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Performance Evaluation of Different Frequency Bands of WiMAX and Their Selection Procedure

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Abstract

Worldwide Interoperability for Microwave Access (WiMAX) and other broadband wireless technologies are associated with a variety of frequency spectrums. It is essential to identify optimal frequency spectrum for implementing a technologically sturdy and strong WiMAX network. This paper compares different frequency spectrums centering various parameters like path loss, interference factors, coverage area, data rate, mobility, etc. This paper particularly focuses on comparison of frequency spectrums in terms of path loss using dissimilar propagation models. Simulations are done separately in three different environments (Urban, Suburban and Rural). The simulation results are compared and analyzed to identify an optimal frequency spectrum in the three different environments. The study shows that 2.5GHz frequency band performs better than 3.5GHz frequency band for the same radio frequency conditions and environments.

Keywords: WiMAX, Frequency spectrum, Path loss, 2.5GHz, 3.5GHz, Coverage

1. Introduction

WiMAX is a telecommunication technology which enables wireless transmission of voice and data in many ways, ranging from point-to-point links to full mobile access, the so-called Broadband Wireless Access (BWA), where availability of bandwidth combined with the mobility should provide the users with a better experience of high data rate services such as web browsing or video streaming. The availability of frequency spectrum is pivotal to providing broadband wireless services. Several frequency bands can be used for deploying WiMAX network. Each band has unique characteristics that have a significant impact on system performance. The operating frequency often dictates fundamental bounds on achievable data rates and coverage range. Selection of a suitable frequency spectrum within 2-11GHz is found to be most lucrative as commercial and technical feasibility studies are being conducted by many researchers to find the optimal range [1, 2, 3]. From a global perspective, the 2.5GHz and 3.5GHz bands are most likely to see WiMAX deployments. The WiMAX Forum has identified these bands for initial interoperability certifications [4].

In this paper, we presented a detailed quantitative analysis on the performance of two frequency bands (2.5GHz and 3.5GHz) under different conditions. The comparative analysis is performed based on numerous factors with an emphasis on path loss. The result presented in this paper provides an insight on the comparison of the two spectrums to allow network planners to select the optimum spectrum for their requirements.

The paper is organized as follows: Section 2 presents background study concerning frequency spectrums of WiMAX. Section 3 describes the factors based on which the two frequency bands are compared. Section 4 presents some path loss models. In Section 5, numerical result and discussion are provided and section 6 concludes this paper.

2. Background Study

From the characteristics of frequency spectrum for wireless solutions, it is evident that frequencies in GHz are Microwave frequencies. Frequencies below and above 10GHz are referred to as centimeter band and millimeter band respectively. As large data capacities are provided by wider channel bandwidths, millimeter bands are generally most suitable for very high data rate, line-of-sight (LOS) backhauling applications, while centimeter bands are well suited for multipoint, non-line-of-sight (NLOS), tributary and last mile distribution. Microwaves have wavelengths approximately in the range of 30 cm (1GHz) to 1 mm (300GHz). However, the boundaries between far infrared light, terahertz radiation, microwaves, and ultra-high-frequency radio waves are fairly arbitrary and are used variously between different fields of study. The term microwave generally refers to "alternating current signals with frequencies between 300MHz and 300GHz. This range of wavelengths has led to many questions. The existence of electromagnetic waves, of which microwaves are part of the frequency spectrum, was predicted by James Clerk Maxwell in 1864 from his Maxwell's equations. Above 300GHz, the absorption of electromagnetic radiation by Earth's atmosphere is so great that it becomes effectively opaque, until the atmosphere becomes transparent again in the so-called infrared and optical window frequency ranges. Microwaves are used in broadcasting transmissions because microwaves pass easily through the earth's atmosphere with less interference than longer wavelengths. There is also much more bandwidth in the microwave spectrum than in the rest of the radio spectrum. Metropolitan Area Network (MAN) such as WIMAX is based on the IEEE 802.16 specification. The IEEE 802.16 specifications were designed to operate between 2 to 11GHz. The commercial implementations are in the 2.5GHz, 3.5GHz and 5.8GHz ranges. This paper focuses on the performance of the frequency bands which exist between 2GHz and 6GHz portion of the spectrum, where allocated bandwidths are relatively narrow comparing to those which are available in the 10GHz to 66GHz range [1].

3. Factors of Comparison

To find a definitive conclusion, the frequency spectrums are compared on the basis of the following criteria.

3.1. Path Loss

The first comparable factor between the 2.5GHz & 3.5GHz spectrums is path loss as path loss is one of the most important quantitative performance measurements indexes of a communication link. A radio frequency (RF) signal experiences propagation loss, also known as path loss, and the degree of loss is frequency dependent. For large coverage, it is necessary that the losses are small. The presence of several losses cause WiMAX signal strength to decay as it propagates from transmitter to receiver. The smaller the frequency, the smaller will be the path loss, as a result, the greater distance a signal will propagate. Higher frequencies experience greater path loss. Also, different frequency bands may have different propagation characteristics. Extremely high frequencies (>10 GHz) cannot go around obstacles and require line-of-sight conditions. At low frequencies, RF waves can go around small obstacles. Therefore, the range of a signal will be low [5].

3.2. Free Space Loss (FSL)

Free space loss is governed by the equation [6]

FSL (dB) =32.45+20log10 (d) +20log10 (f)

Where, d is the distance between transmitter and receiver in meter and f is frequency in MHz

3.3. Shadow Margin

Shadow margin is related to path loss and shadow variance. Both these parameters increase as frequency increases. Given the impact of terrain and man-made objects on signal power, additional margin is needed to achieve a given reliability of service. Without this additional margin, shadowing can cause outages in large areas of the cell. The higher the reliability required, the higher the shadowing margin and the cell count. Most wireless systems are designed for 95 percent reliability, which requires a budget of 7dB shadow margin. To avoid the 5 percent outages, solutions such as indoor distributed antenna or deployment of antennas at the terminals can provide coverage for the shadowed areas [5].

