Frequency Diversity Improvement Factor Using Different MIMO Techniques for Rain Fade Mitigation in South-East Asia

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Abstract:

Signal attenuation due to rain is an important barrier in the Microwave Communication field. In the terrestrial region like South-East Asia the microwave signals operating at higher frequency ranges are attenuated due to rain and other atmospheric obstacles like water vapor, ice particle etc. In this paper we have used different MIMO techniques like 2x2, 3x3 and 4x4 and also constructed a model. We study the frequency diversity improvement factor for the developed model for different fade margins using 4X4 MIMO techniques. Then we compare this study with ITU-R model. We have got the better result for prediction model using 4x4 MIMO techniques for the frequency range 50-90 GHz.

Keywords : Frequency diversity, Diversity improvement factor, Rain fade mitigation, MIMO Techniques

I.   Introduction

Rain attenuation occurs due to scattering and absorption of microwave radio frequency signal (RF signal) by rain. The water molecules of the rain drops are polarized by the electric field of the radio wave. Now the rain drop is operated as a small   electric dipole and radiates over a vast solid angle. When the rain is heavy then the drop size is large and it looks like an ellipsoidal. Thus the wave which is horizontally polarized will be more attenuated than a vertically polarized wave. When the electric field does not exist along both the axes of the rain drop then depending on the speed of the wind

this above incident also causes depolarization of the wave. Due to these reasons some countries have developed rain attenuation prediction model from 1960s. Among various models ITU-R model is very popular model and is widely used [XV].

Day by day Telecommunication technology is being developed and a reliable system with high speed and large bandwidth is needed by the increasing number of users. Reduction of signal power level by rain attenuation due to high rain rate leads to an unreliable and poor quality communication system. It is very difficult to design microwave link in the terrestrial region like Malaysia, Indonesia i.e. South–East Asia as the rain intensity is very high in these regions. Modern telecommunication technology demands higher frequency bands specifically in the microwave region but unfortunately rain has major fade attenuation at the microwave frequencies [III].

In this paper the operating microwave frequency range for communication system is considered to be in the range 50-90 GHz. At this range the propagating electromagnetic wave is highly affected by rain. We have adopted fade mitigation technique (FMT) to minimize rain fade and further incorporated multi-input multi-output (MIMO) technique to increase the performance of the communication link [I]. Using MIMO technique we develop rain attenuation predicted model and estimate the frequency diversity improvement factor. Then we compare this with the calculated frequency diversity improvement factor obtained from ITU-R model.

II.   Rain Fade Mitigation Concept

Fade mitigation technique is a countermeasure technique that minimizes the signal attenuation caused by rain in the terrestrial region and improves the space-earth link's performance. Various diversity techniques are used to overcome rain fade. Various researchers carried out their research to mitigate rain fade and to improve the signal performance [XI].

This fading problem can also be overcome by using other techniques like uplink/downlink power control, adaptive coding, adaptive modulation, data rate reduction etc. Most of the techniques are still developing. In the uplink and downlink section high power capacity is needed by the power control technique and it increases barrier on the user terminal side. As this technique estimates and coordinates a link so this introduces a delay in the system and it is good for fade mitigation in the uplink section. Adaptive coding technique increase the code rate and decreases data rate. As a result the BER (Bit Error Rate) always meet the system requirements. The diversity techniques involve time diversity, space diversity, site diversity, frequency diversity etc. The application of diversity technique requires identical sources like frequency bands, earth stations etc. This technique is efficient but in the case where a huge number of small user terminals are required it is not applicable [IX].

The figure below shows a simple link model for rain fading.

Satellite

Signal fading for uplink
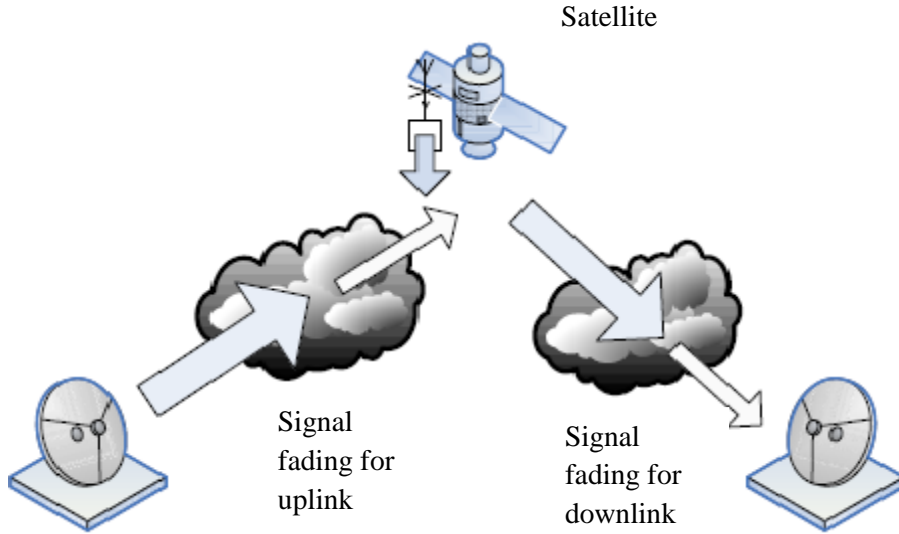
Signal fading for downlink

Fig1: A simple link model for signal fading

Fading actually occurs independently, i.e. it occurs at different uplink and downlink location. The separate uplink and downlinks are governed by the following link equation:

$$C_O/N_O = EIRP_O + G_O/T_O - 10Log10 (K) - Loss - Fade \text{ [dB]} \tag{1}$$

Where C_O/N_O is the carrier to noise power ratio. $EIRP_O$ is the effective isotropic radiated power of the transmitter. G_O/T_O is the gain to noise temperature at the receiving antenna. K is the Boltzmann's constant. Loss is the free space loss. Fade is the loss from channel fading. Fading mitigation requires manipulation of one of the parameters in above basic link equation [XII].

