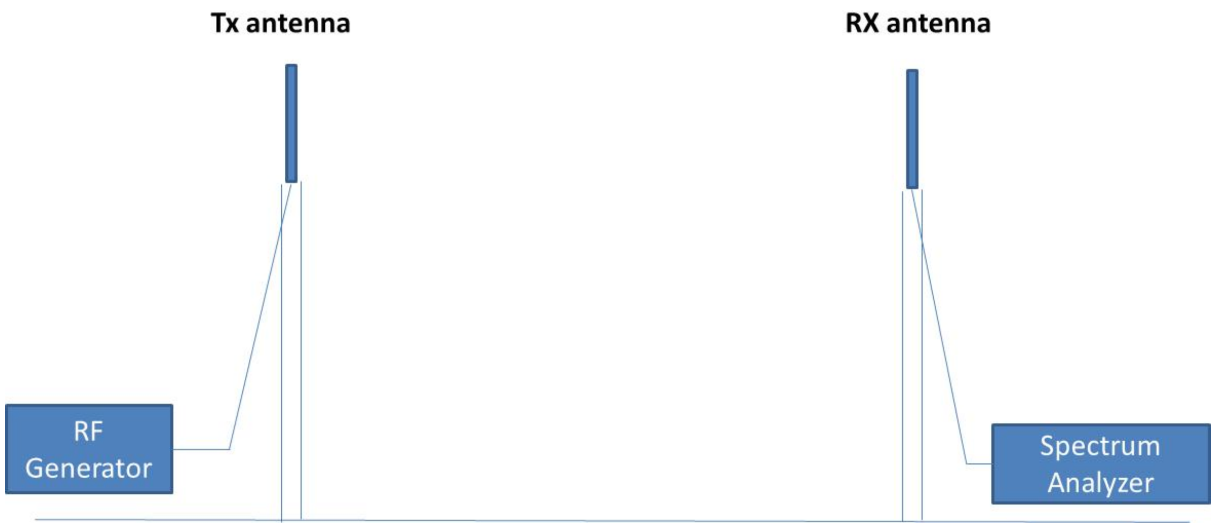

Fig. 1: Measurement setup.

4- MEASUREMENT RESULTS

Results will be presented for one studied scenario. It is 17 m semi open passage with a width of 2.36 m as shown in Fig. 2. At one side of it, 1.8 m height metallic lockers exist. One the other side, a wall of 1m height and a 4 concrete column exist. The break point is determined in such a way that the standard deviation of the approximation residual error is the minimum.

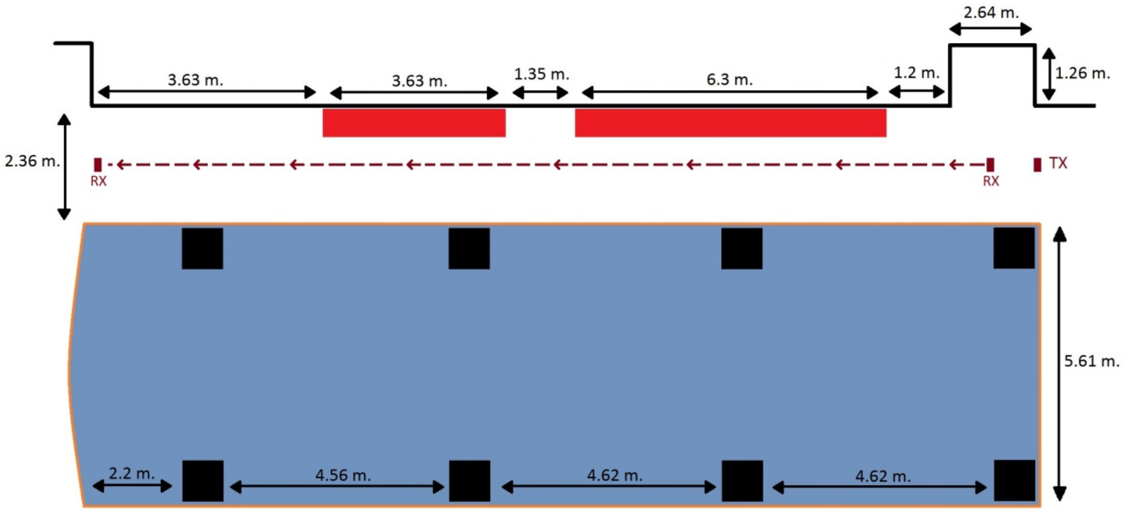

Fig. 2: Studied Scenario.

First of all, we will present the propagation loss for a channel bandwidth of 300 MHz using the vertical and horizontal polarization. Here we will give the propagation loss at (5.4-5.7) GHz for vertical polarization and antenna gain of 18 dB for both the transmitting and the receiving one. Fig. 3 shows the propagation gain (loss) for this case. Here two propagation zones can be seen. The mean value of the propagation loss is given by:

$$L_{mean}(dB) = \begin{cases} 47.41 + 19.97\ \log_{10} d & d \leq 9\,m \\ 67.55 + 1.3\ \log_{10} \left(d/9 \right) & d > 9\,m \end{cases} \qquad \textbf{(4)}$$

Propagation loss can be presented by the two exponent propagation model (two slope propagation model). It can be noticed that the first propagation exponent is near to 2. The second one is near to zero. The first zone is almost free space zone.

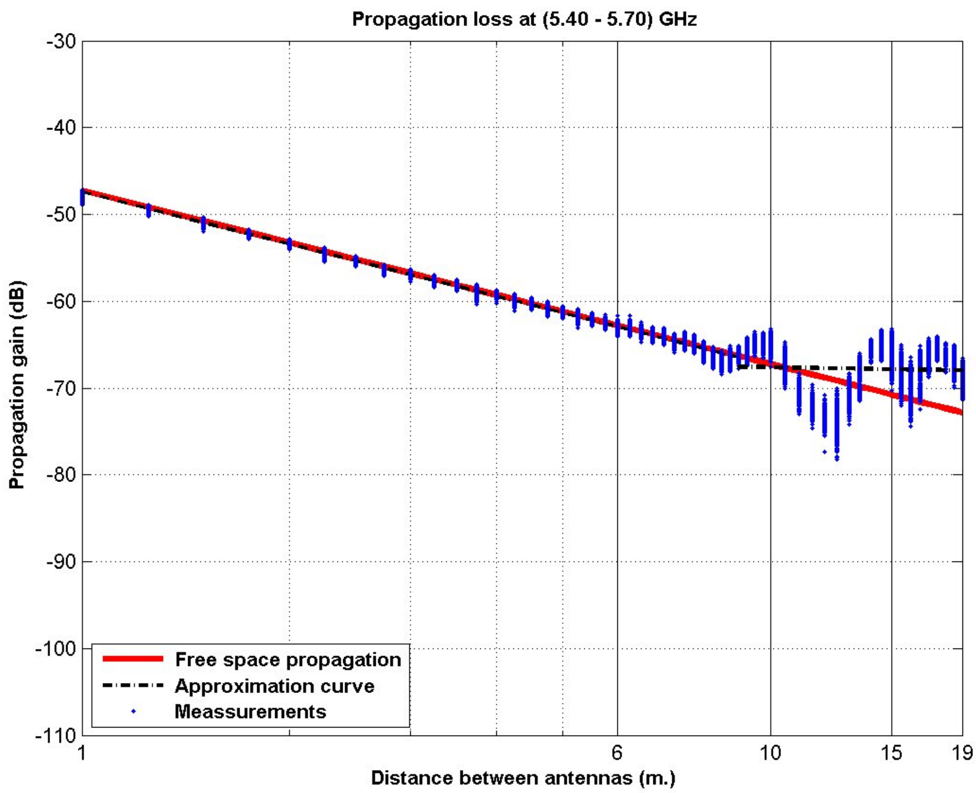

Fig. 3: Propagation loss for vertical polarization at (5.4-5.7) GHz with a transmitting antenna gain of 18 dB and a receiving antenna gain of 18 dB.

Fig. 4 shows the Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone. It can be approximated by two Gaussian distributions , the first one with a weight of 93%, mean value of 0.07 dB and a standard deviation of 0.52 dB and the second one with a weight of 7%, mean value of -0.75 dB and a standard deviation of 0.52 dB.

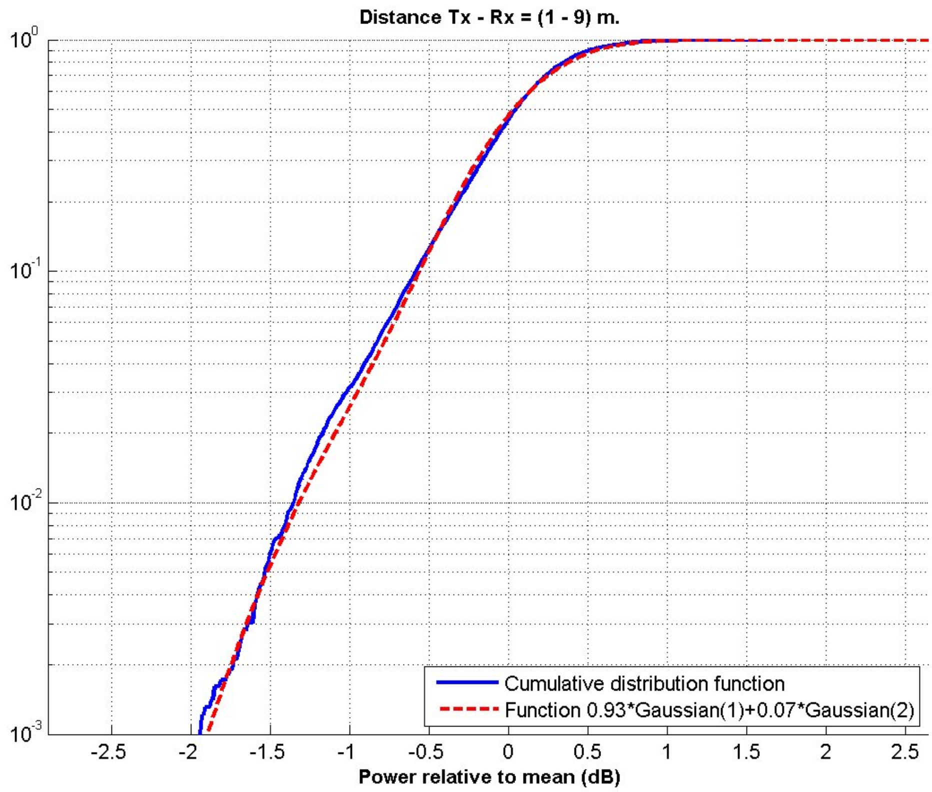

Fig. 4: Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone.

Fig. 5 shows the Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone. It can be approximated by two Gaussian distributions, the first one with a weight of 55%, mean value of 2.2 dB and a standard deviation of 1.2 dB and the second one with a weight of 45%, mean value of -2.7 dB and a standard deviation of 2.5 dB.

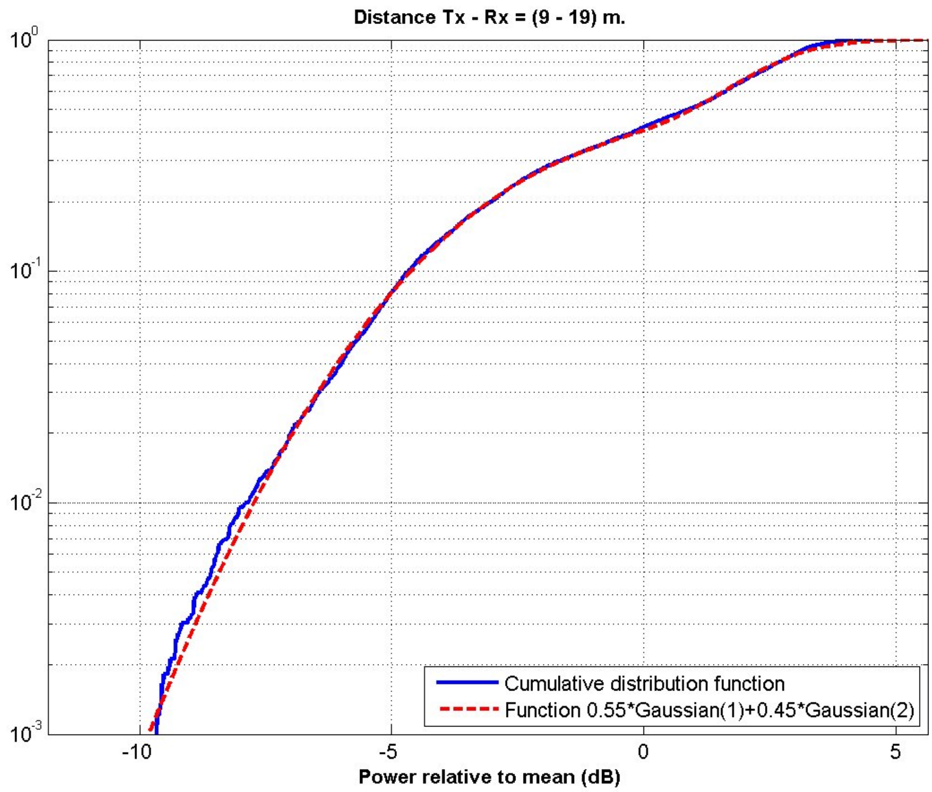

Fig. 5: Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone.

It is noted that, the deviation of the propagation loss from its main value in the first propagation zone is lower than the deviation of the propagation loss from its main value in the second propagation zone. **Reflections from the ground, the ceil and metallic lockers have a lower effect in the first zone than its effect in the second zone. This is due to the radiation pattern of the used directive antennas. At near points, the incidence and the reflection angles are higher and the relative incident power is lower, thus the reflection has lower effect compared with the second zone where the incidence and reflection angles are lower and thus the relative incident power is higher.**

Now we will present the propagation loss at (5.4-5.7) GHz for horizontal polarization using a transmitting antenna and a receiving one with 18 dB gain for both. Fig. 6 gives the propagation gain (loss) for this case. Here two propagation zones can be noticed. The mean value of the propagation loss is given by:

$$\boldsymbol{L_{mean}(dB)} = \begin{cases} \mathbf{47.42 + 19.45\ log_{10}\, d} & \boldsymbol{d \leq 9\, m} \\ \mathbf{65.81 + 29.94\ log_{10}\left(d/9\right)} & \boldsymbol{d > 9\, m} \end{cases} \quad \textbf{(5)}$$

It can be noticed that the first propagation exponent is positive and near to 2. The second one is almost 3. The first zone is almost free space zone.

