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UHF Band Short Range Propagation Model

Bazil Taha Ahmed, bazil.taha@uam.es
Universidad Autonoma de Madrid

Abstract: The purpose of this study is to characterize the indoor and indoor-outdoor propagation in different scenarios, using monopole antennas working at 410 MHz and 890 MHz. Propagation of narrow band and wide bands have been studied. In scenarios with a continuous variation of the distance between the transmitter and receiver antenna (1 D scenarios), we use a log-distance path loss model to determine the equations that describe the mean value of the path loss. In scenarios where the position of the receiver is not a uniform function of the distance between the transmitter and the receiver, we represent the basic propagation gain as a function of the measurement point index. Results show that the indoor propagation gain can be described using two slopes propagation model. For the multiwall attenuation loss it is shown that each wall has an attenuation of almost 2.5 dB at 410 MHz increasing to almost 4 dB at 890 MHz. The obstruction gain (loss) due to human beings shows that this can be within a 40 dB interval.

Keywords: UHF, Indoor propagation, Indoor-outdoor propagation, Propagation loss

1. Introduction

It is very important to study the indoor propagation since it can be used in many applications, namely, indoor communications and localization [1–9]. Here we will give a brief idea about the UHF band and the indoor propagation mechanism.

Ultra High Frequency (UHF) designates the ITU Radio frequency range of electromagnetic waves between 300 MHz and 3 GHz (3,000 MHz), also known as the decimetre band or decimetre wave as the wavelengths range from one to ten decimetres (10 cm to 1 metre).

The UHF antenna incorporated in the UHF transceivers is short and light, so it can be carried by a soldier without so much effort. In [10] it is shown that monopole antennas were becoming popular, and had been proposed for modern and future wideband wireless applications. Because of the potential implementation of many communications systems in the UHF band, it is important to understand propagation of signals in the UHF band inside buildings.

Here, we will present related works that can be used to introduce the UHF and Super High frequency (SHF) propagation in indoor and indoor-outdoor scenarios.

In [11], it is shown that the characteristics of radio signals in the UHF band present fundamental limits on the design and performance of wireless communications systems, such as Cellular Mobile Radio (CMR), Wireless LAN´s, and Personal Communication Services, (PCS) [8].

Work [12] explored features of office buildings of modern construction that influences the propagation between transmitter and receiver located on the same floor. In reference [13], the principles of radio propagation in indoor environments were reviewed. In [14], the propagation modes and the temporal variations along a lift shaft in UHF band have been given. Propagation in corridors using the Super High Frequency (SHF) band has been studied using dynamic multi-link MIMO measurement at 5.3 GHz [15]. Propagation in tunnels and urban street canyons using the UHF band has been studied in [16].

In [17], a new model for UHF propagation in large buildings was presented. That model was based on the knowledge of the interior arrangement of the building without requiring much detail. The guiding of radiation along hallways is the most significant propagation process at distances more than 10 m from the transmitter. The wave guide model predicts the power loss rate along the hallways. The coupling results due to the roughness of the surfaces in the building were predicted in an average manner using the average deviation of the walls from perfect smoothness. The model predictions were compared with the measurements in an office building and ray tracing predictions. In [18], a UWB signal propagation measurements were carried out in a typical modern office building in order to characterize the signal propagation channel. Robustness of the UWB signal to fades was quantified through histogram and cumulative distribution of the received energy in various locations of the building. In work [19] the indoor channel for IEEE 802.16 (WiMAX) at 3.5 GHz frequency band has been characterized. In [20], techniques for the measurement of local mean signal strength at 900 MHz have been explored. In [21], an indoor propagation model based on a novel multi wall attenuation loss formula at frequencies 900MHz and 2.4 GHz is given where up to 6 successive walls are used in the propagation loss measurements. In [7], an exponent of propagation of 1.8 is measured in indoor propagation measurements. In [8], a simple indoor pathloss prediction algorithm in living lab is given. Measurements have been carried out at 2.4 GHz band.

In this work we will study the indoor and indoor-outdoor propagation (at the UHF band) for short distance that can be used in Tactical Communication in Urban Terrain (TCUT).

The main contribution of this work is to characterize the short range (up to 50m) indoor and indoor-outdoor propagation in the UHF band. This distance (50m) is sufficient for the special squads operations.

This work is organised as follow. In Section 2, the propagation models used along this work are given. In Section 3, details about the measurement campaign including some of the studied scenarios are given. In Section 4, indoor propagation results are presented. In Section 5, indoor-outdoor results are given. In Section 6, the multiwall attenuation loss is detailed. In Section 7, the effect of the human being on the propagation loss is shown. Finally, in Section 8, conclusions are drawn.

2. Propagation Models

In indoor environment, with low distance between Tx and Rx, propagation could be due to the direct ray and four reflection rays (reflection from the two 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 also exist. Thus, in general, indoor propagation cannot be represented by the Two Rays Model (direct ray and ground reflection one).

For very short distance between the transmitting and receiving one, the indoor propagation loss is well described by the single slope propagation model represented by [9]:

$$L_p = L_0 + 10\, n_1 \log_{10}\left(\frac{d}{d_0}\right) + \xi_1 \qquad (1)$$

Where L_0 is the propagation loss at the reference distance d_0 of 1m; n_1 is the propagation exponent; and ξ_1 is a random variable (Gaussian, Rayleigh or a combination of both) representing the deviation from the mean value. This deviation is due to the small scale (fast) and large scale (slow) induced fading.

For a high distance between the transmitting antenna and the receiving one, the indoor propagation loss model is given generally represented by the two slope model. In this case, the propagation loss at a distance d higher than the breakpoint distance d_b can be written as [9]:

$$L_p(dB) = \begin{cases} L_0 + 10\, n_1 \log_{10}(d) + \xi_1 & d \le d_b \\ L_1 + 10\, n_2 \log_{10}\left(\dfrac{d}{d_b}\right) + \xi_2 & d > d_b \end{cases} \tag{2}$$

Where L_1 is the mean propagation loss of the distance d_b at which the propagation exponent changes, and n_2 is the second propagation exponent. ξ_2 is a random variable (Gaussian, Rayleigh or a weighted combination of both) that represents the slow (large scale) and fast (small scale) fading effect.

In narrow indoor environment (corridors for example), n_2 will be lower than 2 (1.3 to 1.8) representing the waveguide mode of propagation. In wide indoor environment, n_2 will be in higher than 2 (3 to 4). For an indoor distance of 50 m or higher, third propagation exponent could be appear with a value higher than 4 in general.

The radio link balance can be represented by:

$$P_{rx} = P_{tx} + G_{atx} + G_{arx} - L_p \tag{3}$$

Where

- P_{rx} is the received power
- P_{tx} is the transmitted power
- G_{atx} is the transmitting antenna gain
- G_{arx} is the receiving antenna gain
- L_p is the propagation loss

We can therefore express the propagation loss as:

$$L_p = P_{tx} - P_{rx} + G_{atx} + G_{arx} \tag{4}$$

Basic propagation loss L_{pb} is given by:

$$L_{Pb} = P_{tx} - P_{rx} \tag{5}$$

In our case, we will present the basic propagation gain (G_{bp}) given by:

$$G_{bp} = -L_{pb} \tag{6}$$

It is well known that the large scale fading is presented by a Gaussian random variable N and that the small scale fading is presented by a Rayleigh random variable Rayleigh [12]. Thus, in the rest of the paper, we will present ξ_1 and ξ_2 as:

$$\xi_1, \xi_2 = W \;\; N(0,\sigma) + (1-W) \;\; Rayleigh \tag{7}$$

Where W is the weight of the Normal (Gaussian) fading contribution.

Rician fading is generated when a strong line of sight component is received by a directive receiving antenna. To get that, a directive transmitting antenna should be also used which is not our case since that we use an omnidirectional antennas in transmission and reception. Rician fading with a strong line of sight component can be approximated by a Gaussian random variable with low σ.

3. Measurement Campaign

Measurements have been carried out at different sites within the Escuela Politecnica Superior of the Universidad Autónoma de Madrid.

For the indoor and the indoor-outdoor scenarios, monopoles antennas that work (with a SWR $\leq$ 2) between 880 MHz and 900 MHz and others that work between 400 MHz to 420 MHz have been used. The radiation pattern of the antenna that works at the 400 MHz to 420 MHz band is given by Fig. 1. The radiation pattern of the antenna that works at the 880 MHz to 900 MHz band is almost the same.

For the indoor scenarios, A Network Analyzer (6 GHz ZVL of Rohde & Schwarz) has been used to measure the propagation loss up to 15 m. For a distance higher than 15 m, a signal generator (SMB100A of Rohde & Schwarz) and a spectrum analyzer (FSL of R&S) have been used to measure the propagation loss.

For the indoor-outdoor scenarios, we have used a signal generator (SMB100A of Rohde & Schwarz) and a spectrum analyzer (FSL of R&S) to measure the propagation loss. The transmitted power in all the measurements was 10 dBm. We have to mention that this transmitted power is lower than the transmitted power by military radio.

In all of the Campaign, both of the transmitting and receiving antennas have been placed at a height of 1.5 m in all the scenarios. This height has been chosen because it’s more or less the height at which the user (soldier for example) will carry the radio equipment. Fig. 2 shows the block diagram of the equipment connection.

