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Penetration Loss of Walls and Data Rate of IEEE802.16m WiMAX including Adaptive Modulation and Coding (AMC)

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Abstract The study reported here includes propagation analysis and coverage as well as the available downlink (DL) throughput of OFDMA-based IEEE802.16m WiMAX system as a function of distance to the Base Station (BS) for a number of outdoor and indoor propagation scenarios. Moreover, Walls penetration loss is also considered. Adaptive modulation and Coding (AMC) schemes will be assumed in the present study for 5 MHz and 20 MHz channel bandwidth.

Keywords: *WiMAX, propagation analysis, walls penetration loss, broadband wireless, adaptive modulation*

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1. Introduction

One of the newest technologies, that satisfy the ongoing demand for faster data rates with longer transmission ranges and that are thus suitable for new applications is mobile WiMAX. Mobile WiMAX will compete with cellular, Wi-Fi, and last-mile Internet access technologies such as DSL and cable.

The next generation of mobile WiMAX is IEEE 802.16m amends the IEEE 802.16e, j specification to provide an advanced air interface for operation in licensed bands. It is a recommended candidate for 4G. Unlike other wireless standards, WiMAX allows data transport over multiple broad frequency ranges. This lets the technology avoid frequencies that would interfere with other wireless applications.

Pushed by the increasing market demand for wireless wideband services, strong industry support and a competitive edge over deployed 3.5G systems Orthogonal Frequency Division Multiple Access (OFDMA) based Mobile WiMAX is on the verge of becoming a reality all over the globe [1].

In wireless communication systems, random fluctuations prevent the continuous use of highly bandwidth-efficient modulation schemes, and therefore Adaptive Modulation and Coding (AMC) has become a standard approach in recently developed wireless standards, including WiMAX. The idea behind AMC is to dynamically adapt the modulation and coding scheme to the channel conditions so as to achieve the highest spectral efficiency at all times. Adaptive modulation changes the coding scheme and/or modulation method depending on channel-state information (choosing it in such a way that it squeezes the most out of what the channel can transmit) [3].

The aim of the study is to determine the Path loss (PL) inside residences using locally available materials found in INDOOR 1, INDOOR 2 and INDOOR 3 propagation scenarios. The PL used to determine the coverage of the base station and mobile station's cell-range. Results of the study can help in system planning by making it possible to adjust the appropriate transmitter parameters. Moreover, a preliminary analysis of the data rate as a function of the distance to the BS is developed, considering different propagation environments and 3.5 GHz carrier frequency.

This paper is organized as follows. Section 2 presents frequency bands, OFDMA parameters frame and subchannel structure, modulation and coding modes, and propagation environments. Section 3 represents mathematical analysis and computer simulation using Matlab is considered. Finally, section 4 presents conclusions and future work.

2. System Parameters

2.1. Frequency Bands

Considering the 3.3-3.8 GHz spectrum, the WiMAX Forum™ Mobile System Profile [2] specifies the channel bandwidth combinations, Fast Fourier Transform (FFT) sizes and duplexing modes as shown in Table 1, for the possible frequency range configurations.

2.2. OFDMA Parameters

OFDMA is a multiple access technique which divides the total Fast Fourier Transform (FFT) space into a number of sub-channels (set of sub-carriers that are assigned for data exchange) whereas the time resource is divided into time slots (i.e. in WiMAX OFDMA PHY [3], the minimum frequency time unit of sub-channel is one slot, which is equivalent to 48 sub-carriers) and a frame is constructed from number of slots. Define the size of FFT as NFFT which denotes the total number of sub-carriers of all types (pilots, guard and data). Let Ndata denote the total number of data sub-carriers after reserving the pilot and guard sub-carriers. Ndata is divided into L groups, each with K = Ndata /L data sub-carriers.

For the possible channel bandwidth, Table 2 summarizes the standard IEEE 802.16 OFDMA parameters.

Table 1. Possible WiMAX configurations for the 3.3-3.8 GHz band [2]

Frequency Range (GHz)	Channel Bandwidth (MHz|)	FFT Size	Duplexing Mode
3.3-3.4	5	512	TDD
	7	1024	TDD
	10	1024	TDD
3.4-3.8	5	512	TDD
	7	1024	TDD
	10	1024	TDD
3.4-3.6	5	512	TDD
	7	1024	TDD
	10	1024	TDD
3.6-3.8	5	512	TDD
	7	1024	TDD
	10	1024	TDD

Table 2. OFDMA Parameters [11]

Parameter	Fixed WiMAX OFDM-PHY	Mobile WiMAX Scalable OFDMA-PHY			
FFT Size	256	128	512	1024	2048
Number of used data subcarriers	192	72	360	720	1440
Number of pilot data subcarriers	8	12	60	120	240
Number of null/guard band data subcarriers	56	44	92	184	368
Cyclic prefix of guard time (Tg/Tb)	1/32, 1/16, 1/8, 1/4				
Oversampling rate (Fs/BW)	Depends on bandwidth:7/6 for 256 OFDM, 8/7 for multiples of 1.75MHz, and 28/25 for multiples of 1.25 MHz, 1.5 MHz, 2 MHz ,or 2.75 MHz				
Channel bandwidth (MHz)	3.5	1.25	5	10	20
Subcarrier frequency spacing (KHz)	15.625	10.94			
Useful symbol time (μs)	64	91.4			
Guard time assuming 12.5% (μs)	8	11.4			
OFDM symbol duration (μs)	72	102.9			
Number of OFDM symbols in 5 ms frame	69	48.0			

In the present study frame duration of 5 ms has been assumed, since, at least initially all WiMAX equipments will only support this duration.