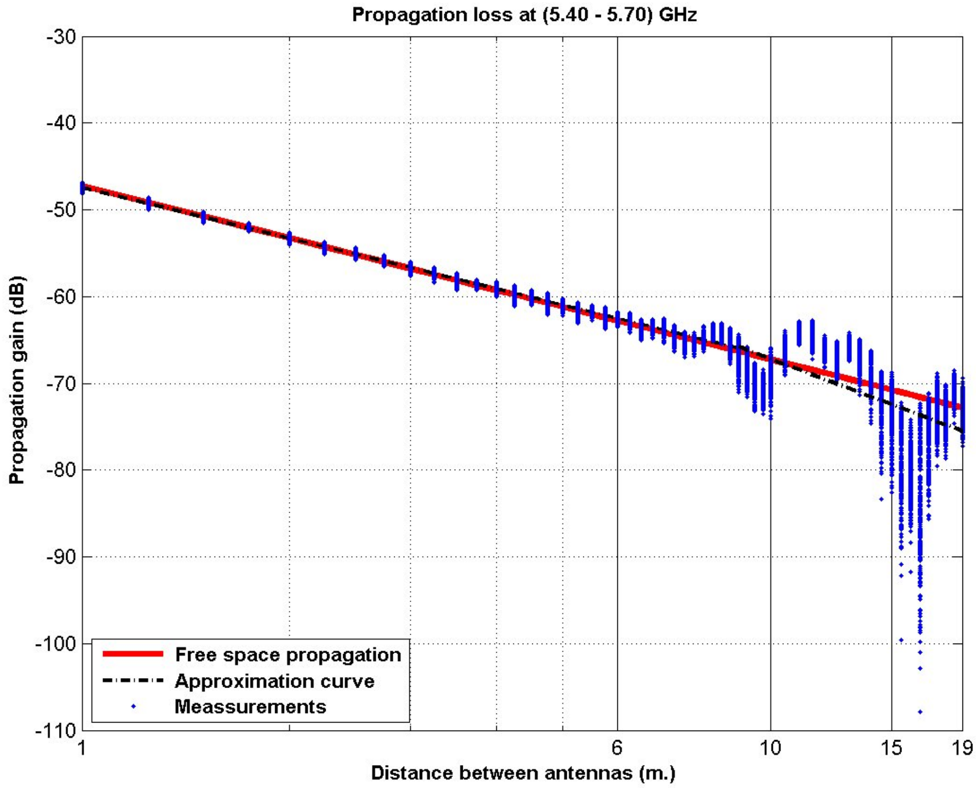

Fig. 6: Propagation loss for horizontal polarization at (5.4-5.7) GHz with a transmitting antenna gain of 18 dB and a receiving antenna gain of 18 dB.

Fig. 7 shows the Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone. It can be approximated by the sum of two Gaussian distributions, the first one with a weight of 93%, mean value of 0.07 dB and a standard deviation of 0.48 dB and the second one with a weight of 7%, mean value of -0.8 dB and a standard deviation of 1.2 dB.

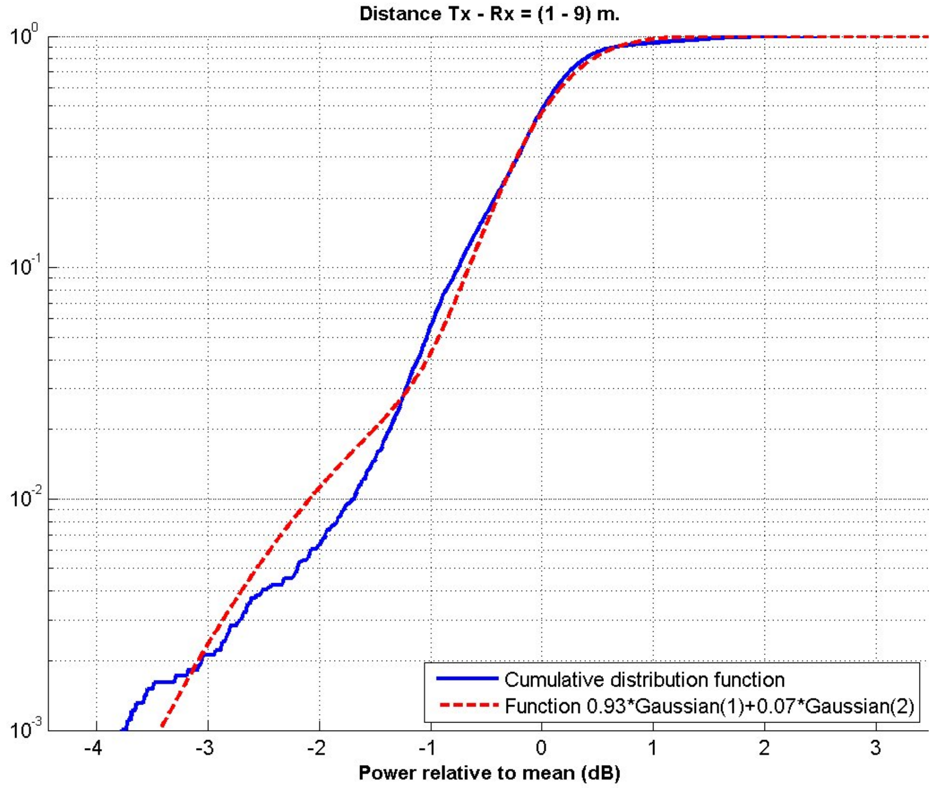

Fig. 7: Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone.

Fig. 8 shows the Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone. It can be approximated by the sum of two Gaussian distributions and a Rayleigh one. The first one of the Gaussian is with a weight of 40%, mean value of 3.5 dB and a standard deviation of 1.4 dB and the second one with a weight of 10%, mean value of -3.9 dB and a standard deviation of 1.2 dB. The Rayleigh distribution has a weight of 50%.

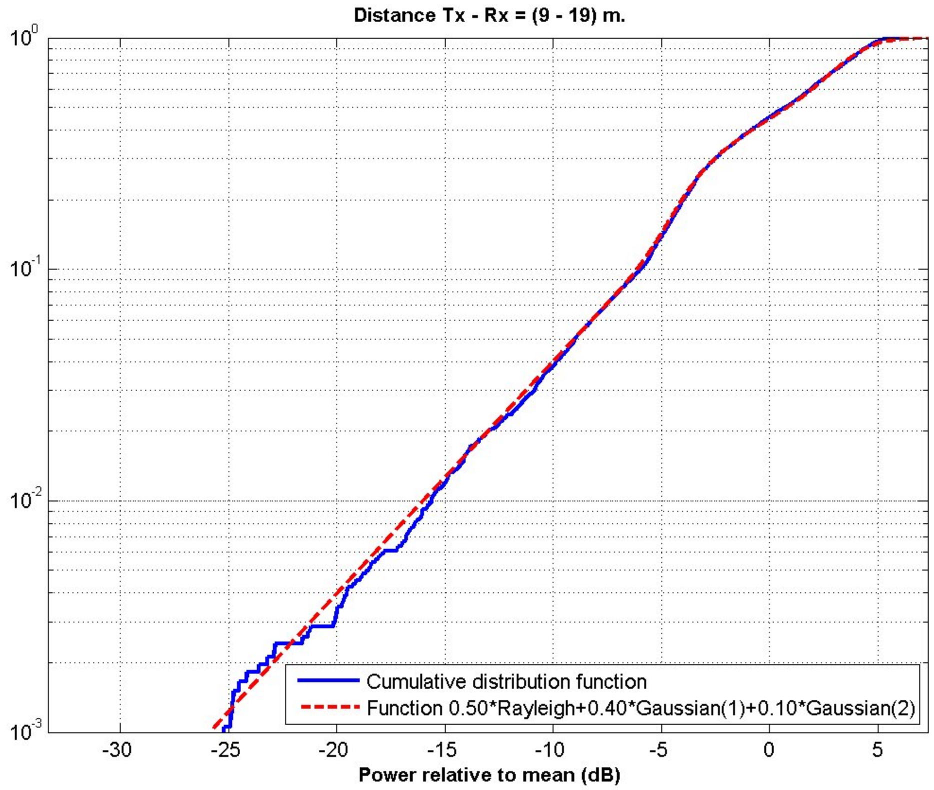

Fig. 8: Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone.

Here also, it is noted that, the deviation of the propagation loss from its main value in the first propagation zone is lower than the deviation of the propagation loss from its main value in the second propagation zone.

Comparing the results given by Figures 4, 5, 7 and 8, it can be noticed that the propagation loss deviation from the main value is lower when the vertical polarization is used.

Here we will give the propagation loss at (5.4-5.7) GHz for vertical polarization and antenna gain of 18 dB for the transmitting one and 8 dB for the receiving one. Fig. 9 shows the propagation gain (loss) for this case. Here two propagation zones can be seen. The mean value of the propagation loss is given by:

$$L_{mean}(dB) = \begin{Bmatrix} 47.89 + 20.52\ \log_{10} d & d \leq 9\ m \\ 68.43 + 1.31\ \log_{10} \left(d/9\right) & d > 9\ m \end{Bmatrix} \quad (6)$$

It can be noticed that the first propagation exponent is near to 2. The second one is almost zero. The first zone is almost free space zone.

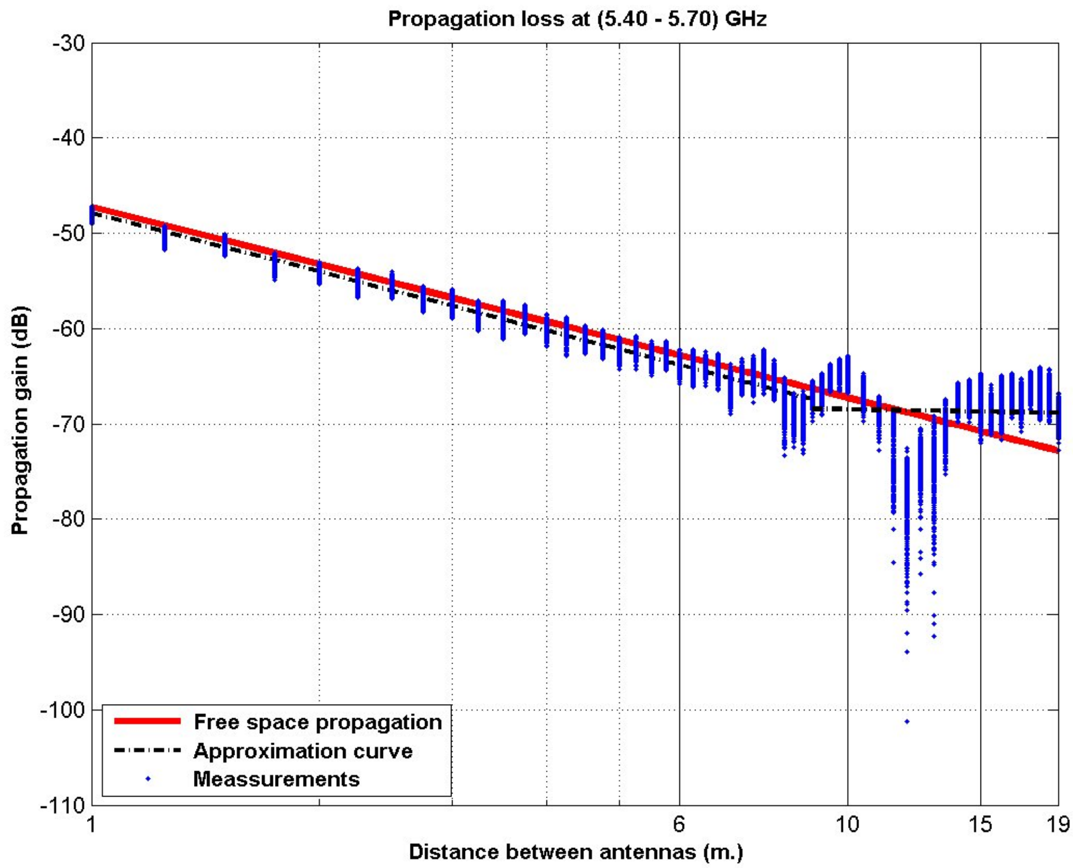

Fig. 9: Propagation loss for vertical polarization at (5.4-5.7) GHz with a transmitting antenna gain of 18 dB and a receiving antenna gain of 8 dB.

Fig. 10 shows the Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone. It can be approximated by the sum of two Gaussian distributions, the first one with a weight of 85%, mean value of 0.2 dB and a standard deviation of 0.8 dB and the second one with a weight of 15%, mean value of -1.1 dB and a standard deviation of 1.7 dB.

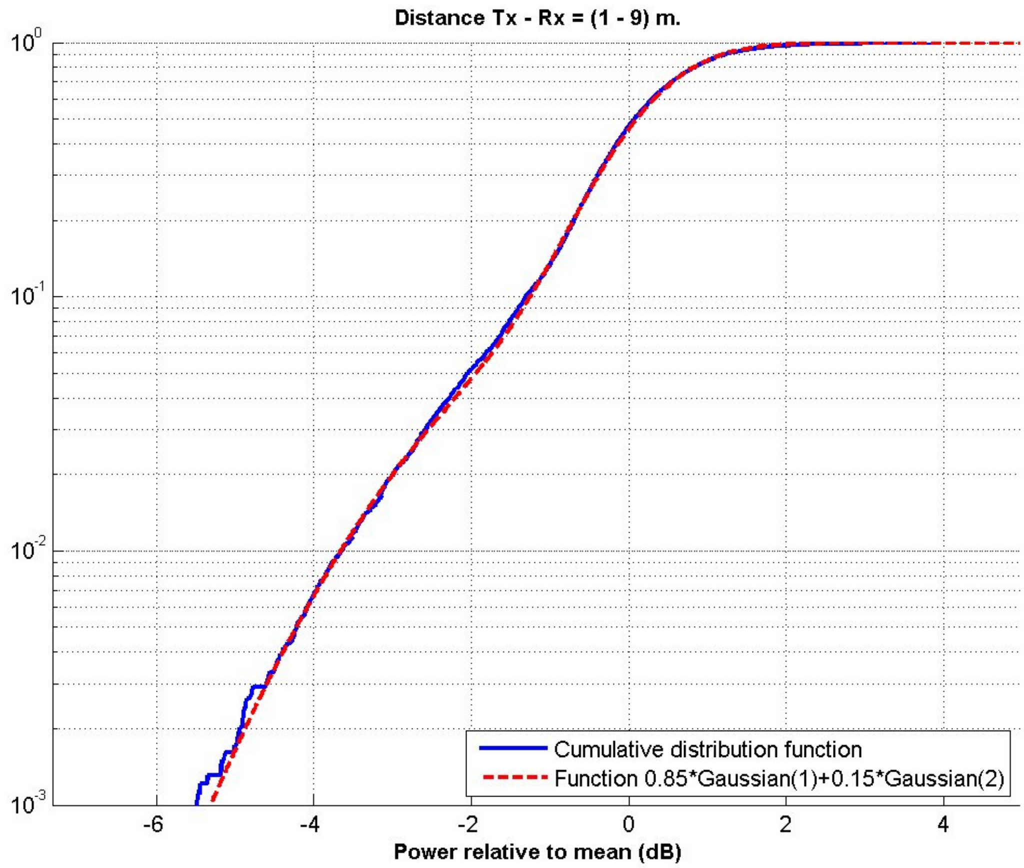

Fig. 10: Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone.

Fig. 11 shows the Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone. It can be approximated by the sum of two Gaussian distributions and a Rayleigh one. The first one of the Gaussian is with a weight of 82%, mean value of 1.7 dB and a standard deviation of 1.9 dB and the second one with a weight of 8%, mean value of -6.5 dB and a standard deviation of 1.8 dB. The Rayleigh distribution has a weight of 10%.