III.   Concept of Frequency Diversity Improvement Factor

The performance of frequency diversity may be described in terms of outage percentage of time. The frequency diversity improvement factor I_{FD} (P) is defined as the ratio between the outage percentages of time with a specific fade margin without diversity P_{WD} (A) and the outage percentage of time with the same fade margin at the diversity frequency P_D (A). It is represented by the following equation [XI]:

$$\mathbf{I_{FD} (P) = P_{WD} (A)/P_D (A)} \tag{2}$$

Percent of
Time, p

P_{WD}

$I_D(A)$

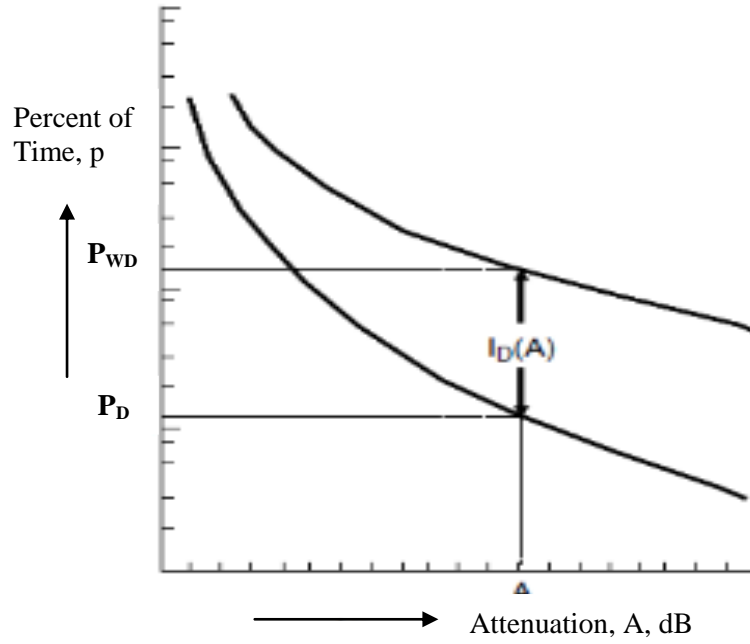P_D

A

Attenuation, A, dB

Fig2: Diagram for frequency diversity improvement factor

IV. Progress of Frequency Diversity Improvement Factor Model

Here the proposed model is for 10 GHZ separation and the frequency range is 50-90 GHz. We have used here different MIMO techniques like 2x2, 3x3 and 4x4 and then plotted the graph of outage percentage vs. specific rain attenuation using ITU-R model[IV][XIII] given by the equation-

$$\gamma_R = kR_{\%P}{}^{\alpha} \text{ dB/km}$$

Here k and α denote the scattering co-efficient. $R_{\%P}$ is the rain rate at P outage percentage. In South-East-Asia the measured rain rate is 118-120 mm/hr at 0.01%. This is used to predict the different rain attenuation for 50-90 GHz and for different MIMO techniques using equation (2) and these graphs are shown below-
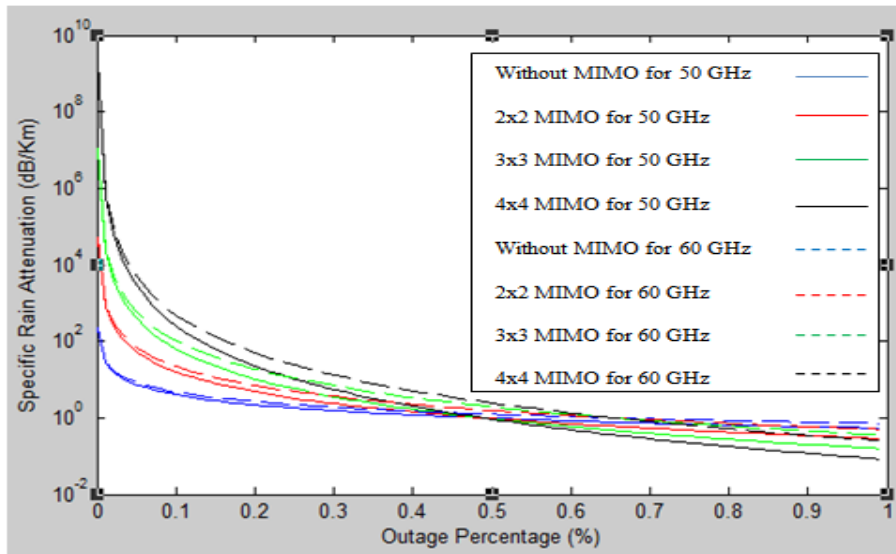
Fig3. Specific rain attenuation (dB/Km) predicted for 50 GH and 60 GHz based on measured rain rate in South-East Asia.
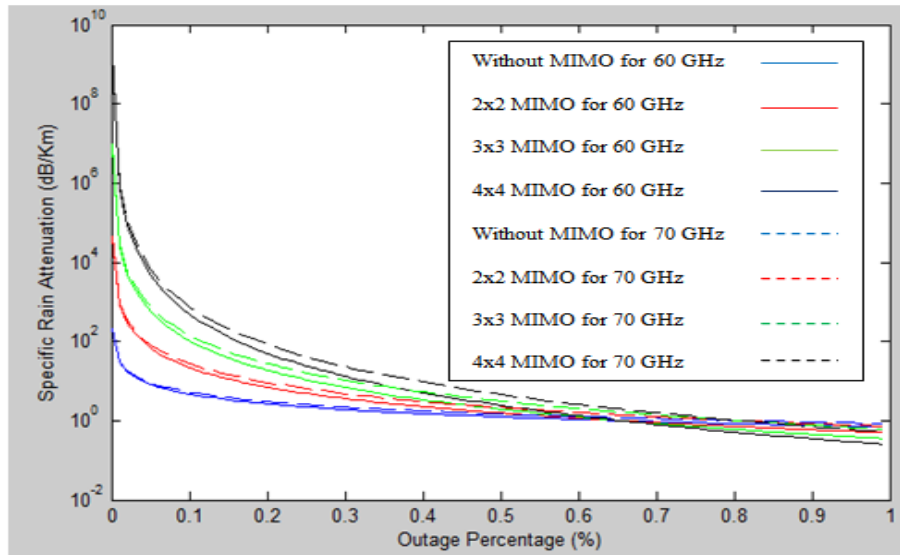