2.3. Frame and Subchannel Structure

The 802.16e PHY [3] supports TDD, FDD; however the initial release of Mobile WiMAX certification profiles is includes only TDD. With ongoing releases, FDD profiles is considered by the WiMAX Forum to address specific market opportunities where local spectrum regulatory requirements either prohibit TDD or are more suitable for FDD deployments. To counter interference issues, TDD does require system-wide synchronization; nevertheless.

One should note that the first system profiles released by the WiMAX Forum only contemplate time division duplexing (TDD) modes, due to a number of advantages over frequency division duplexing (FDD). TDD is the preferred duplexing mode for the following reasons:

- TDD enables adjustment of the DL/ UL ratio to efficiently support asymmetric downlink/uplink traffic, while with FDD, downlink and uplink always have fixed (and most times equal) and generally, equal DL and UL bandwidths.
- TDD assures channel reciprocity because the DL and UL frames are sent in the same band, for better support of link adaptation, MIMO, and other closed loop advanced antenna technologies (AAS).
- Unlike FDD, which requires a pair of channels, TDD only requires a single channel for both downlink and uplink providing greater flexibility for adaptation to varied global spectrum allocations.
- Transceivers design for TDD implementations are less complex and therefore less expensive.

Figure 1 illustrates the OFDM frame structure for a Time Division Duplex (TDD) implementation. Each frame is divided into DL and UL sub-frames separated by Transmit/Receive and Receive/Transmit Transition Gaps (TTG and RTG, respectively) to prevent DL and UL transmission collisions. In a frame, the following control information is used to ensure optimal system operation:

1). **Preamble:** The preamble, used for synchronization, is the first OFDM symbol of the frame.

2). **Frame Control Head (FCH):** The FCH follows the preamble. It provides the frame configuration information such as MAP message length, coding scheme and usable sub-channels.

3). **DL-MAP and UL-MAP:** The DL-MAP and UL-MAP provide sub-channel allocation and other control information for the DL and UL sub-frames respectively.

4). **UL Ranging:** The UL ranging sub-channel is allocated for mobile stations (MS) to perform closed-loop time, frequency, and power adjustment as well as bandwidth Requests.

5). **UL CQICH:** The UL CQICH channel is allocated for the MS to feedback channel state information.

6). **UL ACK:** The UL ACK is allocated for the MS to feedback DL HARQ acknowledgement.

The overheads in Figure 1 have variable size depending on the type of traffic carried. In this analysis Full Buffer FTP traffic will be assumed, and a corresponding typical distribution of OFDMA symbols in the frame is shown in Table 3.

This option is somehow conservative, since most applications have a traffic which is bursty in nature and can operate efficiently with less overhead.

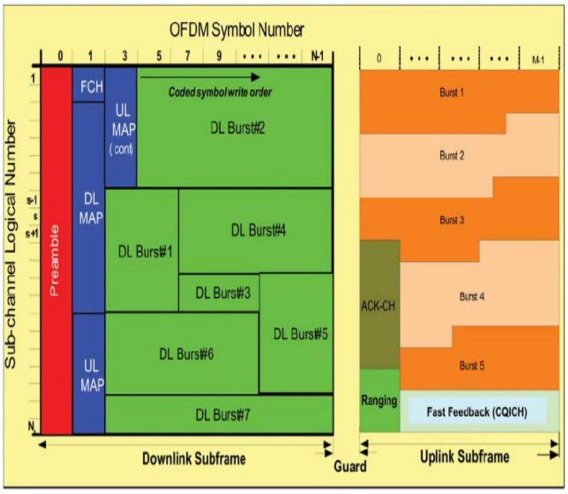

Figure 1. WiMAX OFDMA TDD Frame. (Extracted from [4])

Moreover, as previously referred, TDD allows for flexible DL/UL ratios to cope with different traffic profiles. In this study a 3:1 DL: UL ratio will be analyzed, the respective data symbols distribution is also shown in Table 3.

Table 3. TDD Frame configurations used [4]

Parameter		Values		
Channel bandwidth (MHz)		5	10	7
Number of OFDMA Symbols/Frame		48	48	34
Total Number of OFDMA Overhead Symbols		10	10	7
Number of OFDMA Symbols for TTG (guard)		1	1	1
Total Number of OFDMA Data Symbols		37	37	26
DL:UL 3:1	DL OFDMA Data Symbols	28	28	19
	UL OFDMA Data Symbols	9	9	7

IEEE 802.16 also allows different subcarrier permutations schemes, although the initial WiMAX system profile [5] only includes for the DL, Downlink Partial Usage of Subcarriers (DL PUSC) and Band Adaptive Modulation and Coding (Band AMC), with only the first being mandatory. Therefore, DL PUSC is considered as the subchannel permutation scheme.