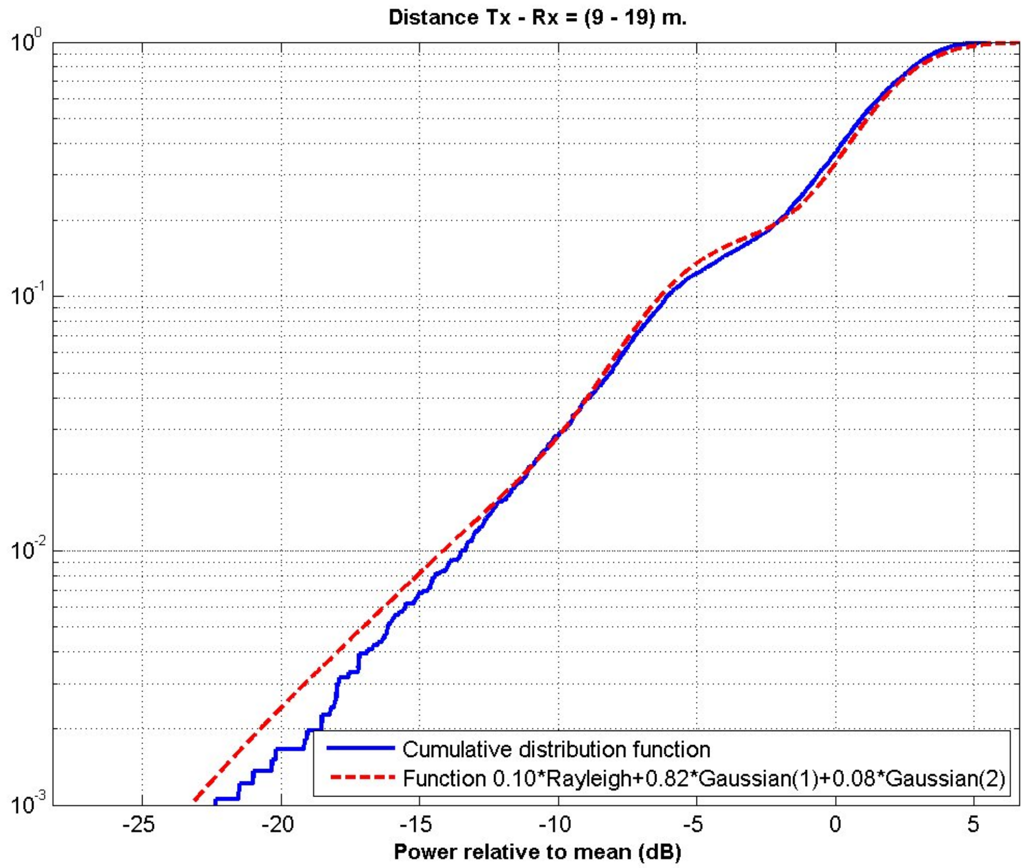

Fig. 11: Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone.

Here we will give the propagation loss at (5.4-5.7) GHz for horizontal polarization and antenna gain of 18 dB for the transmitting one and 8 dB for the receiving one. Fig. 12 shows the propagation gain (loss) for this case. Here two propagation zones can be seen. The mean value of the propagation loss is given by:

$$L_{mean}(dB) = \begin{cases} 47.73 + 19.38 \ log_{10} d & d \leq 7\,m \\ 63.76 + 23.86 \ log_{10}\left(d/7\right) & d > 7\,m \end{cases} \quad (7)$$

Propagation loss can be presented by the two exponent propagation model (two slope propagation model). It can be noticed that the first propagation exponent is positive and near to 2. The second one is almost 2.4. The first zone is almost free space zone.

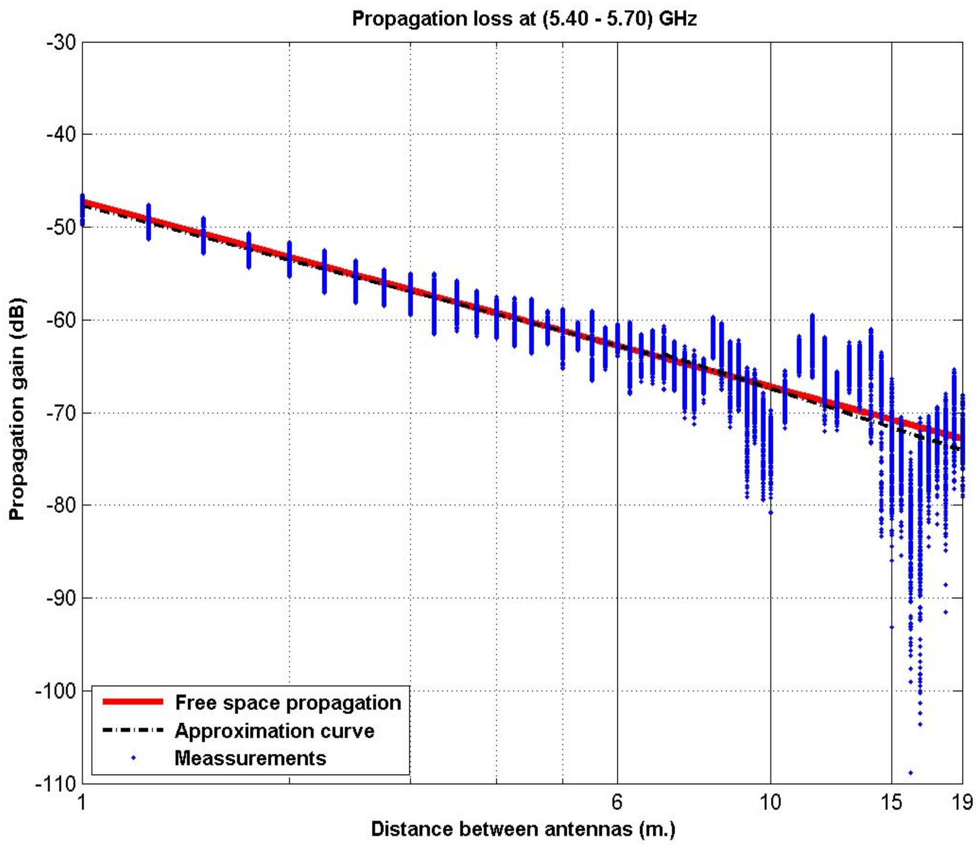

Fig. 12: Propagation loss for horizontal polarization at (5.4-5.7) GHz with a transmitting antenna gain of 18 dB and a receiving antenna gain of 8 dB.

Fig. 13 shows the Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone. It can be approximated by the sum of two Gaussian distributions, the first one with a weight of 85%, mean value of 0.2 dB and a standard deviation of 1.2 dB and the second one with a weight of 15%, mean value of -1.1 dB and a standard deviation of 1.5 dB.

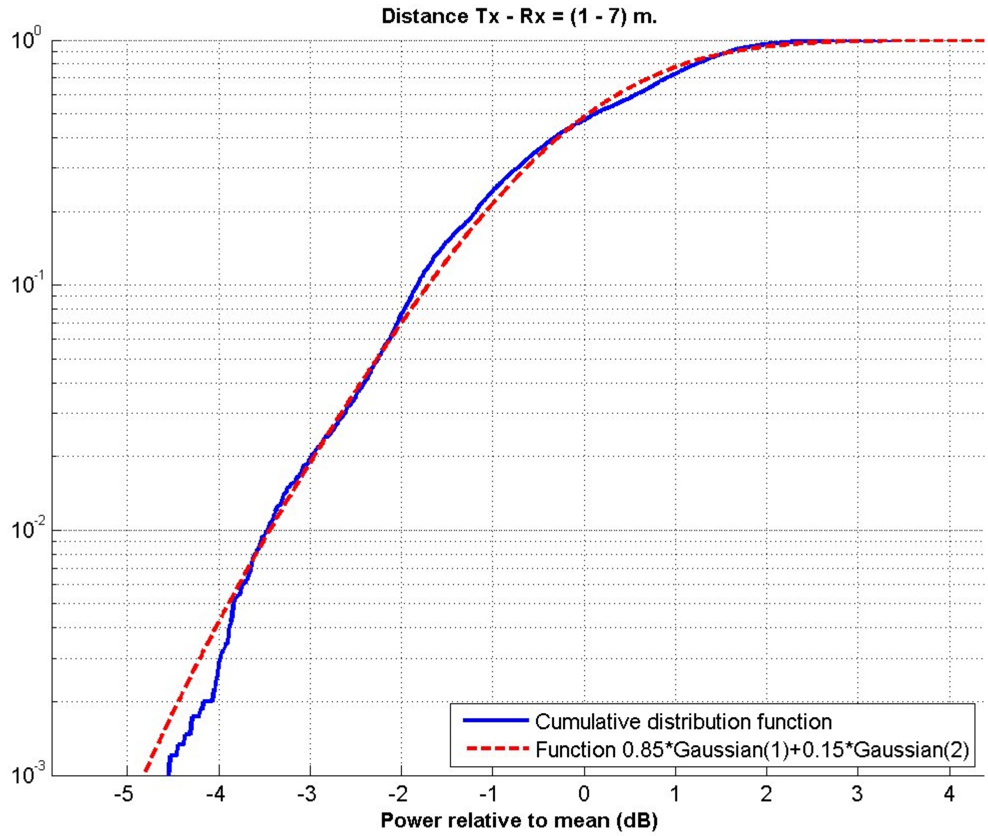

Fig. 13: Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone.

Fig. 14 shows the Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone. It can be approximated by the sum of two Gaussian distributions and a Rayleigh one. The first one of the Gaussian is with a weight of 15%, mean value of -0.5 dB and a standard deviation of 2 dB and the second one with a weight of 25%, mean value of 5.0 dB and a standard deviation of 1.6 dB. The Rayleigh distribution has a weight of 60%.

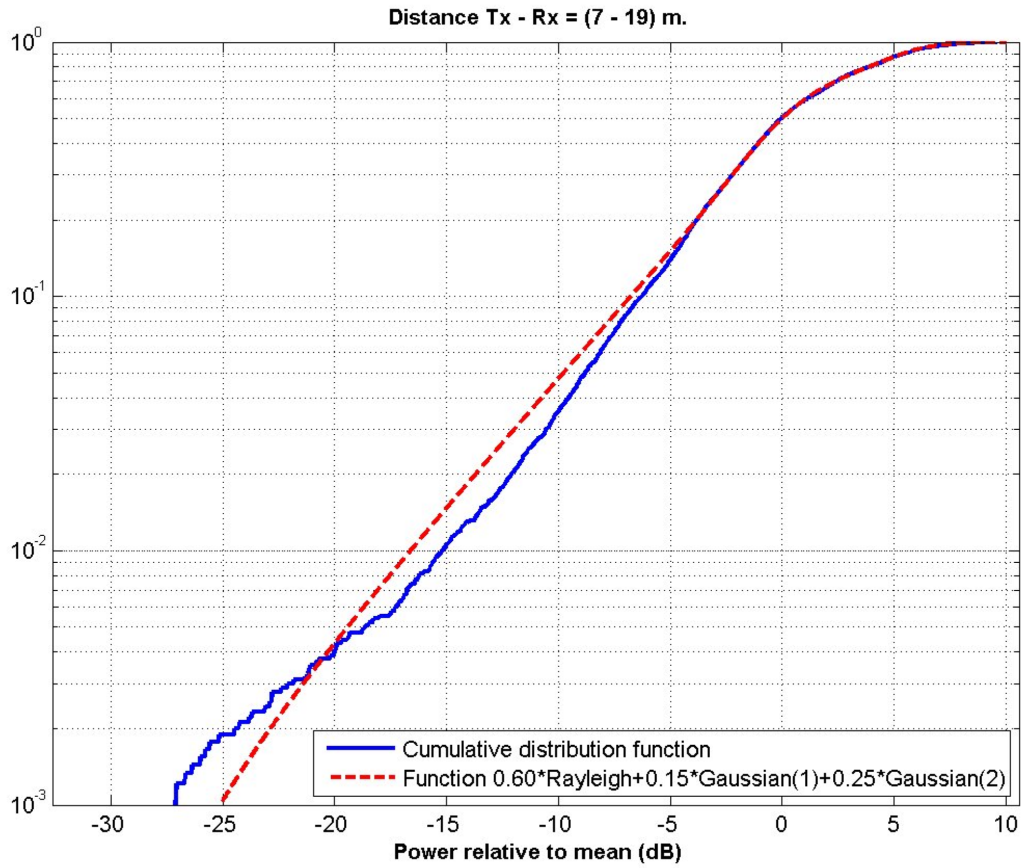

Fig. 14: Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone.

Here we will give the propagation loss at (5.4-5.7) GHz for vertical polarization and antenna gain of 11 dB for the transmitting one and 8 dB for the receiving one. Fig. 15 shows the propagation gain (loss) for this case. Here two propagation zones can be seen. The mean value of the propagation loss is given by:

$$\boldsymbol{L_{mean}(dB)} = \begin{cases} \mathbf{47.76 + 19.09\ log_{10}\, d} & \mathbf{d \leq 7\ m} \\ \mathbf{65.76 + 5.91\ log_{10}\left(d/7\right)} & \mathbf{d > 7\ m} \end{cases} \qquad \textbf{(8)}$$

It can be noticed that the first propagation exponent is near to 2. The second one is almost 0.6. The first zone is almost free space zone.

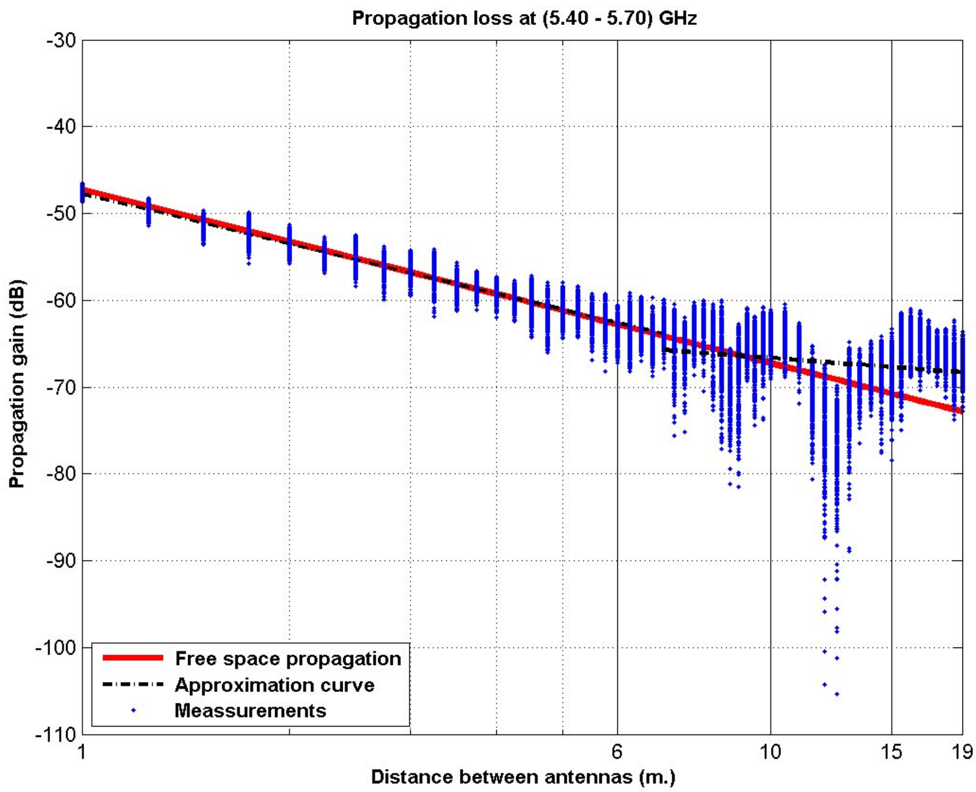

Fig. 15: Propagation loss for vertical polarization at (5.4-5.7) GHz with a transmitting antenna gain of 11 dB and a receiving antenna gain of 8 dB.

Fig. 16 shows the Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone. It can be approximated by the sum of two Gaussian distributions, the first one with a weight of 85%, mean value of 0.15 dB and a standard deviation of 1.25 dB and the second one with a weight of 15%, mean value of -0.8 dB and a standard deviation of 1.75 dB.