Fig.4. Specific rain attenuation (dB/Km) predicted for 60 GH and 70 GHz based on measured rain rate in South-East Asia.
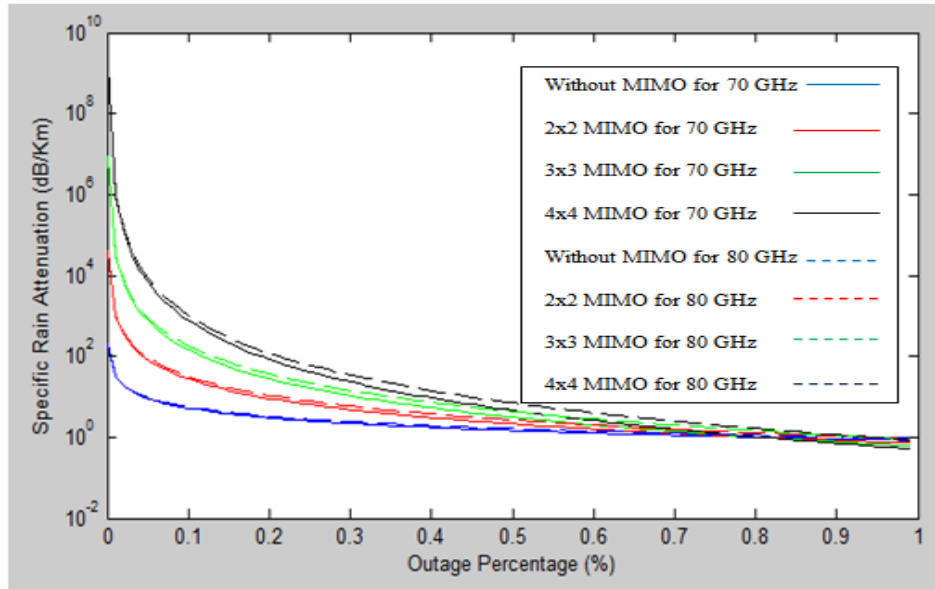
Fig.5. Specific rain attenuation (dB/Km) predicted for 70 GH and 80 GHz base on measured rain rate in South-East Asia.
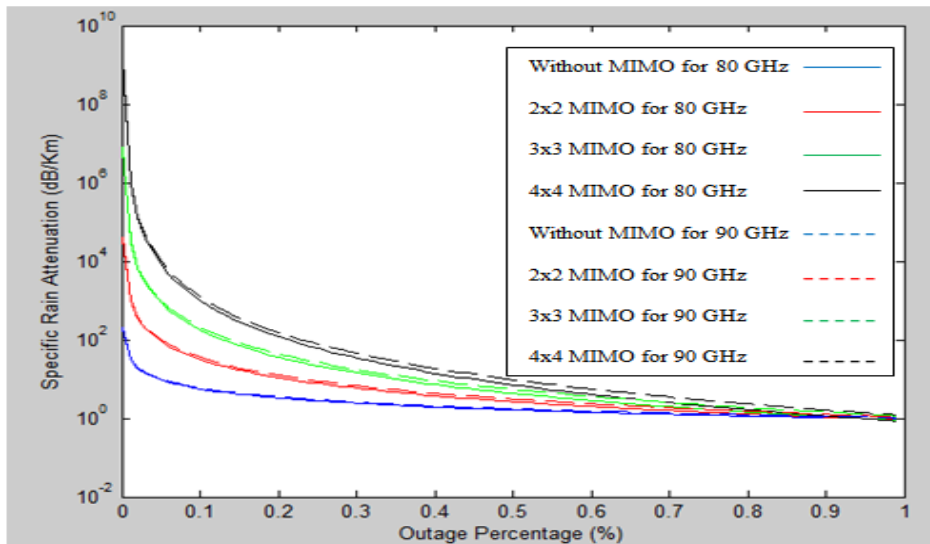

Fig.6. Specific rain attenuation (dB/Km) predicted for 80 GH to 90 GHz based on measured rain rate in South-East Asia.

All the above graphs show the variation of outage percentage with respect to the specific rain attenuation for different MIMO techniques and the corresponding fade margin is required for the system. For 10GHz frequency separation we apply the

equation (2) to the above graphs shown in Fig 3, Fig 4, Fig 5 and Fig 6 at different fade margins from 10dB/Km to 14dB/Km. Then the estimated Improvement Factors are presented in the table 1depicted below : --

f_d (GHz)	f_b (GHz)	Different Techniques	IMPROVEMENT FACTOR				
			10 dB	11 dB	12 dB	13 dB	14 dB
50	60	Without MIMO	1.40	1.58	2.00	2.48	2.62
		2X2 MIMO	1.37	1.42	1.68	1.76	1.86
		3X3 MIMO	1.33	1.38	1.56	1.68	1.78
		4x4 MIMO	1.26	1.30	1.48	1.52	1.62

f_d (GHz)	f_b (GHz)	Different Techniques	IMPROVEMENT FACTOR				
			10 dB	11 dB	12 dB	13 dB	14 dB
60	70	Without MIMO	1.35	1.48	1.85	2.12	2.32
		2X2 MIMO	1.25	1.39	1.66	1.69	1.76
		3X3 MIMO	1.21	1.36	1.44	1.58	1.64
		4x4 MIMO	1.17	1.25	1.36	1.48	1.54

f_d (GHz)	f_b (GHz)	Different Techniques	IMPROVEMENT FACTOR				
			10 dB	11 dB	12 dB	13 dB	14 dB
70	80	Without MIMO	1.27	1.42	1.78	1.82	2.14
		2X2 MIMO	1.12	1.34	1.56	1.63	1.68
		3X3 MIMO	1.09	1.32	1.34	1.46	1.58
		4x4 MIMO	1.08	1.12	1.28	1.33	1.42

f_d (GHz)	f_b (GHz)	Different Techniques	IMPROVEMENT FACTOR				
			10 dB	11 dB	12 dB	13 dB	14 dB
80	90	Without MIMO	1.26	1.38	1.66	1.76	1.92
		2X2 MIMO	1.11	1.31	1.48	1.58	1.54
		3X3 MIMO	1.05	1.22	1.27	1.38	1.44
		4x4 MIMO	1.03	1.04	1.14	1.28	1.36