3.4. Physical Environment

The physical surroundings of a cell site play a major role in determining the cell radius. Factors such as flatness of terrain and density of trees and foliage have significant impact on RF propagation. Building penetration loss does not seem to vary significantly in the 1.9/2.5/3/3.5GHz frequency bands. Higher frequency bands have shorter wavelengths, which can enter buildings through small openings, but suffer significant losses along metal and concrete surfaces. In contrast, these shorter wavelengths suffer lower losses through glass [5].

3.5. Cable Loss

Cable loss increases with increasing frequency. In higher frequency bands, this could severely disadvantage coverage in places where tall towers are used (rural). There are products that place the entire transceivers on tower top, eliminating the cable losses [5].

3.6. Interference

Since an interfering RF source disrupts transmission and decreases performance by making it difficult for a receiving station to interpret a signal, this factor has a great significance in developing a comparison model. Forms of RF interference frequently encountered are multipath interference and attenuation. Multipath interference is caused when signals are reflected off objects resulting in reception distortion. Attenuation occurs when an RF signal passes through a solid object, such as a tree, the strength of the signal reduces and subsequently its range [7].

The 2.5GHz band contains Multichannel Multipoint Distribution Services (MMDS) spectrum which includes 31 channels of 6MHz spacing in the 2500MHz to 2690MHz range and includes the Instructional Television Fixed Service (ITFS).

In contrary, IEEE 802.15.3a uses the 3.1GHz to 10GHz spectrum. The 3400-4200MHz band is heavily used by Fixed Satellite Station (FSS) satellites for any essential telecommunication needs and its use is constantly developing in Asia, the Pacific, Africa, the Arab States, Parts of Europe and USA.

3.6.1. Adjacent Frequency Interference Effects

Possible solutions to the problem of Frequency Interference Effects may include:

- WiMAX base station needs to use narrow band filter to attenuate the interference
- FSS needs additional high performance band-pass filter to enhance the receiver capability
- Add 25MHz protected band between WiMAX and FSS frequency band

3.7. Capital Expenditure (Capex) and Operational Expenditure (Opex)

As a licensed spectrum technology platform, WiMAX investment decisions are predicated by access to appropriately regulated spectrum. Almost three quarters of the spectrum allocated for WiMAX globally is focused in the 2.5GHz and 3.5GHz bands.

WiMAX networks deployed at 3.5GHz may require almost 30% more sites for a given coverage area than a 2.5GHz installation. The increase in sites at 3.5GHz results in approximately 13% increase in total cost of ownership for the system over 2.5GHz. Fixed costs common to both a 2.5GHz and 3.5GHz network including such operational line items as subscriber acquisition, systems integration and network management results in the 30% increase of sites to contribute only a 13% increase in cost of ownership. It is important to note that over time as capacity increases and the 2.5GHz system requires investments in new build out earlier than the 3.5GHz system – both the 2.5GHz and 3.5GHz system will demonstrate parity in cost of ownership [8].

3.8. Cell Radius and Range

To obtain the same cell radius in the 2.5GHz band, an additional link budget of 4dB is needed. In a coverage-limited design, this corresponds to a 21 to 24 percent reduction in cell radius and a 62 to 75 percent increase in the cell count across different environments (urban, suburban and rural). For the 3.5GHz band, you would need an additional link budget of 9dB. In a coverage-limited design, this corresponds to a 42 to 46 percent decrease in cell radius and a 200 to 250 percent increase in cell count. This information illustrates the impact that path loss can have, especially when deploying in higher frequency bands [5].

3.9. Mobility

Most mobile applications are best adapted in the < 3GHz bands range. However, for fixed applications typically 3.5GHz spectrum is mostly adopted. Thus IEEE 802.16-2004 mainly focuses on 3.5GHz spectrum while IEEE 802.16e standard works with 2.5GHz spectrum [7]. For mobile networks and mobile applications including mobile ad hoc network (MANET) based systems, it is necessary to remain connected at least above the Transport layer. For this purpose the 802.16e is the standard which supports mobility and its main focus is on the 2.5GHz frequency spectrum. The 2.5GHz spectrum provides the provision of diversified terminal like modem, personal computer memory card international association (PCMCIA), handset and personal digital assistant (PDA). In contrast, the 3.5GHz spectrum is associated with small number of terminal like desktop modem, PCMCIA.

3.10. Data Rate

Throughput or data rate is one of the most important quantitative performance measurement indexes of a communication link, which directly determines the number of subscribers the base station (BS) is able to serve with acceptable quality. It is also the major parameter that determines the link budget analysis. The net throughput deliverable over a link is affected by the effects of multipath, scattering, relative subscriber velocity and path loss to various degrees. In order to implement a network infrastructure, it is advisable to inspect the performance of the link in terms of net throughput delivered under different channel conditions. The 3.5GHz frequency band marginally surpasses the 2.5GHz frequency band in terms of data rate [9].

3.11. Licensing Issues and Technical Limitations

While WiMAX spectrum is mostly unlicensed, WiMAX also offers operability with a licensed band, specifically in the 5GHz range for WIMAX. So, designers and engineers have choice to select licensed or unlicensed frequency spectrum for implementing and installing application adaptable suitable solutions. One important point is that the total avoidance of license free band may not offer the quality that a licensed solution may provide. While licensed spectrum provides better quality-of-service (QoS), better NLOS reception at lower frequencies and better security, unlicensed spectrum has limitations like poor security measurement, poor QoS due to interference issues and poor NLOS reception.