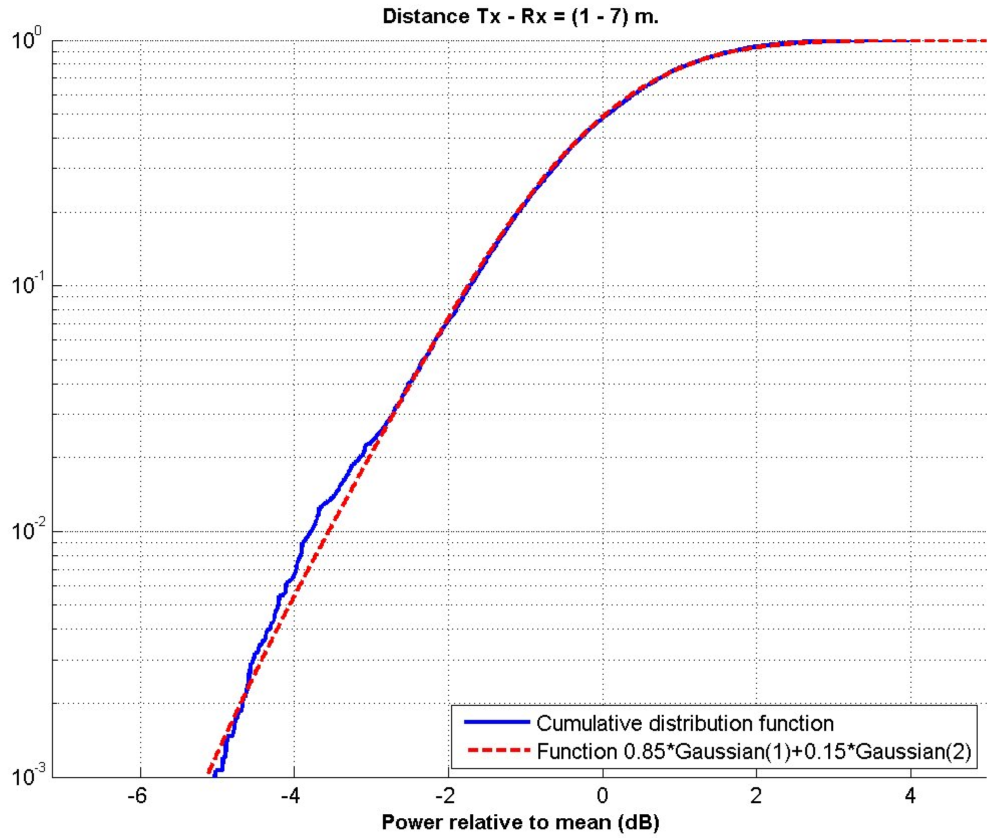

Fig. 16: Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone.

Fig. 17 shows the Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone. It can be approximated by the sum of two Gaussian distributions and a Rayleigh one. The first one of the Gaussian is with a weight of 40%, mean value of 1.9 dB and a standard deviation of 2.1 dB and the second one with a weight of 10%, mean value of -0.5 dB and a standard deviation of 3.3 dB. The Rayleigh distribution has a weight of 50%.

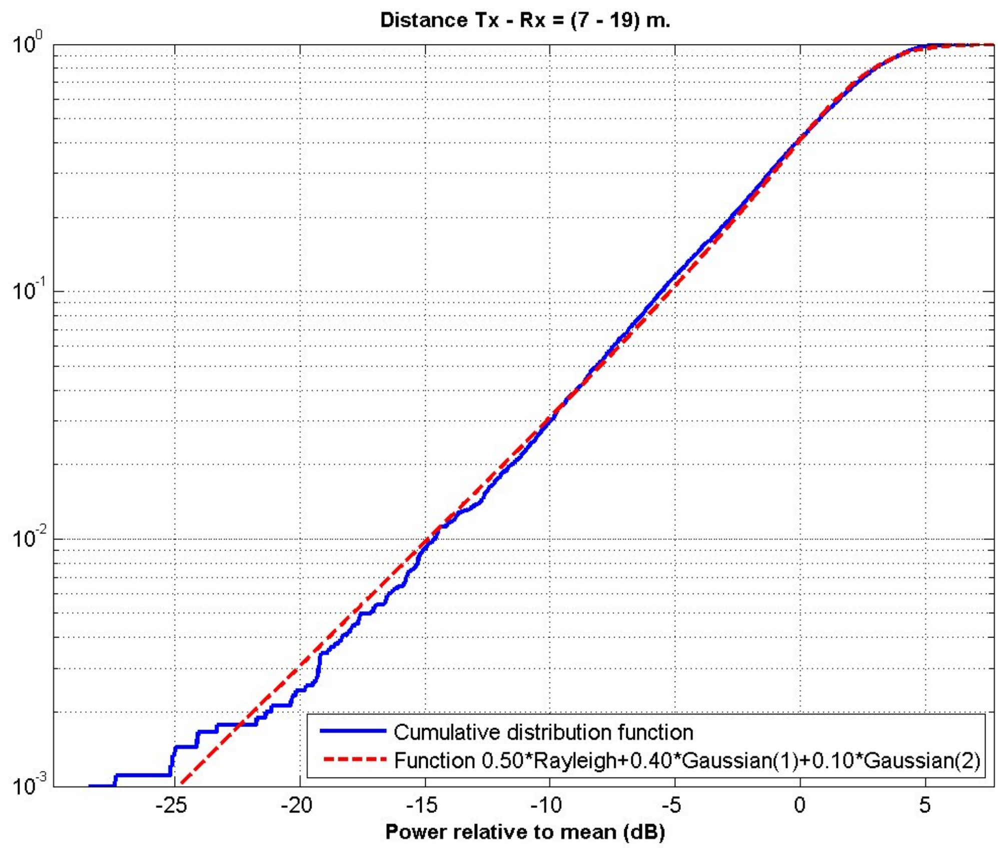

Fig. 17: Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone.

Here we will give the propagation loss at (5.4-5.7) GHz for horizontal polarization and antenna gain of 11 dB for the transmitting one and 8 dB for the receiving one. Fig. 18 shows the propagation gain (loss) for this case. Here two propagation zones can be seen. The mean value of the propagation loss is given by:

$$L_{mean}(dB) = \left\{ \begin{array}{ll} 47.66 + 19.72\ log_{10}\, d & d \leq 7\, m \\ 63.52 + 19.98\ log_{10}\left({}^{d}/_{7} \right) & d > 7\, m \end{array} \right\} \qquad (9)$$

It can be noticed that the first propagation exponent is positive and near to 2. The second one is almost 2. The first zone is almost free space zone.

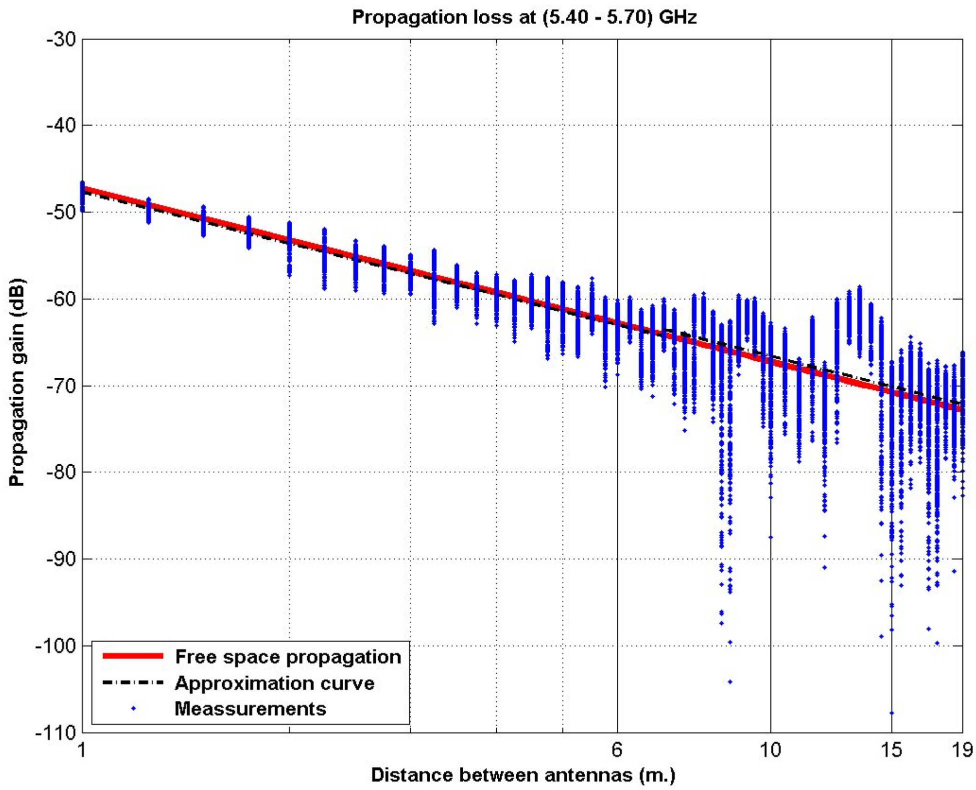

Fig. 18: Propagation loss for horizontal polarization at (5.4-5.7) GHz with a transmitting antenna gain of 11 dB and a receiving antenna gain of 8 dB.

Fig. 19 shows the Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone. It can be approximated by the sum of two Gaussian distributions, the first one with a weight of 85%, mean value of 0.35 dB and a standard deviation of 1.25 dB and the second one with a weight of 15%, mean value of -2.1 dB and a standard deviation of 1.7 dB.

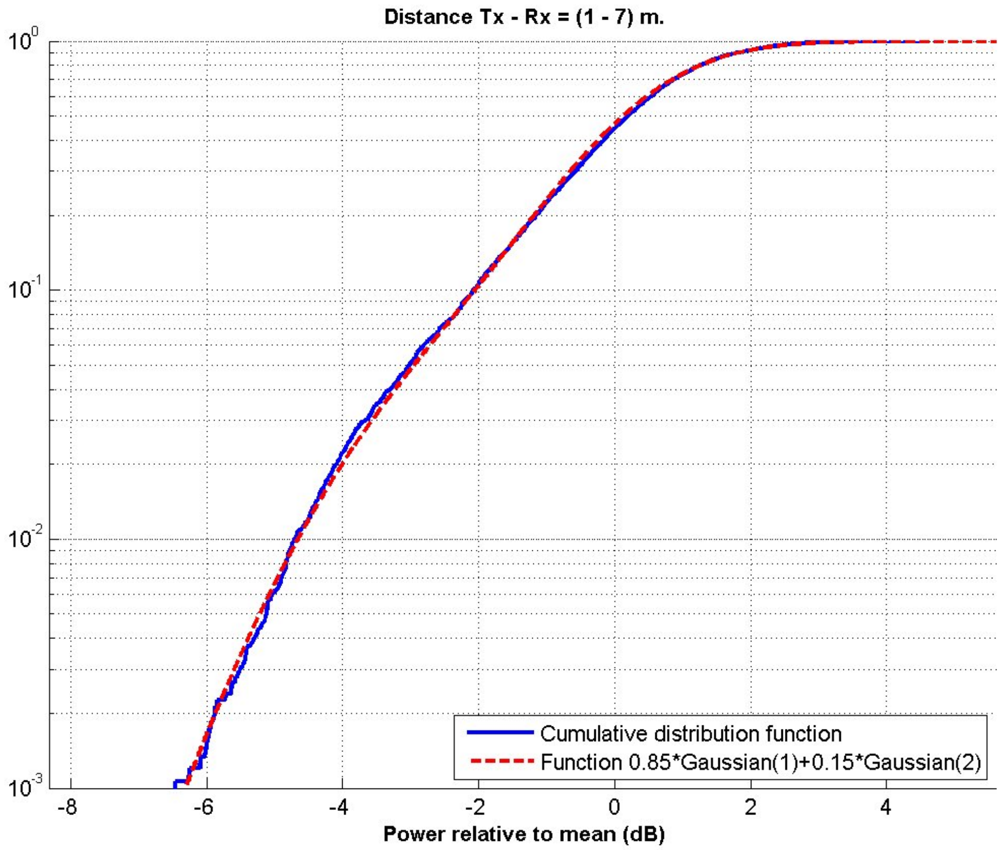

Fig. 19: Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone.

Fig. 20 shows the Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone. It can be approximated by the sum of two Gaussian distributions and a Rayleigh one. The first one of the Gaussian is with a weight of 45%, mean value of 2.7 dB and a standard deviation of 2.3 dB and the second one with a weight of 5%, mean value of 7.5 dB and a standard deviation of 1.0 dB. The Rayleigh distribution has a weight of 50%.

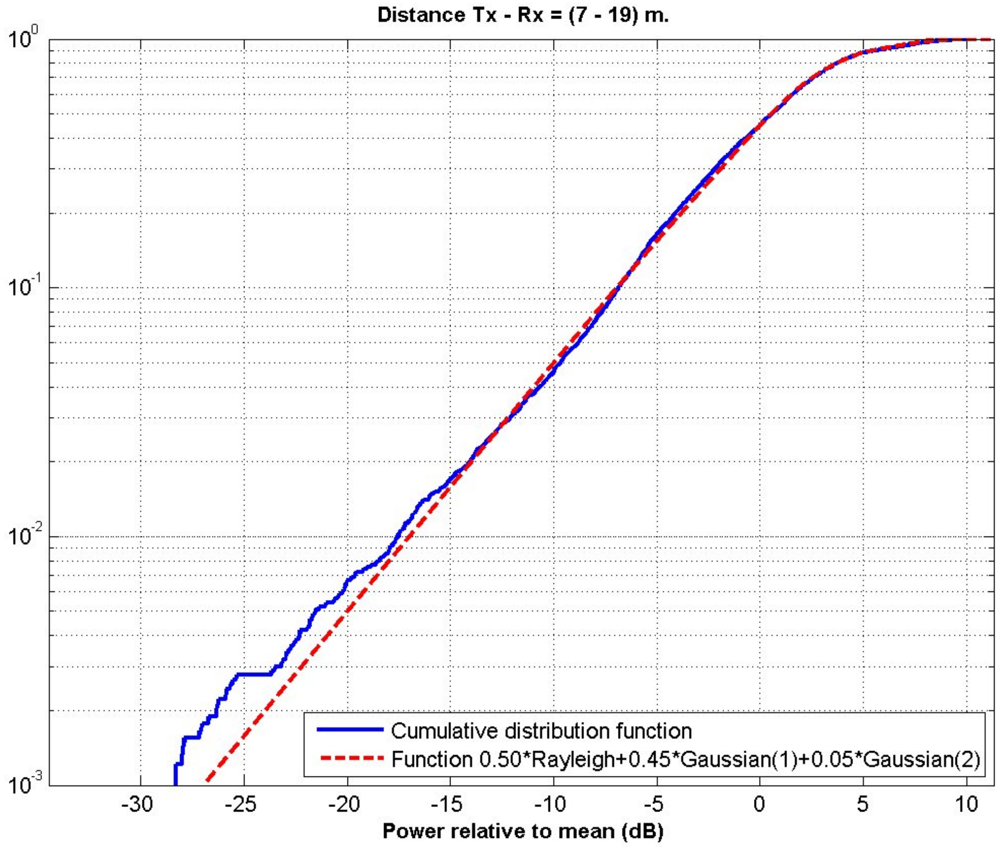

Fig. 20: Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone.

Comparing the previous results, it can be noticed that in the first and second zones of propagation, the deviation of the propagation loss from its main value is higher when antennas with lower gain are used in the measurements.

Comparing the previous results, it can be noticed that the break point distance is lower when the ultimate set of antennas (a transmitting antenna with 11 dB gain and a receiving antenna of 8 dB gain) is used.

It can be noticed that, for vertical polarization, the second zone propagation exponent is low (lower than 0.6) while it has a value of 2 or higher for horizontal polarization.

Here we will present the propagation loss results for a channel bandwidth of 20 MHz using both the vertical and horizontal polarizations. First of all, we will give the propagation loss at (5.6-5.62) GHz for vertical polarization and antenna gain of 18 dB for both the transmitting and the receiving one. Fig. 21 shows the propagation gain (loss) for this case. Here two propagation zones can be seen. The mean value of the propagation loss is given by:

$$L_{mean}(dB) = \begin{cases} 49.17 + 19.97\ \log_{10} d & d \leq 9\,m \\ 69.38 + 1.29\ \log_{10} \left(d/9\right) & d > 9\,m \end{cases} \qquad \textbf{(10)}$$

Propagation loss can be presented by the two exponent propagation model (two slope propagation model). It can be noticed that the first propagation exponent is near to 2. The second one is near to zero. The first zone is almost free space zone.

