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FADE MARGINS PREDICTION FOR BROADBAND FIXED WIRELESS ACCESS (BFWA) FROM MEASUREMENTS IN TROPICS

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Abstract—The fade margins for 15, 23, 26 and 38 GHz frequency bands are predicted based on one-minute rain rate measurements for four years at Universiti Teknologi Malaysia (UTM) Skudai and the specifications of the given four MINI-LINKS. The availabilities of terrestrial microwave links are also investigated based on rain attenuation data collected from seven operational microwave links at 15 GHz and one at 23 GHz for more than one year. The fade margins for all eight links are measured based on the rain attenuation data collected with different hop lengths. In this paper, the feasibility to design outage-free wireless broadband radio link also highlighted. These results will contribute to the better design of outage-free Broadband Fixed Wireless Access (BFWA) system such as, Local Multipoint Distribution Service (LMDS) and IEEE802.16 in tropical regions.

1. INTRODUCTION

Cellular planned systems are usually used to deliver integrated multimedia services such as Video on Demand (VoD), High-speed Internet Access, Digital Telephony, Video Conference, High Definition Television (HDTV), Tele-medicine, Tele-education, etc. They are termed as Broadband Fixed Wireless Access (BFWA) or Local Multipoint Distribution Service (LMDS) and are a promising wireless solution to connect fixed users to the backbone network instead of broadband wired networks (Digital Subscriber Line (DSL), Cable TV (CATV), Hybrid Fiber Coax (HFC), Fiber To The Curb (FTTC), Fiber To The Home (FTTH)) due to their cost efficiency, easy

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and fast installation, and re-configurability. They are designed to deliver broadband services from a central transmitter (Base Station) to individual subscribers within its cell size, thus employing a Point to Multi-Point (PMP) transmission technique on the downlink while on the uplink, Point-To-Point (PTP) is employed [1].

Since, there is a growing interest in providing broadband services to individual users (households and businesses) through local access networks [2], the IEEE Computer Society and Microwave Theory and Techniques Society have developed a BFWA standard within their 802.16 working group. The scope includes P-MP systems operating in the frequency range 10–66 GHz and includes both the Physical and MAC layers [3, 4].

For the wireless broadband link operating at frequencies higher than 10 GHz, rain-induced degradations are significant [5, 6]. The severity of rain impairment increases with frequency and varies with regional locations [7]. Hence rain study is very important for frequencies as low as about 7 GHz especially for tropical and equatorial countries that experience high rainfall rate throughout the year such as in Malaysia [8, 9]. Major degradations caused by rain that affect the reliability and availability of terrestrial links are rain attenuation [10]. Besides attenuation, rain fade is another major factor affecting the performance of microwave links. Rain fade is the dynamic fluctuation of receive signal due to in homogeneities of the signal path, ranging from a few seconds to a few minutes. Rain fade provides additional information on understanding the characteristics of rain-induced degradations. Therefore, it is very vital for communication engineers to know link performance factors to design microwave links that meet performance expectations such as system availability and reliability in the given environment [11]. Link budget calculations are used to determine the placement of network elements. Link budget is the difference between transmit power and receiver sensitivity and indicates the amount of attenuation while still supporting communication. Fade margin is a design cushion allowance for fluctuations of the received signal's strength.

There are many methods which permit to estimate rain attenuation on radio link paths. The most popular are the ITU-R models [12–14]. Researchers use ITU-R model for more convenience and effectiveness.

For fade margins prediction, four experimental links were installed at UTM Skudai campus. The 23, 26 and 38 GHz links were installed on April 2001 and the 15 GHz link was on January 2003. All links are set up between Wireless Communication Research Lab (WCRL) and the Celcom Tower, the distance of which is close to 350 meter.

The rain attenuation data were collected from seven 15 GHz and one 23 GHz operational microwave links of DiGi Telecommunications and three microwave links at 7 GHz of Binariang.

The rain rate data were measured for three years at UTM Kuala Lumpur campus using OSK rain gauge. The same were collected for four years at UTM Skudai campus using Casella rain gauge and one and a half year using OSK rain gauge. Both are tipping bucket type and having 0.5 mm sensitivity. Casella records the total rainfall occurring in each minute without recording non-raining time. Therefore the rain rate from Casella is recorded as integral multiple of 0.5 mm/min or 30 mm/hour. On the other hand, OSK records the exact tipping time up to decimal of seconds.

In this paper, we have estimated the required fade margin for broadband link installed in UTM Skudai campus based on the rain data collected over several years. Along with this, we have calculated the rain induced attenuation using ITU-R model and compared it with measurements. These results will help to design broadband wireless link which will ensure link availability and reliable communication during rain events and Quality of Service (QoS) for the end-user.

2. PREDICTION OF RAIN FADE FOR MINI-LINK E

Four experimental microwave links at 15, 23, 26 and 38 GHz were installed at UTM Campus in Johor Bahru, Malaysia. The rain rates were measured for four years at the same location with one minute integration time and are given in Table 1. The maximum transmit power, antenna gain and receive signal threshold for 10^{-6} BER with 2×2 Mbs traffic for all four experimental links are given in Table 2.

Now the receive signal level (RSL) for any terrestrial line-of-sight microwave link can be expressed as follows [15]

$$RSL = P_t + G_t + G_r - FSL - A_g - A_R - A_W - L_r - L_t \qquad (1)$$

where P_t is transmit power, L_t is the loss in transmit systems, G_t is the transmit antenna gain, FSL is free space loss, A_g loss in gaseous absorption, G_r is the receive antenna gain, L_r is the loss in receive systems, A_R is the excess attenuation due to rain on propagation path, A_W is the wet antenna loss on both antennas during rain, i.e., $(A_{W1} + A_{W2})$.

