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Propagation Path Loss and Materials Insertion Loss in Indoor Environment at WiMAX Band of 3.3 to 3.6 GHz

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Abstract: The purpose of this study is to characterize the indoor channel for IEEE 802.16 (WiMAX) at 3.3 to 3.6 GHz frequency. This work presents a channel model based on measurements conducted in commonly found scenarios in buildings. These scenarios include closed corridor, wide corridor and semi open corridor. Path loss equations are determined using log-distance path loss model and a Rayleigh multipath induced fading, Normal multipath induced fading or a combination of both. A numerical analysis of measurements in each scenario was conducted and the study determined equations that describe path loss for each scenario. Propagation loss is given for 300 MHz bandwidth. This work also represents the insertion loss of different materials and the obstruction loss due the existence of human beings between the transmitting antenna and the receiving one.

Keywords: WiMAX, indoor propagation, Rayleigh multipath induced fading, Normal multipath induced fading.

1- Introduction

The design and the deployment of wireless broadband access systems, and notably of WiMAX, represents nowadays one of the main challenges for telecommunication service providers, which need to perform cost/performance analyses, the costs being related to infrastructure deployment, required bandwidth and power consumption and the benefits to offered bit rate and coverage.

Different coverage strategies are used to guarantee higher bit rates both in outdoor and indoor environments. In order to support WiMAX broadband mobile access also in indoor environments the introduction of WiMAX picocells and femtocells is needed in addition to conventional macrocellular and microcellular base stations. Due to the high penetration loss at the 3.5 GHz WiMAX frequency operation, picocells and/or femtocells base stations are likely to be essential to provide good indoor service quality.

Therefore, a layered cellular structure is expected for WiMAX coverage. This implies that propagation phenomena will be very different for each cellular layer and a suitable and adaptable propagation model will be required to correctly evaluate WiMAX coverage in all different propagation conditions.

In [1] 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 [2] propagation losses are measured at different frequency bands (1, 2.4 and 5.8 GHz) within an arched cross section tunnels. Results show that fast multipath induced 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 [3] propagation loss in narrow tunnels is presented. Measurements results at 374 MHz, 915 MHz, and 2400 MHz are given. Studied scenarios were unobstructed, 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 [4], 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. In [5], the modelling of new WLAN models for indoor and outdoor environments. Based on the standard Opnet models for WLAN nodes, the propagation loss estimation for these two types of environment has been improved. Work [6] describes and evaluates a new algorithm for the purpose of Indoor propagation prediction for centimetric waves. Their approach started from a formalism similar to the famous TLM approach in the frequency domain. In [7], 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 [8], the propagation modes and the temporal variations along a lift shaft in UHF band have been given.

2- Propagation Model

For a short distance between the transmitting and receiving antennas, the propagation loss for an indoor environment is 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 d_o (1 m in our case),
n_1 is the propagation exponent, and
ξ_1 is a random variable (Rayleigh, Normal or a combination of both) that represents the deviation from the mean value.
Sometimes, second mode of propagation exists due to the waveguide mode of propagation which is generated in narrow corridors. In this case, the propagation loss at a distance d higher than the breakpoint distance d_b can be written as:

$$L_p = L_1 + 10\, n_2 \log_{10}\left(\frac{d}{d_b}\right) + \xi_2 \qquad (2)$$

Where L_1 is the propagation loss of the distance d_b at which the waveguide mode starts, n_2 is the second propagation exponent usually lower than n_1 and ξ_2 is a random variable (Rayleigh, Normal, or a combination of both) that represents the deviation from the main value. In wide indoor environment, n_2 will be in general higher than 2 (3 to 4).
For indoor environment with the transmitting antenna mechanically inclined pointing at a given distance, propagation loss can be represented by:

$$L_p(dB) = \begin{cases} L_o + 10\, n_1 \log_{10}(d_o) + \xi_1, & d \le d_o \\ L_1 + 10\, n_2 \log_{10}\left(\frac{d}{d_o}\right) + \xi_2, & d > d_o \end{cases} \qquad (3)$$

In this case, L_o has a value higher than the propagation loss in free space. L_1 has a value lower than L_o. The first propagation exponent n_1 has a negative value mean while n_2 has a positive one.

3- Measurements campaign

A network analyzer (6 GHz ZVL of Rohde & Schwarz) has been used to measure the propagation loss at the WiMAX band of (3.3-3.6) GHz. Calibration has been carried out with a 20 m cable. The gain of the antennas used in the study has been measured with an error lower than 0.1 dB using the standard method. Transmitting and receiving antennas are single element wideband patch antennas with a gain of 6.9 dB. In this way, 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. Measurements have been carried out in different sites within the Escuela Politecnica Superior of the Universidad Autonoma de Madrid. Fig. 1 illustrates one of the measurement scenarios.

4- Results

Here we will present some of the results of the measurements campaign.

Firstly, we will present the measurements result for a semi open corridor with 3m width. Here metallic lockers are placed in one side of it. The other side is an open one. Both transmitting and receiving antennas are at 1.4 m height. Figure 2a represents the propagation loss at different distance from the transmitting antenna. At a given distance d, 31 points are presented to show the propagation loss within the entire band (3.3-3.6) GHz with a 10 MHz step. This means that each WiMAX channel with a bandwidth of 10 MHz has been presented by a given point. To calculate the propagation exponent, the Minimum Mean Square Error Method (MMSEM) has been used to calculate it. This procedure has been adapted to give a single or double slope propagation loss model depending upon the measurement results.

From Fig. 2a, it can be noticed that the propagation loss can be presented by the one slope propagation loss model given by (1). The propagation exponent has been obtained as 2.185. Mean value of the propagation loss is given by:

$$L_p(\mathrm{dB}) = 42.18 + 21.85\ \log_{10}(d) \qquad (4)$$

The histogram of the measurement point is presented by Fig. 2b. Fig. 2c represents the CDF (Cumulative Distribution Function) of the measurement points which can be approximated by Rayleigh Distribution. **The deviation of the measurements from the**

median value is due to the fact that the received signal is the result of the vector sum (amplitude and phase) of the multipath components. This gives a rise to instructive vector sum at given frequencies and a destructive vector sum at other ones. The theoretical difference between them can be infinity. In practice, it can reach a value of 40 dB depending on the gain of the transmitting and receiving antennas (lower value for higher gain). Since we present at each single position the response of the WiMAX channel due to a bandwidth of 300 MHz (represented by 31 points with a frequency separation of 10 MHz), we have not to strange that a deviation of up to 40 dB can be noticed.

Secondly, we will present the measurements result for a 18 m corridor with 1.2 m width. Both transmitting and receiving antennas are at 1.4 m height. From Fig. 3a, two modes of propagation can be noticed. The first one is till 4.25m is the deformed LOS mode of propagation that converts into the waveguide mode of propagation with lower propagation loss for a higher distance. First propagation exponent has been calculated as 2.108 and the second one as 0.351 representing possible waveguide mode. Propagation losses mean value can be represented by:

$$L_p(\mathrm{dB}) = \begin{cases} 42.88 + 21.08\ \log_{10}(\mathrm{d}), & \mathrm{d} \le 4.25\mathrm{m} \\ 56.08 + 3.51\ \log_{10}(\mathrm{d}/4.25), & \mathrm{d} > 4.25\mathrm{m} \end{cases} \tag{5}$$

The histograms of the measured power are shown in Fig. 3b and 3d and the CDF of the measured power are depicted in Fig. 3c and 3e. Both of them can be approximated by a Rayleigh Distribution.