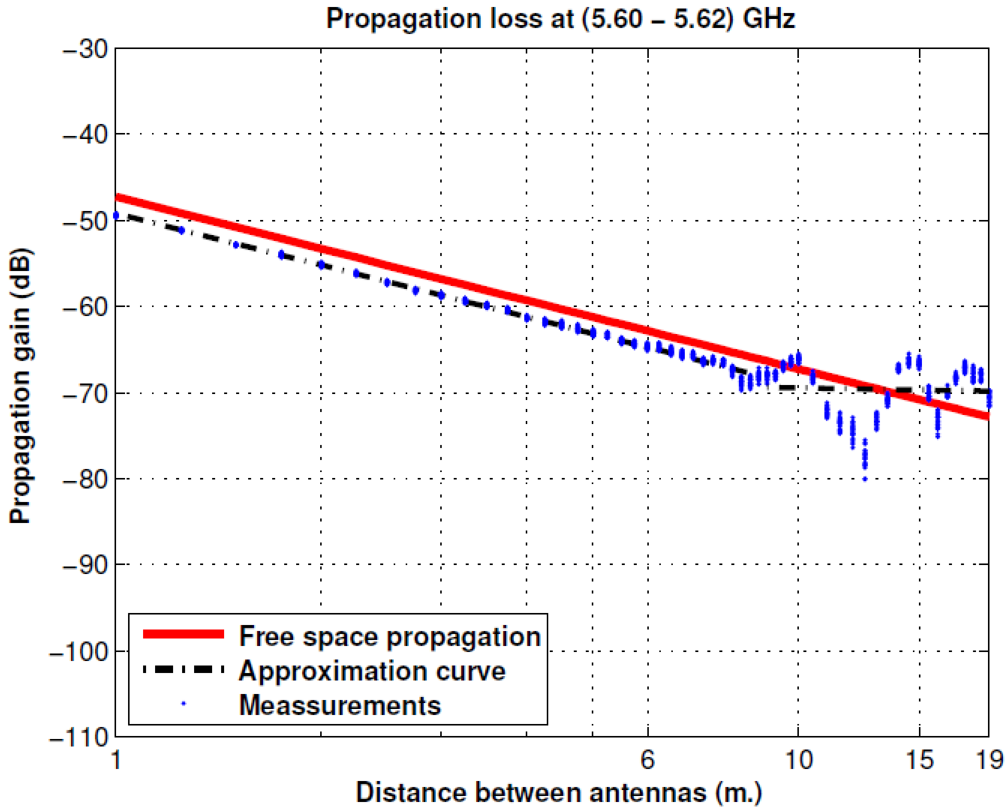

Fig. 21: Propagation loss for vertical polarization at (5.6-5.62) GHz with a transmitting antenna gain of 18 dB and a receiving antenna gain of 18 dB.

Fig. 22 shows the Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone. It can be approximated by the sum of two Gaussian distributions, the first one with a weight of 90%, mean value of 0.1 dB and a standard deviation of 0.33 dB and the second one with a weight of 10%, mean value of -0.78 dB and a standard deviation of 0.67 dB.

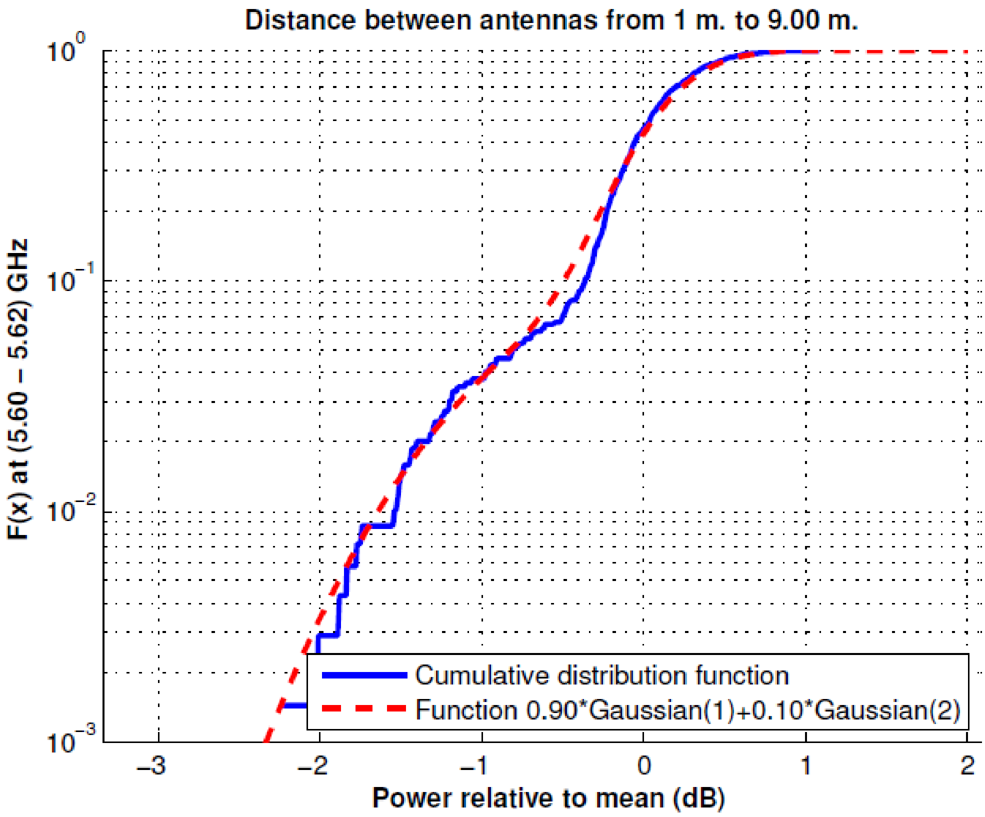

Fig. 22: Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone.

Fig. 23 shows the Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone. It can be approximated by the sum of two Gaussian distributions and a Rayleigh one. The first one of the Gaussian is with a weight of 45%, mean value of 2.5 dB and a standard deviation of 1.0 dB and the second one with a weight of 45%, mean value of 2.5 dB and a standard deviation of 2.4 dB. The Rayleigh distribution has a weight of 10%. **The Rayleigh distribution could be replaced by a Hypo-Rayleigh distribution to fit in a good manner the tail of the CDF.**

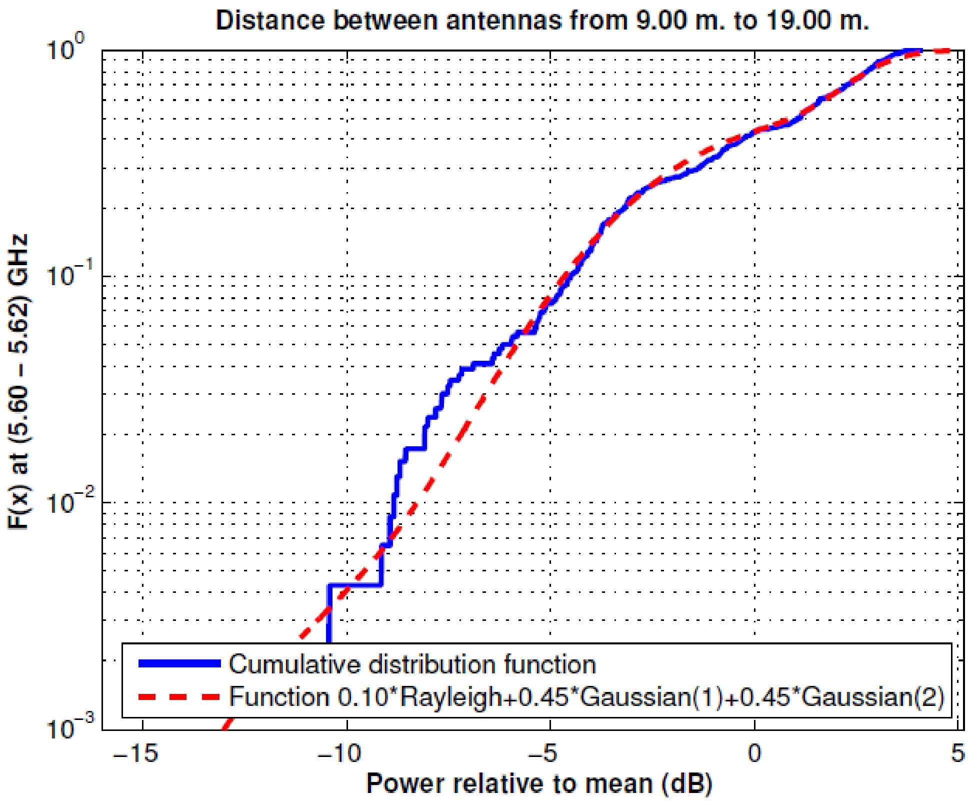

Fig. 23: Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone.

Here we will give the propagation loss at (5.6-5.62) GHz for vertical polarization and antenna gain of 18 dB for the transmitting one and 8 dB for the receiving one. Fig. 24 shows the propagation gain (loss) for this case. Here two propagation zones can be seen. The mean value of the propagation loss is given by:

$$L_{mean}(dB) = \begin{cases} 49.97 + 20.60 \; log_{10} d & d \leq 9\,m \\ 70.45 + 2.40 \; log_{10} \left(d/_{9} \right) & d > 9\,m \end{cases} \qquad (11)$$

Propagation loss can be presented by the two exponent propagation model (two slope propagation model). It can be noticed that the first propagation exponent is near to 2. The second one is near to zero. The first zone is almost free space zone.

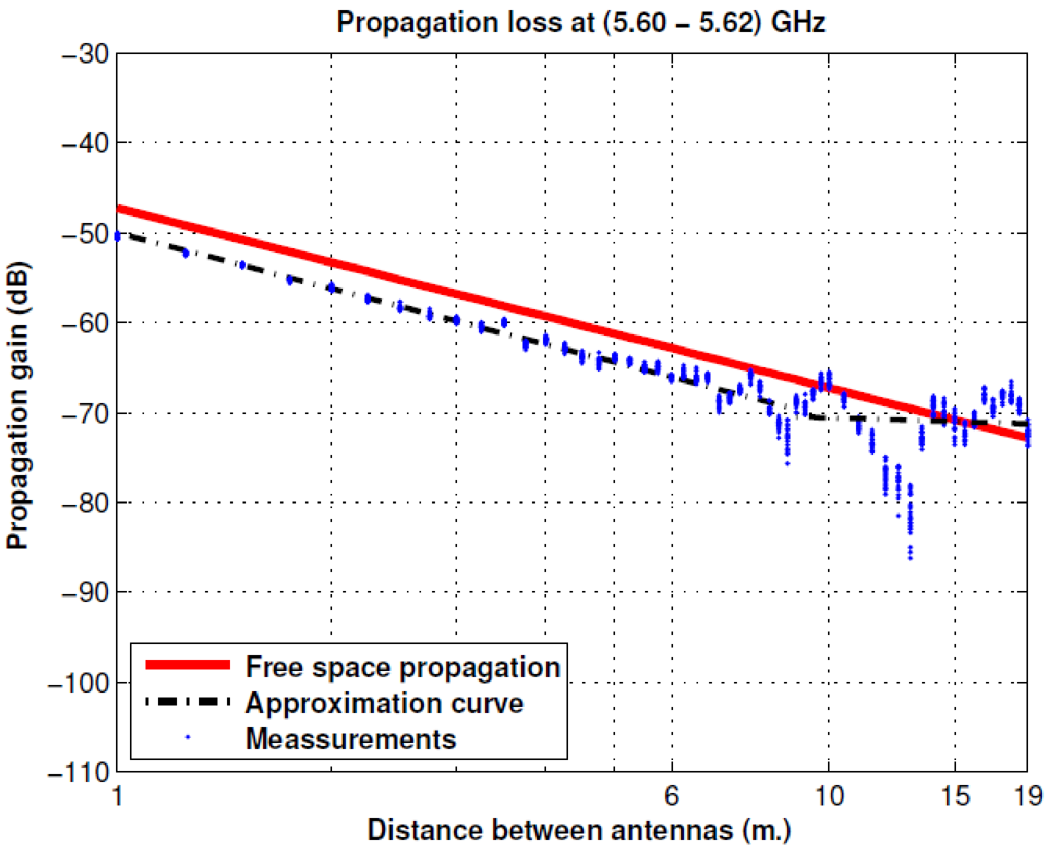

Fig. 24: Propagation loss for vertical polarization at (5.6-5.62) GHz with a transmitting antenna gain of 18 dB and a receiving antenna gain of 11 dB.

Fig. 25 shows the Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone. It can be approximated by the sum of two Gaussian distributions, the first one with a weight of 91%, mean value of 0.1 dB and a standard deviation of 0.7 dB and the second one with a weight of 9%, mean value of -1.9 dB and a standard deviation of 1.8 dB.

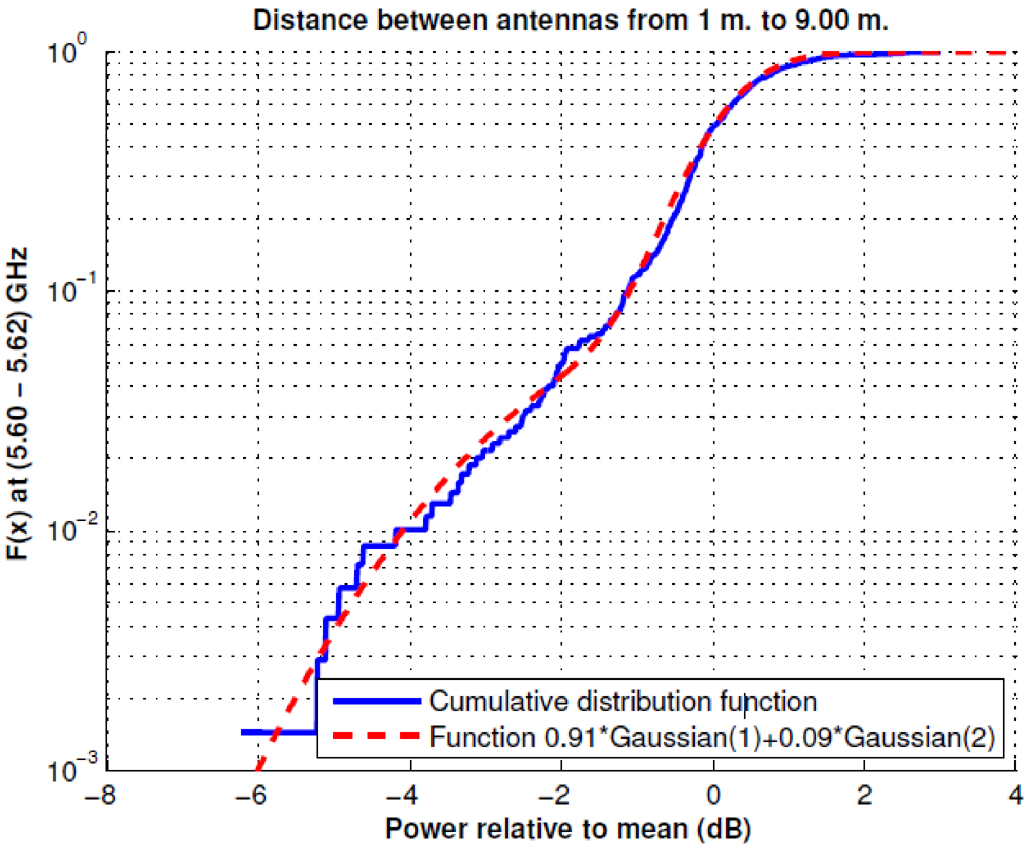

Fig. 25: Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone.