Table1: Improvement factor from definition with 10 GHz separation

From the above table we have plotted the frequency vs. Improvement factor graphs for without and with MIMO (2X2,3X3,4X4) Techniques at different fade margins like 10 dB,11 dB,12 dB, 13 dB and 14 dB.
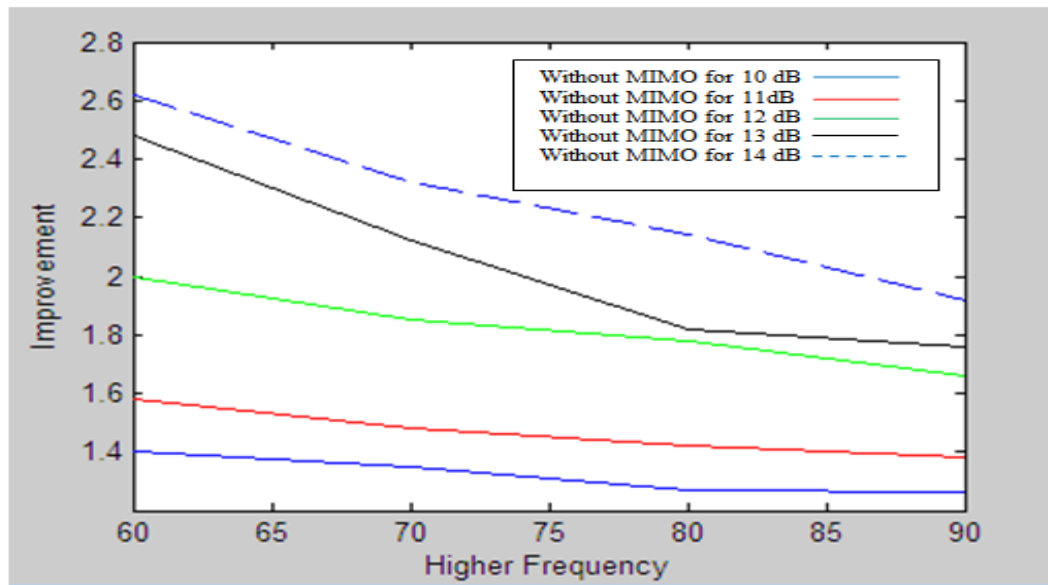
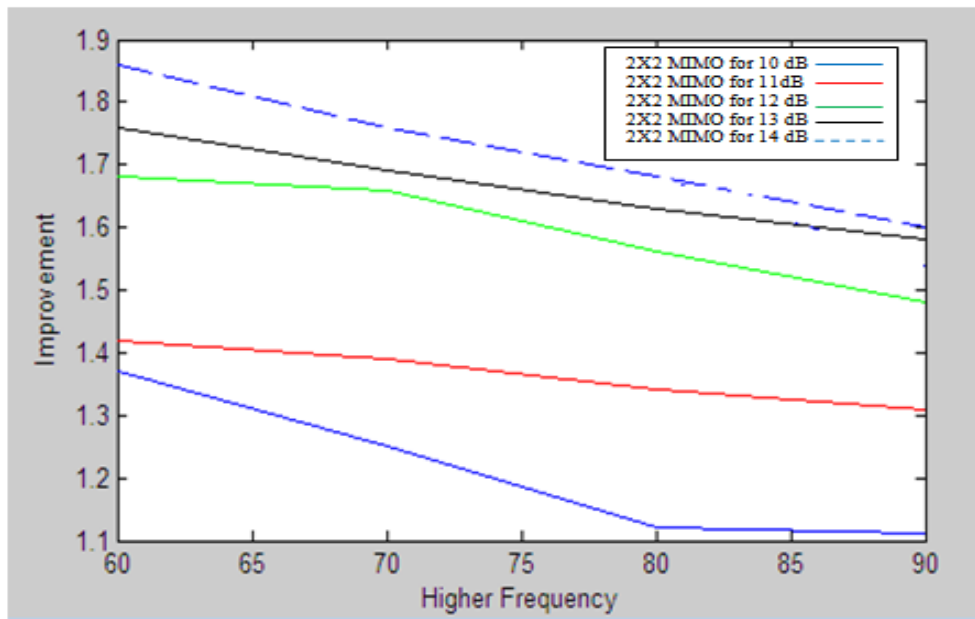Fig7: Improvement factor for 10 GHz separation in frequency diversity scheme for without MIMO Techniques

Fig 8: Improvement factor for 10 GHz separation in frequency diversity scheme for2x2 MIMO Techniques
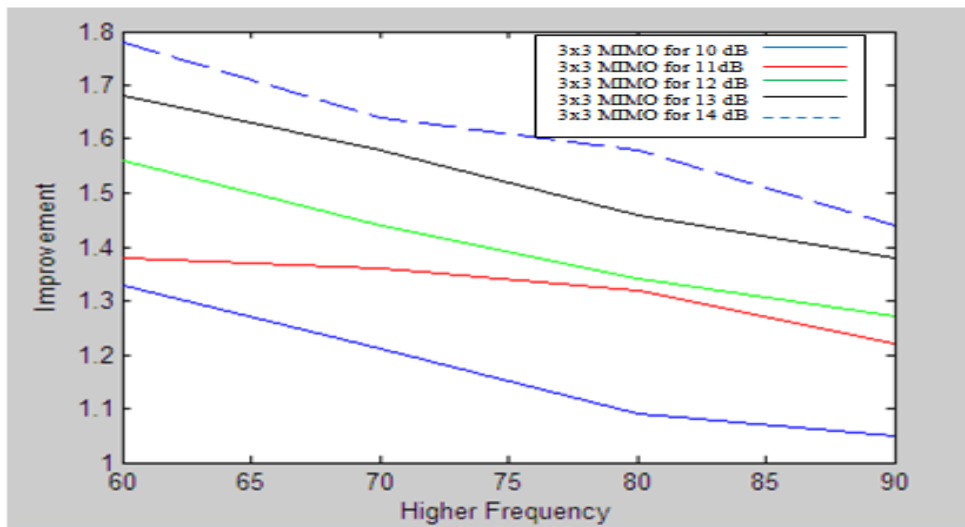