Thirdly, we will present the measurements result for the same corridor when the transmitting antenna with 2.5m height points at a distance of 16 m. In this case, the receiving antenna is maintained at 1.4m height. Form Fig. 4a, two propagation exponents can be noticed. The first one with a value of - 0.261 and the second has a value of 0.142. At 1 m distance the propagation loss mean value is almost 60 dB very high compared with the free space loss of 42.5 dB. It has the same value at a distance of 18m. Propagation losses mean value can be represented by:

$$L_p(\mathrm{dB}) = \begin{cases} 59.78 + (-2.61)\ \log_{10}(d), & d \le 4.5\mathrm{m} \\ 58.48 + 1.42\ \log_{10}(d/4.5), & d > 4.5\mathrm{m} \end{cases} \quad (6)$$

In this case, the minimum mean value of propagation loss is expected at a point between 1 m and 18 m. The histograms of the measured power are shown in Fig. 4b and 4d and the CDF of the measured power are depicted in Fig. 4c and 4e. Both of them can be approximated by a Rayleigh Distribution.

Fourthly we present the propagation loss for a wide corridor with two columns a distance of 8m from the transmitting antenna. Fig. 5a shows the propagation loss a function of TR distance. In this case, the mean value of the propagation loss is given by:

$$L_p(\mathrm{dB}) = \begin{cases} 43.8 + 19.76\ \log_{10}(d), & d \le 8\mathrm{m} \\ 61.48 + 22.3\ \log_{10}(d/8), & d > 8\mathrm{m} \end{cases} \quad (7)$$

First and second propagation exponents have values of 1.976 and 2.23 respectively.

The histograms of the measured power are shown in Fig. 5b and 5d and the CDF of the measured power are depicted in Fig. 5c and 5e. For the first zone of propagation ($d \le 8$m), Gaussian (Normal) multipath induced fading can be noticed (Fig. 5c). For the second zone of propagation, the multipath induced fading **can be approximated by** a combination of Normal (with σ = 2 dB) and Rayleigh induced multipath fading (Fig. 5e).

5- Obstruction caused by persons

Obstruction loss has been measured in the narrow corridor scenario with a distance of 18 m between the transmitting antenna and the receiving one. First of all a calibration process for the parameter (S_{21}) has been carried out in the absence of the human subject. Then the received signal representing S_{21} has been recorded in the presence of the human subject. This value (neglecting the negative sign) represents the obstruction loss due to the human subject.

It has been noticed that when a person exists at a distance of 10m from the receiving antenna, an obstruction loss of 4 to 6 dB has been measured. A higher obstruction loss of 14 to 18 dB has been measured when the person exists at a distant of 4 m from the receiving antenna. Obstruction loss depends on the length and weight of the person that exists between the transmitting antenna and the receiving one. Also it depends on the distance of the person from the transmitting antenna and the receiving one. Insertion loss, reflection and diffraction are the three mechanisms that create the obstruction loss.

6- Insertion loss of different materials

Two directive antennas with a gain of 18 dB for each one were used to measure the insertion loss of different materials. The far field distance of each one was calculated to be 1.2 meter. To ensure the minimum possible reflection from the surface between the two antennas, an absorbing material was placed between them. Measurements were done in 9 points for each material under study insuring that the main lobe of the antenna illuminates only the material under study. With a distance of 2.5 meters between the used antennas we calibrated the parameter S_{21} of the network analyzer in the band (3.3 to 3.6) GHz. Then the material is inserted between them and the S_{21} parameter (which presents the insertion loss) was recorded. The surface of the material under test was more than 2m*2m. This is not applicable in the case of the humans. Table (1) shows the lower and the upper value of the combination of the 9 records. Most of the recorded values are very close to the medium value.

7- Conclusions

This article presents a channel model based on measurements conducted in commonly found scenarios in buildings. These scenarios include narrow corridor, wide corridor and semi open corridor. Path loss equations are determined using log-distance path loss model and a Gaussian o Rayleigh multipath induced fading. A numerical analysis of measurements in each scenario was conducted and the study determined equations that describe path loss for each scenario. Propagation loss is given for 300 MHz bandwidth.

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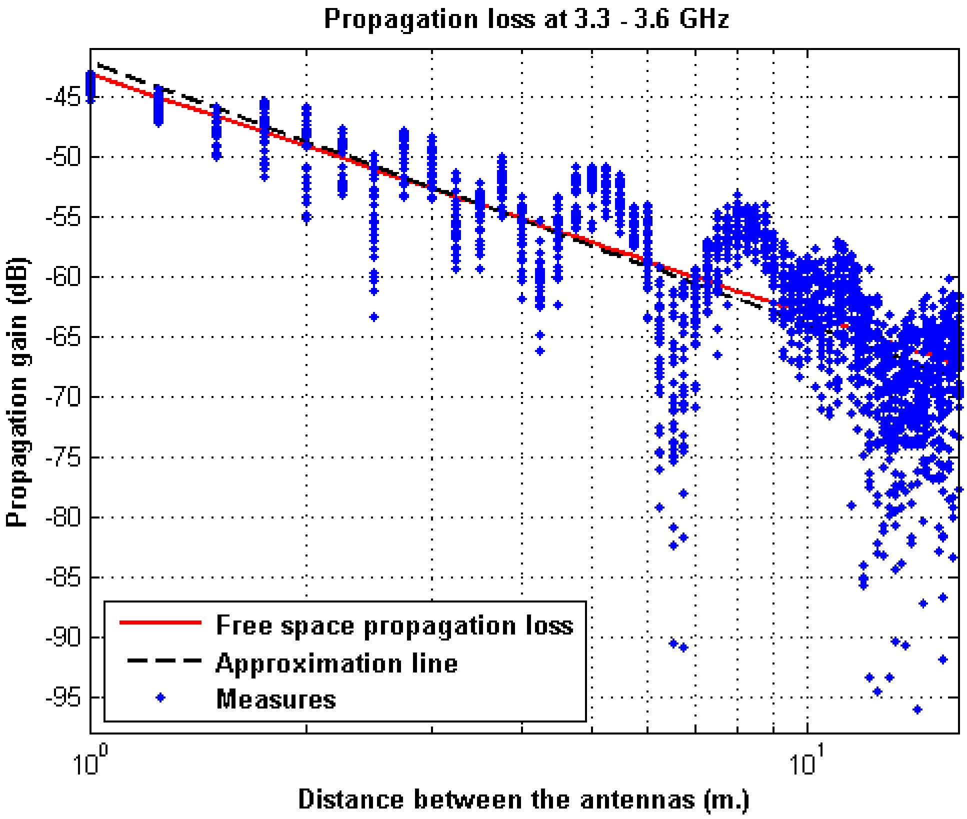
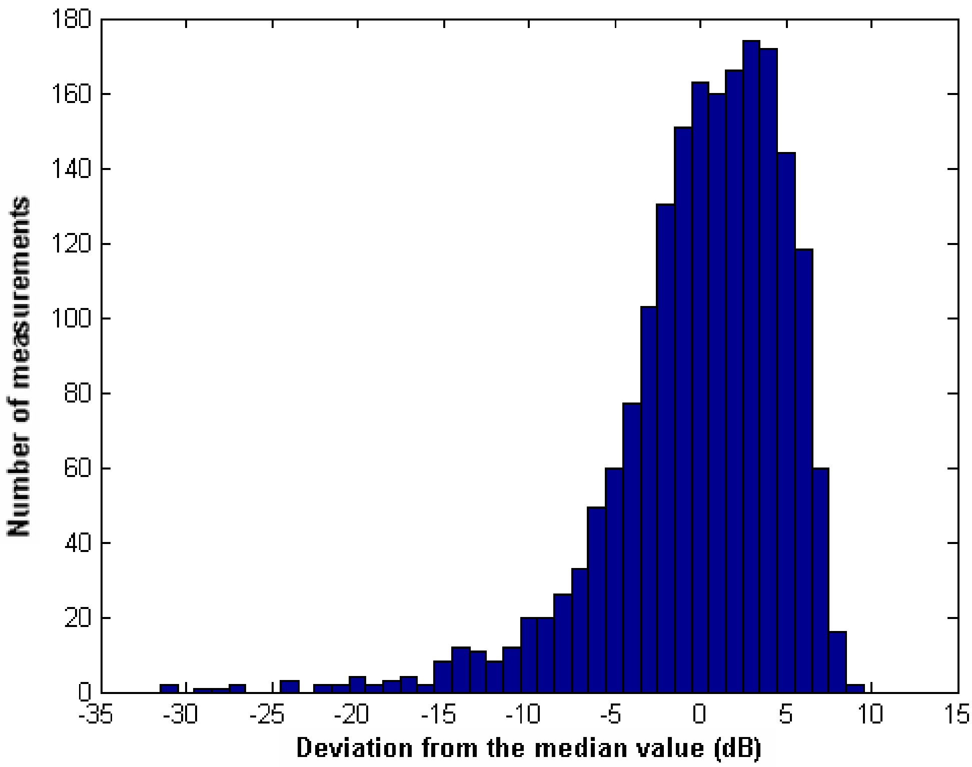
[8] X. H. Mao, Y. H. Lee, B. C. Ng, " Propagation Modes and Temporal Variations Along a Lift Shaft in UHF Band", IEEE Transactions on Antennas and propagation, Vol. 58, No. 8, pp. 2700-2709, August 2010.