Fig. 26 shows the Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone. It can be approximated by the sum of two Gaussian distributions and a Rayleigh one. The first one of the Gaussian is with a weight of 40%, mean value of 3.0 dB and a standard deviation of 1.2 dB and the second one with a weight of 40%, mean value of 0.0 dB and a standard deviation of 1.7 dB. The Rayleigh distribution has a weight of 20%. **The Rayleigh distribution could be replaced by a Hypo-Rayleigh distribution to fit in a good manner the tail of the CDF.**

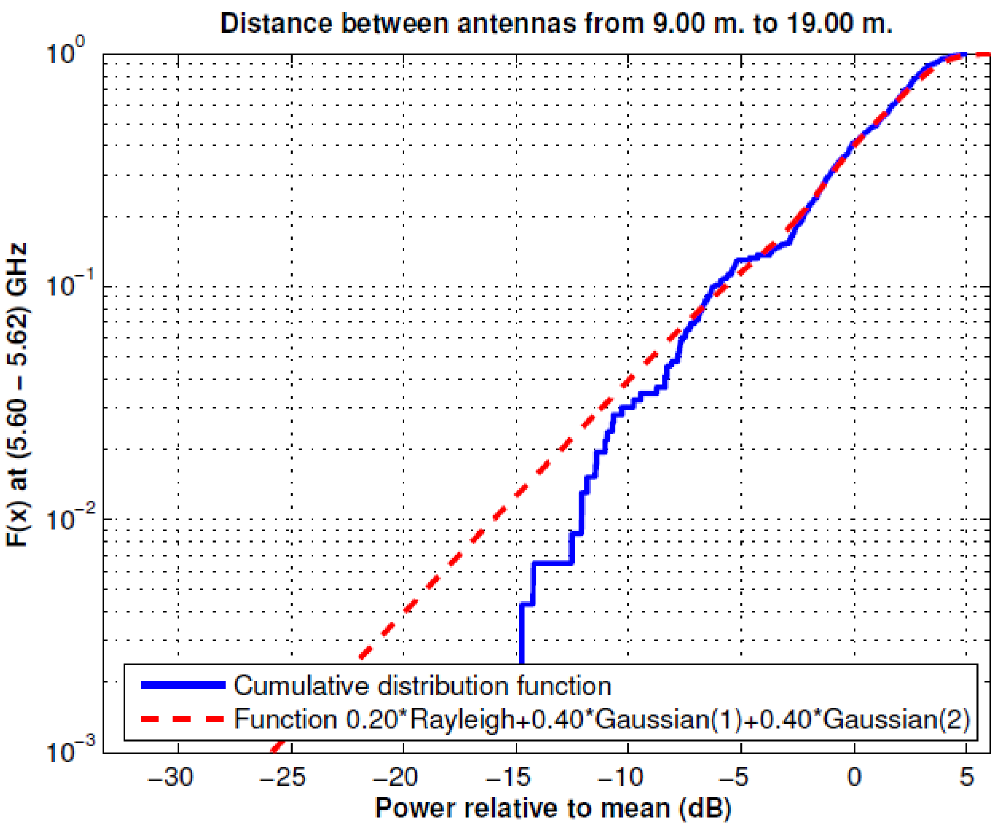

Fig. 26: Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone.

Here we will give the propagation loss at (5.6-5.62) GHz for vertical polarization and antenna gain of 11 dB for the transmitting one and 8 dB for the receiving one. Fig. 27 shows the propagation gain (loss) for this case. Here two propagation zones can be seen. The mean value of the propagation loss is given by:

$$L_{mean}(dB) = \begin{Bmatrix} 47.96 + 19.55\ log_{10}\, d & d \leq\ 7\, m \\ 66.55 + 5.00\ log_{10}\left({}^{d}/_{7}\right) & d > 7\, m \end{Bmatrix} \quad (12)$$

Propagation loss can be presented by the two exponent propagation model (two slope propagation model). It can be noticed that the first propagation exponent is positive and near to 2. The second one is 0.5. The first zone is almost free space zone.

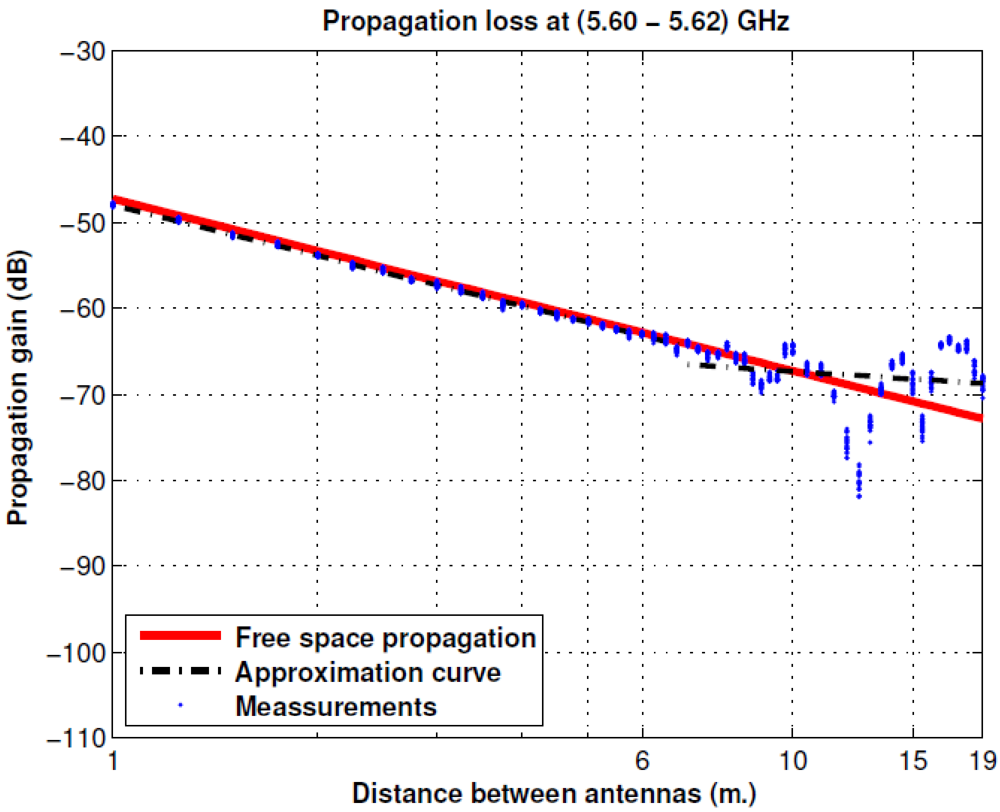

Fig. 27: Propagation loss for vertical polarization at (5.6-5.62) GHz with a transmitting antenna gain of 11 dB and a receiving antenna gain of 8 dB.

Fig. 28 shows the Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone. It can be approximated by the sum of two Gaussian distributions, the first one with a weight of 97%, mean value of 0.05 dB and a standard deviation of 0.3 dB and the second one with a weight of 3%, mean value of -0.7 dB and a standard deviation of 0.4 dB.

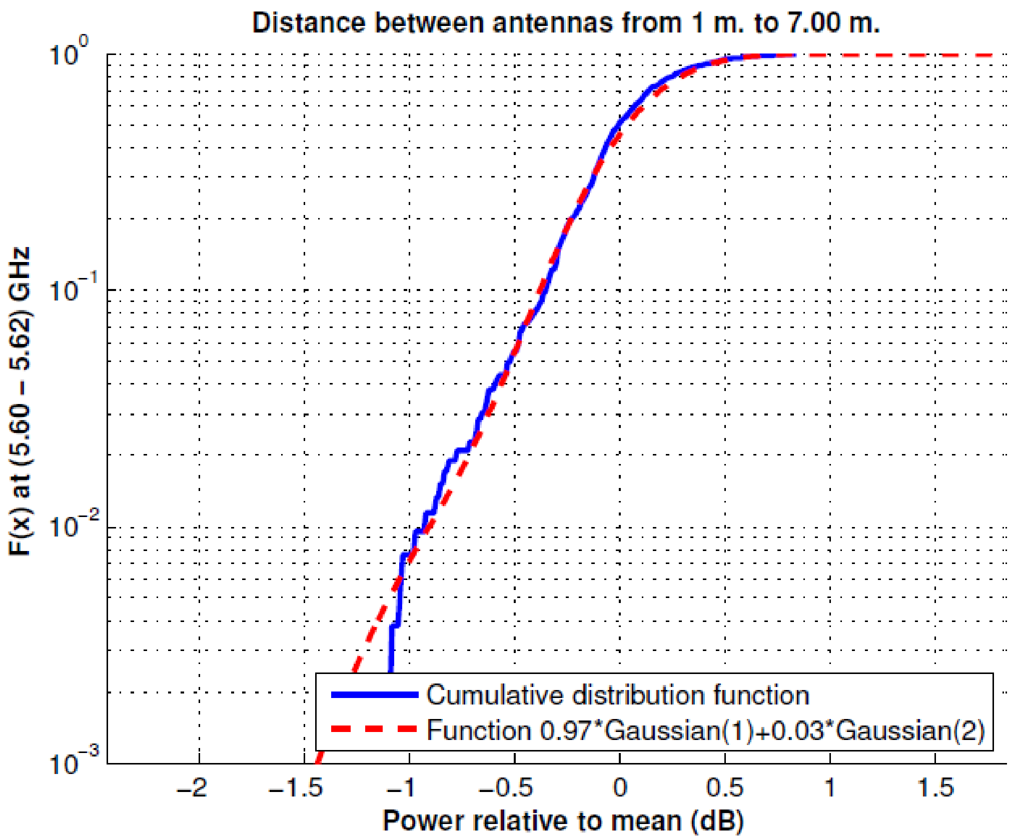

Fig. 28: Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone.

Fig. 29 shows the Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone. It can be approximated by the sum of two Gaussian distributions and a Rayleigh one. The first one of the Gaussian is with a weight of 65%, mean value of 1.5 dB and a standard deviation of 1.9 dB and the second one with a weight of 15%, mean value of -5.0 dB and a standard deviation of 3.5 dB. The Rayleigh distribution has a weight of 20%. **The Rayleigh distribution could be replaced by a Hypo-Rayleigh distribution to fit in a good manner the tail of the CDF.**

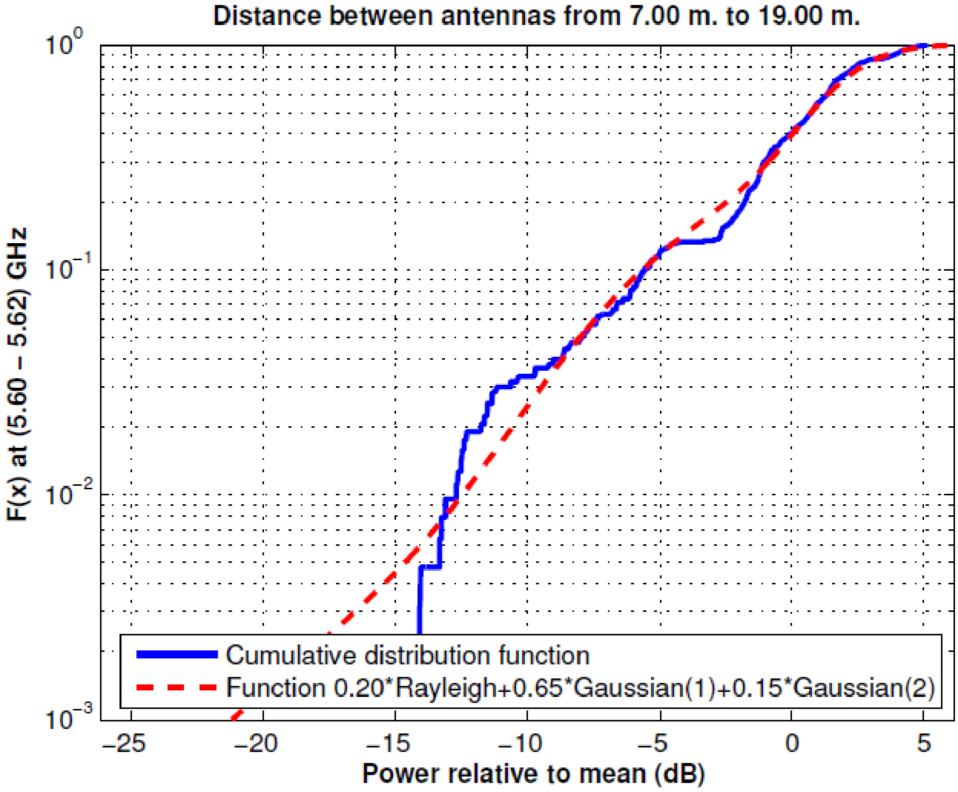

Fig. 29: Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone.

Here we will present the propagation loss results for a channel bandwidth of 20 MHz using the horizontal polarization. First of all, we will give the propagation loss at (5.6-5.62) GHz for antenna gain of 18 dB for both the transmitting and the receiving one. Fig. 30 shows the propagation gain (loss) for this case. Here two propagation zones can be seen. The mean value of the propagation loss is given by:

$$L_{mean}(dB) = \begin{cases} 49.37 + 19.15\ log_{10} d & d \leq 9\ m \\ 66.94 + 34.39\ log_{10}\left(d/_{9} \right) & d > 9\ m \end{cases} \quad (13)$$

Propagation loss can be presented by the two exponent propagation model (two slope propagation model). It can be noticed that the first propagation exponent is near to 2. The second one is 3.4. The first zone is almost free space zone.

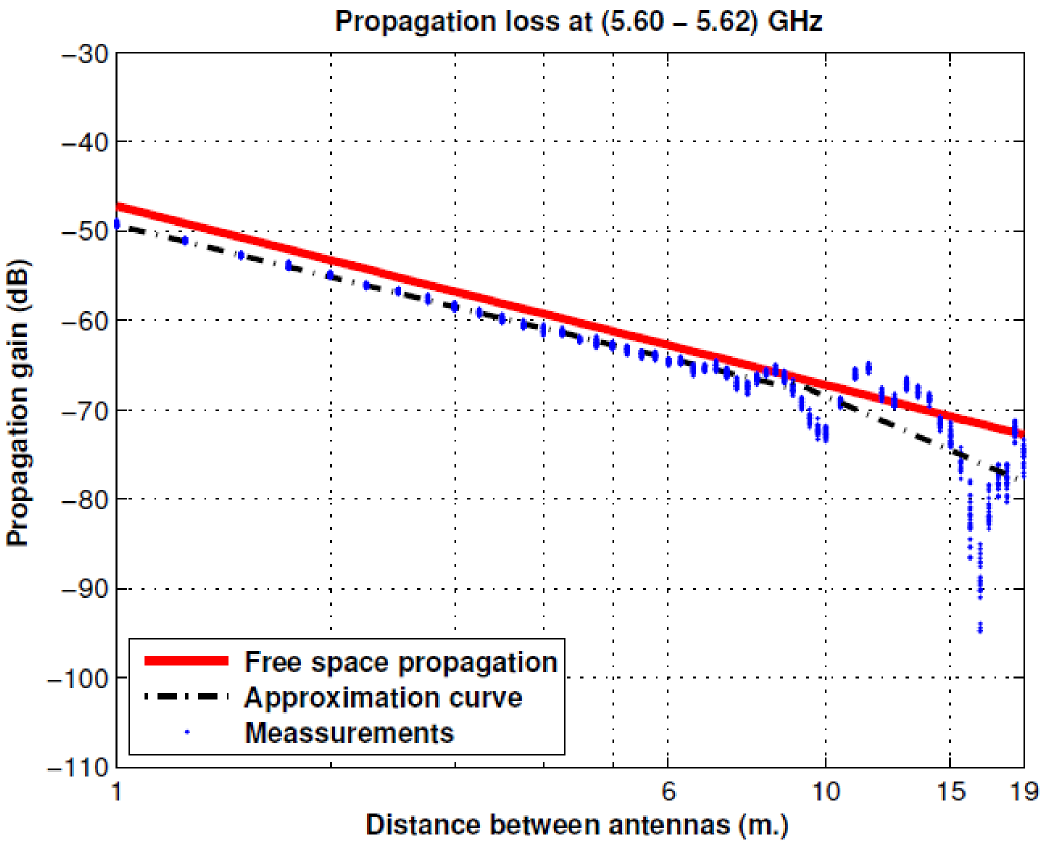

Fig. 30: Propagation loss for horizontal polarization at (5.6-5.62) GHz with a transmitting antenna gain of 18 dB for both the transmitting and the receiving one.