2.4. Modulation and Coding Modes (Burst Profile)

Adaptive modulation and coding (AMC), Hybrid Automatic Repeat Request (HARQ) and Fast Channel Feedback (CQICH) were introduced with Mobile WiMAX to enhance coverage and capacity for WiMAX in mobile applications.

Support for QPSK, 16QAM and 64QAM are mandatory in the DL with Mobile WiMAX. In the UL, 64QAM is optional. Both Convolutional Code (CC) and Convolutional Turbo Code (CTC) with variable code rate and repetition coding are supported. Block Turbo Code and Low Density Parity Check Code (LDPC) are supported as optional features.

Table 4, summarizes the coding and modulation schemes supported in the Mobile WiMAX profile.

Table 4. Supported Code and Modulations [11]

		DL	UL
Modulation		QPSK,16QAM,64QAM	QPSK, 16QAM, 64QAM
Code Rate	CC	1/2, 2/3, 3/4, 5/6	1/2, 2/3, 5/6
	CTC	1/2, 2/3, 3/4, 5/6	1/2, 2/3, 5/6
	Repeteition	X2, X4, X6	X2, X4, X6

From several burst profiles allowed by IEEE 802.16, the six listed in Table 5, along with the minimum required SNR, have been considered.

Table 5. SNR required for considered burst profiles. (CTC – Convolution Turbo Codes)

Burst Profile	SNR Required (d B)
QPSK CTC 1/2	3.5
QPSK CTC 3/4	6.5
16- QAM CTC 1/2	9.0
16- QAM CTC 3/4	12.5
64- QAM CTC 2/3	16.5
64- QAM CTC 3/4	18.5

2.5. Propagation Environments

2.5.1. Propagation Model

Propagation models are used to estimate the Path loss (PL) value in wireless communications and to predict the level of SNR at the receiver. The PL value is used to determine the coverage of the base station and mobile station's cell-range.

The propagation model COST 231 Hata [6] has been adopted. Although this model is based on empirical data obtained at 2 GHz, [7] it is also valid model at 3.5 GHz.

2.5.2. Penetration Loss

Penetration will be modeled as an excess loss introduced by the penetrated walls, using the model suggested in [8]

$$L_{ex} = L_{wi} k[\frac{k+1.5}{k+1} - b][dB] \quad (1)$$

$$b = -0.064 + 0.0705 L_{wi} - 0.0018 L^2_{wi} \quad (2)$$

Where L_{wi} is the average excess attenuation per wall and k is the number of penetrated walls. Table 6a shows the penetration loss (L_{wi}) as a function of frequency for thin board dividing between rooms and thick walls made of reinforced concrete.

Table 6a. Penetration loss as a function of frequency for two types of walls [9]

Frequency [GHz]	Loss for thin Walls[d B]	Loss for thick Walls[d B]
2	3.3	10.9
3.5	3.4	11.4
5	3.4	11.8

Three indoor scenarios have then been considered. These are listed in Table 6b along with the respective attenuations calculated by equations (1) and (2) for a 3.5

GHz frequency. The chosen Indoor scenarios try to represent possible limiting situations on propagation. The analysis was limited to two walls, since when the number of walls increases, other propagation mechanisms become dominant.

Table 6b. Penetration Loss Parameters

Parameter	Indoor1 Thick Wall	Indoor 2 Thick Wall + Thin Wall	Indoor 3 2 Thick Walls
Total Penetration Loss [d B]	11.4	12.9	18.0

2.5.3. Fading

The diverse fading components due to the propagation environment will be taken into account in the form of propagation margins.

Table 8, illustrates the adopted margins and the total margin for the different considered scenarios. WiMAX Forum™ reference studies have provided the guideline for this parameterization [10].

Table 7. Fading Margins Adopted

Margin	
Log Normal Fade Margin	5.56 dB
Fast Fading Margin	2.0 dB
Interference Margin	2.0 dB

The value of 5.56 dB for the shadow fade margin is based on a log-normal shadowing standard deviation of 8 dB assuring a 75% coverage probability at the cell edge and 90% coverage probability over the entire area. The interference margin assumes a cellular reuse pattern of 1 with 3 sectors per site.

2.5.4. Station Parameters

Tables 8 presents the parameters used for the link budget calculations for the BS and SS, again based on WiMAX Forum™ analysis [10].