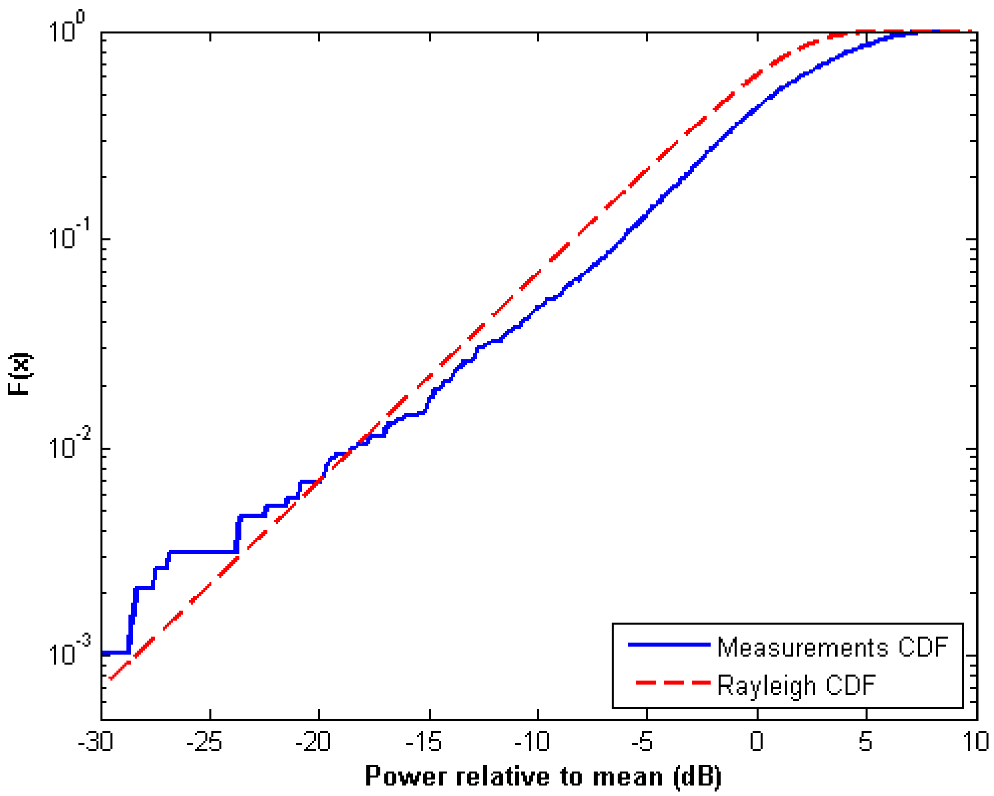
Fig. 1: Measurements scenario 4.


Propagation loss at 3.3 - 3.6 GHz
Propagation gain (dB)
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
Free space propagation loss
Approximation line
Measures
10^0
10^1
Distance between the antennas (m.)

(a)


180
160
140
120
100
80
60
40
20
0
Number of measurements
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
Deviation from the median value (dB)

(b)



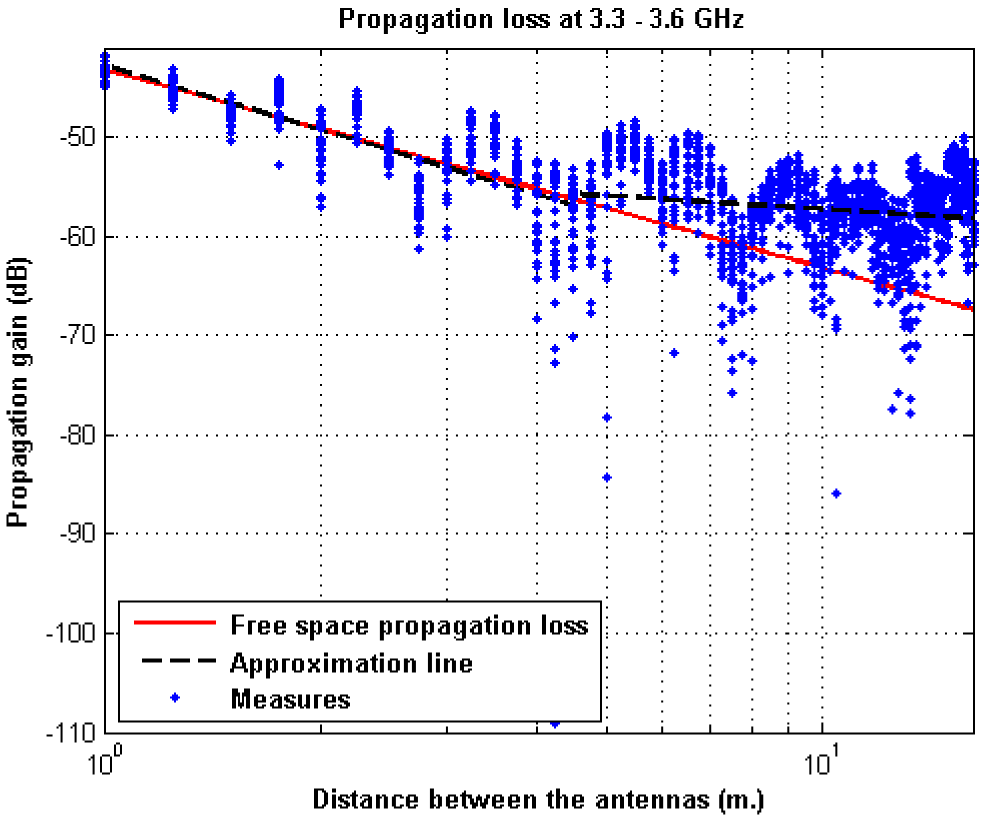
(c)

Fig. 2: Propagation loss results for the open corridor.