Table 1. Comparison between 2.5GHz and 3.5GHz frequency spectrums

Factors	2.5GHz Frequency Spectrum	3.5GHz Frequency Spectrum
Path Loss	Low	Comparatively High
Shadow Margin	Low	High (Approximately 2dB more than 3.5GHz band)
Physical Environment	High losses due to metal and concrete surfaces as well as foliage	More loss than 2.5GHz band
Free Space Loss	Less	3dB more than 2.5GHz
Cable Loss	For a 30 m cable, the loss is 0.58dB less than 3.5GHz	Comparatively more
Interference	Comparatively Low	High due to heavy congestion around this spectrum
Power	More than 35dBm	35dBm output power for antenna defined by European Telecommunications Standards Institute (ETSI)
Coverage	High coverage for both indoor Customer-premises equipment (CPE) and PCMCIA	Less than 2.5GHz
CAPEX	About half the cost to build a 3.5GHz network	About 2 times than that of 2.5GHz
OPEX	CPE cost is about $100	From $300-500
Cell Radius	According to standard for mobile application, standard cell radius is 1-3 miles	According to standard for fixed application, standard cell radius is 3-5 miles
Range	2-5 km	7-10 km
Mobility	75-93 miles/hr or 120 km/hr	For fixed applications only
Data Rate	For 5MHz channel, data rate is 15Mbps	For the same channel, data rate is 15-18Mbps
Licensing Issues	Licensed	Licensed

4. Path Loss Models

In WiMAX system, transfer of information between the transmitting antenna and the receiving antenna is achieved by means of electromagnetic waves. The interaction between the electromagnetic waves and the environment reduces the strength of the signal sent from transmitter to receiver that causes path loss. We theoretically measure this path loss in different areas like rural, urban, and suburban with the help of path loss models. These models can be broadly categorized into three types: empirical, deterministic and stochastic. Empirical models are based on observations and measurements alone. These models are mainly used to predict path loss, but models that predict rain-fade and multipath have also been proposed [10]. The deterministic models make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. Deterministic models often require complete 3-D map of the propagation environment. An example of a deterministic model is ray tracing model [11]. Stochastic models, on the other hand, model the environment as a series of random variables. These models are least accurate but require least information about the environment and use much less processing power to generate predictions. Empirical models can be split into two subcategories namely, time dispersive and non-time dispersive [12]. Some of them are described based on which 2.5GHz and 3.5GHz are compared in terms of path loss [13].

4.1. Free Space Path Loss (FSPL) Model

Path loss in free space (PL_{FSPL}) defines how much strength of the signal is lost during propagation from transmitter to receiver. Free space path loss is diverse on frequency and distance. The calculation is done by using the following equation [6]:

$$PL_{FSPL} = 32.45 + 20\log_{10}(d) + 20\log_{10}(f)$$

Where, f is frequency in MHz, d is the distance between transmitter and receiver in meter.

4.2. Ericsson Model

To predict path loss in urban, suburban and rural areas, network planning engineers use software provided by Ericsson Company based on a model called Ericsson model. Path loss according to this model is given by [14]:

$$PL = a_0 + a_1\log_{10}(d) + a_2\log_{10}(h_b) + a_3\log_{10}(h_b)\log_{10}(d) - 3.2[\log_{10}(11.75h_r)]^2 + g(f)$$

Where, g(f) is defined by:

$$g(f) = 44.49\log10(f) - 4.78[\log(f)]^2$$

Where, f is the frequency in GHz, h_b is transmitter antenna height and h_r is receiver antenna height in meter.

The default values of these parameters (a_0, a_1, a_2 and a_3) for different terrains are given in Table 2.

Table 2. Values of parameters for Ericsson model [15]

Environment	a_0	a_1	a_2	a_3
Urban	36.2	30.2	12.0	0.1
Suburban	43.20	68.93	12.0	0.1
Rural	45.95	100.6	12.0	0.1

The values of parameters a_0 and a_1 in suburban and rural areas are based on the Least Square (LS) method [16].

4.3. COST 231 Hata Model

The Hata model is introduced as a mathematical expression to mitigate the best fit of the graphical data provided by the classical Okumura model [17]. The basic path loss equation for this COST 231 Hata model can be expressed as [18]:

$$PL=46.3+33.9\log_{10}(f)-13.82\log_{10}(h_b)-ah_m+[44.9-6.55\log_{10}(h_b)]\log_{10}(d)+c_m$$

Where, h_b is transmitter antenna height in meter.

The parameter c_m has different values for different environments like 0dB for suburban and 3dB for urban areas and the parameter ah_m is defined in urban areas as:

$$ah_m=3.20[\log_{10}(11.75h_r)]^2-4.79 \qquad \text{for } f > 400\text{MHz}$$

The value of ah_m in suburban and rural (flat) areas is given by:

$$ah_m=[1.11\log_{10}(f)-0.7]h_r-[1.5og_{10}(f)-0.8]$$

Where, h_r is the receiver antenna height in meter.

4.4. COST 231 Walfisch-Ikegami Model

This model is a combination of J. Walfisch and F. Ikegami model. The equation of the proposed model is expressed as [6]:

For line-of-sight condition

$$PL_{LOS}=42.6+26\log_{10}(d)+20\log_{10}(f)$$

And for non-line-of-sight (NLOS) condition

$$PL_{NLOS}=L_{FSL}+L_{rts}+L_{msd} \qquad \text{for urban and suburban}$$

$$PL_{NLOS}=L_{FSL} \qquad \text{if } L_{rts+}L_{msd}>0$$

Where, L_{FSL} is free space loss, L_{rts} is roof top to street diffraction and L_{msd} is multi-screen diffraction loss.