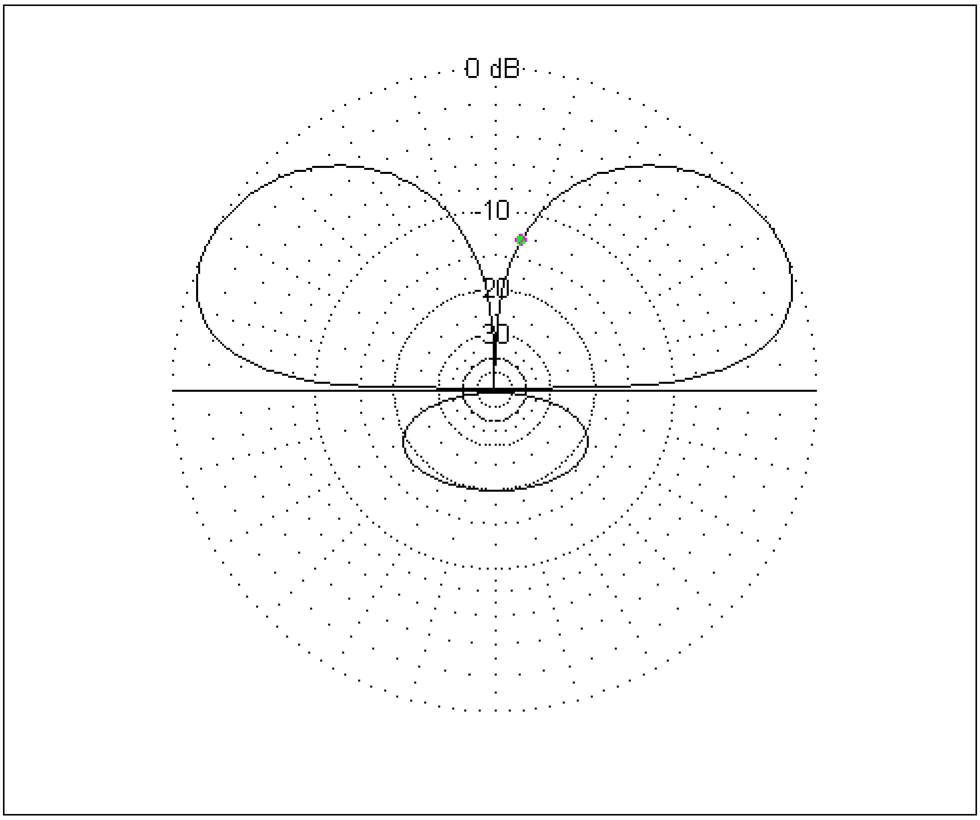
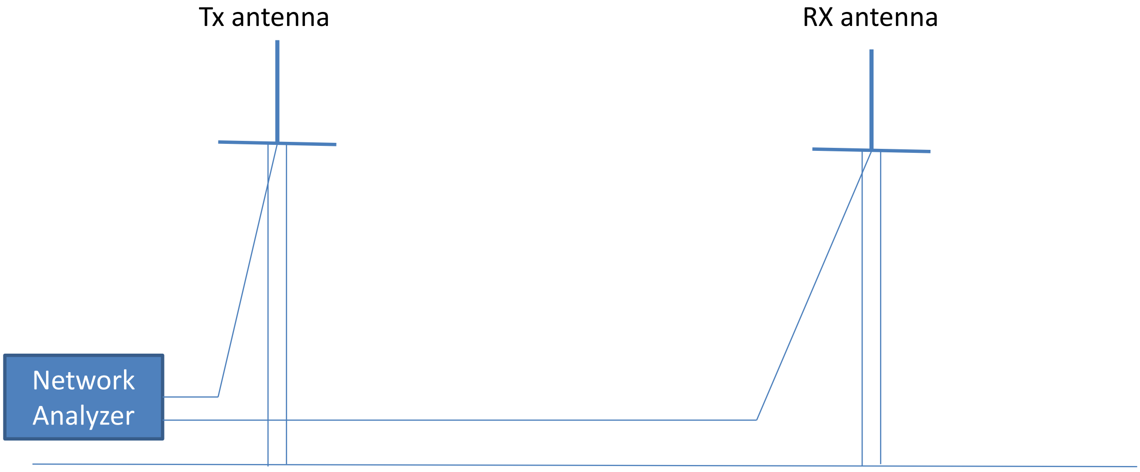


Figure 1: Monopole radiation pattern at 410 MHz.



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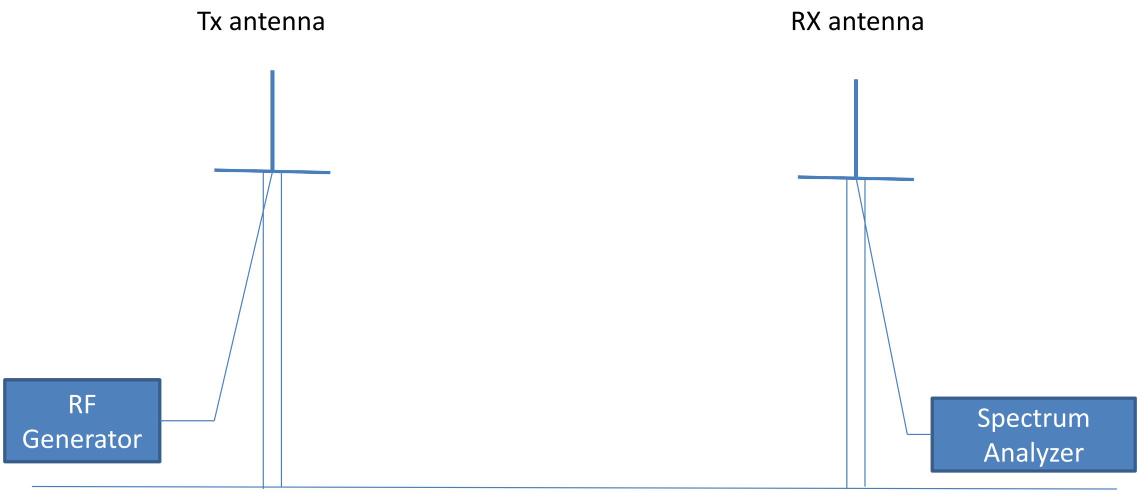

B

Figure 2: Measurement equipments,

A- Measurement scheme for distances lower than 15 m.

B- Measurement scheme for distances higher than 15 m.

Scenario 1 shown by Fig. 3 represents a wide corridor of 7 m width and 60 m length with 12 concrete columns with different distances between them. Five metallic doors of laboratories can be seen also seen in Fig. 3. In this scenario, Rx distance varied from 1 m up to 50 m with a 0.25 m step.

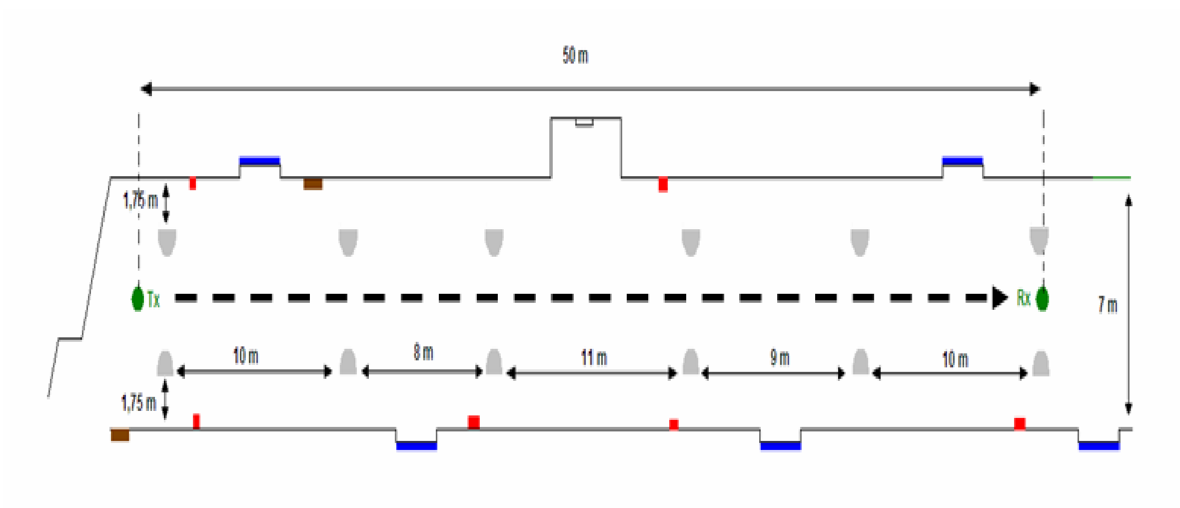

Figure 3: Scenario 1-Wide corridor.

Scenario 2 represents the stairs zone of the building C of EPS where measurement has been carried out at different points of the stairs, as shown in Fig.4.