Table 8. BS and SS the parameters

Base Station Parameters			Subscriber Station Parameters		
BS Height	hb	32 m	Subscriber Station Height	hm	1.5 m
Tx Power per Antenna Element	PE	10 W	Number of Rx Antenna Elements		2
Number of Tx Antenna Elements		2	Antenna Diversity Gain	GDW	3 dB
Cyclic Combining Gain	GCYC	3dB	Rx Antenna Gain(Hand held Outdoor)	GR	-1 dBi
Tx Antenna Gain	GE	15 dBi	Rx Antenna Gain(Fixed in door)	GR	6 dBi
Pilot Power Boosting Attenuation	APILOT	-0.7dB	Noise Figure		7 dB

3. Mathematical Analysis and Computer Simulation

In order for the system to work correctly, the data rate in WiMAX can be calculated as:

$$R = \frac{N_{used} b_m c_r}{T_S} \tag{3}$$

Where: R is the data rate in a WiMAX OFDM physical layer, b_m is the number of bits per modulation symbol and is 1 for BPSK, 2 for QPSK, 4 for 16-QAM and in general if M is the modulation level in a M-QAM constellation, $M = 2^{b_m}$ .The c_r is the coding rate that can be found in [10,11] for each different burst profile. The symbol duration T_S, T_b is the useful symbol time, T_g is the guard time according to Figure 2, expressed as:

$$\begin{aligned} T_S &= T_g + T_b \\ T_S &= [G+1]T_b \end{aligned} \tag{4}$$

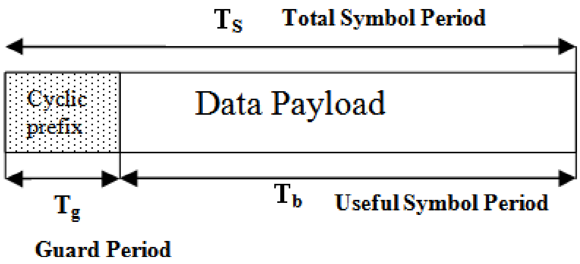

Figure 2. OFDM Symbol Structure with Cyclic Prefix

Where G is the ratio *Tg/Tb*, this value can be: 1/4, 1/8, 1/16 or 1/32. And $Tb = 1/\Delta f$, with the sub-carrier spacing Δf given as

$$\Delta f = \frac{F_S}{N_{FFT}} \tag{5}$$

$$F_S = floor\left(nBW/8000\right)8000 \tag{6}$$

Where F_S is the sampling frequency, n is the sampling factor, BW is the nominal channel bandwidth. The sampling factor in conjunction with BW value has changed from OFDMA 802.16-2004 Standard and is set to 8/7 as follows: for channel bandwidths that are a multiple of 1.75 MHz then n = 8/7 else for channel bandwidths that are a multiple of any of 1.25, 1.5, 2 or 2.75 MHz then n = 28/25 else for channel bandwidths not otherwise specified then n = 8/7.

Sensitivity or minimum received power S_R (receiver sensitivity) is different for each modulation and is expressed as [12]:

$$\begin{aligned} S_R &= -102 + SNR_{(Rx)} \\ &+ 10\log(Fs \times \left(\frac{N_{data}}{N_{FFT}}\right) \times \left(\frac{N_{subchannels}}{16}\right)) \end{aligned} \tag{7a}$$

Equation (7a) may be re-expressed as [11]:

$$\begin{aligned} S_R &= -114 + SNR_{(Rx)} - 10\log R \\ &+ 10\log\left(\frac{F_S N_{used}}{N_{FFT}}\right) + \mathrm{Im}\,pLoss + NF \end{aligned} \tag{7b}$$

Where: N_{FFT} is the number of points for FFT or total number of subcarriers. N_{data} is number of used data subcarries, and $N_{subchannels}$ is the number of subchannels. N_{used} (the active subcarriers = total subcarriers – null subcariers). ImpLoss is the implementation loss, which includes non-ideal receiver effects such as channel estimation errors, tracking errors, quantization errors, and phase noise. The assumed value is 7 dB. NF is the receiver noise figure, referenced to the antenna port. The assumed value is 8 dB, and R is the data rate in a WiMAX OFDM physical layer [13].

Table 9, Table 10 present the different values of SR and Channel Capacity Cmodulation [Mbps] for each modulation at 5 MHZ and 20 MHZ bandwidth using SNR required for considered burst profiles. (CTC–Convolutional Turbo Codes).

Table 9. Receiver Sensitivity for Each Modulation Type at 5MHZ

Parameters	SNR (Rx) [dB]	RESICEVER Sensitivity S_R [dB]	Usefull Channel Capacity Cmodulation [Mbps]
QPSK CTC 1/2	3.5	-98.6561	4.0816
QPSK CTC 3/4	6.5	-97.4170	6.1224
16-QAM CTC1/2	9.0	-96.1664	8.1633
16-QAM CTC 3/4	12.5	-94.4273	12.245
64-QAM CTC 2/3	16.5	-91.6767	16.327
64-QAM CTC 3/4	18.5	-90.1883	18.367

The received power may be calculated using link budget equations given as:

$$P_R = P_T + G_T + G_R - L_S - PL \tag{8}$$

Where: P_R is the received power, P_T is the transmitted power, G_T is the transmit antenna gain, G_R is the receiver antenna gain, L_S is the system loss and P_L is the path loss.

$$\mathrm{PATHLOSS} = \mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R} - \mathrm{P_R} - \mathrm{Lex} \tag{9}$$

Table 10. Receiver Sensitivity for Each Modulation Type at 20MHZ [13]