Free space loss:

$$L_{FSL}=32.45+20\log(d)+20\log(f)$$

Roof top to street diffraction:

$$L_{rts}=-16.9-10\log_{10}(w)+10\log_{10}(f)+20\log_{10}(h_{mobile})+L_{ori}$$

$$=0 \qquad \text{for } h_{roof}>h_{mobile}$$

$$L_{ori}=-10+0.345\,\Phi \qquad \text{for } 0<\Phi<35$$

$$=2.5+0.075\,(\Phi-35) \qquad \text{for } 35<\Phi<55$$

$$=4-0.114\,(\Phi-55) \qquad \text{for } 55<\Phi<90$$

Note that

$$\Delta h_{mobile}=h_{roof}-h_{mobile}$$

$$\Delta h_{base}=h_{base}-h_{roof}$$

The multi-screen diffraction loss is:

$L_{msd}= L_{bsh}+k_a+k_d \log_{10} (d) +k_f \log_{10} (f) -9 \log_{10} (f)-9 \log_{10} (B)$ for $L_{msd}>0$

$=0$ for $L_{msd}<0$

Where,

$L_{bsh}= -18 \log_{10} (1+ \Delta h_{base})$ for $h_{base}> h_{roof}$

$= 0$ for $h_{base}< h_{roof}$

$k_a=54$ for $h_{base}> h_{roof}$

$= 54-0.8 \Delta h_{base}$ for $d>0.5$ km and $h_{base}< h_{roof}$

$=54-0.8\Delta h_{base} (d/0.5)$ for $d<0.5$ km and $h_{base}< h_{roof}$

$k_d= 18$ for $h_{base}> h_{roof}$

$=18-15(h_{base}/h_{roof})$ for $h_{base}<h_{roof}$

$k_f= -4+0.7[(f/925)-1]$ for suburban or medium size cities with moderate tree density

$= -4+1.5[(f/925)-1]$ for metropolitan or urban area

Where, d is the distance between transmitter and receiver antenna in meter, f is frequency in GHz, B is building to building distance in meter, W is street width in meter, Φ is street orientation angel w.r.t. direct radio path in degree.

4.5. Stanford University Interim (SUI) Model

The SUI model is used to predict path loss in three types of environments: Type A, Type B and Type C. The basic path loss formula with correction factors is given as [6, 19]:

$PL=A+10 \gamma \log_{10} (d/d_0) +X_f +X_h +s$ for $d>d_0$

Where, d is the distance between Access Point (AP) antenna and CPE antenna in meter, d_0=100m and s is a log distributed factor that is used to account the effect for the shadow fading owing to trees and other obstacles having value between 8.2dB and 10.6dB.

The parameter A is defined as:

$A=20\log_{10} (4\pi d_0/\lambda)$

and the path loss exponent γ is given by:

$\gamma=a-bh_b+(c/h_b)$

Where, the parameter h_b is the base station antenna height in meter. This is between 10 m and 80 m. The constants a, b and c depend upon the types of terrain, that are given in Table 3. The value of parameter γ is 2 for free space propagation in an urban area, $3 < \gamma < 5$ for urban NLOS environment and $\gamma > 5$ for indoor propagation [14].

Table 3. The parameter values of different terrains for SUI model [18]

Model Parameter	Terrain A	Terrain B	Terrain C
a	4.6	4.0	3.6
b(m^{-1})	0.0075	0.0065	0.005
c(m)	12.6	17.1	20

The frequency correction factor X_f and the correction for receiver antenna height X_h for this model is expressed as:

$X_f=6.0 \log_{10} (f/2000)$

$X_h=-10.8\log_{10} (h_r/2000)$ for terrain type A and B

$X_h=-20.0\log_{10} (h_r/2000)$ for terrain type C

Where, f is the operating frequency in MHz, and h_r is the receiver antenna height in meter.

4.6. ECC-33 Model

Recently, through the ITU-R Recommendation P.529, the International Telecommunication Union (ITU) encouraged Hata-Okumura model for further extension up to 3.5GHz [20]. The tentatively proposed propagation model of Hata-Okumura model with report is referred to as ECC-33 model or Electronic Communication Committee model. In this model path loss is given by [18]:

$PL=A_{fs}+A_{bm}-G_b-G_r$

Where, A_{fs} is free space attenuation in dB, A_{bm} is basic median path loss in dB, G_b is transmitter antenna height gain factor and G_r is receiver antenna height gain factor.

These factors can be separately described and given as:

$A_{fs}= 92.4+20\log_{10} (d) +20\log_{10} (f)$

$A_{bm}= 20.41+9.83\log_{10} (d) +7.894\log_{10} (f) +9.56[\log_{10} (f)]^2$

$G_b= \log_{10} (h_b/200) [13.958+5.8[\log_{10}(d)]^2]$

When dealing with gain for medium cities, the G_r will be expressed in:

$G_r= [42.57+13.7\log_{10} (f)] [\log_{10} (h_r)-0.585]$

For large city

$G_r= 0.759h_r-1.892$

Where, d is the distance between transmitter and receiver antenna in km, f is frequency in GHz, h_b is transmitter antenna height in meter and h_r is receiver antenna height in meter.