Fig9: Improvement factor for 10 GHz separation in frequency diversity scheme for 3x3 MIMO Techniques
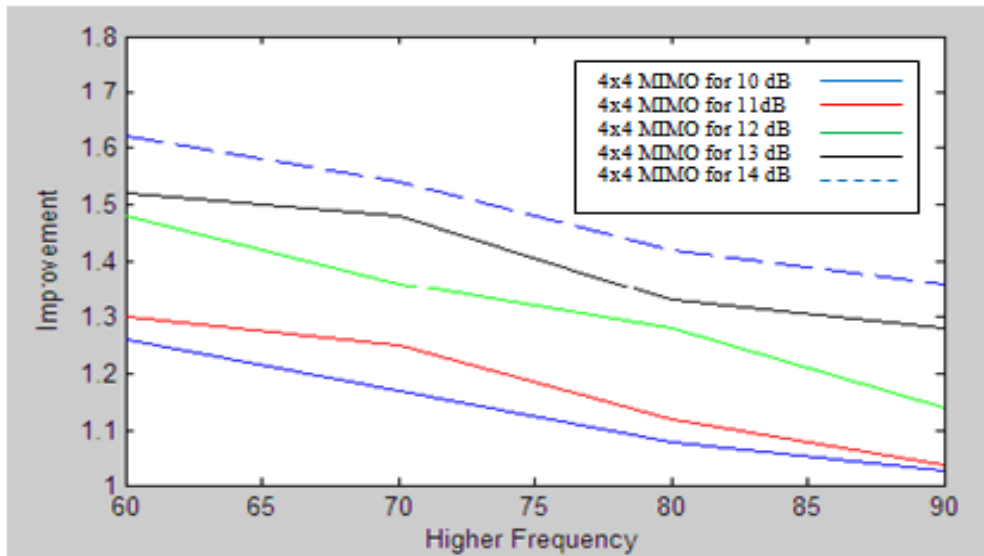
Fig10: Improvement factor for 10 GHz separation in frequency diversity scheme for 4x4 MIMO Techniques

From the above figure it is observed that diversity improvement factor is lowest at 4x4 MIMO Techniques. So we use 4x4 MIMO Techniques to design a new predicted model. To develop a prediction model, each graph of Fig. 7, Fig 8, Fig 9 and Fig 10 reflects an equation between the diversity Improvement factor and the diversity frequency. To establish a model consisting of these equations, all the curves are fitted with respect to the fade margin (F) as shown in Fig.11
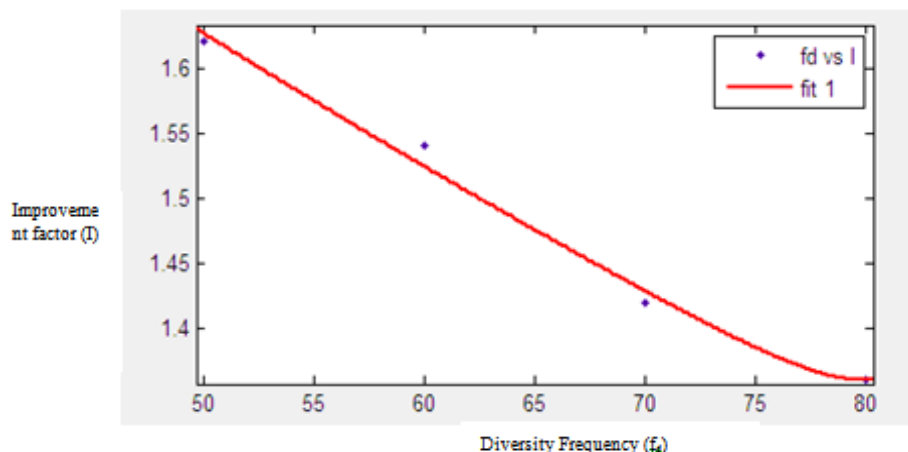

Fig11: Estimated improvement factor fitting at 12dB/Km fade margin

The above figure 11 shows a simple frequency diversity improvement model and is represented by the following equation-

$$I = ae^{\wedge}(f_d\, b) + ce^{\wedge}(f_d\, d) \tag{3}$$

Where a, b, c and d are fading related coefficients. Each co-efficient has a specified value for different fade margins. These values are given in the following table 2. The co-efficient a, b, c and d are also plotted in figure 12.

F dB/Km	a	b	c	d
10	1.854	-0.00771	6.736exp(-017)	0.4213
11	2.175	-0.00931	-1.29exp(+012)	-0.6123
12	-6.897exp(-017)	0.4263	2.125	-0.007299
13	2.289	-0.007427	-1.613exp(+013)	-0.6649
14	2.255	-0.006524	2.674exp(-017)	0.4292