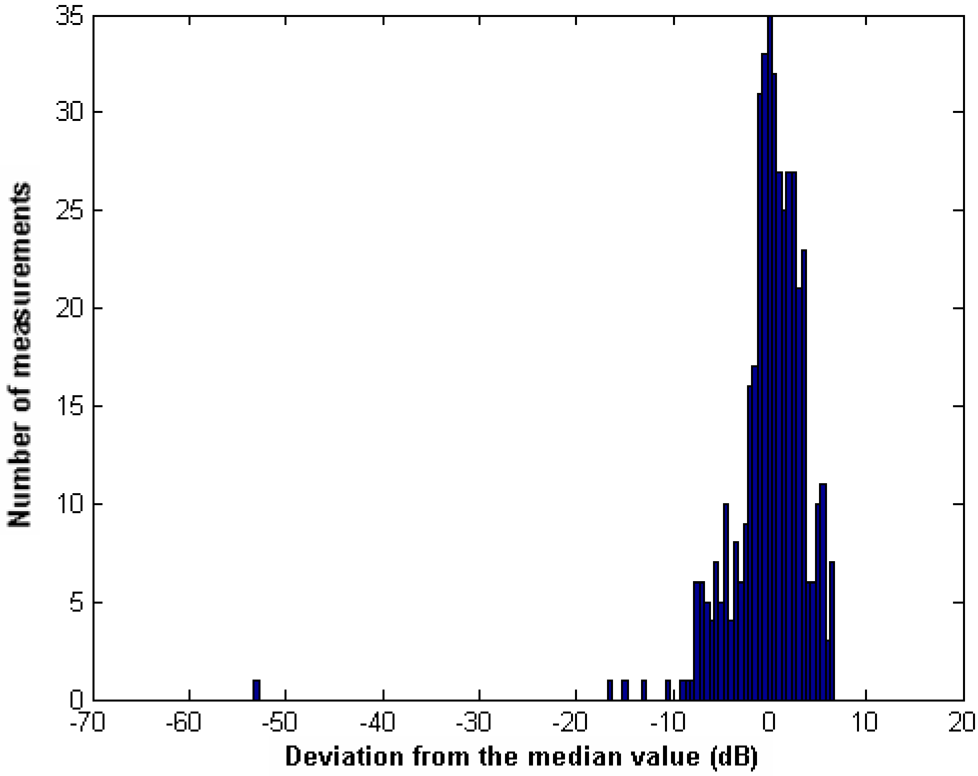
a- Propagation loss regression as a function of the TR distance,

b- Histogram of the measured power.

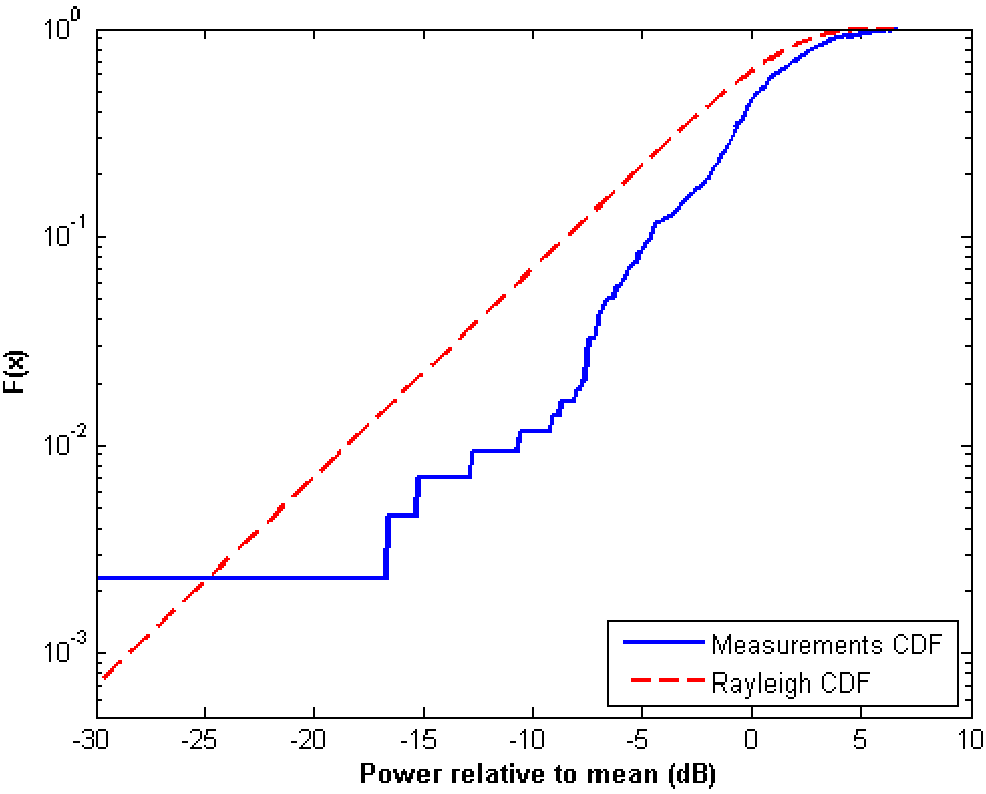
c- CDF of the measured power.


Propagation loss at 3.3 - 3.6 GHz
Propagation gain (dB)
Distance between the antennas (m.)
Free space propagation loss
Approximation line
Measures
-50
-60
-70
-80
-90
-100
-110
10^0
10^1

(a)

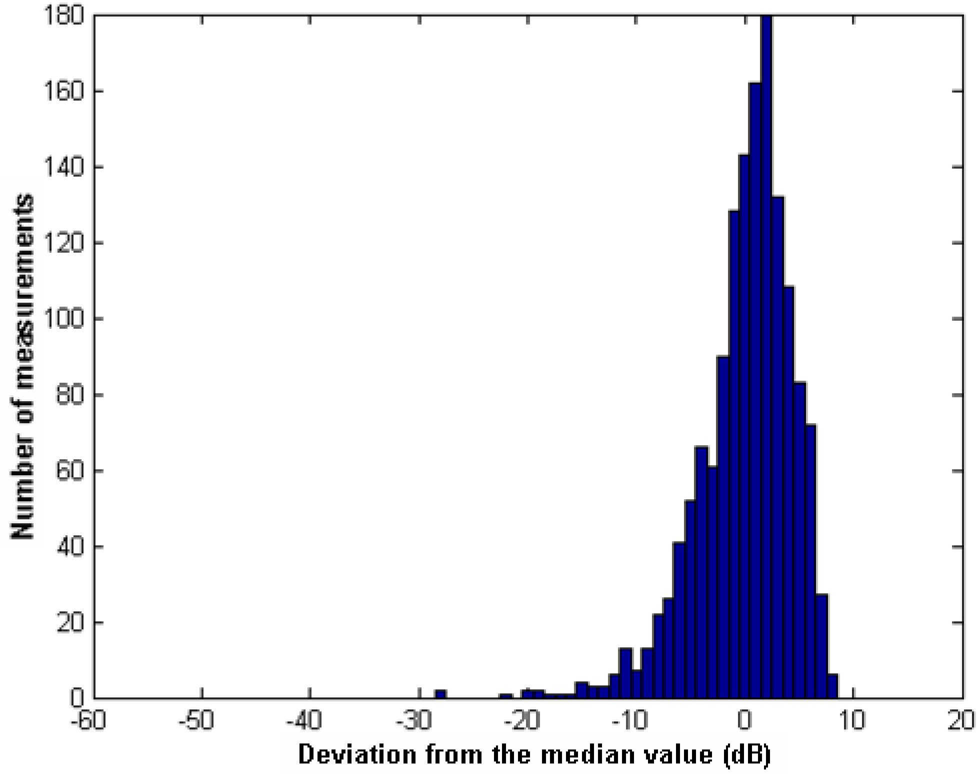

Number of measurements
Deviation from the median value (dB)
35
30
25
20
15
10
5
0
-70
-60
-50
-40
-30
-20
-10
0
10
20

(b)