5. Numerical Results and Discussion

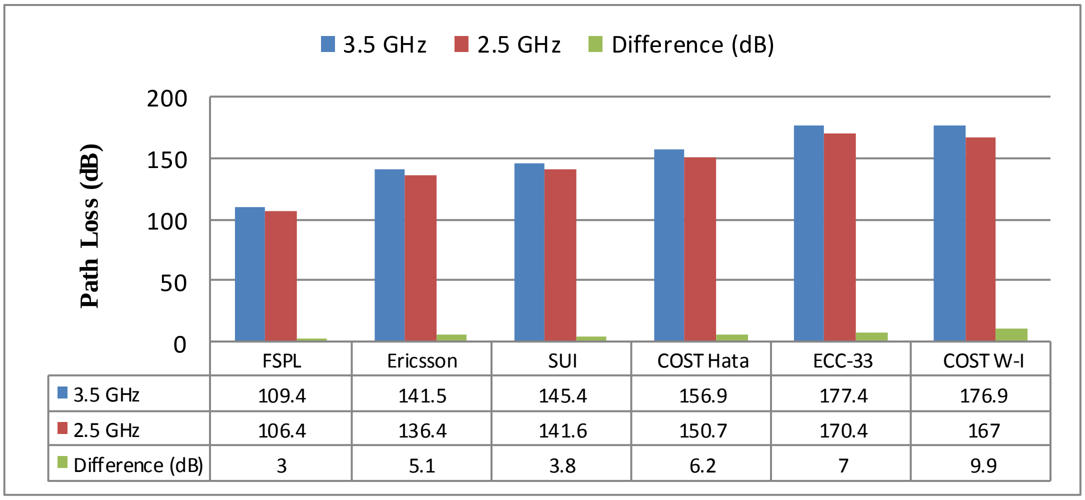
The desired WiMAX transmitter to receiver distance is varied up to 5 km and the carrier frequency is set to 2.5GHz and 3.5GHz. Here, three different receiver antenna heights (3 m, 6 m, 10 m) have been considered and all the path loss are predicted at a reference distance of 2km . The models that we worked with provided two different conditions i.e. LOS and NLOS. The simulation is carried out with MATLAB. The following table presents the parameters applied in simulation for three different environments.

Table 4. Simulation parameters

Parameter	Value
Base Station Transmitter Power	43dBm
Mobile Transmitter Power	30dBm
Transmitter Antenna Height	30 m for urban and suburban areas 20 m for rural area
Receiver Antenna Height	3 m,6 m and 10 m
Operating Frequency	2.5GHz and 3.5GHz
WiMAX Cell (BS) Distance	0.5-5 km
Street Orientation Angle	30 degree for urban and 40 degree for suburban area
Correction for Shadowing	10.6dB for urban and 8.2dB for suburban area

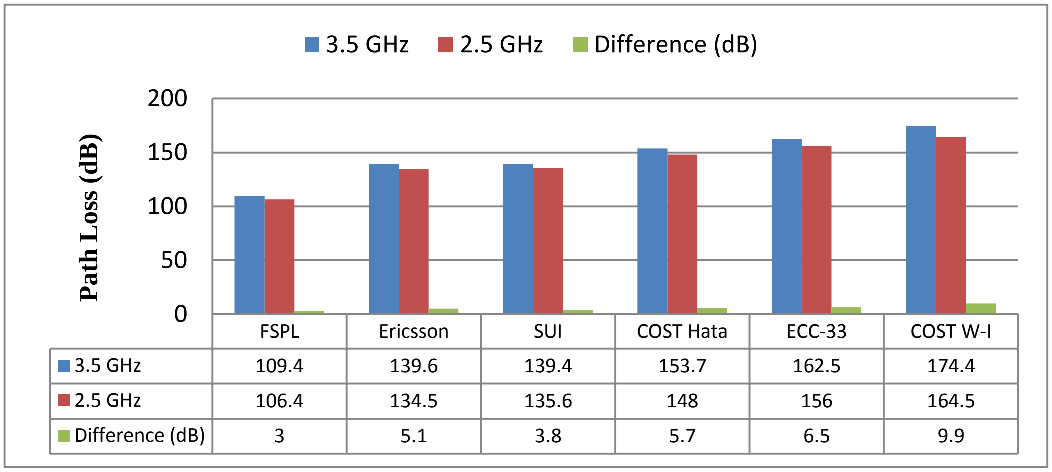
5.1. Simulation Results for Urban Area

Figure 1, Figure 2 and Figure 3 show the simulation path loss values for three different receiver antenna heights in urban environment at 2.5GHz and 3.5GHz, as well as a comparative picture of simulation results for the two frequency bands in terms of path loss difference.



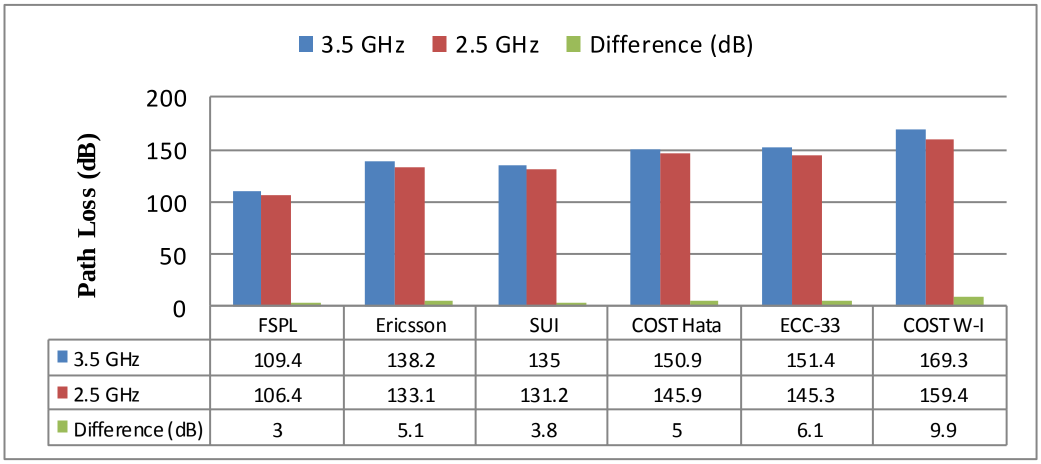
	FSPL	Ericsson	SUI	COST Hata	ECC-33	COST W-I
🟦 3.5 GHz	109.4	141.5	145.4	156.9	177.4	176.9
🟥 2.5 GHz	106.4	136.4	141.6	150.7	170.4	167
🟩 Difference (dB)	3	5.1	3.8	6.2	7	9.9

Figure 1. Comparative results for urban environment at 3m receiver antenna height



	FSPL	Ericsson	SUI	COST Hata	ECC-33	COST W-I
🟦 3.5 GHz	109.4	139.6	139.4	153.7	162.5	174.4
🟥 2.5 GHz	106.4	134.5	135.6	148	156	164.5
🟩 Difference (dB)	3	5.1	3.8	5.7	6.5	9.9