Table 2: Model co-efficient

F (dB/Km)
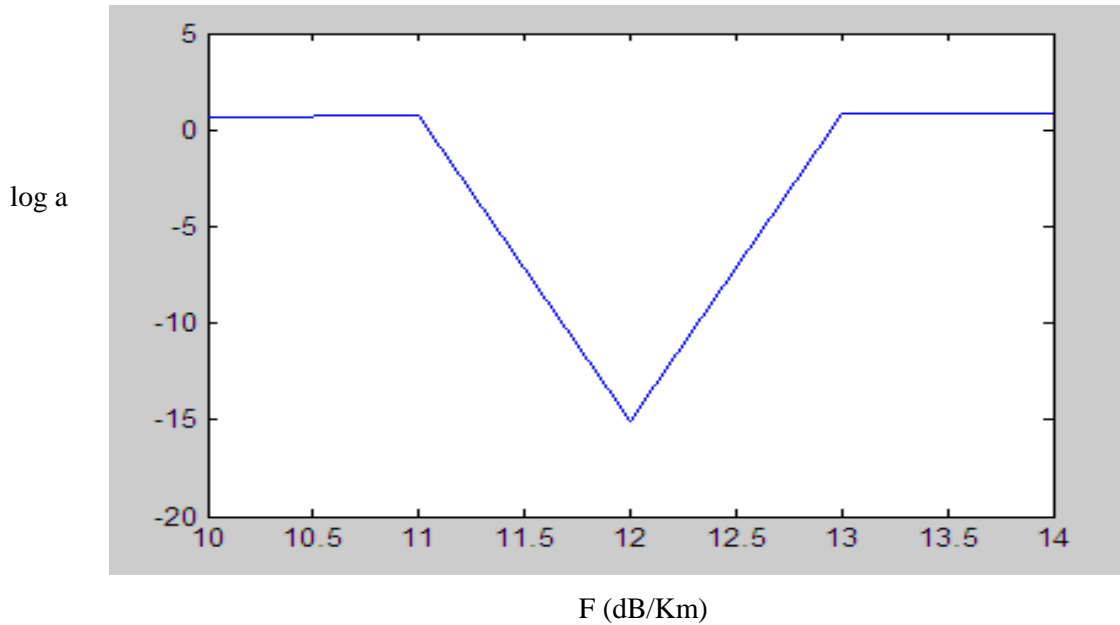
Fig 12(a) plot of co-efficient a
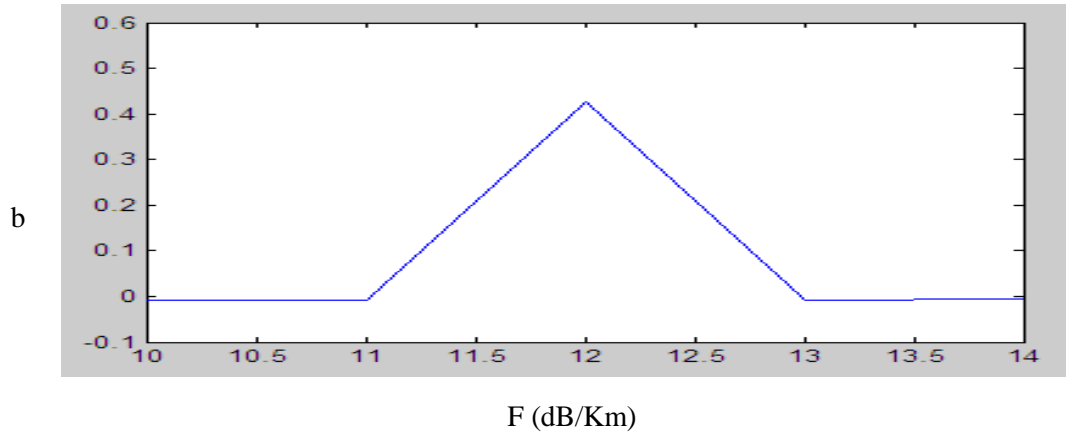
F (dB/Km)

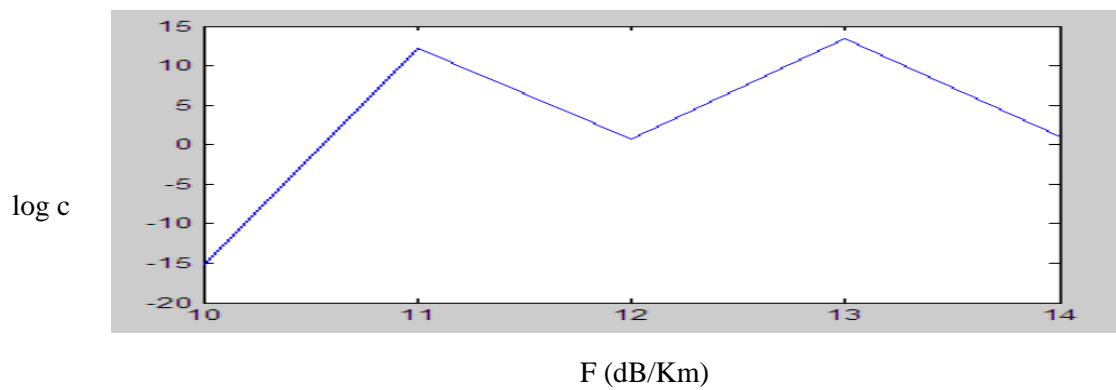Fig12 (b) plot of co-efficient b

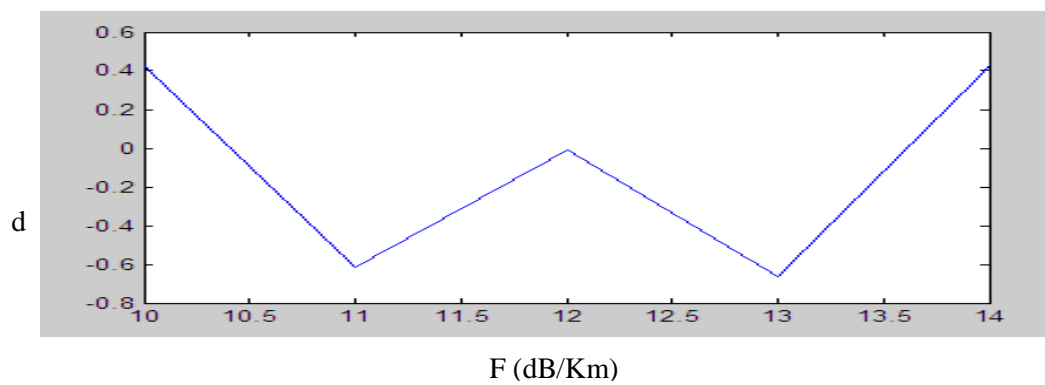F (dB/Km)

Fig12 (c) plot of co-efficient c

F (dB/Km)