Parameters	SNR(Rx) [dB]	RESICEVER Sensitivity S_R [dB]	Usefull Channel Capacity Cmodulation [Mbps]
QPSK CTC 1/2	3.5	-98.6561	16.327
QPSK CTC 3/4	6.5	-97.4170	24.490
16-QAM CTC 1/2	9.0	-96.1664	32.653
16-QAM CTC 3/4	12.5	-94.4273	48.980
64-QAM CTC 2/3	16.5	-91.6767	65.306
64-QAM CTC 3/4	18.5	-90.1883	73.469

A- Cost-231 Hata Model

In this model, five parameters are used for propagation loss estimation. These are frequency f MHz, distance from base station to mobile station d (Km), base station height hb (m), the height of the mobile hm (m), and standard deviation constant Cm (dB). The path loss in Hata model is expressed as:

$$\begin{aligned} PL = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - ah_m \\ -(44.9 - 6.55\log_{10}(h_b))\log_{10} d + C_m \end{aligned} \tag{10}$$

Where the parameters Cm and ahm are used to specify the environmental characteristics as given below:

*Urban:

$$C_m = 3dB$$

$$ah_m = 3.20(\log_{10}(11.75h_m))^2 - 4.97 \tag{11}$$

*Suburban/Rural:

$$C_m = 0dB$$

$$ah_m = (1.11\log_{10} f - 0.7)h_m - (1.56\log_{10} f - 0.8) \tag{12}$$

Using the above equations, the relationship between the distance d and the propagation loss may be formulated as:

$$d = 10^{\left(\begin{array}{l}\text{(PATHLOSS-46.3-33.9*log10(f)+13.82*log10(hb)+ahm-cm)} \\ \text{/(44.9-6.55*log10(hb))}\end{array}\right)} \tag{13}$$

Where the PATHLOSS is calculated using Equation (9).

In the work reported here, the variation of DL data rate, the Power received as a function of the distance to the BS, and the pathloss for each propagation scenarios with respect to the previously obtained information is calculated. Figure 3 illustrates a flow chart for this methodology.

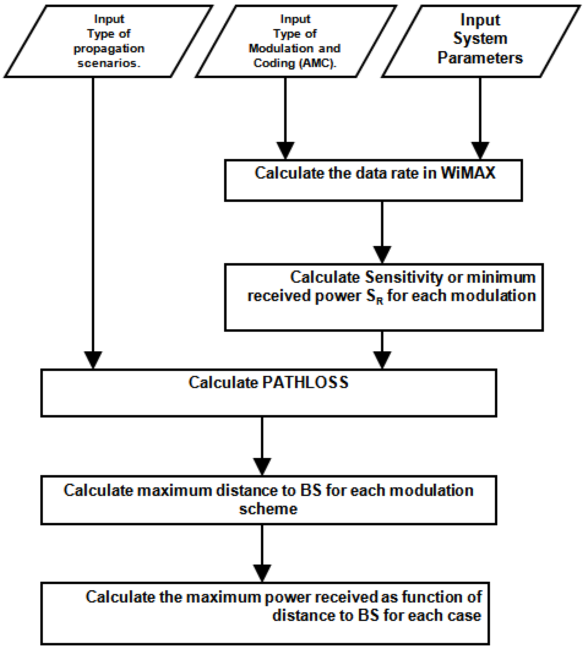

Figure 3. Pathloss and Power received for each propagation scenarios Calculation Algorithm

The simulation parameters are shown in Table 6, Table 7, Table 8. Four propagation scenarios (OUTDOOR; INDOOR 1, INDOOR 2 and INDOOR 3) are considered.

The SNR (Rx) [dB] and useful channel capacity (C modulation) for each modulation at 5 MHZ and 20 MHZ bandwidth are shown in Table 9, Table 10 are considered too.

The variation of the DL data rate as a function of the distance to the BS has been computed for the 5 MHz and 20 MHz bandwidth and are shown in Figure 4 and Figure 5.

The maximum distance to BS for each modulation scheme in the four propagation scenarios (OUTDOOR; INDOOR 1, INDOOR 2 and INDOOR 3), for both urban and suburban at frequency band 3.5GHZ, are shown in Table 11-Table 14.

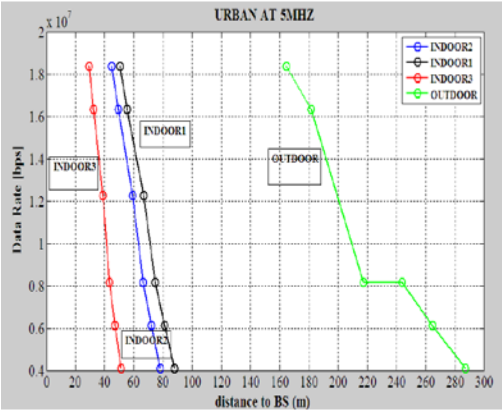

Figure 4a. Data Rate with distance to the BS for COST 231-Hata Urban at (5MHZ)