Figure 2. Comparative results for urban environment at 6m receiver antenna height



	FSPL	Ericsson	SUI	COST Hata	ECC-33	COST W-I
🟦 3.5 GHz	109.4	138.2	135	150.9	151.4	169.3
🟥 2.5 GHz	106.4	133.1	131.2	145.9	145.3	159.4
🟩 Difference (dB)	3	5.1	3.8	5	6.1	9.9

Figure 3. Comparative results for urban environment at 10m receiver antenna height

We see that, the COST W-I model shows the highest path loss prediction for all the cases of receiver antenna heights and for both cases of frequencies. The FSPL model shows the lowest path loss in all the cases due to LOS condition. In contrast, the Ericsson model shows the lowest path loss at 3m (136.4dB and 141.5dB for 2.5GHz and 3.5GHz respectively) and 6m (134.5dB and 139.6dB for 2.5GHz and 3.5GHz respectively) receiver antenna heights while it is the SUI model at 10m receiver antenna height (131.2dB and 135dB for 2.5GHz and 3.5GHz respectively) in both LOS and NLOS conditions.

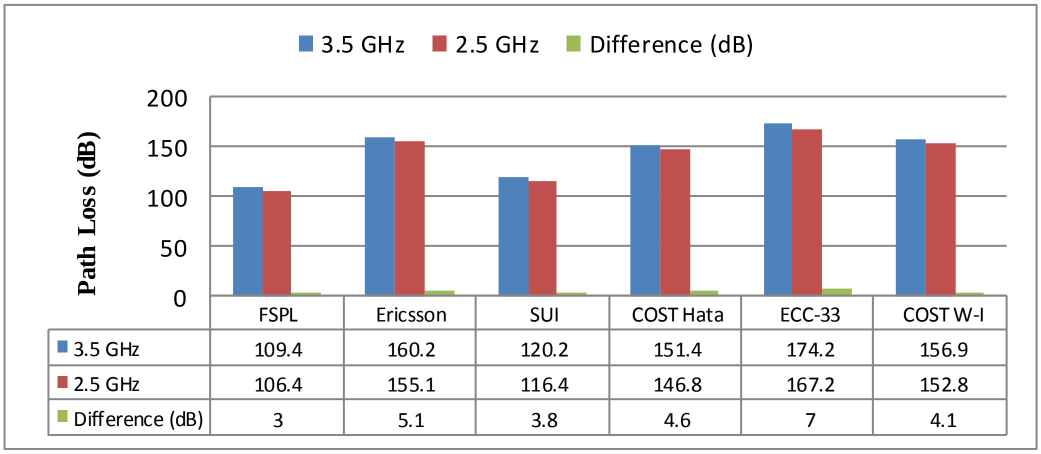
By observing these figures, the most obvious trend is that maximum path loss difference between 3.5GHz and 2.5GHz is observed by the COST W-I model (9.9dB). On the other hand, the FSPL model exhibits the lowest difference (3dB).

The second biggest trend in these figures is that FSPL, Ericsson, SUI and COST W-I models show a constant path loss difference (3dB, 5.1dB, 3.8dB and 9.9dB respectively) between 3.5GHz and 2.5GHz with changing receiver antenna heights (3m, 6m and 10m). The change of operating frequency band has a moderate influence on COST Hata and ECC-33 models. For both of these models, the difference in path loss decreases as we change the operating frequency from 3.5GHz to 2.5GHz.

It is clear from the data given that, the 2.5GHz frequency band observe less path loss than 3.5GHz frequency band for all the models and for all the different receiver antenna heights.

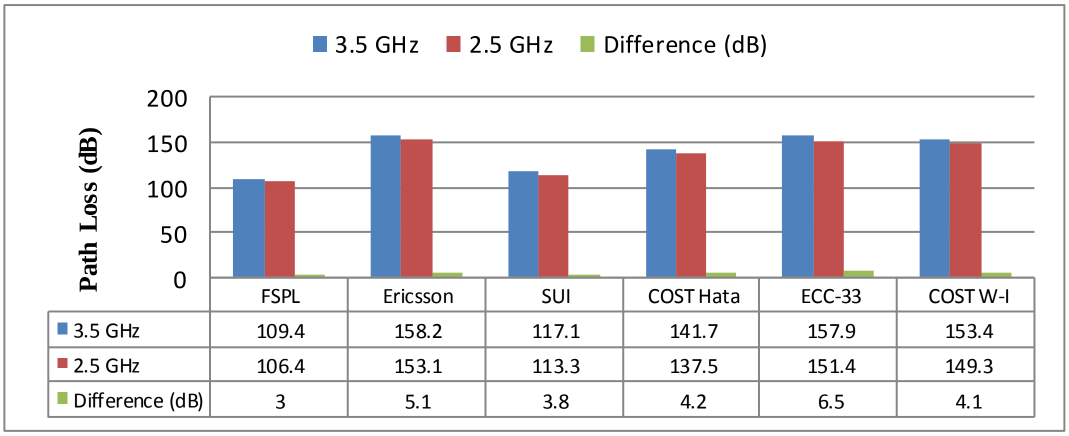
5.2. Simulation Results for Suburban Area

The variations of path loss with the change of receiver antenna height along with the change of operating frequency in suburban environment are illustrated in Figure 4, Figure 5 and Figure 6.