Fig. 31 shows the Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone. It can be approximated by the sum of two Gaussian distributions, the first one with a weight of 40%, mean value of 0.1 dB and a standard deviation of 0.8 dB and the second one with a weight of 60%, mean value of 0.0 dB and a standard deviation of 0.45 dB.

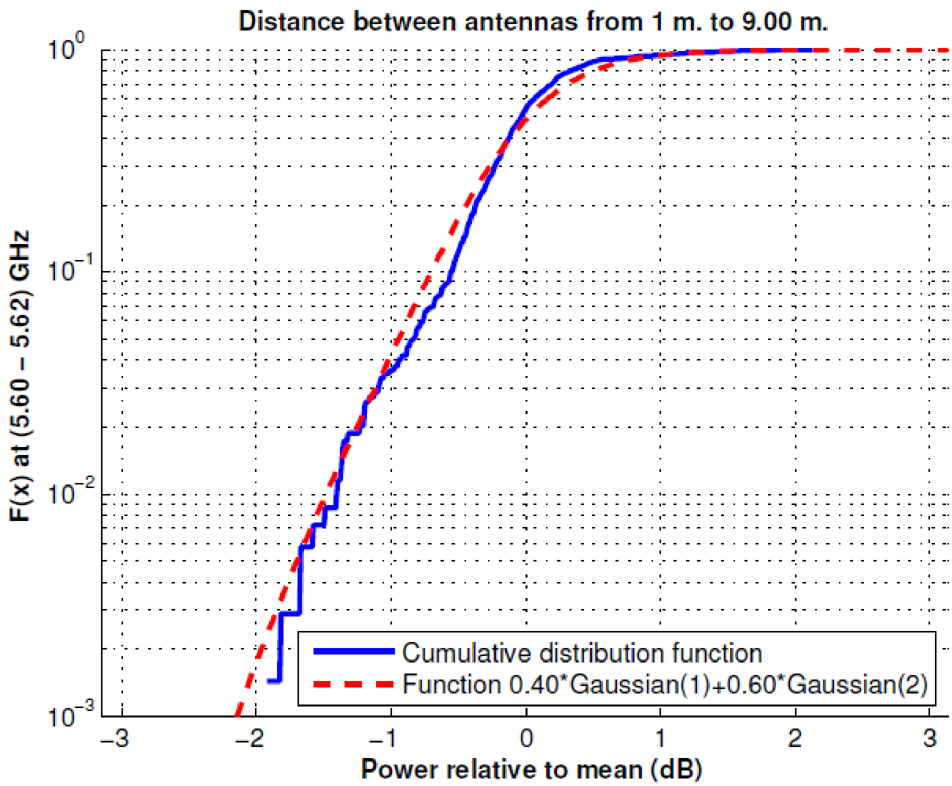

Fig. 31: Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone.

Fig. 32 shows the Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone. It can be approximated by the sum of two Gaussian distributions and a Rayleigh one. The first one of the Gaussian is with a weight of 40%, mean value of 3.5 dB and a standard deviation of 1.5 dB and the second one with a weight of 15%, mean value of -3.0 dB and a standard deviation of 2.0 dB. The Rayleigh distribution has a weight of 45%. **The Rayleigh distribution could be replaced by a Hypo-Rayleigh distribution to fit in a good manner the tail of the CDF.**

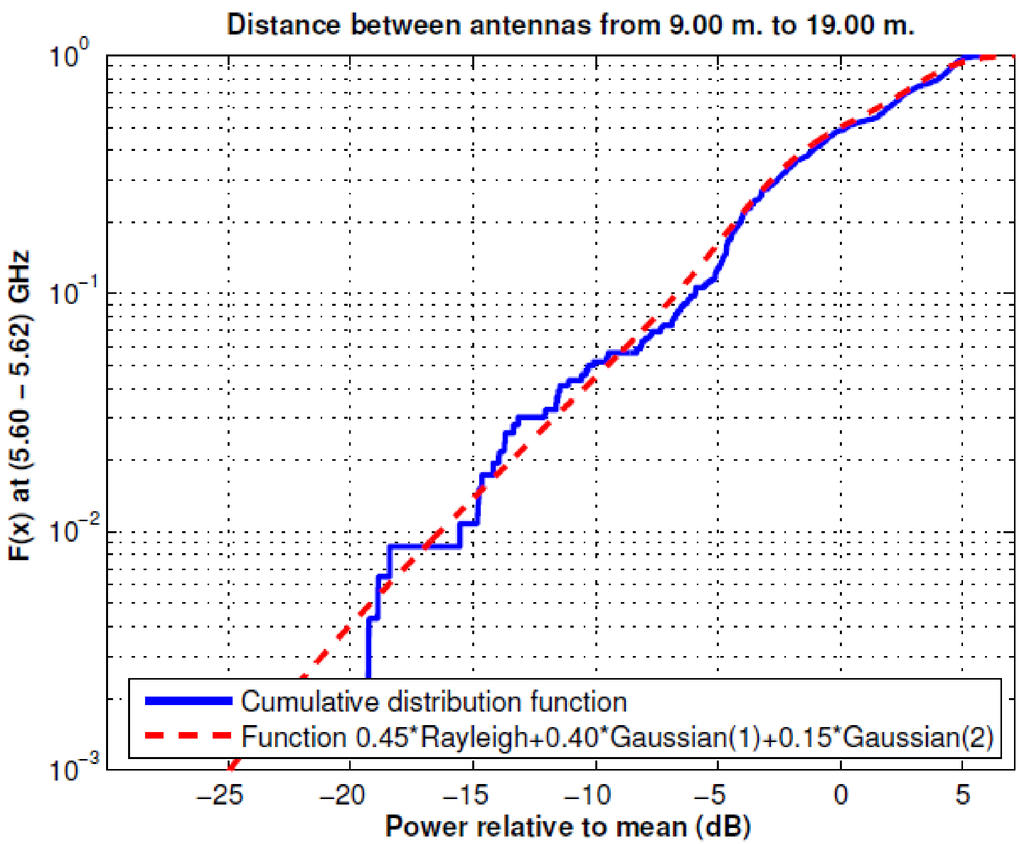

Fig. 32: Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone.

Comparing the results shown by Figures 21 and 30, It can be noticed that the for the second zone of propagation, the propagation loss deviation from its main value is higher for the horizontal polarization.

Here we will give the propagation loss at (5.6-5.62) GHz for horizontal polarization and antenna gain of 18 dB for the transmitting one and 8 dB for the receiving one. Fig. 33 shows the propagation gain (loss) for this case. Here two propagation zones can be seen. The mean value of the propagation loss is given by:

$$L_{mean}(dB) = \begin{cases} 48.45 + 19.69\ log_{10}\, d & d \leq\ 7\,m \\ 65.50 + 24.0\ log_{10}\left({}^{d}/_{9}\right) & d > 7\,m \end{cases} \qquad (14)$$

Propagation loss can be presented by the two exponent propagation model (two slope propagation model). It can be noticed that the first propagation exponent is near to 2. The second one is near 2.4. The first zone is almost free space zone.

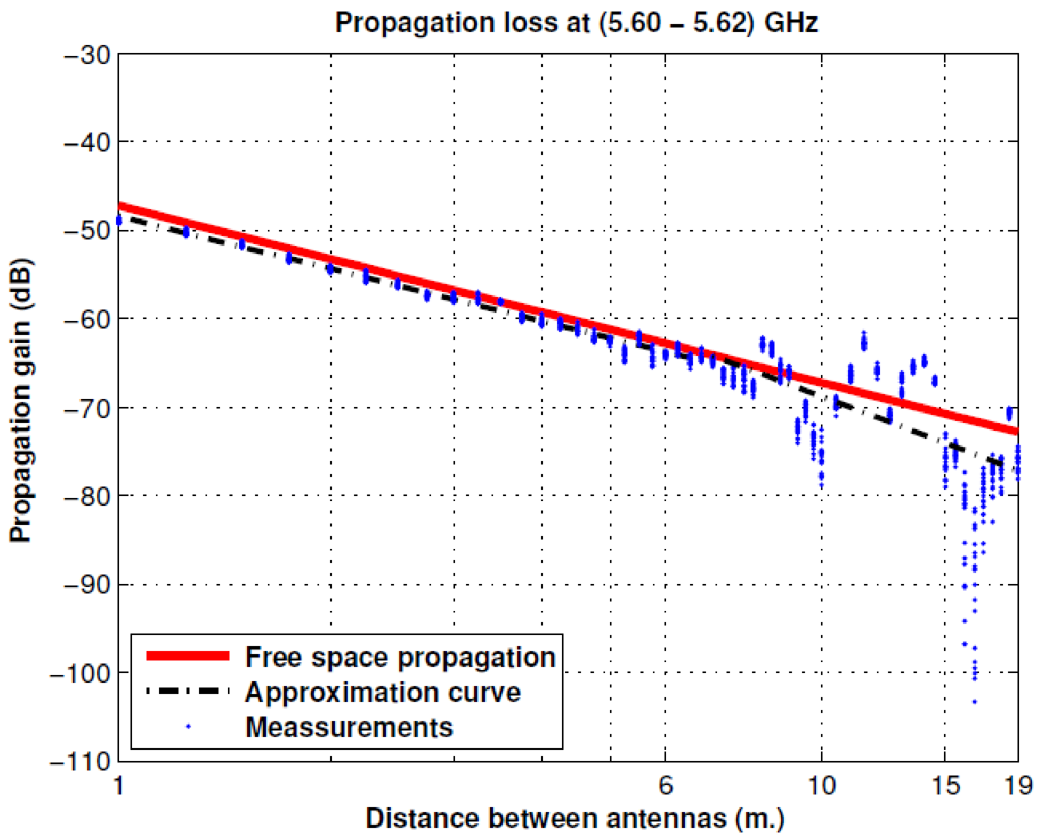

Fig. 33: Propagation loss for vertical polarization at (5.6-5.62) GHz with a transmitting antenna gain of 18 dB and a receiving antenna gain of 11 dB.

Fig. 34 shows the Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone. It can be approximated by the sum of two Gaussian distributions, the first one with a weight of 97%, mean value of 0.1 dB and a standard deviation of 0.6 dB and the second one with a weight of 3%, mean value of -1.9 dB and a standard deviation of 0.45 dB.

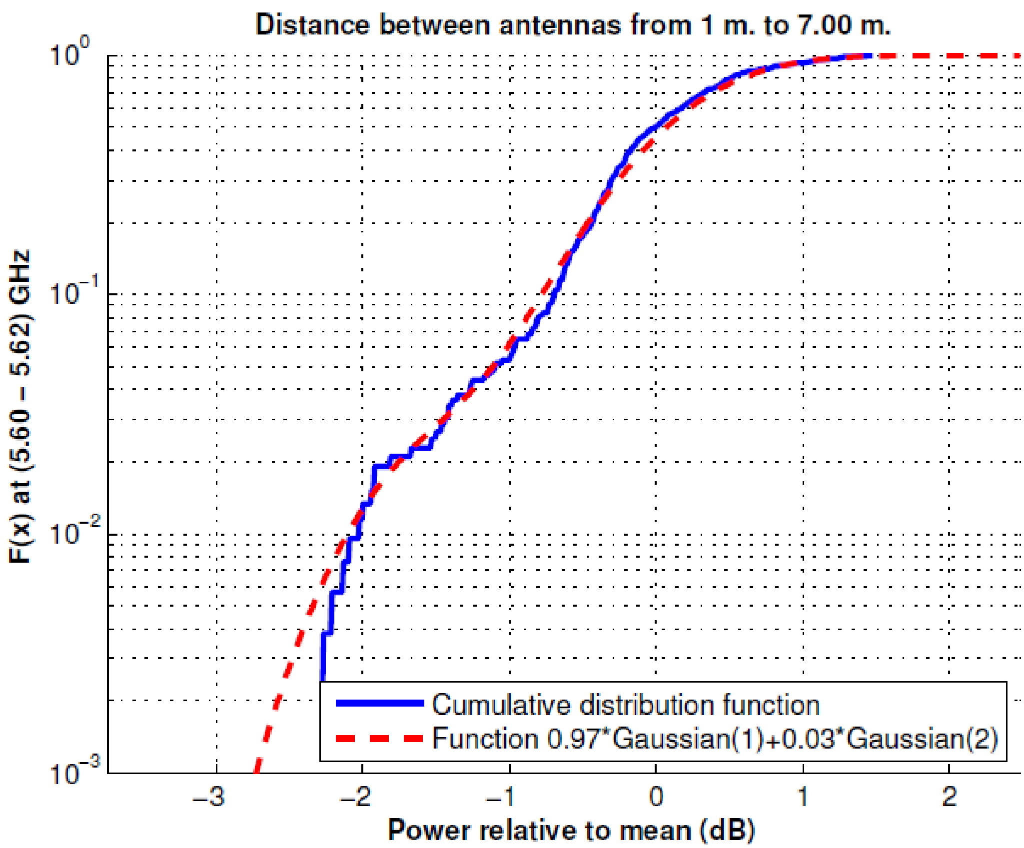

Fig. 34: Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone.

Fig. 35 shows the Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone. It can be approximated by the sum of two Gaussian distributions and a Rayleigh one. The first one of the Gaussian is with a weight of 40%, mean value of 4.0 dB and a standard deviation of 1.9 dB and the second one with a weight of 40%, mean value of -1.5 dB and a standard deviation of 1.7 dB. The Rayleigh distribution has a weight of 20%.

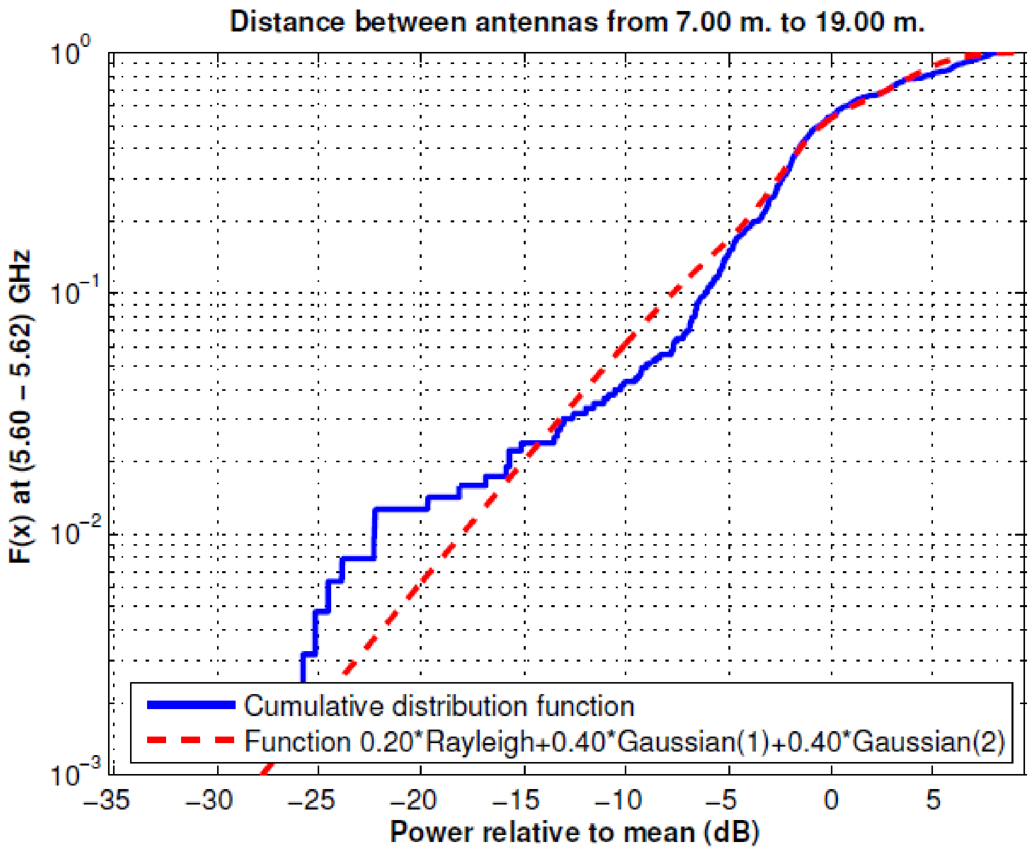

Fig. 35: Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone.