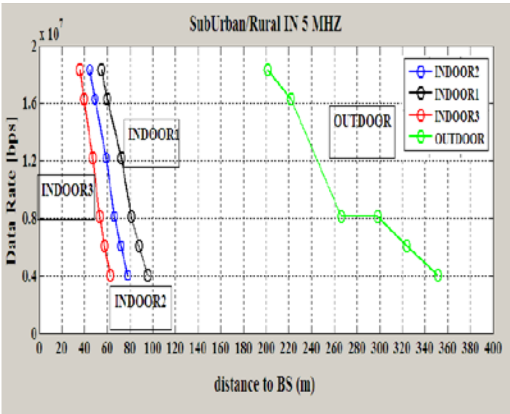

Figure 4b. Data Rate with distance to the BS for COST 231-Hata SubUrban at (5MHZ)

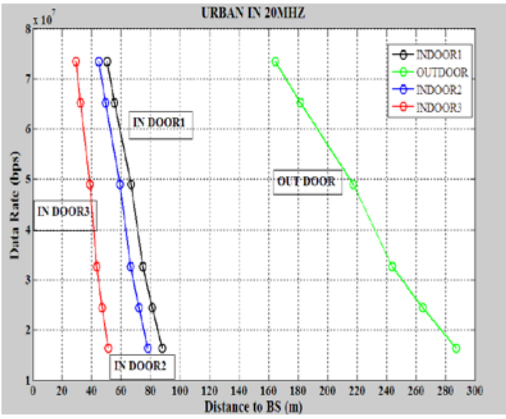

Figure 5a. Data Rate with distance to the BS for COST 231-Hata Urban at (20MHZ)

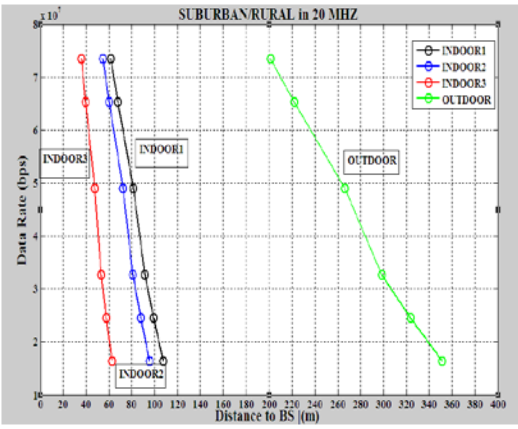

Figure 5b. Data Rate with distance to the BS for COST 231-Hata Suburban at (20MHZ)

The results from the above Figure 4 and Figure 5 showed that the maximum distance to base station in the suburban case is increased by 22%, 22.3%, 22.5%, and 18.5% for INDOOR1, INDOOR2, INDOOR3, and OUTDOOR respectively as compared to the urban case.

Comparing OUTDOOR, INDOOR1, INDOOR 2 and INDOOR 3 scenarios, it is observed that the maximum distance to base station in INDOOR 2 increased by 34.4 % more than INDOOR 3, where in INDOOR1 this distance increase by 11.3% comparing INDOOR2, where without any Penetration Loss in OUTDOOR scenario this distance increase by 69% comparing INDOOR1.

Table 11a. COST 231-Hata model-3.5GHZ- Urban environment-Indoor1

Parameters	Maximum Distance To base station d[km]	Pathloss (d B) Indoor1 [Thick Wall]
QPSK CTC 1/2	0.0879	111.6320
QPSK CTC 3/4	0.0810	110.3929
16-QAM CTC 1/2	0.0746	109.1423
16-QAM CTC 3/4	0.0665	107.4032
64-QAM CTC 2/3	0.0555	104.6526
64-QAM CTC 3/4	0.0504	103.1642

Table 11b. COST 231-Hata model -3.5GHZ- (SubUrban/Rural) environment- Indoor1

Parameters	Maximum Distance To base station d[km]	Pathloss(d B) Indoor1 [Thick Wall]
QPSK CTC 1/2	0.1075	111.6320
QPSK CTC 3/4	0.0991	110.3929
16-QAM CTC1/2	0.0913	109.1423
16-QAM CTC 3/4	0.0814	107.4032
64-QAM CTC 2/3	0.0680	104.6526
64-QAM CTC 3/4	0.0616	103.1642

Table 12a. COST 231-Hata model-3.5GHZ- (Urban) environment-Indoor2

Parameters	Maximum Distance To base station d[km]	Pathloss (d B) Indoor2 [Thick Wall and Thin Wall]
QPSK CTC 1/2	0.0780	109.8200
QPSK CTC 3/4	0.0719	108.5809
16-QAM CTC1/2	0.0662	107.3303
16-QAM CTC 3/4	0.0591	105.5912
64-QAM CTC 2/3	0.0493	102.8406
64-QAM CTC 3/4	0.0447	101.3522

Table 12b. COST 231-Hata model-3.5GHZ- (SubUrban/Rural) environment-Indoor2

Parameters	Maximum Distance To base station d[km]	Pathloss(d B) Indoor2 [Thick Wall and Thin Wall]
QPSK CTC 1/2	0.0954	109.8200
QPSK CTC 3/4	0.0880	108.5809
16-QAM CTC1/2	0.0810	107.3303
16-QAM CTC 3/4	0.0723	105.5912
64-QAM CTC 2/3	0.0603	102.8406
64-QAM CTC 3/4	0.0547	101.3522