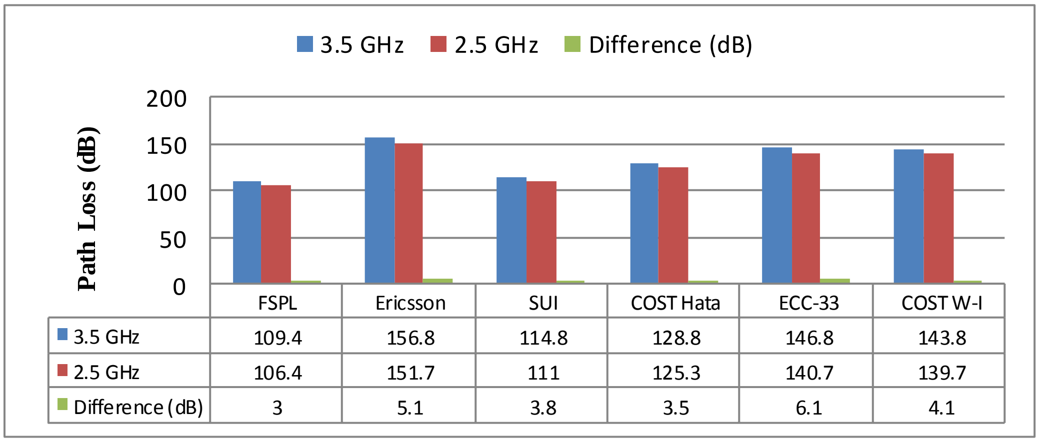
	FSPL	Ericsson	SUI	COST Hata	ECC-33	COST W-I
3.5 GHz	109.4	160.2	120.2	151.4	174.2	156.9
2.5 GHz	106.4	155.1	116.4	146.8	167.2	152.8
Difference (dB)	3	5.1	3.8	4.6	7	4.1

Figure 4. Comparative results for suburban environment at 3m receiver antenna height



	FSPL	Ericsson	SUI	COST Hata	ECC-33	COST W-I
3.5 GHz	109.4	158.2	117.1	141.7	157.9	153.4
2.5 GHz	106.4	153.1	113.3	137.5	151.4	149.3
Difference (dB)	3	5.1	3.8	4.2	6.5	4.1

Figure 5. Comparative results for suburban environment at 6m receiver antenna height



	FSPL	Ericsson	SUI	COST Hata	ECC-33	COST W-I
🟦 3.5 GHz	109.4	156.8	114.8	128.8	146.8	143.8
🟥 2.5 GHz	106.4	151.7	111	125.3	140.7	139.7
🟩 Difference (dB)	3	5.1	3.8	3.5	6.1	4.1

Figure 6. Comparative results for suburban environment at 10m receiver antenna height

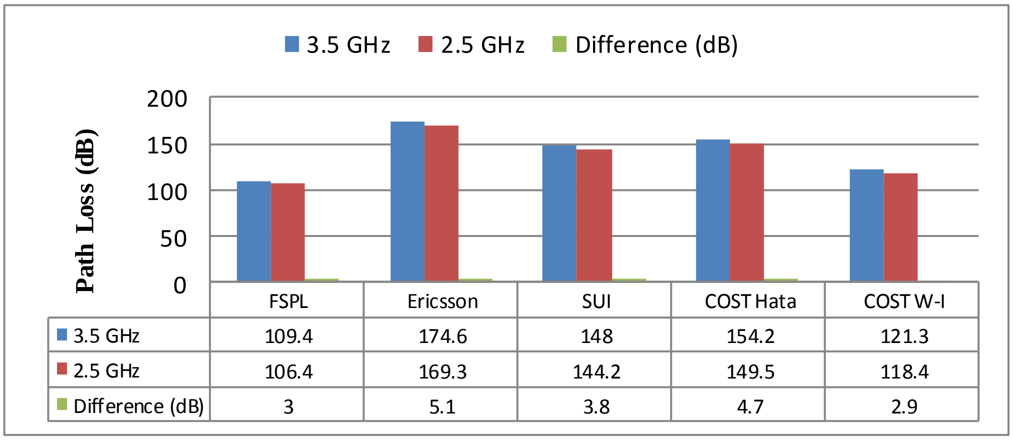
Among the colligated models, ECC-33 model predicts highest path loss (167.2dB and 174.2dB for 2.5GHz and 3.5GHz respectively) at 3m receiver antenna height in this terrain with a remarkable fluctuation of path loss while the prediction is highest for Ericsson model for both 6m and 10m receiver antenna heights with a moderate path loss fluctuation. On the other hand, prediction of path loss is lowest in the case of SUI model with a small path loss fluctuation for the same set of parameters. The COST W-I shows moderate result with little wavering of path loss relating to receiver antenna height change. The COST 231 HATA model also shows remarkable fluctuations of path loss with respect to receiver antenna height change.

In terms of path loss difference between the two operating frequencies, the ECC-33 model provides the maximum difference (7dB, 6.5dB and 6.1dB for 3m, 6m and 10m respectively) in comparison to all the other models though the minimum difference (3dB) is depicted by the FSPL model. The Ericsson model exhibits the second highest constant path loss difference (5.1dB) with SUI, COST W-I models giving moderate and constant difference. However, the COST Hata model gives gradually decreasing path loss difference with increasing receiver antenna height.

Likewise in urban environment, estimated path losses are lower at 2.5GHz compared to path losses at 3.5GHz for the three receiver antenna heights as well as for all the propagation models.

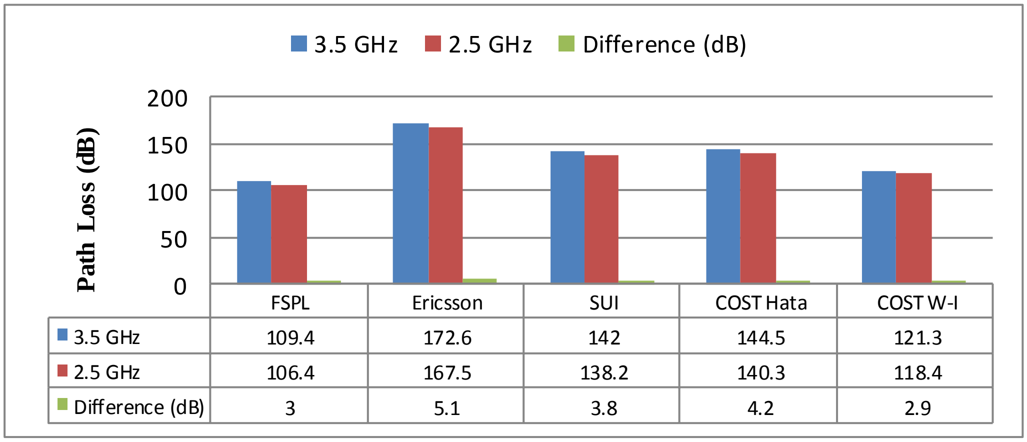
5.3. Simulation Results for Rural Area

The numerical results for different models in rural area for different receiver antenna heights and different frequency bands are illustrated in Figure 7, Figure 8 and Figure 9.