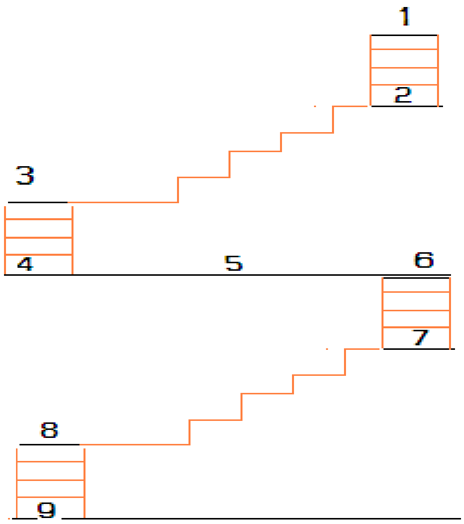

Figure 4: Scenario 2- Frontal representation of indoor stairs.

If we stretch out the stairs, we will get a view that presented by Fig. 5.

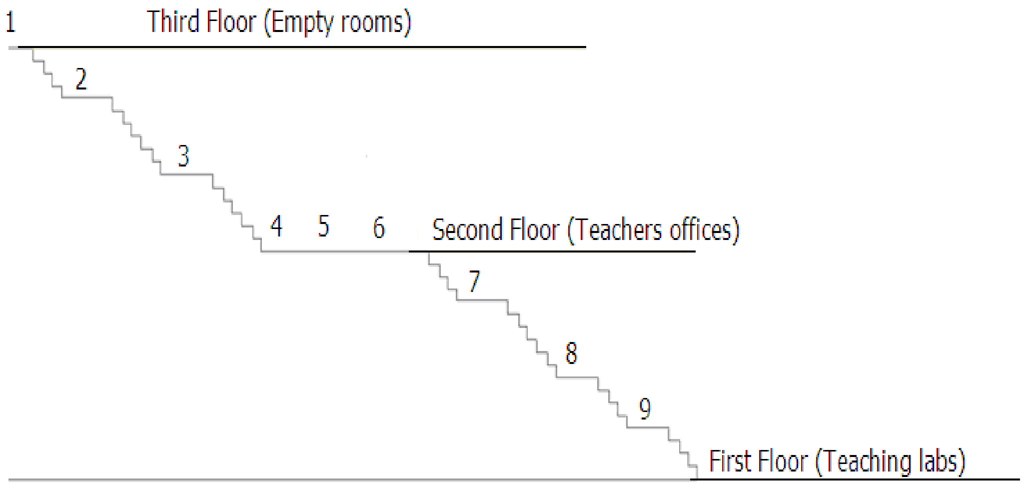

Figure 5: Profile representation of the indoor stretched stairs.

Scenario 3 shown by Fig. 6 represents an indoor-outdoor scenario. The transmitting antenna has been placed at the fourth floor of the EPS C building. The receiving antenna has been placed outside of the building at a distance of starting at 2m from the building's door increasing it up to 22 m in steps of 2 m. Initially a distance step of only

1m has been used. Noting a small variation of the received signal power we then decided to increase it to 2 m.

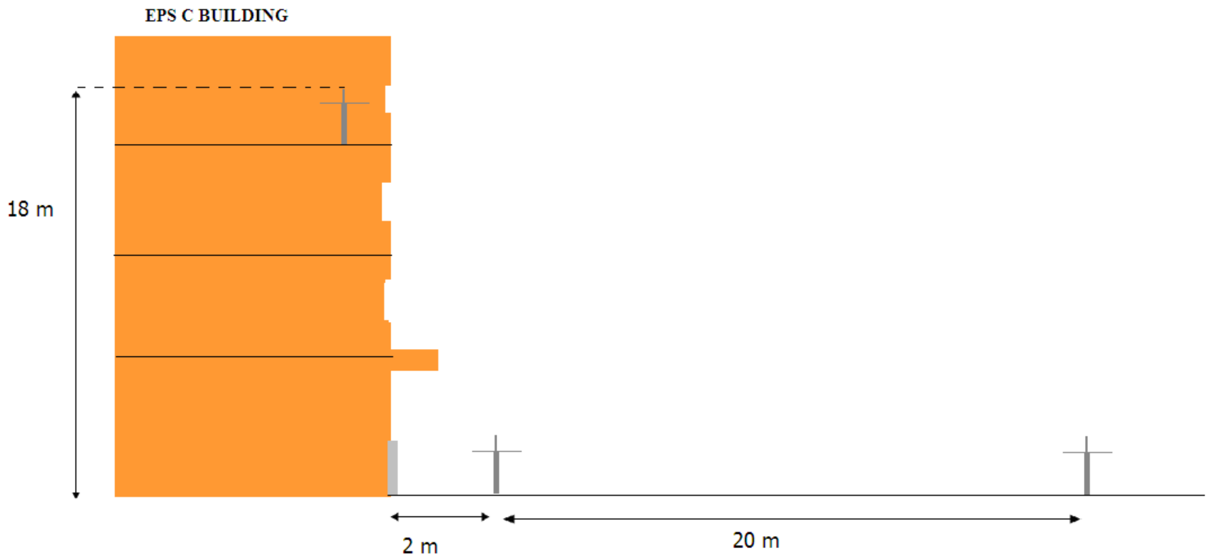

Figure 6: Scenario 3- First indoor-outdoor scenario

Scenario 4 is also an indoor-outdoor scenario, with the measurements carried out in the opposite side of Scenario 4. The transmitting antenna has been placed in the third floor of the EPS C building. The receiving antenna has been placed in 10 different points starting near the building door with the last point at a distance of almost 10 m.

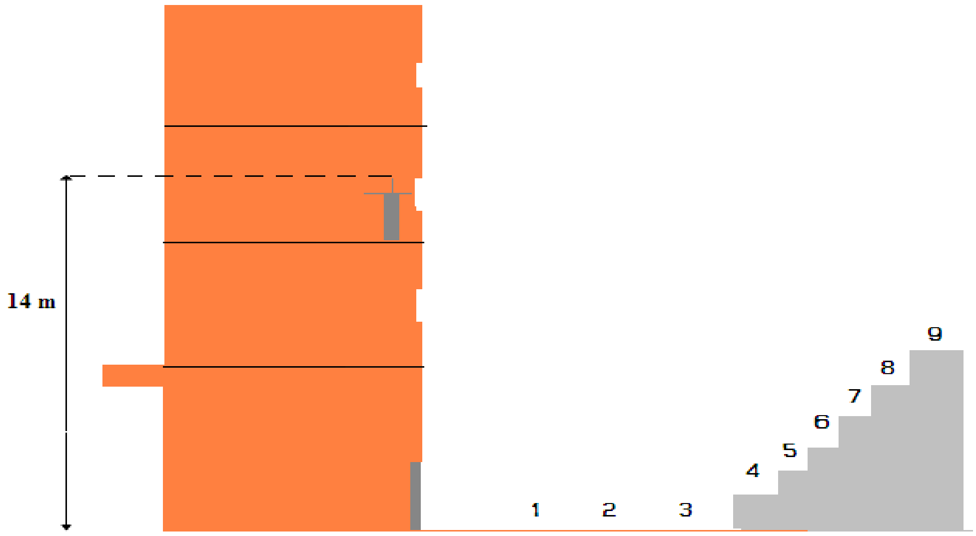

Figure 7: Scenario 4- Second outdoor scenario

4. Indoor scenarios Results

In this section, some of the results of the measurements campaign will be given.

For the first scenario, Let us start with the narrow band case with 890 MHz central frequency has been considered. The results for this scenario 1 are shown in Fig 8 where the vertical lines represent the position (centre) of the semicircle columns. From Fig. 8, it can be noticed that the basic propagation gain can be also presented by the two slope propagation loss model given by (2).

The mean value of the basic propagation gain is given by:

$$G_{pb}\,(dB) = \begin{cases} -\{28.84 + 24.46\,\log_{10}(d)\} & d \le 7\,m \\ -\left\{49.51 + 15.3\,\log_{10}\left(\dfrac{d}{7}\right)\right\} & 50 \ge d > 7\,m \end{cases} \tag{8}$$

Equation (8) shows that n_1 (2.44) is higher than the free space propagation exponent of 2 while the propagation exponent for the second part of the path n_2 (1.53) is lower than 2. The propagation exponent n1 and n2 are calculated using the Least Square Method. It can be noticed that, in the second part of the measurements zone (d >7 m), the deviation from the mean value is higher than the deviation from the mean value at the first part of the measurements zone (d < 7 m). This is due to the multipath effect which can be strongly noted at high distance between the transmitting and receiving antennas.