Table 13a. COST 231-Hata model-3.5GHZ- (Urban) environment-Indoor3

Parameters	Maximum Distance To base station d[km]	Pathloss(d B) Indoor3 [2 Thick Wall]
QPSK CTC 1/2	0.0511	103.3962
QPSK CTC 3/4	0.0471	102.1571
16-QAM CTC1/2	0.0434	100.9065
16-QAM CTC 3/4	0.0387	99.1674
64-QAM CTC 2/3	0.0323	96.4168
64-QAM CTC 3/4	0.0293	94.9284

Table 13b. COST 231-Hata model-5MHZ –3.5GHZ-(SubUrban/Rural) environment-Indoor3

Parameters	Maximum Distance To base station d[km]	Pathloss(d B) Indoor3 [2 Thick Wall]
QPSK CTC 1/2	0.0626	103.3962
QPSK CTC 3/4	0.0577	102.1571
16-QAM CTC1/2	0.0531	100.9065
16-QAM CTC3/4	0.0474	99.1674
64-QAM CTC2/3	0.0396	96.4168
64-QAM CTC3/4	0.0359	94.9284

Table 14a. COST 231-Hata model-3.5GHZ- Urban environment-outdoor

Parameters	Pathloss(d B) outdoor	Distance (km)
QPSK CTC 1/2	129.6561	0.2872
QPSK CTC 3/4	128.4170	0.2647
16-QAM CTC1/2	127.1664	0.2438
16-QAM CTC 3/4	125.4273	0.2175
64-QAM CTC 2/3	122.6767	0.1815
64-QAM CTC 3/4	121.1883	0.1646

Table 14b. COST 231-Hata model-3.5GHZ- (SubUrban/Rural) environment- outdoor

Parameters	Pathloss(d B) outdoor	Distance (km)
QPSK CTC 1/2	129.6561	0.3514
QPSK CTC 3/4	128.4170	0.3239
16-QAM CTC1/2	127.1664	0.2983
16-QAM CTC 3/4	125.4273	0.2661
64-QAM CTC 2/3	122.6767	0.2221
64-QAM CTC 3/4	121.1883	0.2014

The results from the above Table 11- Table 14 comparing OUTDOOR, INDOOR1, INDOOR 2 and INDOOR 3 scenarios, it is observed that an increase in the maximum cell radius in OUTDOOR model causes increased path loss so, the path loss in QPSK CTC 1/2 for example is reached to 129.6561 dB, as compared to 103.3962 dB, 109.8200 dB and 111.6320 dB in INDOOR3, INDOOR 2, and INDOOR 1 respectively.

While the maximum cell radius in OUTDOOR model is reached to 0.3514 km in QPSK CTC 1/2 as compared to 0.0626 km, 0.0954 km, and 0.1075 km in INDOOR3, INDOOR 2, and INDOOR 1 respectively. As expected, decreasing the system data rates, the cell radius is slightly increased.

The variation of the Power received as a function of the distance to the BS has been computed using equations 8, 10, and the parameters given in Tables 6a, 6b, 7, 8, for the propagation scenarios (OUTDOOR; INDOOR 1, INDOOR 2 and INDOOR 3) in the cases of urban and suburban at frequency band 3.5GHZ, and the results are shown in Figure 6-Figure 9.

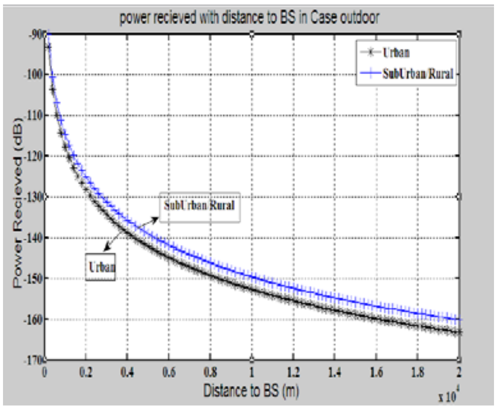

Figure 6. Power received with distance to BS (COST 231-Hata model) in case outdoor

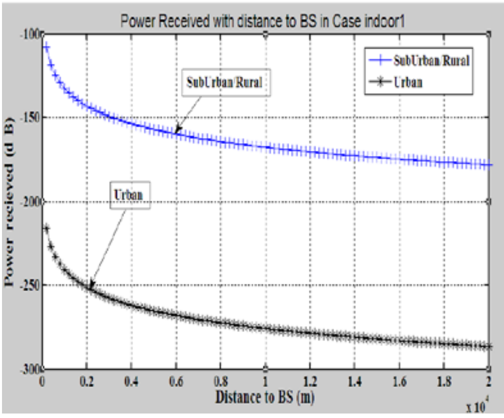

Figure 7. Power received with distance to BS (COST 231-Hata model) in case indoor1