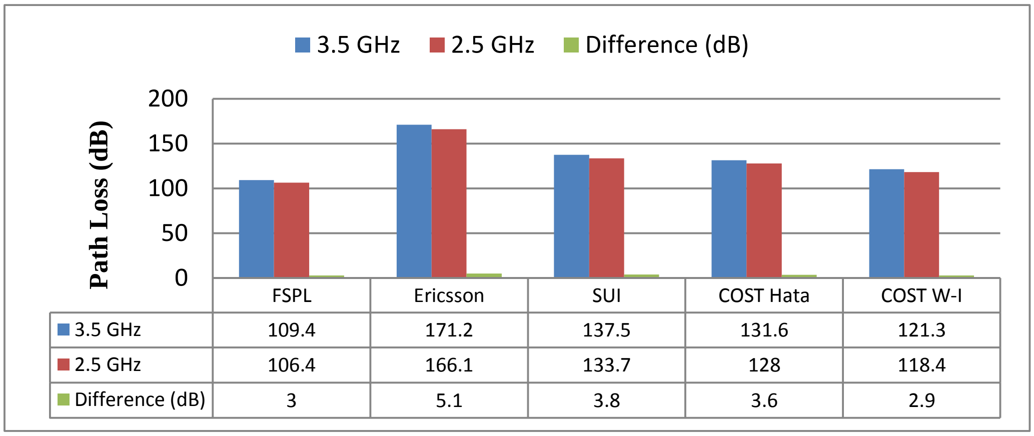
	FSPL	Ericsson	SUI	COST Hata	COST W-I
🟦 3.5 GHz	109.4	174.6	148	154.2	121.3
🟥 2.5 GHz	106.4	169.3	144.2	149.5	118.4
🟩 Difference (dB)	3	5.1	3.8	4.7	2.9

Figure 7. Comparative results for rural environment at 3m receiver antenna height



	FSPL	Ericsson	SUI	COST Hata	COST W-I
🟦 3.5 GHz	109.4	172.6	142	144.5	121.3
🟥 2.5 GHz	106.4	167.5	138.2	140.3	118.4
🟩 Difference (dB)	3	5.1	3.8	4.2	2.9

Figure 8. Comparative results for rural environment at 6m receiver antenna height



	FSPL	Ericsson	SUI	COST Hata	COST W-I
🟦 3.5 GHz	109.4	171.2	137.5	131.6	121.3
🟥 2.5 GHz	106.4	166.1	133.7	128	118.4
🟩 Difference (dB)	3	5.1	3.8	3.6	2.9

Figure 9. Comparative results for rural environment at 10m receiver antenna height

Transmitter antenna height of 20 m is considered in this case and in addition, the ECC-33 model is not applicable in rural area and the COST 231 W-I model has no specific parameters for rural area. Based on the comparison among the path loss models, the lowest path loss is predicted by FSPL and COST W-I models for the same set of parameters due to LOS condition. There is no fluctuation of path loss with respect to receiver antenna heights for these models as the probability of getting LOS condition in rural area is higher than the other two types of environments. If the area is flat enough with less vegetation, where the probability of getting LOS condition for signal is high, in that case, we may consider FSPL model for path loss calculation. Alternatively, if the LOS condition probability is low, in that situation, COST Hata model shows less path loss compared to SUI and Ericsson models especially at 10 m receiver antenna height. In contrary, Ericsson model shows highest path loss for all the three receiver antenna heights with moderate fluctuations due to receiver antenna height changes. The highest fluctuation of path loss with the change of receiver antenna height is predicted by the Ericsson model with SUI model showing moderate fluctuation compared to other models.

Analyzing the simulation results, it is seen that that maximum path loss difference between 3.5GHz and 2.5GHz is observed by the Ericsson model (5.1dB). The COST Hata model shows the second highest path loss difference with slight fluctuation as we increase the receiver antenna height. On the other hand, the COST W-I model exhibits the lowest constant difference (2.9dB). The FSPL and SUI models indicate mediocre and invariant path loss difference (3dB and 3.8dB respectively).

It is evident from the analysis that 2.5GHz frequency band performs better than 3.5GHz frequency band in terms of estimated path loss just like as in urban and suburban environments.

6. Conclusion

This paper presents an insight into the coverage study and performance evaluation of WiMAX system operating at 2.5GHz and 3.5GHz frequency bands in three different environments with the help of a simulation tool. Comparison between these two frequency bands is made in terms of path loss using some path loss models as path loss is one of the most important quantitative performance measurements indexes of a communication link.

The impact of other factors which could determine the overall performance of the network at these frequency bands is also assessed and fully explained.

Differences in the range of 3dB-9.9dB, 3dB-7dB and 3dB-5.1dB are noted in urban, suburban and rural areas respectively.

Based on the simulation results, we can conclude that 2.5GHz frequency band is the preferable choice for optimal implementation of WiMAX network. The 2.5GHz spectrum facilitates with most of the features which are necessary to compete with other concurrent wireless technologies. The range benefit of 2.5GHz band translates to a deployment advantage even in different types of environments in an interference limited scenarios.

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