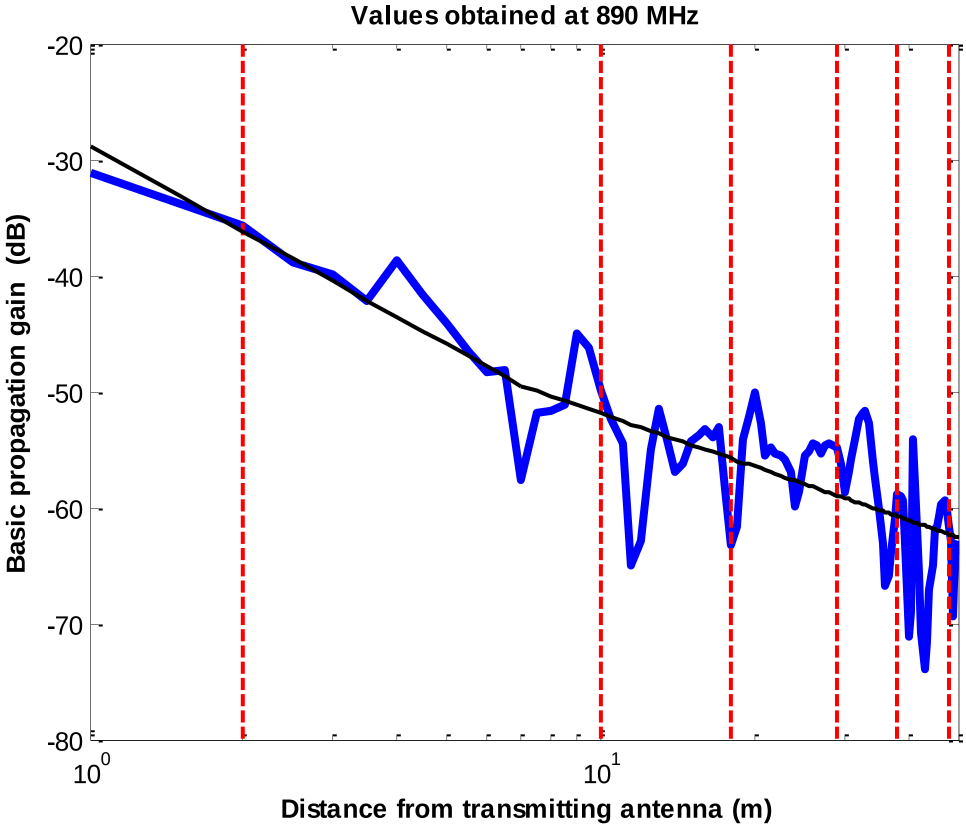

Figure 8: Basic propagation gain for scenario 1 at 890 MHz.

Secondly, we will present the propagation results at 410 MHz.

Fig. 9 shows the basic propagation gain as a function of the distance between the transmitting antenna and the receiver one. It can be noticed that the basic propagation gain can be also presented by the two slope propagation loss model given by (2), where the basic propagation gain is given by:

$$G_{pb}(dB) = \begin{cases} -\{29.53 + 18.71\log_{10}(d)\} & d \le 9.5m \\ -\left\{45.48 + 30.04\log_{10}\left(\dfrac{d}{9.5}\right)\right\} & 50 \ge d > 9.5m \end{cases} \quad (9)$$

Equation (9) shows us that n_1 (1.87) is smaller than the free space propagation exponent of 2 meanwhile the propagation exponent for the second part of the path n_2 (3.00) is higher than 2. Comparing these results with the other shown in Fig. 6, it can be noticed that n_1 and n_2 can have any value higher or lower than 2 and that it can not be judged that n_2 at high distance should be lower than 2 at all frequencies.

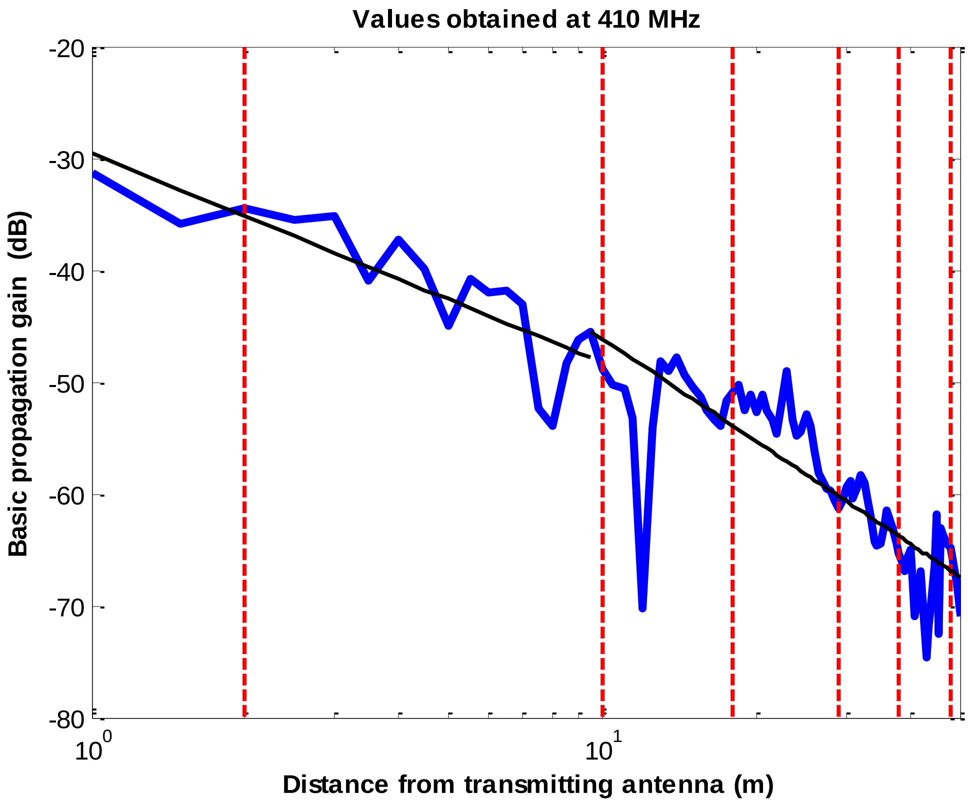

Figure 9: Basic propagation gain for scenario 1 at 410 MHz.

Let us study the case of 5 MHz bandwidth. First of all we start with the frequency band of 407.5 to 412.5 MHz. Fig. 10 shows the basic propagation gain up to 15 m. It can be noticed the mean value of the propagation gain can be approximated by:

$$B_{pg}(dB) = \begin{cases} -\{34.24 + 10.73\log_{10}(d)\} & d \le 4.25m \\ -\left\{40.56 + 8.96\log_{10}\left(\dfrac{d}{4.25}\right)\right\} & d > 4.25m \end{cases} \tag{10}$$

The first propagation exponent is 1.07 while the second one is 0.896.

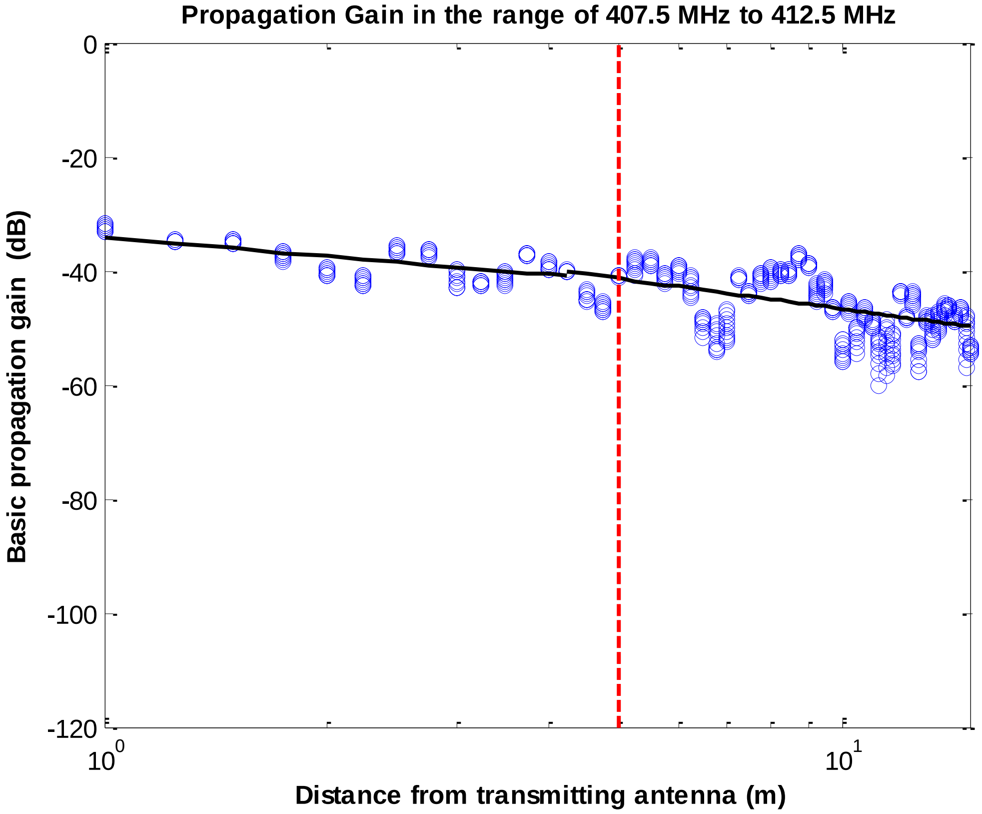

Fig. 10: Basic propagation loss of the (407.5 to 412.5) MHz band.

Secondly, let us now study the case of the frequency band of 887.5 to 892.5 MHz. Fig. 11 shows the basic propagation gain up to 15 m. It can be noticed the mean value of the propagation gain can be approximated by:

$$B_{pg}(dB) = \begin{cases} -\left\{40.74 + 13.95\log_{10}(d)\right\} & d \le 3m \\ -\left\{48.98 + 14\log_{10}\left(\dfrac{d}{3}\right)\right\} & d > 3m \end{cases} \tag{11}$$

The first propagation exponent is 1.39 while the second one is 1.4.