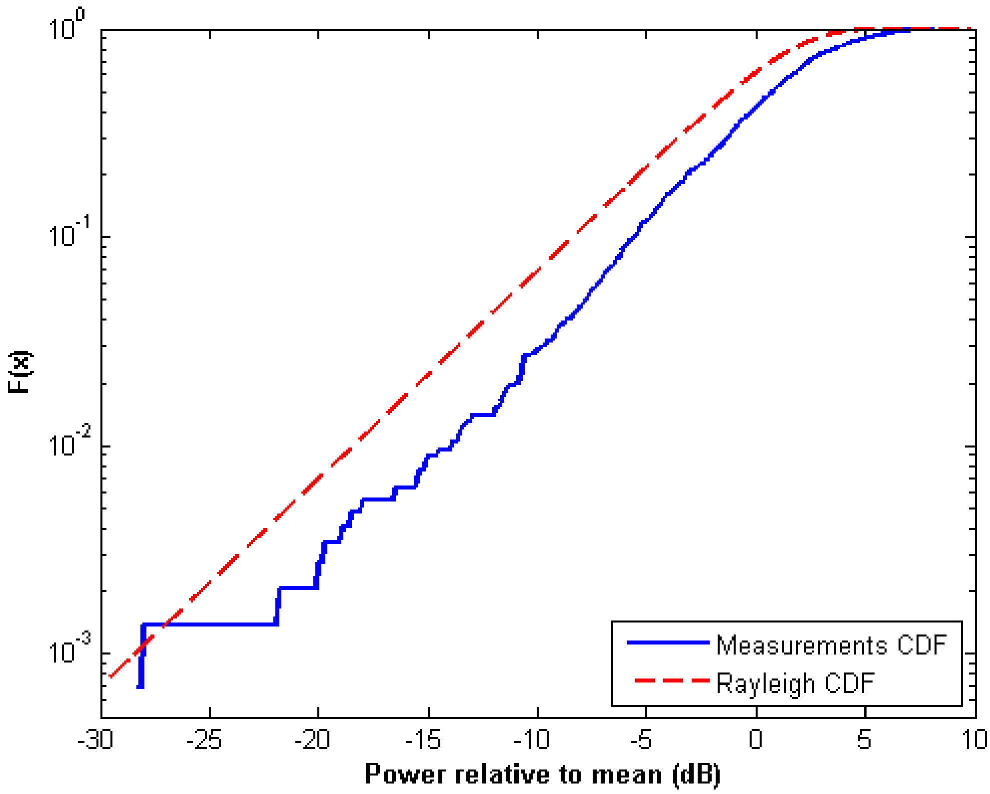
F(x)
Measurements CDF
Rayleigh CDF
Power relative to mean (dB)

(c)



Number of measurements
Deviation from the median value (dB)

(d)



(e)

Fig. 3: Propagation loss results for the narrow corridor.

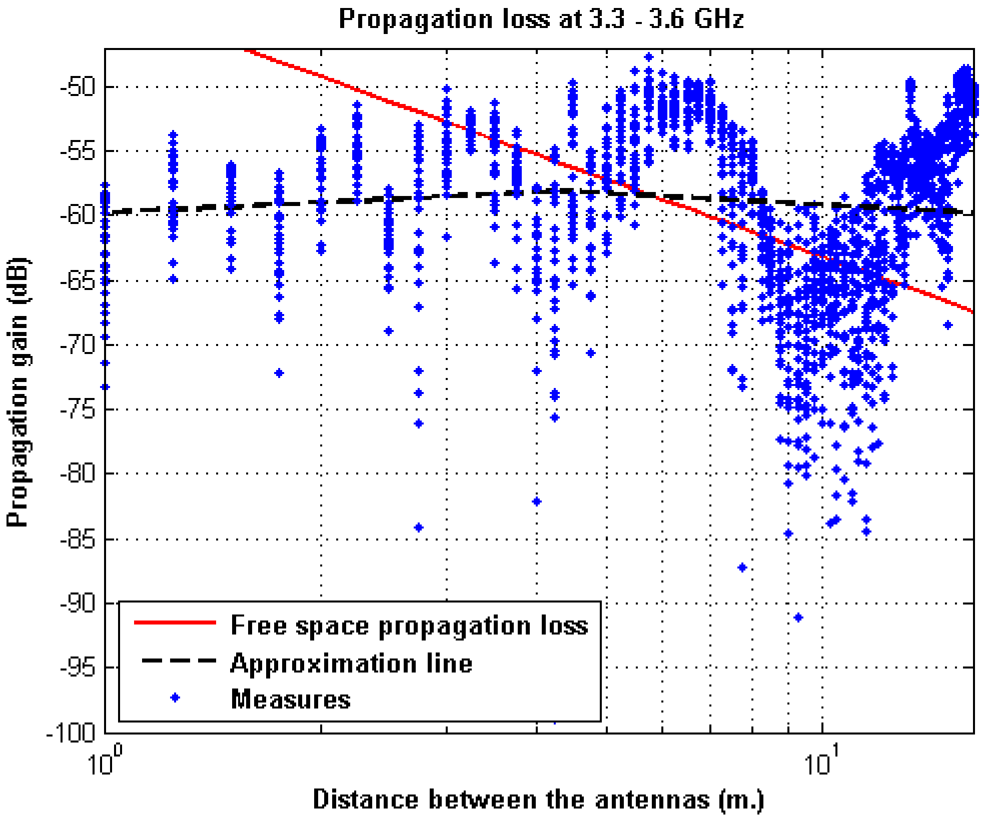
a- Propagation loss regression as a function of the TR distance,

b- Histogram of the measured power for the distance 1 to 4.25 m,

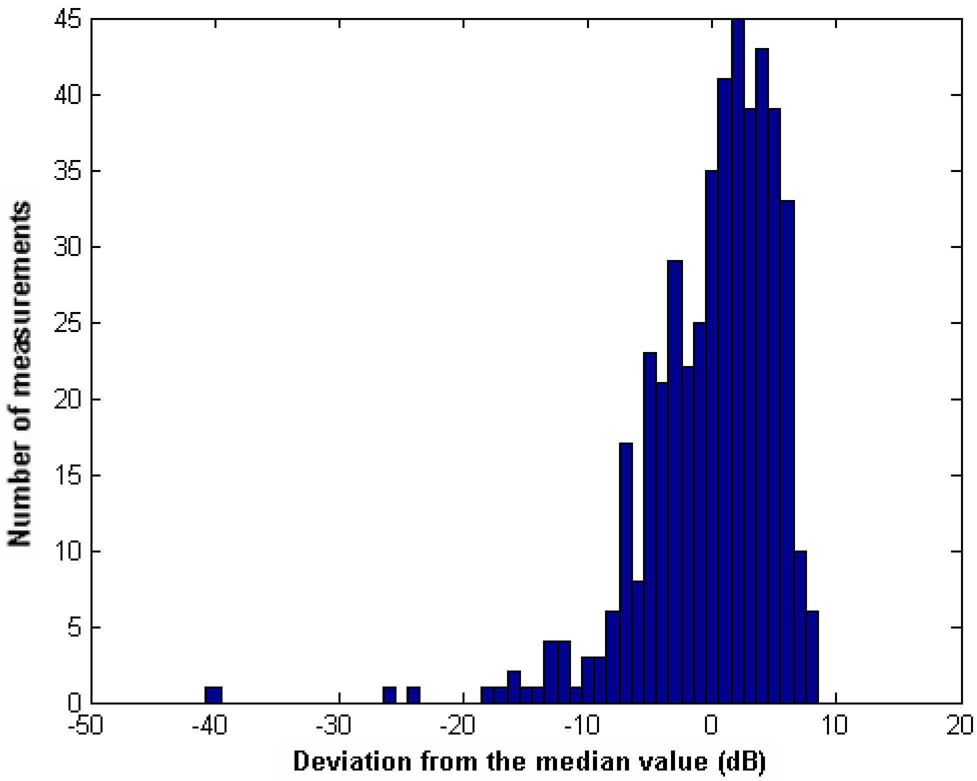
c- CDF of the measured power for the distance 1 to 4.25 m.