Fig12 (d) plot of co-efficient d

Now the predicted improvement factors model for the same specific rain attenuation using equation (3) are shown in Fig 13 below
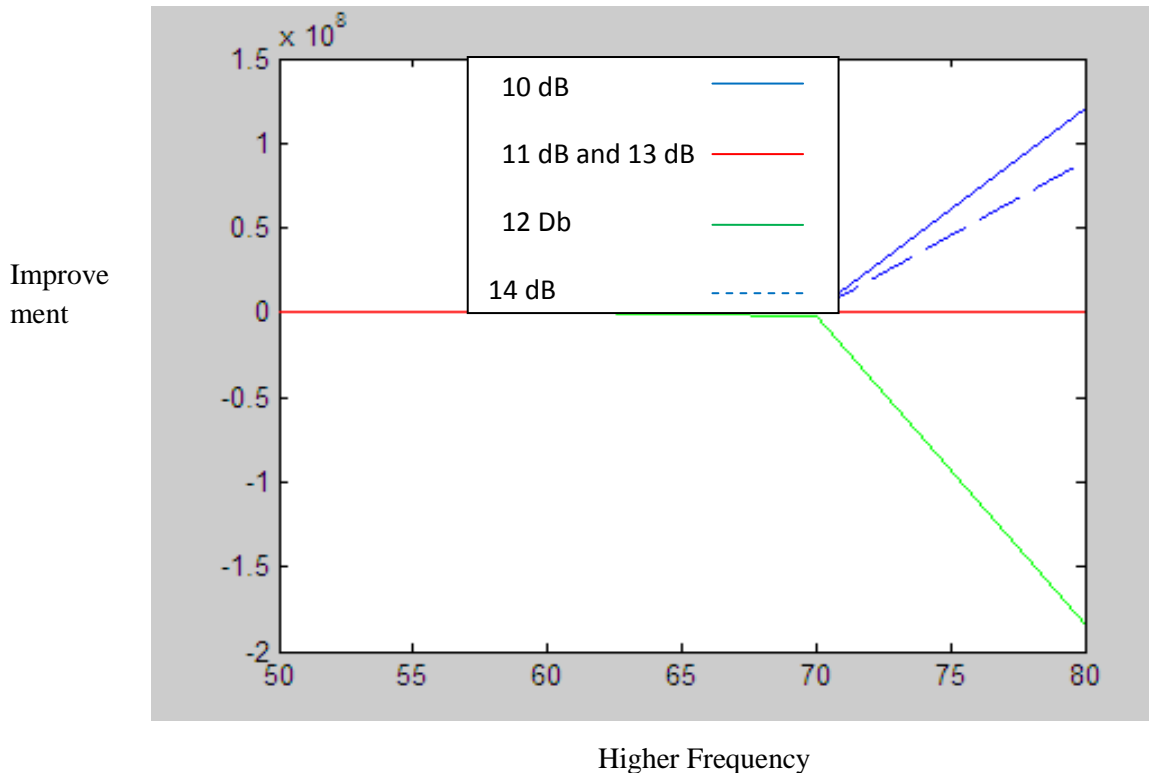
Improve
ment

Higher Frequency

Fig 13: Diversity improvement factor based on proposed model

From the above figure 13 it is observed that the fade margin effect can be divided in to two parts. Up to 70 GHz there is no change of improvement for any fade margin. Above 70 GHz the improvement is minimum for 12 dB fade margin and at 11dB, 13 dB, 14 dB fade margin the improvement is less than the improvement at 10 dB fade margin.

V. Verification

If we compare figure 14 with the figure 7, figure 8, figure 9 and figure 10 then it shows the difference between the improvement factors for calculated value and predicted value. The improvement factor for the predicted model gives the better result than the improvement factor for calculated value obtained from ITU-R model for both 12 dB and 13 dB. This difference is due to the non-linear co-efficient of the predicted model. We may repeat this process for other fade margins. This verification is also supported for measured rain attenuation from 5-40 GHz. [III].
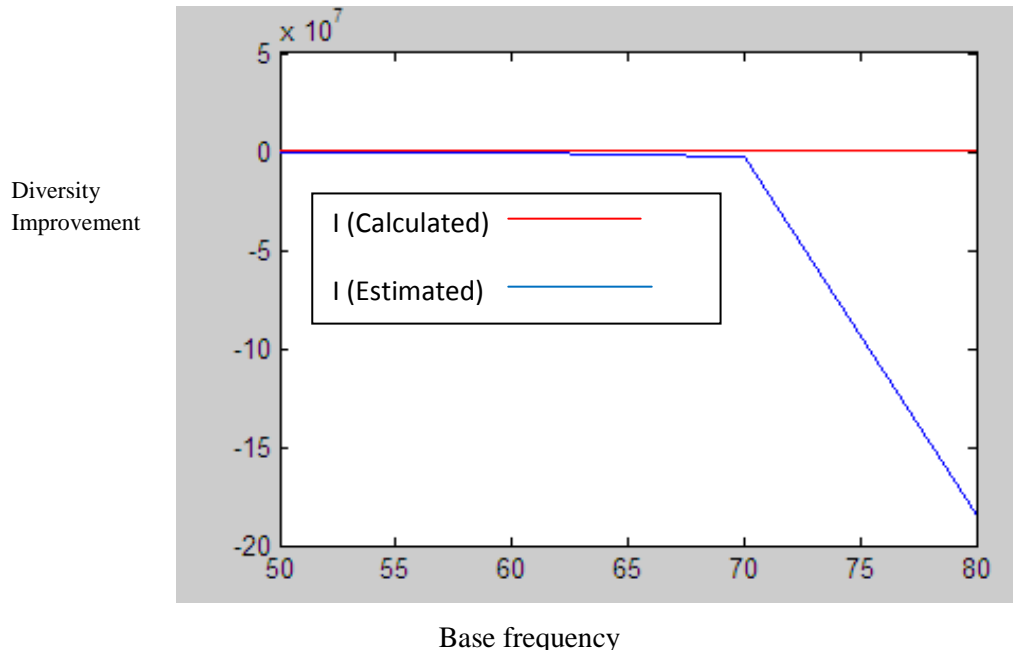
Diversity Improvement