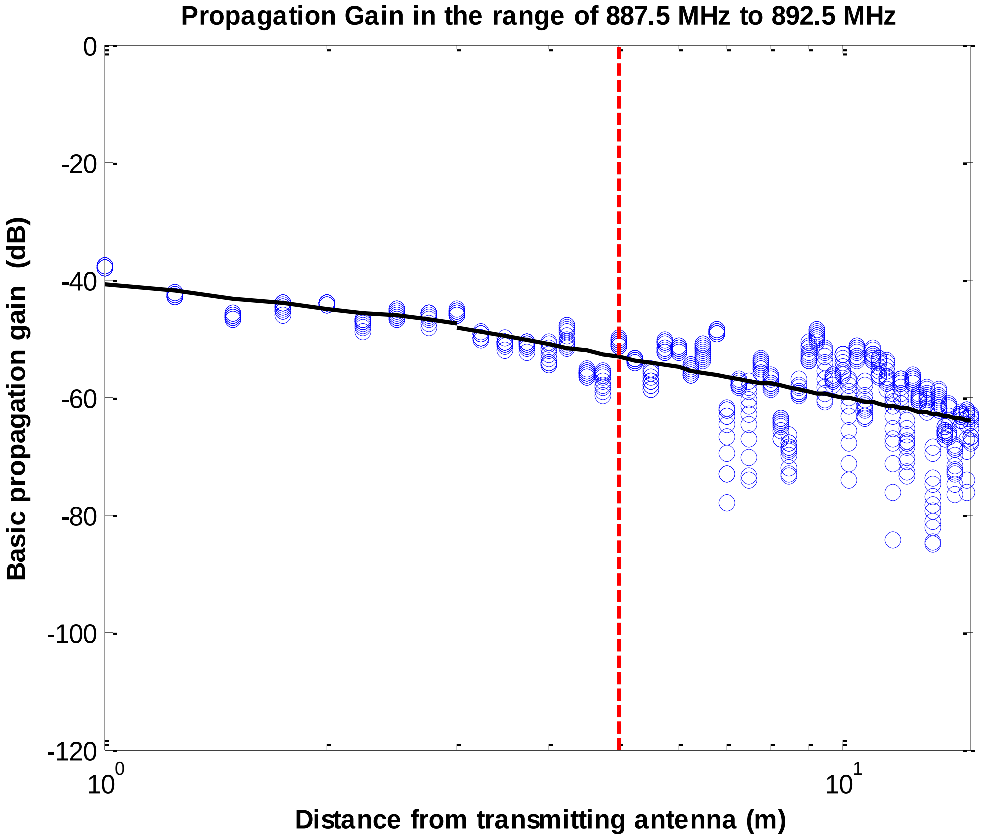

Fig. 11: Basic propagation loss of the (887.5 to 892.5) MHz band.

Now, let us present the results for Scenario 2 using narrow band channel. Figures 12 and 13 represent the basic propagation loss at 410 MHz and 890 MHz respectively. For the 410 MHz band, the basic propagation loss extends from 31 dB up to 87 dB while for the 890 MHz band it extends from 33 dB up to 89 dB. The main conclusion to be drawn from the results of this scenario is that the representation of the basic gain against the index of the measuring points shown in Figure 12 and 13 looks fairly similar to the stairs profile shown in Figure 5, which shows the different points of measurements within the stairs. This represents a particular case since the propagation scenario can be very well estimated using the propagation loss results.

From the above mentioned results, it can be concluded that the value of the propagation exponent depends on the studied scenario and the channel band width. This has been also shown in [9].

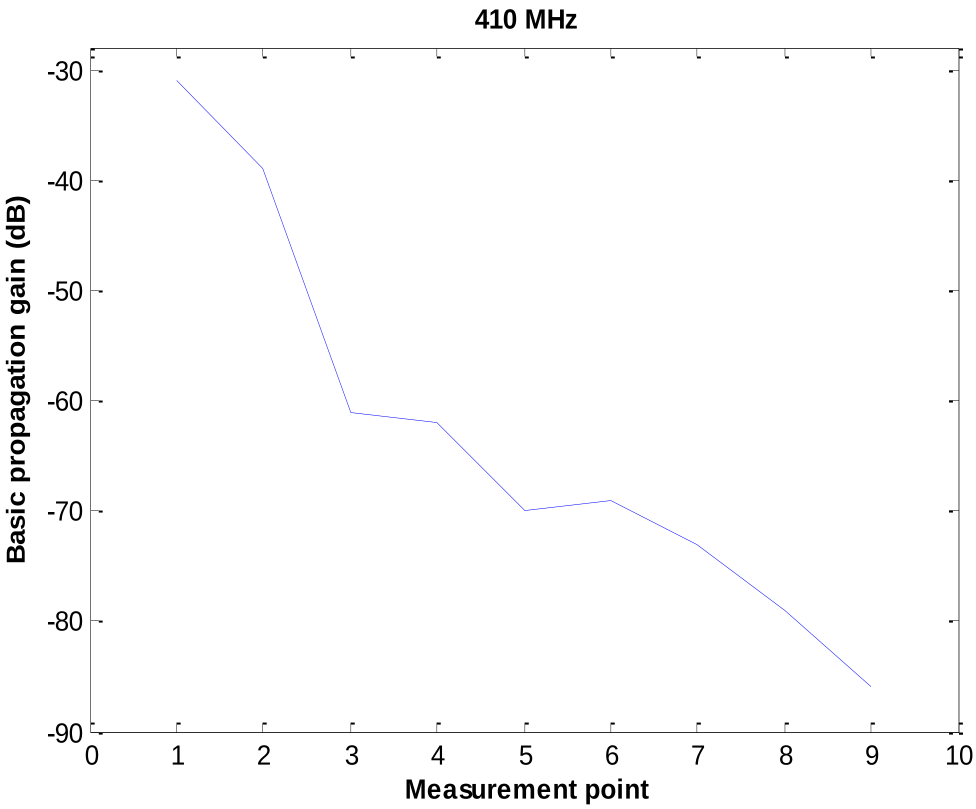

Figure 12: Basic propagation gain of Scenario 2 at 410 MHz.

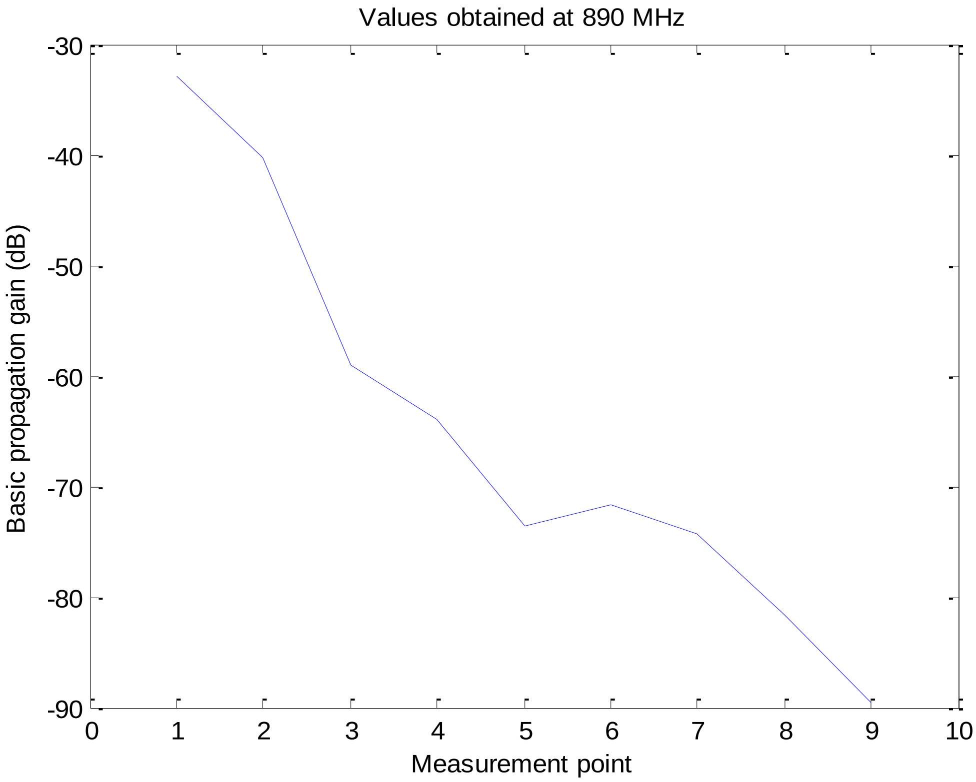

Figure 13: Basic propagation gain of Scenario 2 at 890 MHz.

5. Indoor-Outdoor Scenarios Results

Let us now represent the result of the first outdoor scenario (Scenario 3). Figure 14 shows the basic propagation gain as a function of the distance of the measurement points from the building at 410 MHz. We can notice that the value of the basic propagation gain at a 22 m from the building is little bit higher than its value at a 2m from the building. This is mainly due to the distance increments compensated little bit the increment of the transmitting antenna gain. Free space loss has a value of 49.8 dB for the nearest point to the building and a value of 53.6 dB for the farthest point from the building. The extra propagation loss of almost 20 dB is due to the low gain of the transmitting antenna in the direction of propagation (see Fig. 1). The propagation loss difference of 3.8 dB (due to the distance from the transmitting antenna) is little bit reduced due the fact that antenna gain increases with the increment of the distance of the measurement point from the building. This can be demonstrated using Fig. 1 where the maximum gain at negative vertical angle is at almost -45^o.