d- Histogram of the measured power for the distance 4.25 to 18 m,

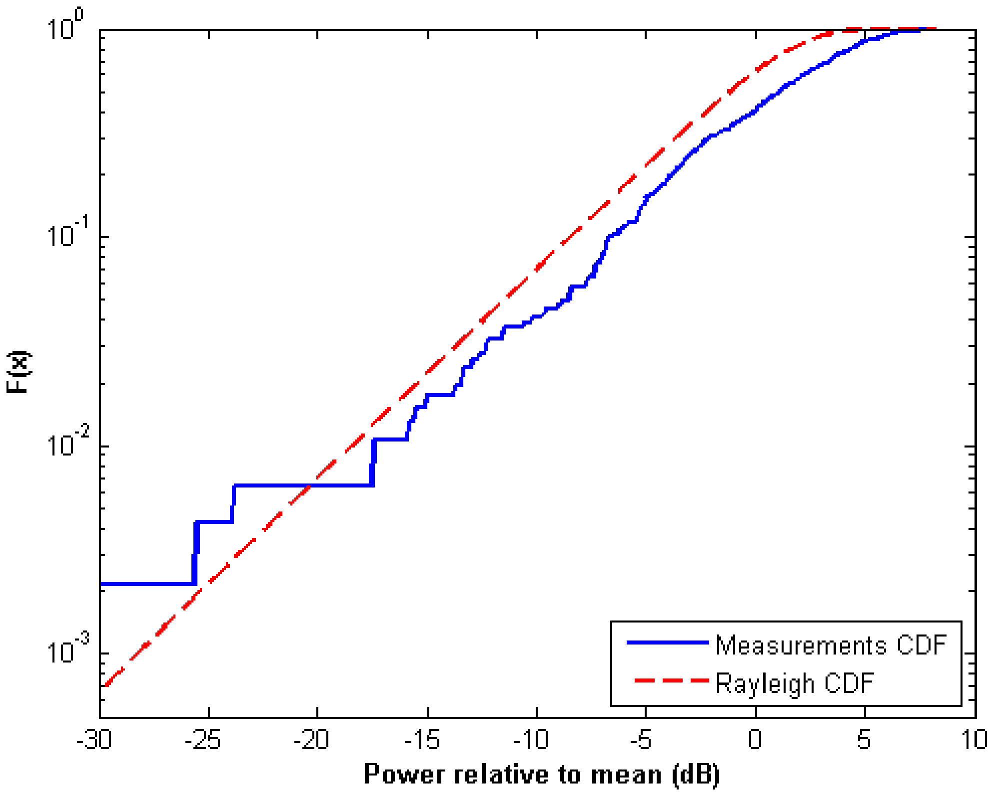
e- CDF of the measured power for the distance 4.25 to 18 m.


Propagation loss at 3.3 - 3.6 GHz
Propagation gain (dB)
Distance between the antennas (m.)
Free space propagation loss
Approximation line
Measures
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
10^0
10^1

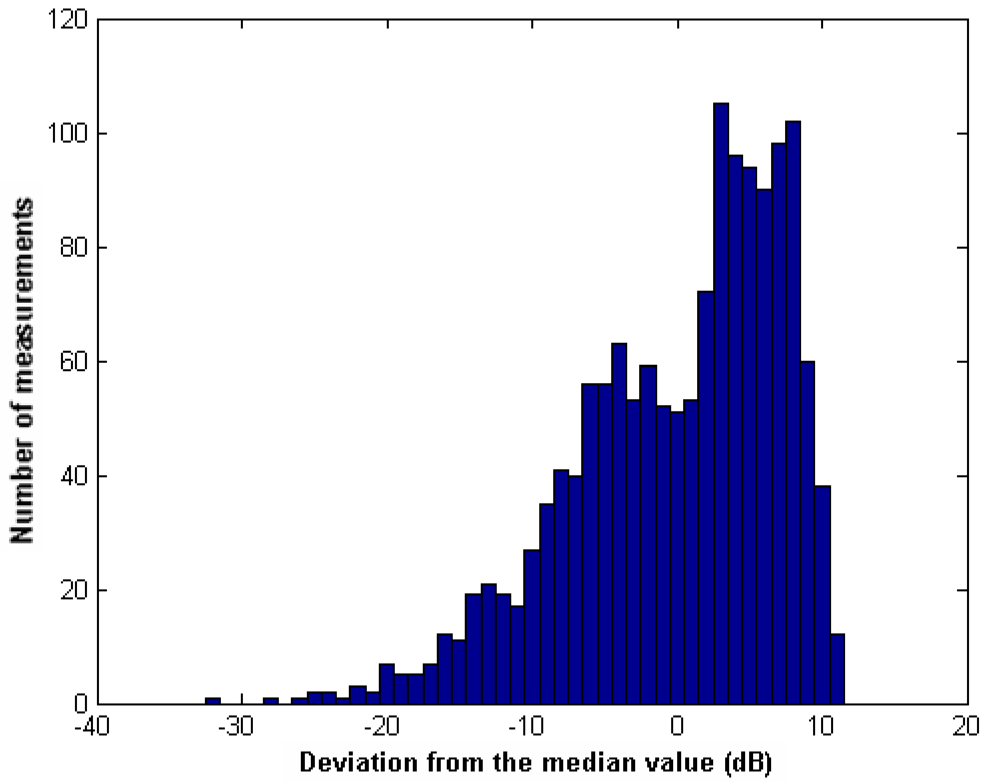
(a)


Number of measurements
Deviation from the median value (dB)
45
40
35
30
25
20
15
10
5
0
-50
-40
-30
-20
-10
0
10
20

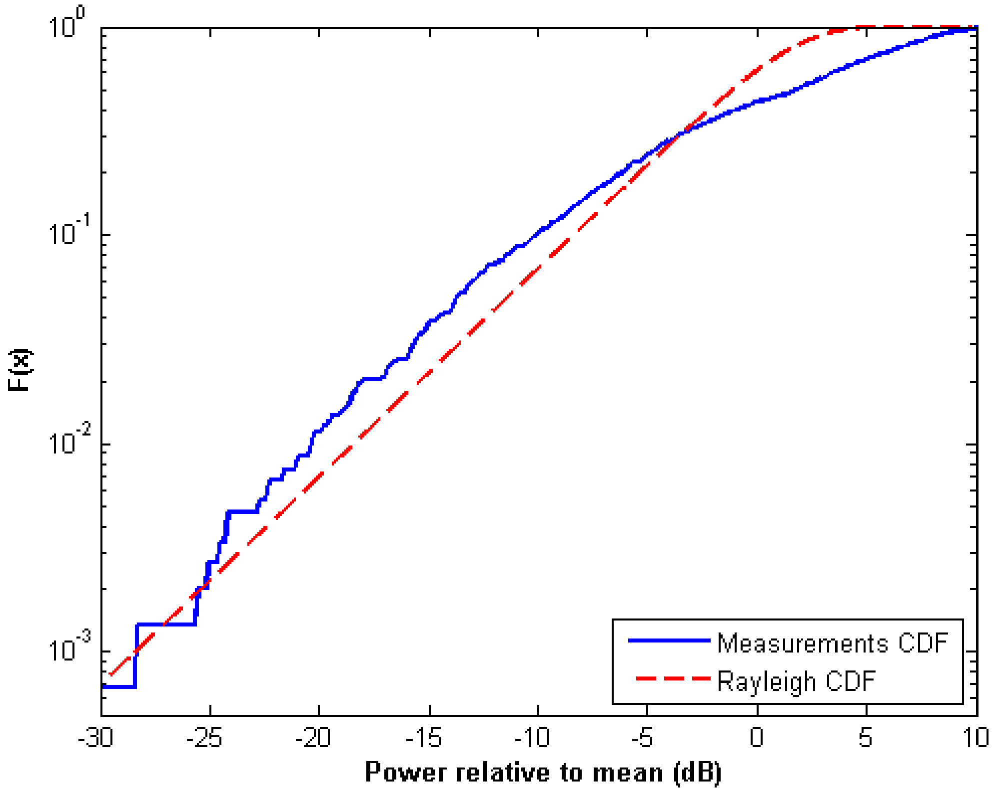
(b)


10^0
10^{-1}
10^{-2}
10^{-3}
F(x)
Measurements CDF
Rayleigh CDF
-30
-25
-20
-15
-10
-5
0
5
10
Power relative to mean (dB)

(c)


120
100
80
60
40
20
0
Number of measurements
-40
-30
-20
-10
0
10
20
Deviation from the median value (dB)

(d)



(e)

Fig. 4: Propagation loss results for the narrow corridor with the transmitting antenna at a height of 2.4 m pointing at 18 m from it.