Base frequency

Fig14 (a): Predicted and estimated frequency diversity improvement factor at12 dB/Km
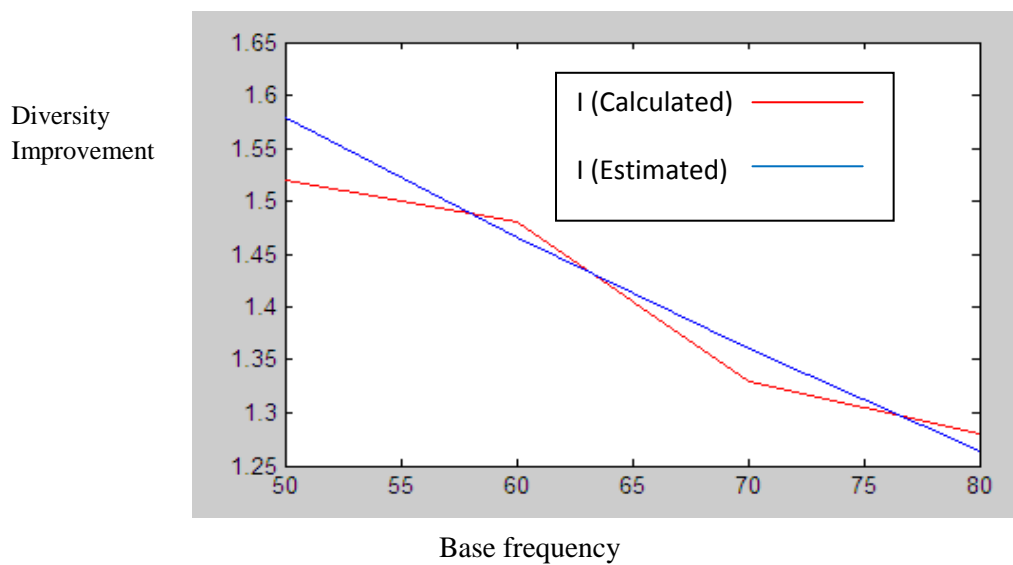

Diversity Improvement

Base frequency

Fig14 (b): Predicted and estimated frequency diversity improvement factor at13 dB/Km

VI. Conclusion

Here we design a model for frequency diversity improvement factor and the frequency diversity can be executed using this model for 10 GHz frequency separation based on the fade margin required for the system design. From the above

figures and tables it is clear that when we use the MIMO system then it gives the better result than without MIMO system. The diversity improvement factor is less when we use the MIMO system rather than without MIMO system. Among 2x2, 3x3 and 4x4 MIMO system 4x4 MIMO system gives the best result i.e. the improvement factor is less. If the improvement factor is less then the outage of the system will be less and the link failure will be less. So the signal transmission will be better. This model will be very useful tool to design a microwave link in the tropical countries where the rain intensity is very high like Malaysia, Indonesia, south –East –Asia etc.

References

I.   Charilaos, I.K. and Athanasios, D.P. ''Multi Satellite MIMO Systems at Ka Band and Above: Outage Capacity Analysis Using Bivariate IG Distribution''. IEEE 8th European conference on Antenna and propagation (EuCAP), The Hague, Netherlands, 6-11 April (2014).

II.   Hodge, B. D. ''An Improved Model for Diversity Gain On Earth-Space Propagation Paths''. Radio Sci., Volume 17, No.6, pp- 1393–1399(1982).

III.   Islam, M.R.; Altajjar, L.M; Rashid, M.M and Bashar, L.K. ''Frequency Diversity Improvement Factor for Rain Fade Mitigation in Malaysia'' IEEE international WIE conference on electrical and computer engineering, BUET, Dhaka, Bangladesh, 19-20 Dec (2015).

IV.   ITU-R (2012). Propagation Data And Prediction Methods Required For the Design of Terrestrial Line-of-Sight Systems. ITU-R P.530-14.

V.   ITU-R (2013) Propagation Data And Prediction Methods Required For the Design Of Earth-Space Telecommunication Systems. ITU-R P.618/11.

VI.   Islam, M.R; Chebil, J and Tharek, A.R. "Frequency Scaling of Rain Attenuation From 23- To 38-GHz Microwave Signals Measured In Malaysia", Proceedings of Asia Pacific Microwave Conference (APMC), Singapore, 30 Nov – 3 Dec (1999).

VII.   Kesavan, U; Tharek, A.R; Rahim, S.K.A & Islam, M.R. "Review of Rain Attenuation Studies in Tropical and Equatorial Regions in Malaysia – An Overview", Antennas and Propagation Magazine, IEEE, Volume: 55, No. 1, pp. 103-113 (2013).

VIII.   Laster, J.D and Stutzman, W.L. ''Frequency scaling of rain attenuation for satellite communication links''. IEEE Transactions on Antennas and Propagation, vol-43,No (11),pp-1207-1216 (1995)

IX.   Majithiya, P; Sisodia, K.A; Muralidhar, V and Garg, K.V. ''Novel down link rain fade mitigation technique for Ka-band multi beam systems'' International journal of Satellite communication and networking, Wiley InterScience, pp-45-51(2006).

X.   Pan, Q. W., Allnutt, J. E., and Tsui C. ''Evaluation of Diversity and Power Control Techniques for Satellite Communication Systems in Tropical and Equatorial Rain Climates''. IEEE Transactions on Antennas and Propagation, Vol. 56, No. 10(2008).

XI.   Patra, T and Sil, S ''Frequency Diversity Improvement factor for Rain Fade Mitigation Technique for 50-90 GHz in tropical region'' IEEE conference (IEMECON), Thailand, 16-18 August (2017).

XII. Saam, J.T. ''Protocols for Rain Fade Mitigation Using Simultaneous X/Ka Communications'' published in IEEE military communication conference, San Jose, CA, USA.,31ST -3RD Nov(2010)

XIII. Sachdeva, N and Sharma, D. ''Diversity: A Fading Reduction technique''. IJARCSSE, Volume 2, No. 6, pp-58-61 (2012).

XIV. Segal, B "Rain Attenuation Statistics for Terrestrial Microwave Links in Canada", Commun. Res. Centre Rep.No. 1351-E, Ottawa, Canada, pp. 14, Jan. (1982).

XV.   Tamrakar, M; Bandyopadhyay, K and De, A ''Comparison of Rain Attenuation Prediction Models with Ku-Band Beacon Measurement for Satellite Communication System'' IEEE international conference on signal processing and communication (SPCOM), Bangalore, India, 18-21 July (2010).