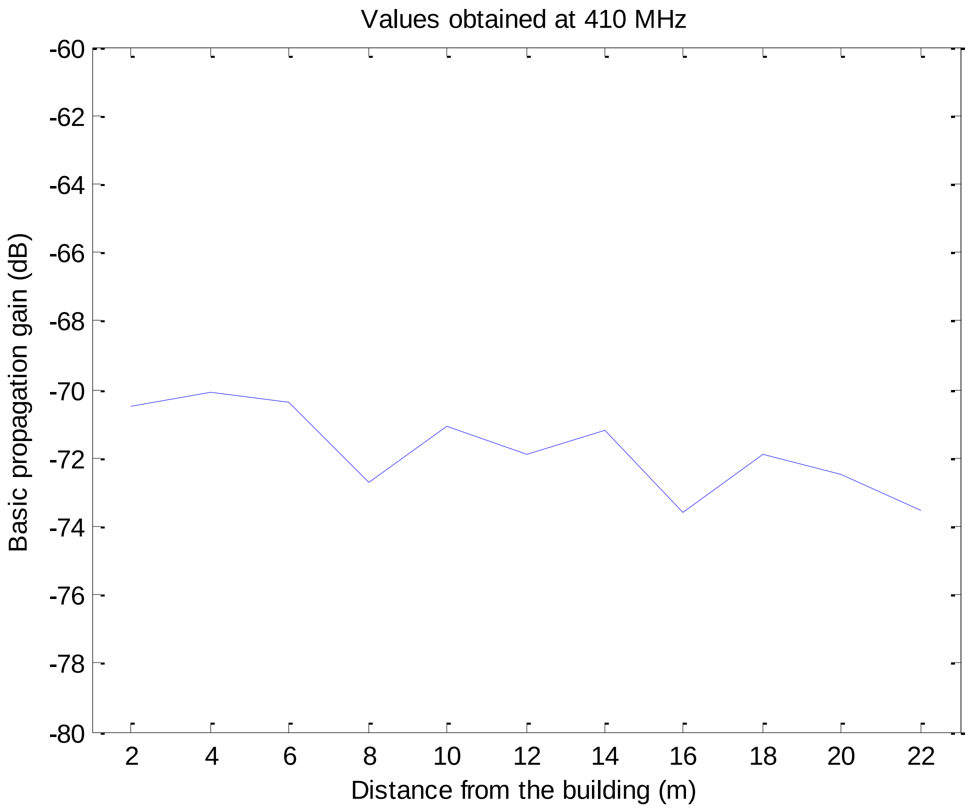

Figure 14: Basic propagation gain of Scenario 3 at 410 MHz.

Figure 15 represent the basic propagation gain as a function of the different measurement points of scenario 3 at 890 MHz. Here, also it can be noticed that the value of the basic propagation gain at a 22 m from the building is little bit than its value at a 2m from the building. Free space loss has a value of 53.2 dB for the nearest point to the building and a value of 57.0 dB for the farthest point from the building. The extra loss of propagation is due to the low gain of the transmitting antenna in the direction of propagation.

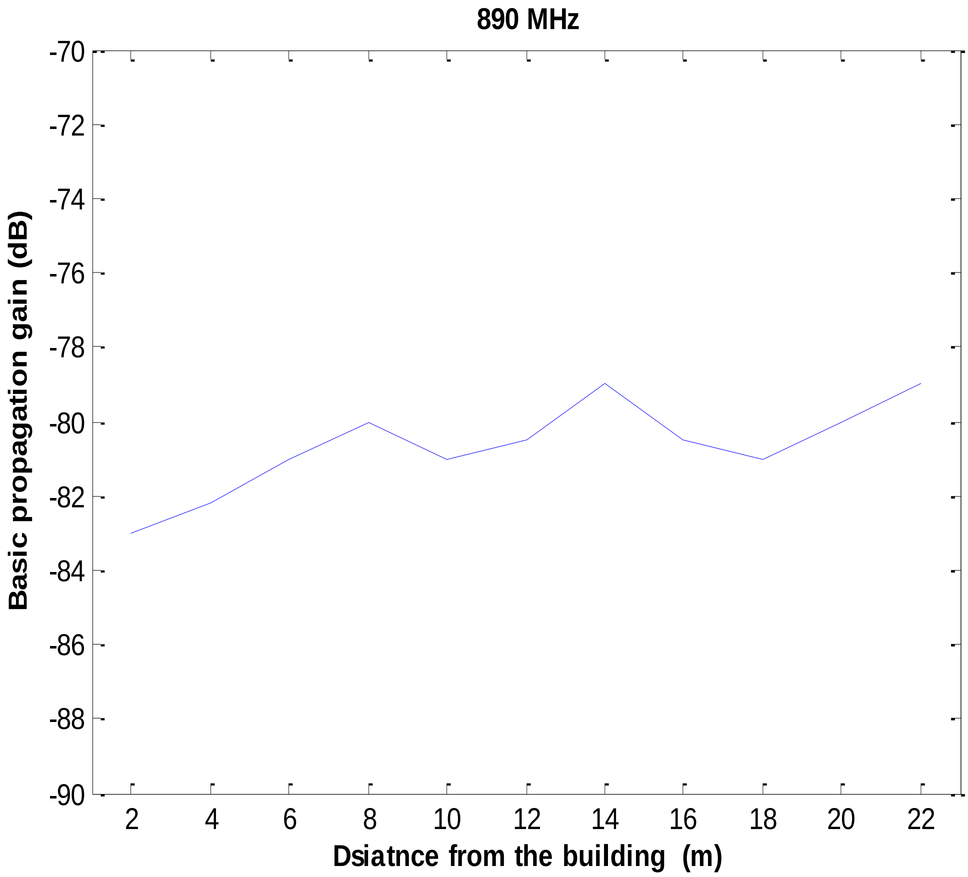

Figure 15: Basic propagation gain of Scenario 3 at 890 MHz.

Figure 16 shows the basic propagation loss of Scenario 4 at 410 Hz. It can be noticed that the propagation gain has a little increment tendency due to the increment of the height of the 4 to 9 measurements points which increases the transmitting antenna gain. Free space loss has a value of 47.7 dB for the nearest point to the building and a value of 49.5 dB for the farthest point from the building. The extra loss of propagation of almost 25 dB is due to the low gain of the transmitting antenna in the direction of propagation.

Finally, Figure 17 shows the basic propagation loss of Scenario 4 at 890 Hz. It can be noticed that the propagation gain has a little increment tendency due to the increment of the height of the 4 to 9 measurements points which increases the transmitting antenna gain. Free space loss has a value of 52.1 dB for the nearest point to the building and a value of 52.9 dB for the farthest point from the building. The extra loss of propagation is due to the low gain of the transmitting antenna in the direction of propagation.

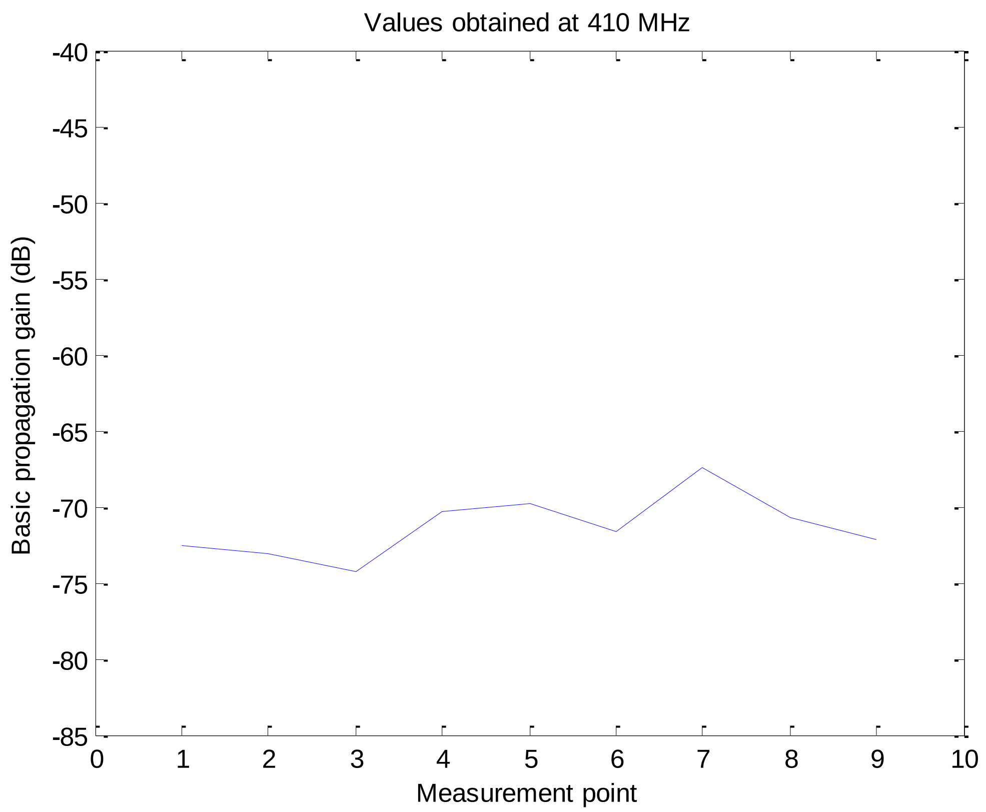

Figure 16: Basic propagation gain in each measurement point of the scenario 4.