Comparing the results shown by Figures 24 and 33, It can be noticed that, for the second zone of propagation, the deviation of the propagation loss from its main value is higher for the horizontal polarization.

Here we will give the propagation loss at (5.6-5.62) GHz for horizontal polarization and antenna gain of 11 dB for the transmitting one and 8 dB for the receiving one. Fig. 36 shows the propagation gain (loss) for this case. Here two propagation zones can be seen. The mean value of the propagation loss is given by:

$$L_{mean}(dB) = \begin{cases} 48.74 + 19.51\ \log_{10} d & d \le 7\ m \\ 64.14 + 27.33\ \log_{10} \left(d/_7 \right) & d > 7\ m \end{cases} \qquad (15)$$

Propagation loss can be presented by the two exponent propagation model (two slope propagation model). It can be noticed that the first propagation exponent is positive and near to 2. The second one is 0.5. The first zone is almost free space zone.

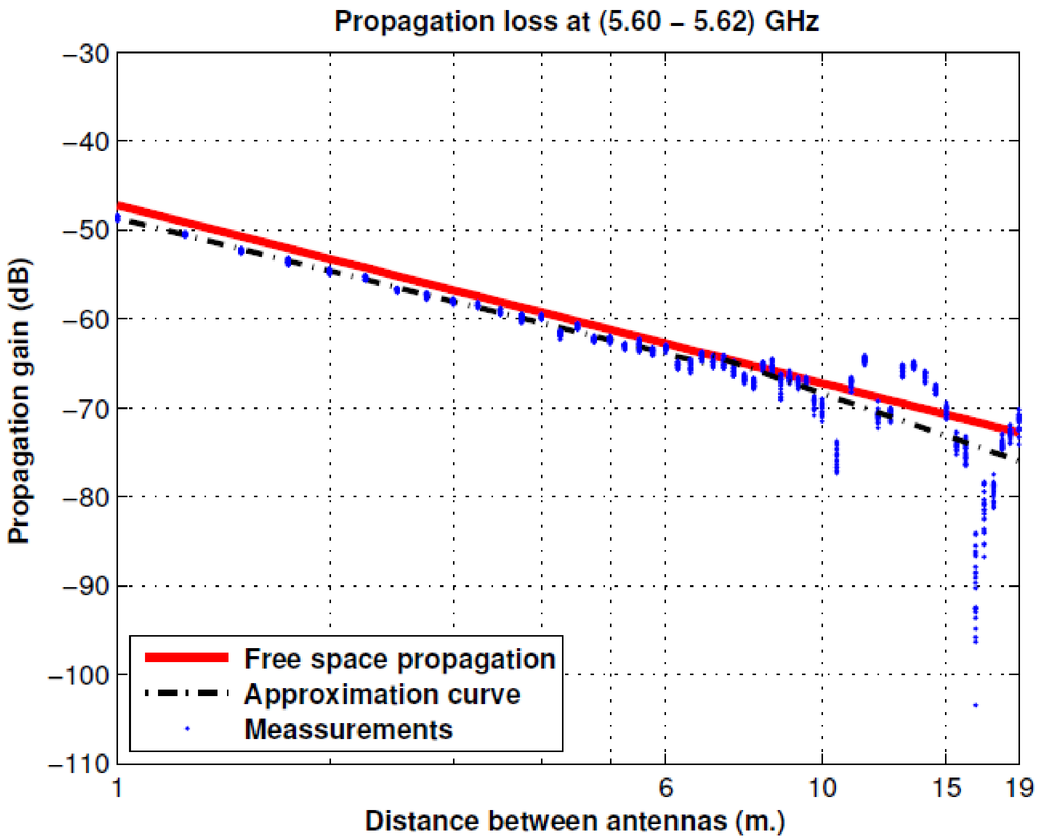

Fig. 36: Propagation loss for vertical polarization at (5.6-5.62) GHz with a transmitting antenna gain of 11 dB and a receiving antenna gain of 8 dB.

Fig. 37 shows the Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone. It can be approximated by the sum of two Gaussian distributions, the first one with a weight of 93%, mean value of 0.1 dB and a standard deviation of 0.4 dB and the second one with a weight of 7%, mean value of -1.0 dB and a standard deviation of 0.25 dB.

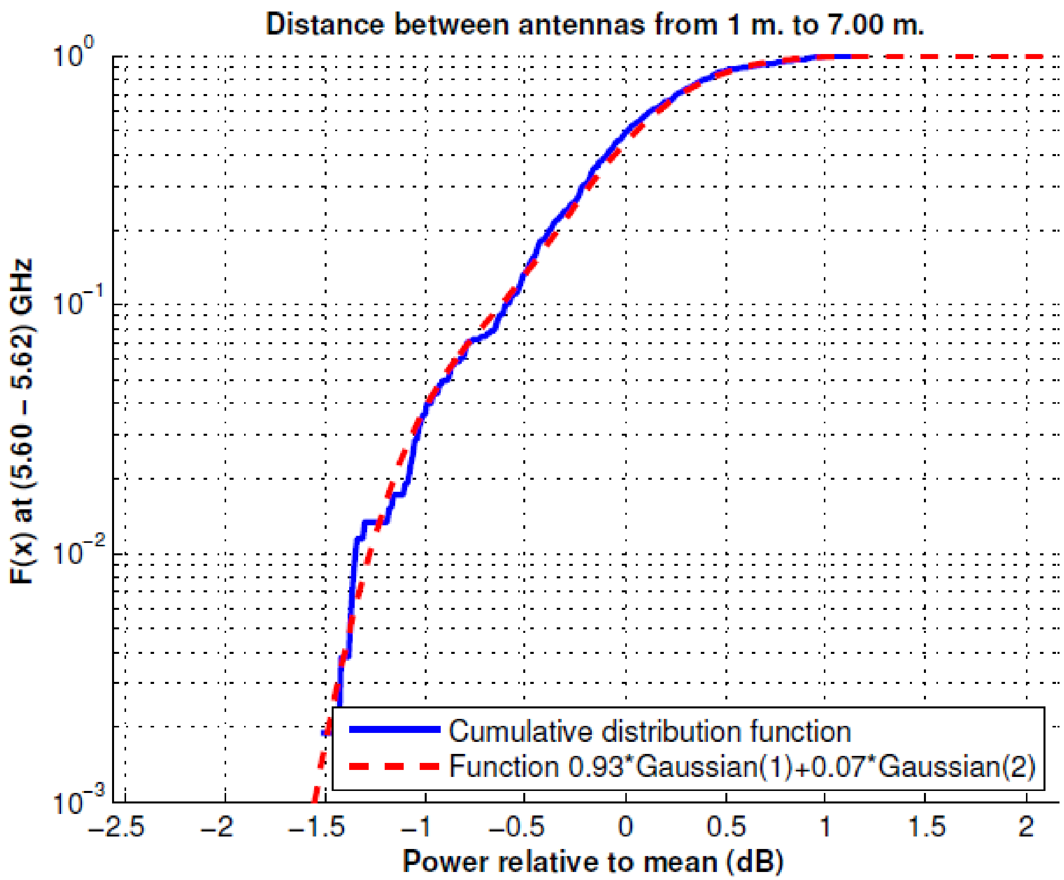

Fig. 37: Cumulative Distribution Function (CDF) of the approximation error for the first propagation zone.

Fig. 38 shows the Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone. It can be approximated by the sum of two Gaussian distributions and a Rayleigh one. The first one of the Gaussian is with a weight of 61%, mean value of -0.3 dB and a standard deviation of 1.5 dB and the second one with a weight of 22%, mean value of -5.0 dB and a standard deviation of 1.4 dB. The Rayleigh distribution has a weight of 17%.

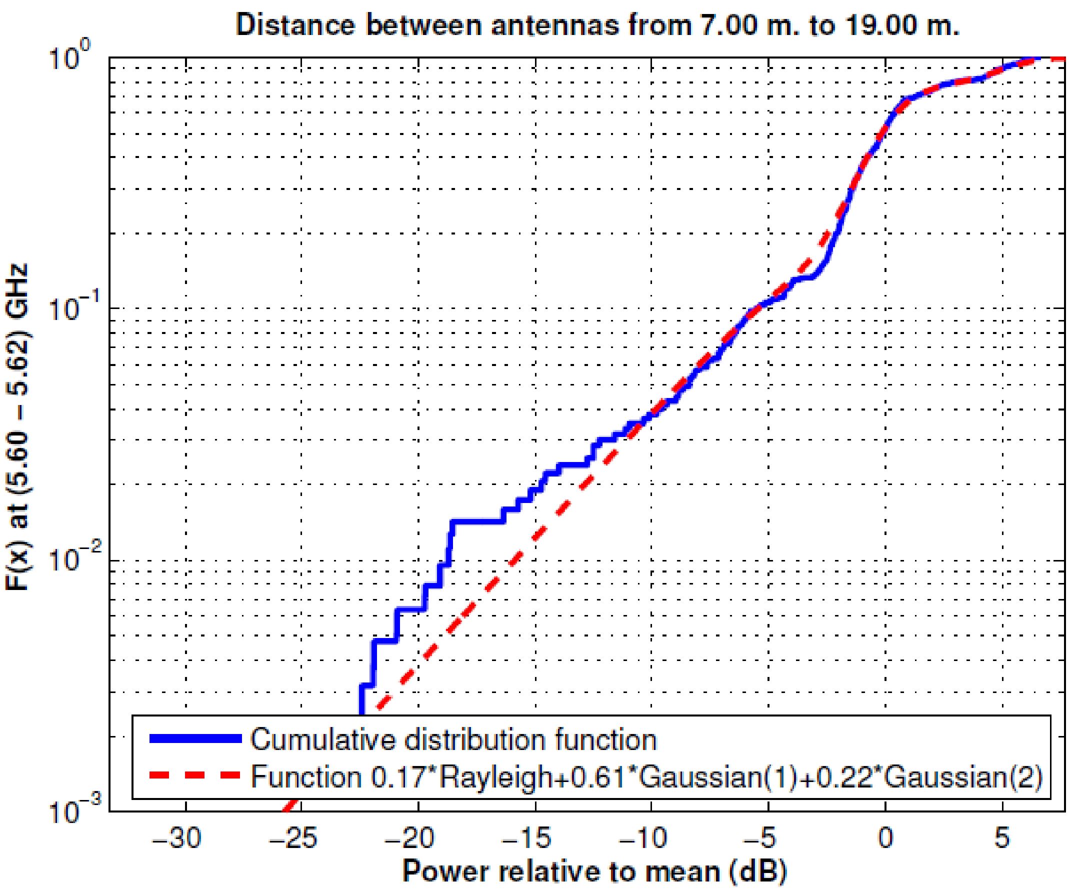

Fig. 38: Cumulative Distribution Function (CDF) of the approximation error for the second propagation zone.

Comparing the results shown by Figures 27 and 36, It can be noticed that the for the second zone of propagation, the propagation loss deviation from its main value is higher for the horizontal polarization.

Conclusions

The directive channel propagation loss in indoor environment at a frequency band of 5.6 GHz has been measured. Propagation loss models for indoor environment have been presented. It has been found that propagation loss is sensitive to the scenario configuration. Also, it has been noticed that the propagation loss can be modelled by a two slopes propagation model. It has been noticed that the first zone of propagation is almost free space propagation zone. The second zone of propagation has a higher deviation from the mean value of propagation loss. For the second zones of propagation, using the horizontal polarization, the deviation of the propagation loss from its main value is higher than the deviation using the vertical polarization.

REFERENCES

1. M. Golparvar Roozbahani and E. Jedari, A. A. Shishegar, “A new link-level simulation procedure of wideband MIMO radio channel for performance evaluation of indoor WLANS”, Progress In Electromagnetics Research, PIER 83, 13–24, 2008.
2. J. Blas, Prieto , Fernández, R. M. Lorenzo, E. J. Abril , S. Mazuelas, A., S. M. Franco, A.B. Martinez, and D. Bulllid, “A model for transition between outdoor and indoor propagation” Progress In Electromagnetics Research, Vol. 85, 147−167, 2008.
3. Tayebi, J. Gomez, F. Saez de Adana, and O. Gutierrez, “The application of ray-tracing to mobile localization using the direction of arrival and received signal strength in multipath indoor environments”, Progress In Electromagnetics Research, PIER 91, 1–15, 2009.
4. Bahillo, and D. Bullido, “A model for transition between outdoor and indoor propagation”, Progress In Electromagnetics Research, PIER 85, 147–167, 2008.
5. N. Yarkoni, N. Blaunstein, “Prediction of propagation characteristics in indoor radio communication environment”, Progress in Electromagnetics Research, PIER 59, 151-174, 2006.
6. L. Howitt, M.S. Khan, “A mode based approach for characterizing RF propagation in conduits”, Progress in Electromagnetics Research B, Vol. 20, 49-64, 2010.
7. Dinesh Tummala, "Indoor propagation modeling at 2.4 GHz for IEEE 802.11 networks", M.Sc Thesis, University of North Texas, December 2005.
8. Emilie Masson et. al., "Radio wave propagation in arched cross section tunnels – Simulations and measurements". Journal of Communications, Vol. 4, No. 4, 276 - 283, May 2009.
9. Erik Kjeldsen and Marshall Hopkins, "An experimental look at RF propagation in narrow tunnels". Scientific Research Corporation (SRC) Atlanta, Georgia.
10. Marina Barbiroli , Claudia Carciofi , Vittorio Degli Esposti , Franco Fuschini , Paolo Grazioso , Doriana Guiducci, Daniel Robalo, Fernando J. Velez, “Characterization of WiMAX propagation in microcellular and

picocellular environments", 2010 Proceedings of the Fourth European Conference on Antennas and Propagation (EuCAP), 1-5, Barcelona, Spain, 2010.

11. Zaballos, G.Corral, A.Carné, and J. L. Pijoan, "Modeling new indoor and outdoor propagation models for WLAN", (On line) Available at: www.salle.url.edu/~zaballos/opnet/OPNET2004b.pdf.
12. J. M. Gorce, K. Runser, G. de la Roche, "FDTD based efficient 2D simulations of Indoor propagation for wireless LAN", (On line) Available at: www. katia.runser.free.fr/Fichiers/GORCE_IMACS_FINAL.pdf
13. C. Nerguizian, C. L. Despins, S. Affes, M. Djadel, " Radio-channel characterization of an underground mine at 2.4 GHz", IEEE Transactions on Wireless Communications, Vol. 4, No. 5, 2441-2453, September 2005.
14. J. Poutanen, K. Haneda, J. Salmi et al., "Analysis of radio wave propagation from an indoor hall to a corridor", IEEE Antennas and Propagation Symposium /USNC/URSI, Vols. 1-6, 2683-2686, 2009.
15. X. H. Mao, Y. H. Lee, B. C. Ng, " Propagation modes and temporal variations along a lift shaft in UHF band", IEEE Transactions on Antennas and propagation, Vol. 58, No. 8, 2700-2709, August 2010.
16. Bazil Taha Ahmed, D. F. Campillo, and J. L. Masa Campos, "Short Range Propagation Model for a Very Wideband Directive Channel at 5.5 GHz Band", Progress in Electromagnetics Research, PIER Journal, Vol. 130, pp. 319-346, 2012.