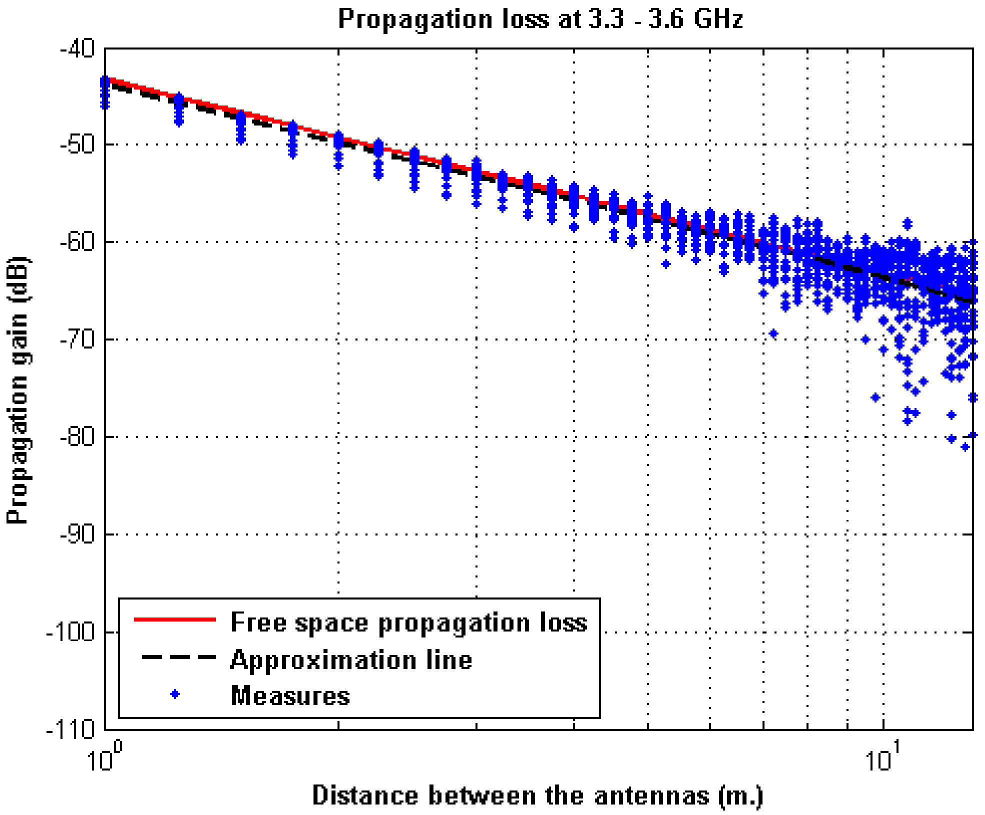
a- Propagation loss regression as a function of the TR distance,

b- Histogram of the measured power for the distance 1 to 4.5 m,

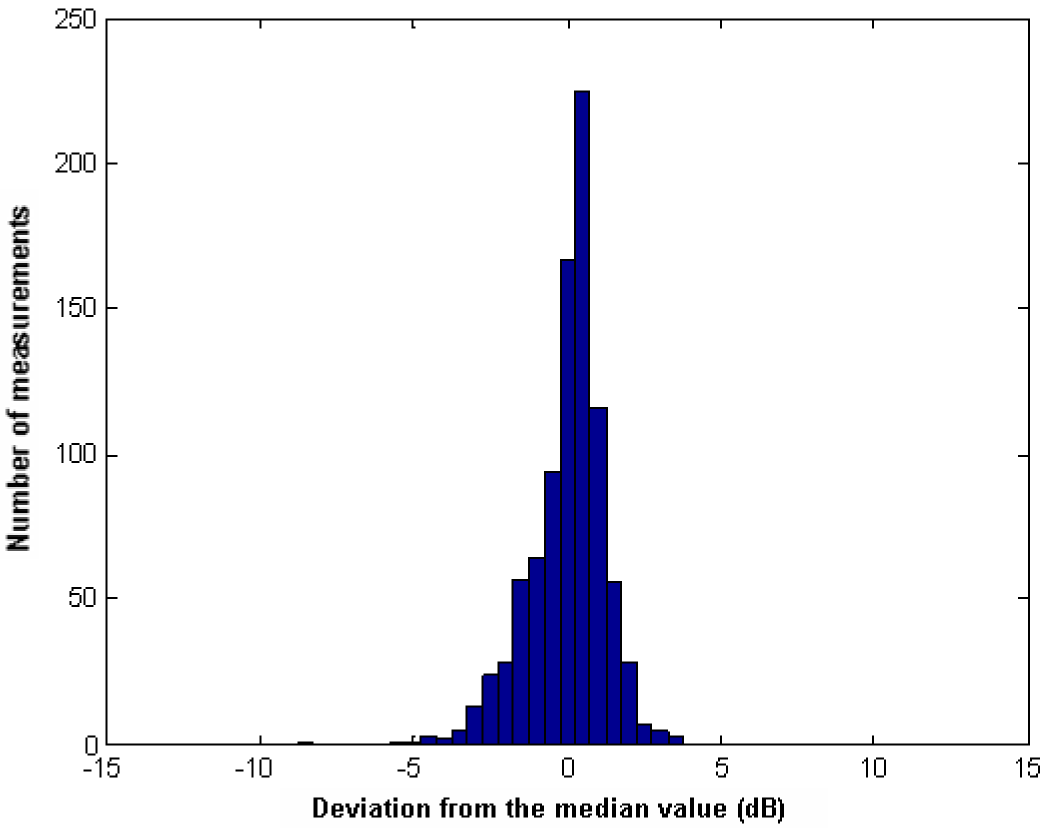
c- CDF of the measured power for the distance 1 to 4.5 m.

d- Histogram of the measured power for the distance 4.5 to 18 m,

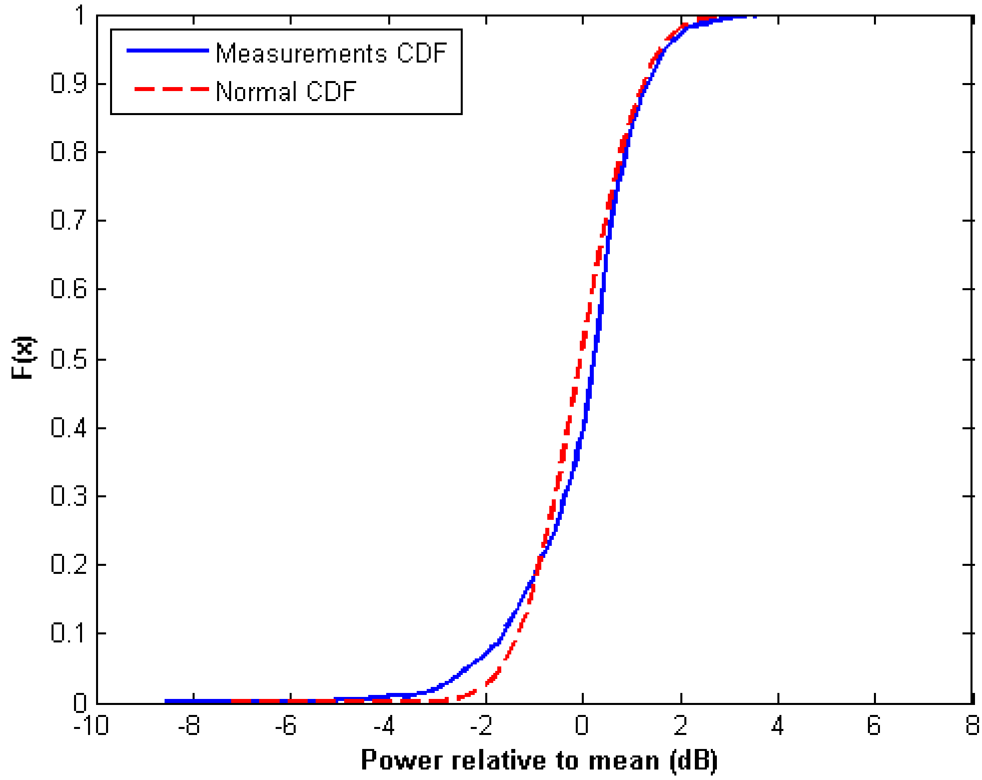
e- CDF of the measured power for the distance 4.5 to 18 m.