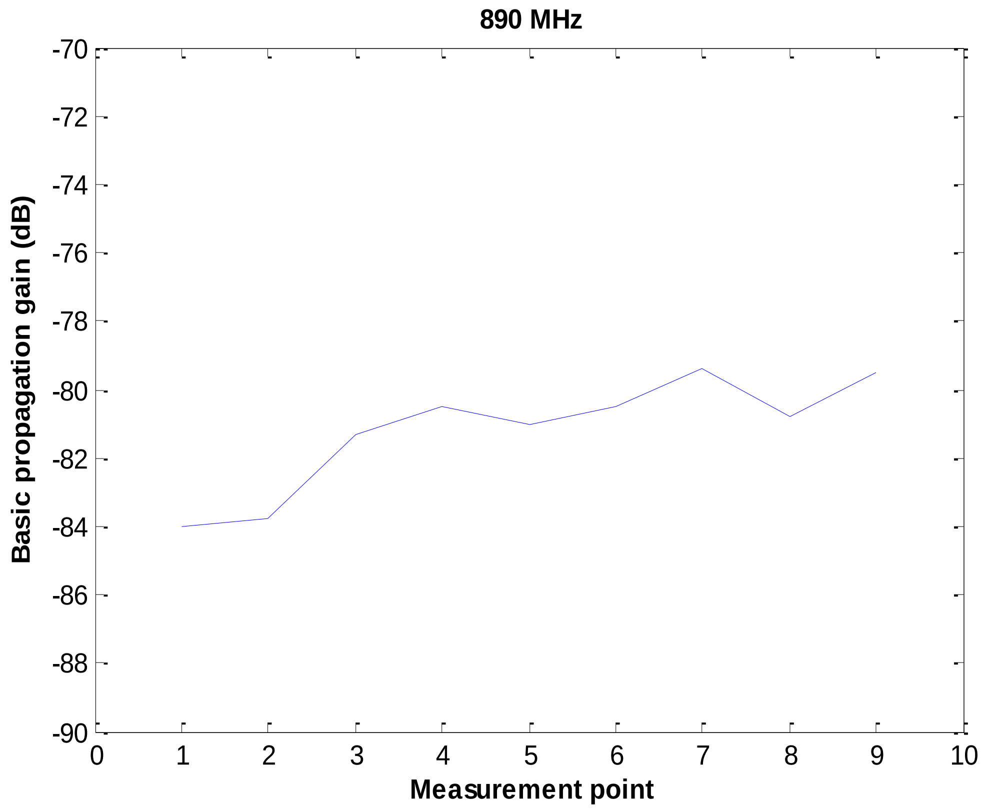

Figure 17: Basic propagation gain in each measurement point of the scenario 4.

6. Multiwall attenuation loss

Here, directive antennas with a nominal gain of 10 dB have been used to measure the wall attenuation loss. The height of each one of the antennas was 1.5 m from the floor. Walls are brick type with a thickness of 11.5cm with a plastering coat at each side. Measurements have been carried out for up to 5 walls in different floors of the C building of the school.

Fig. 18 represents the best curve fitting of the wall attenuation loss at 410 MHz. It can be seen that relation between the attenuation loss and the number of walls is almost linear with an average loss of 2.5 dB per wall.

Fig. 19 represents the best curve fitting of the attenuation loss at 890 MHz. Also here it can be seen that relation between the attenuation loss and the number of walls is almost linear with an average loss of 4 dB per wall.

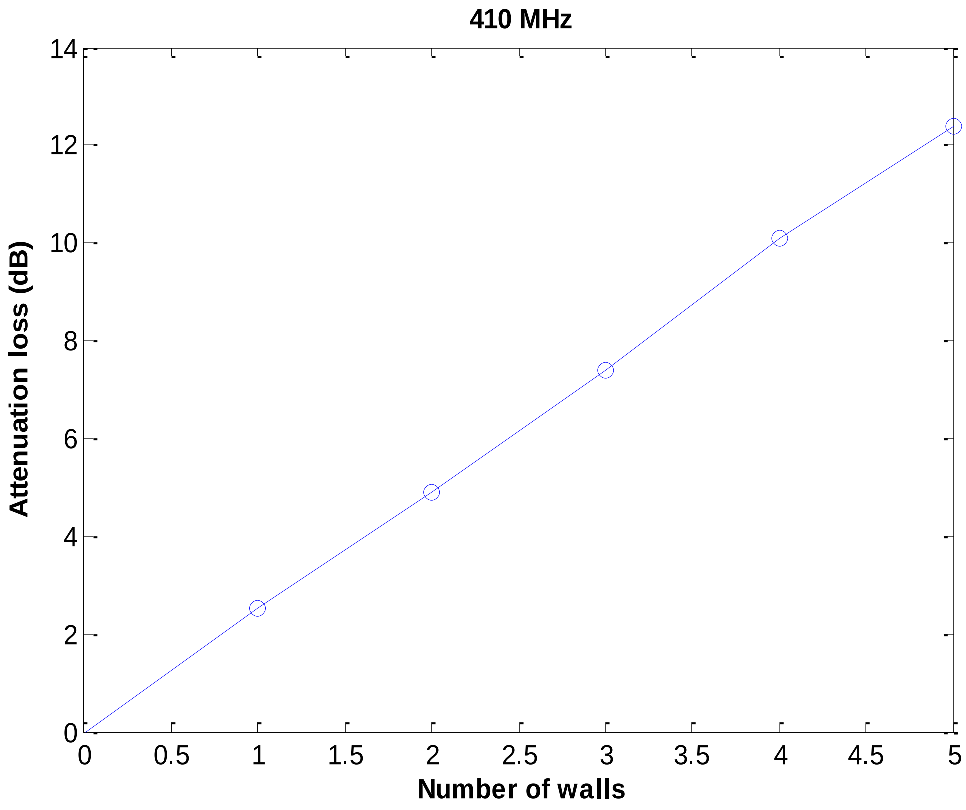

Fig. 18: Best curve fitting of the wall attenuation loss at 410 MHz.

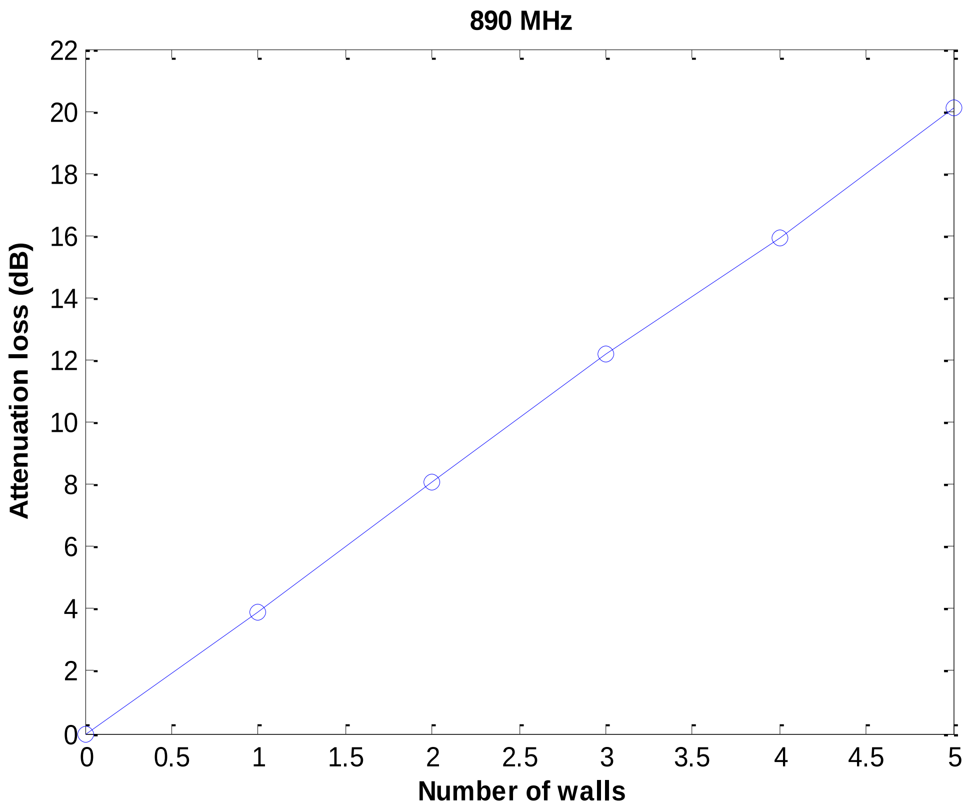

Fig. 19: Best curve fitting of the wall attenuation loss at 890 MHz.