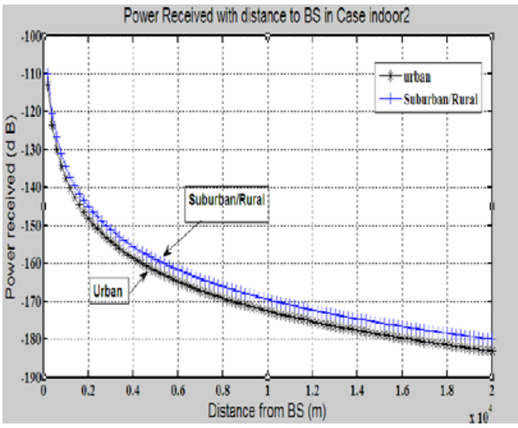

Figure 8. Power received as a function of distance to BS (COST 231-Hata model) in case indoor2

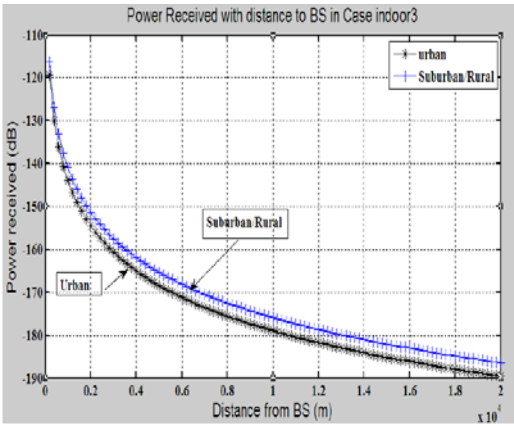

Figure 9. Power received with distance to BS (COST 231-Hata model) in case indoor3

The results from the above Figure 6- Figure 9 showed that the maximum power received in the suburban case is increased by 100%, 3%, 2.5%, and 4% for INDOOR1, INDOOR2, INDOOR3, and OUTDOOR respectively as compared to the urban case.

Comparing OUTDOOR, INDOOR1, INDOOR 2 and INDOOR 3 scenarios it is observed that increase in the maximum power received is -90 dB in OUTDOOR (suburban case), as compared to -100 dB, -110 dB, and -120 dB in INDOOR 1, INDOOR 2, and INDOOR 3 respectively.

While, in (urban case) the maximum power received is -92 dB in OUTDOOR, as compared to -220 dB, -110 dB, and -120 dB in INDOOR 1, INDOOR 2, and INDOOR 3 respectively.

4. Conclusions

Propagation models are used extensively in network planning, particularly for conducting feasibility studies and during initial deployment. They are also very useful for performing interference studies as the deployment proceeds. Knowledge on signal degradation enables RF designers to determine the required field strength for a reliable coverage in a specific area.

In this paper, the data rate for the downlink of OFDMA-based IEEE 802.16m WiMAX system and the available DL throughput as a function of distance to the Base Station (BS) are estimated for a number of propagation scenarios (OUTDOOR; INDOOR 1, INDOOR 2 and INDOOR 3). Moreover, Walls penetration loss is also considered. Adaptive modulation and Coding (AMC) schemes were assumed in the present study for 5 MHz and 20 MHz channel bandwidth.

Three indoor scenarios have then been considered. These are representing with the respective attenuations calculated by equations (1) and (2) for a 3.5 GHz frequency. The chosen Indoor scenarios try to represent possible limiting situations on propagation. The analysis was limited to two walls, since when the number of walls increases, other propagation mechanisms become dominant. The effects of the number of wall, and construction materials for each scenario were considered.

The results showed that the maximum distance to base station in the suburban case is increased by 22%, 22.3%, 22.5%, and 18.5% for INDOOR1, INDOOR2, INDOOR3, and OUTDOOR respectively as compared to the urban case.

In OUTDOOR case, the cell range increased as compared to INDOOR 1, INDOOR 2 and INDOOR 3. It is observed that the maximum distance to base station in INDOOR 2 increased by 34.4 % more than INDOOR 3, where in INDOOR1 this distance increase by 11.3% comparing INDOOR2, where without any Penetration Loss in OUTDOOR scenario this distance increase by 69% comparing INDOOR1.

While the maximum cell radius in OUTDOOR model is reached to 0.3514 km in QPSK CTC 1/2 as compared to 0.0626 km, 0.0954 km, and 0.1075 km in INDOOR3, INDOOR 2, and INDOOR 1 respectively. As expected, decreasing the system data rates, the cell radius is slightly increased.

Comparing OUTDOOR, INDOOR1, INDOOR 2 and INDOOR 3 scenarios it is observed that increase in the maximum power received is -90 dB in OUTDOOR (suburban case), as compared to -100 dB, -110 dB, and -120 dB in INDOOR 1, INDOOR 2, and INDOOR 3 respectively. While, in (urban case) the maximum power received is -92 dB in OUTDOOR, as compared to -220 dB, -110 dB, and -120 dB in INDOOR 1, INDOOR 2, and INDOOR 3 respectively.

In INDOOR 3 case the maximum distance to base station and the maximum power received is decreased as compared to INDOOR 2, INDOOR 1 due to the construction materials for each scenario.

At 20 MHz bandwidth one can observe an increasing in data rate as compared to the 5 MHZ bandwidth.

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