Propagation loss at 3.3 - 3.6 GHz
Propagation gain (dB)
Distance between the antennas (m.)
Free space propagation loss
Approximation line
Measures
-40
-50
-60
-70
-80
-90
-100
-110
10^0
10^1

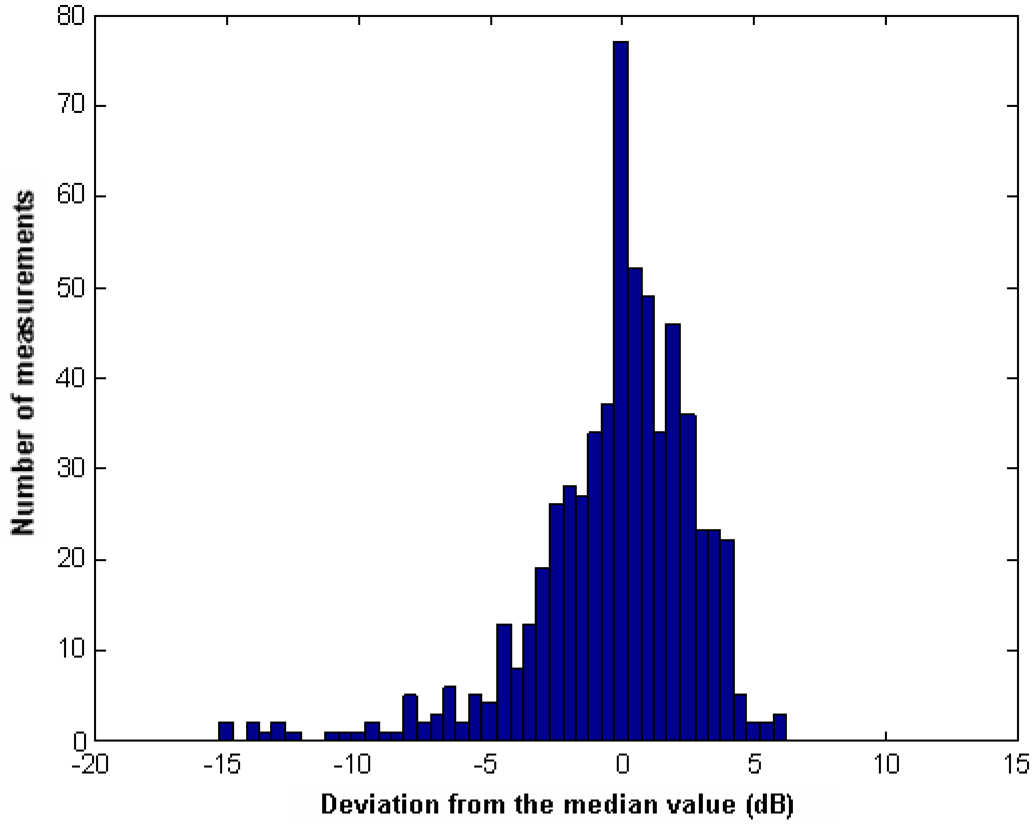
(a)


Number of measurements
Deviation from the median value (dB)
250
200
150
100
50
0
-15
-10
-5
0
5
10
15

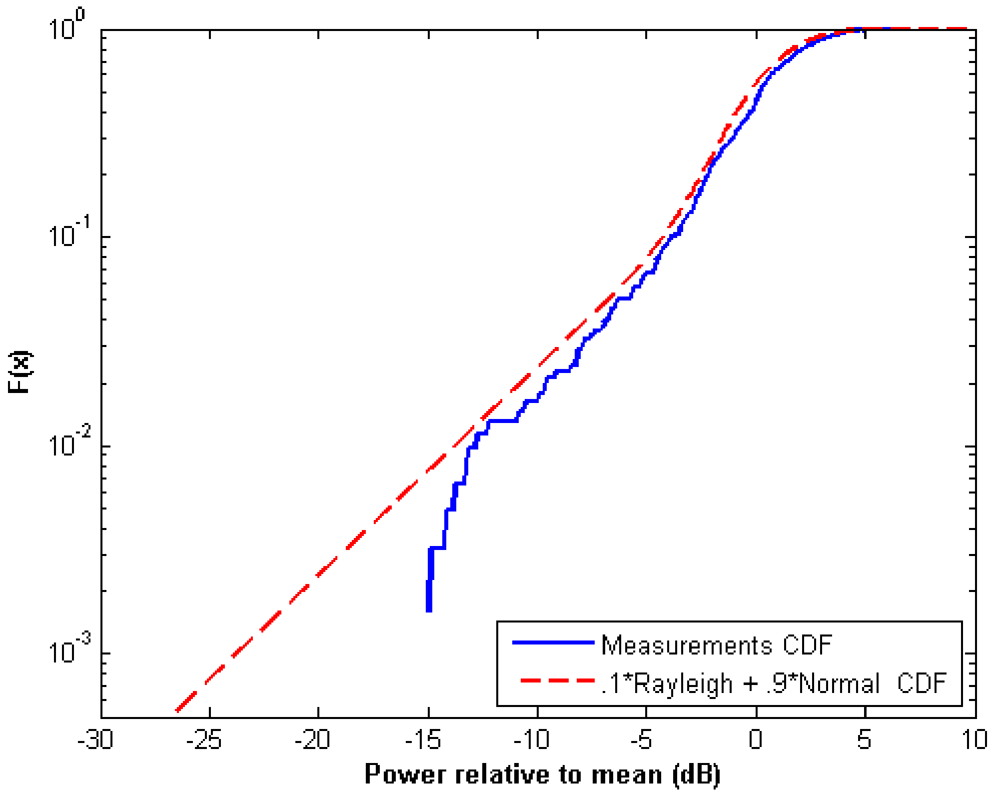
(b)


Measurements CDF
Normal CDF
F(x)
Power relative to mean (dB)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-10
-8
-6
-4
-2
0
2
4
6
8

(c)


Number of measurements
Deviation from the median value (dB)
80
70
60
50
40
30
20
10
0
-20
-15
-10
-5
0
5
10
15

(d)



(e)

Fig. 5: Propagation loss results for the wide corridor with two columns at 8 m from the transmitting antenna.

a- Propagation loss regression as a function of the TR distance,

b- Histogram of the measured power for the distance 1 to 8 m,

c- CDF of the measured power for the distance 1 to 8 m.

d- Histogram of the measured power for the distance 8 to 14 m,

e- CDF of the measured power for the distance 8 to 14 m.

Table (1) - Materials insertion loss within the band (3.3-3.6) GHz.

Material	**Insertion loss (dB)**
Thin walls	**4-6**
Thick walls	**12-15**
Glass	**4-6**
Wood doors	**2-3**
Human beings (frontal)	**10-18**
Human beings (lateral)	**7-12**

***author's picture & biography**

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BAZIL TAHA AHMED was born in Mosul, Iraq, in 1960. He received the B.Sc. and M.Sc. degrees in Telecommunication Engineering from the University of Mosul, in 1982 and 1985, respectively. He got the Ph. D degree in Telecommunication Engineering from the Polytechnic University of Madrid in 2003. Now he is working as an Associate Professor at the Universidad Autonoma de Madrid.

He has published more than 80 scientific journal and conference papers in the area of the electromagnetic propagation and CDMA systems, particularly the CDMA capacity. His research interests include coexistence and wireless access technologies such as UMTS, WiMAX and Ultra Wideband systems.

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