7. Human being obstruction gain (loss)

In this case, the effect of the existence of human beings between the transmitter and the receiver has been studied where frequencies of (400-420) MHz and (880-900) MHz have been used. Fig. 20 shows the studied scenario where the distance between the transmitter and the receiver is 15m. Three persons (two men and a woman) are used to get the results. Fourteen positions are used to get the obstruction loss. The nearest one is at almost 1m from the transmitter and the farthest one with a distance of almost 14m from the transmitter. Using only one person as an obstacle, measurements have been repeated three times at each frequency band. Fig. 21 and 22 shows the range of obstruction gain due to the three persons at the bands (400-420) MHz and (880-900) MHz respectively. At the (400-420) MHz band, the maximum obstruction gain is 8 dB at point 1 while the maximum obstruction loss is 32 dB at point 14. At the (880-900) MHz band, the maximum obstruction gain is 16 dB at point 2 while the maximum obstruction loss is 21.5 dB at the same point. It is worth mentioning that the human being obstruction loss depends on the length and size (weight) of the person present between the transmitter and the receiver node.

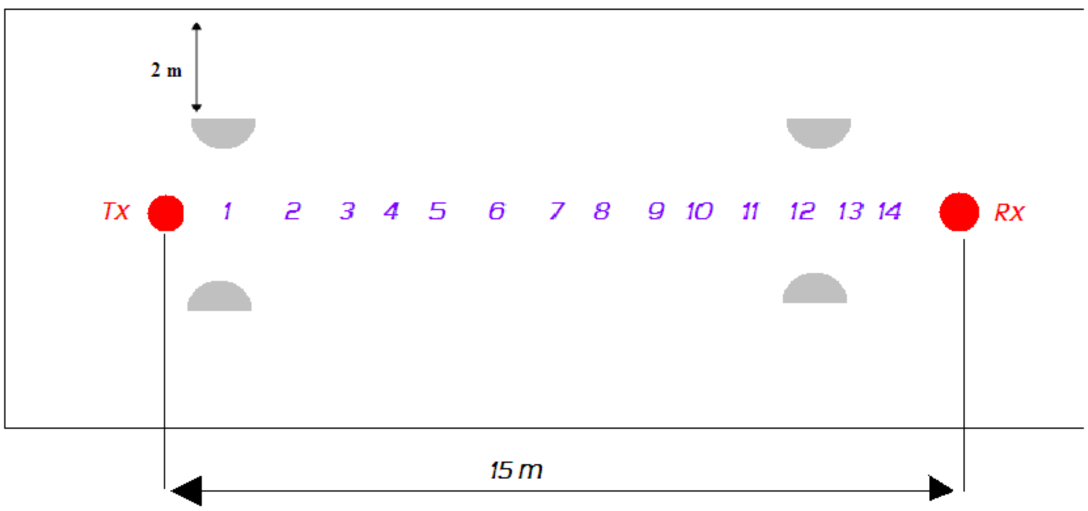

Fig. 20: Scenario used to study the human being obstruction loss.

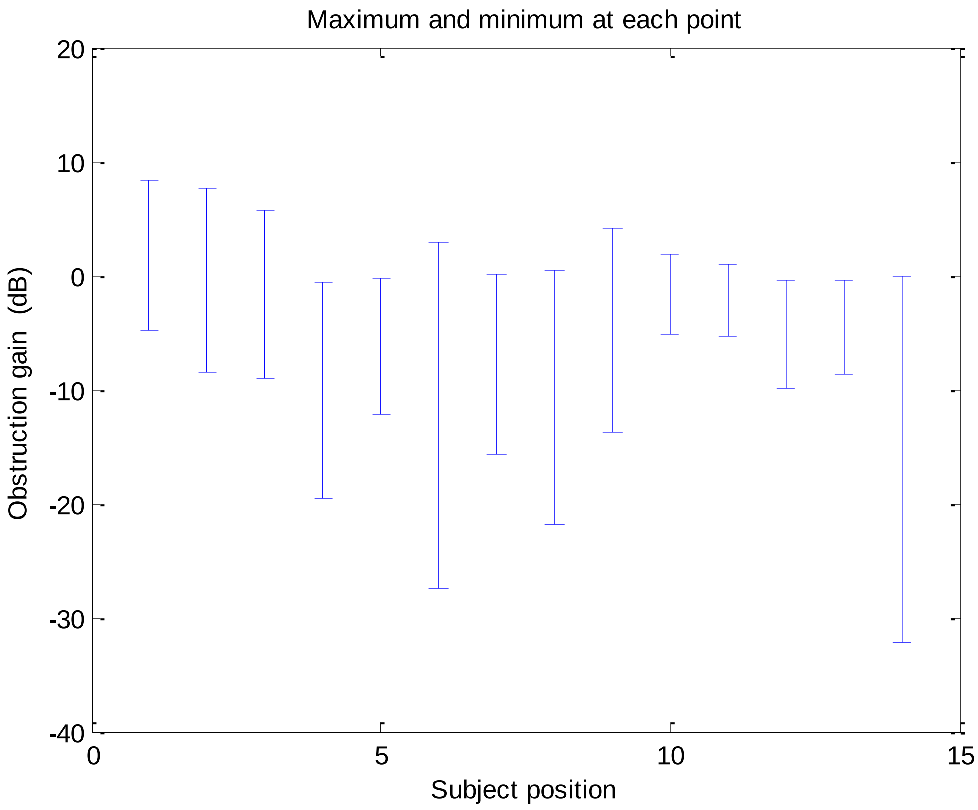

Fig. 21: Human being obstruction gain range at (400-420) MHz.

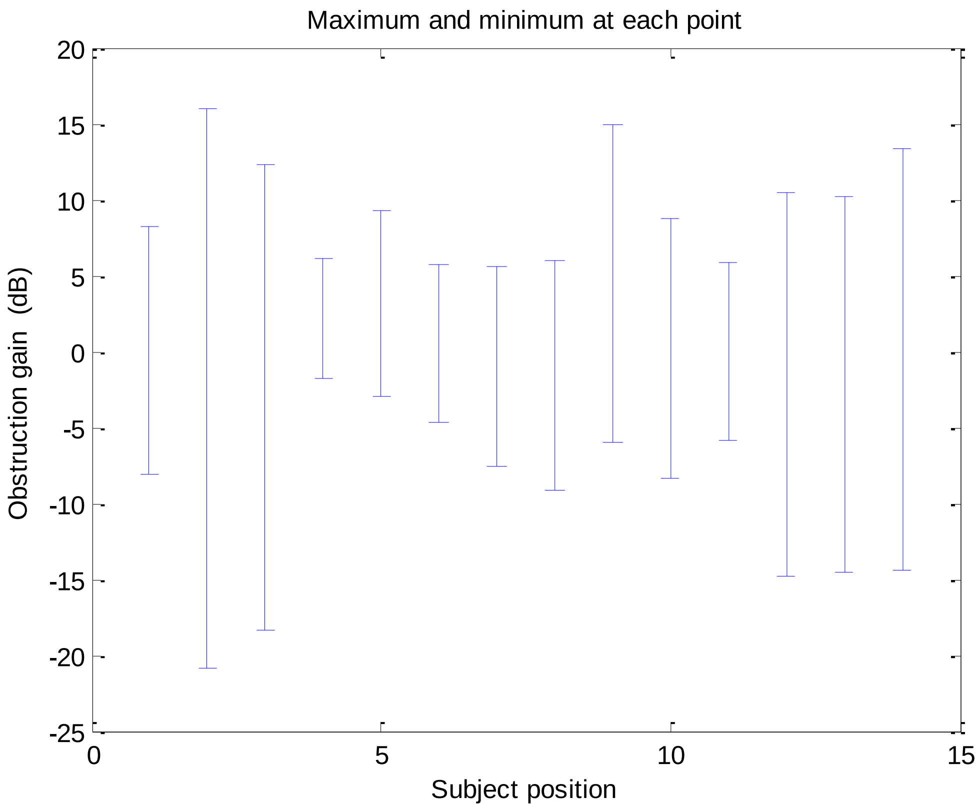

Fig. 22: Human being obstruction gain range at (880-900) MHz.

8. Conclusions

In this work, the UHF short range propagation in indoor and indoor-outdoor scenarios has been studied. Frequencies of 890 MHz and 410 MHz have been used. It has been noticed that the propagation loss of the indoor scenario can be presented by two-slope propagation loss model. For the second studied scenario (the stairs scenario), basic propagation gain have almost the same profile of the stairs. It has been noticed that the received power variation of the indoor-outdoor studied scenarios is small. For the multiwall attenuation loss it has been noticed that each wall has an attenuation of almost 2.5 dB at 410 MHz increasing to almost 4 dB at 890 MHz. The obstruction gain (loss) due to human beings shows that this can be within a 40 dB interval.

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Bazil Taha Ahmed was born in Mosul, Iraq, in 1960. He received the B.Sc. and M.Sc. degrees in Electronics and Telecommunication Engineering from the University of Mosul, in 1982 and 1985, respectively. He got the D. E. A. and the Ph. D degree both in Telecommunication Engineering from the Polytechnic University of Madrid in 2001 and 2003 respectively. Now he is working as an Associate Professor at the Universidad Autonoma de Madrid. He has published more than 100 scientific journal and conference papers in the area of the electromagnetic propagation and CDMA systems, particularly the CDMA capacity. His research interests include CDMA Capacity and Radiocommunication Systems Coexistence.