Table 1. Measured rainfall rate at UTM.

% of Time Rain Rate Exceeded	0.1	0.01	0.001
Measured Rain Rate in mm/h	59	125	175

Table 2. Specifications of four MINI-LINKS E.

Frequency Bands in GHz	Maximum Transmit Power in dBm	10^{-6} BER (2×2 Mbs) Receive Threshold	Antennas for both Transmit & Receive Side	
			Size	Gain
15	+18.0	−84.0 dBm	0.6m	37.0 dBi
23	+20.0	−83.0 dBm	0.6m	40.2 dBi
26	+18.0	−82.0 dBm	0.6m	41.0 dBi
38	+15.0	−79.0 dBm	0.6m	44.9 dBi

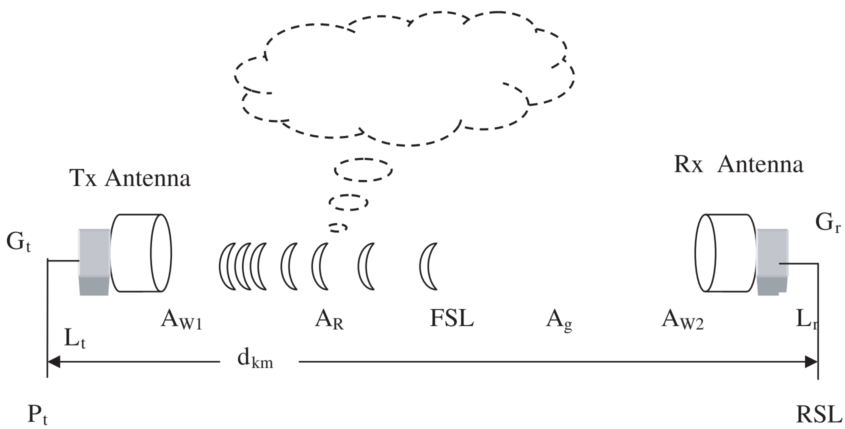


Figure 1. Link budget for a terrestrial line-of-sight radio link.

All the terms mentioned in (1) is expressed in dB and can be understood from Fig. 1. Among all the factors Free Space Loss, loss in gaseous absorption and excess attenuation due to rain depend on the propagation path length, frequency of operation and the location of the link. Free space loss can be derived from the following expression [15]

$$FSL \text{ (in, dB)} = 32.4 + 20\log_{10}(d_{\text{km}}) + 20\log_{10}(F_{\text{MHz}}) \qquad (2)$$

where the path length is in km and frequency is in MHz.

Now the excess attenuation due to rain can be predicted using measured rain rate with different percentage of time as follows

$$A_{\text{rain}} = \alpha R^{k}_{\%P} r_{\%P} d_{\text{km}} + A_W \qquad (3)$$

where, $R_{\%P}$ and $r_{\%P}$ are the measured rain rate in mm/h and the reduction factor proposed for Malaysia at the same percentage of time. The $r_{\%P}$ is also a function of path length d. The parameters α and

k are dependent on frequency and polarization of the microwave. The term A_W is the total wet antenna loss encountered on both antennas which is found significant for these links.

The vapor absorption is significant at 22 GHz (0.16 dB/km) and the Oxygen absorption at 60 GHz (15 dB/km). Therefore, the gaseous absorption loss (A_g) can be neglected in (1). The losses in transmit (L_t) and receive (L_r) systems can also be neglected in (1) since it is not significant with respect to FSL and A_{rain}. The wet antenna loss

Table 3. Fade margins due to rain at 0.1%, 0.01% and 0.001% of time of the year for MINI-LINK 15E.

Freq GHz	Length km.	Tx dBm	G_t, G_r dBi	FSL dB	$A_{0.1}$	$A_{0.01}$	$A_{.001}$	$Rx_{(0.1)}$	$Rx_{(0.01)}$	$Rx_{(0.001)}$	10^{-6} BER_{th}
15	1	18	37.0	116	4.17	6.8	9.6	–28.1	–30.9	–33.8	–84.0 dBm
	2			122	7.72	12.3	17.5	–37.7	–42.3	–47.5	
	3			125.5	10.8	16.7	23.8	–44.2	–50.2	–57.3	
	4			128	13.4	20.4	29.1	–49.4	–56.4	–65.1	
	5			130	15.8	23.6	33.5	–53.8	–61.6	–71.5	
	6			131.5	17.8	26.2	37.3	–57.3	–65.8	–76.8	
	7			132.8	19.6	28.5	40.7	–60.5	–69.3	–81.4	
	8			134	21.3	30.6	43.5	–63.3	–72.6	–85.5	
	9			135	22.8	32.3	45.1	–65.8	–75.3	–89.0	
	10			136	24.5	33.9	48.2	–68.1	–77.9	–92.2	

Table 4. Fade margins due to rain at 0.1%, 0.01% and 0.001% of time of the year for MINI-LINK 23E, 26E and 38E.

Freq GHz	Length km.	Tx dBm	G_t, G_r dBi	FSL dB	$A_{0.1}$	$A_{0.01}$	$A_{.001}$	$Rx_{(0.1)}$	$Rx_{(0.01)}$	$Rx_{(0.001)}$	10^{-6} BER_{th}
23	1	20	40.2	119.6	7.5	11.9	16.4	–26.7	–31.1	–35.6	–83.0 dBm
	2			125.7	13.9	21.3	29.5	–39.2	–46.6	–54.8	
	3			129.2	19.4	29.0	40.2	–48.2	–57.8	–69.0	
	4			131.7	24.2	35.5	49.0	–55.5	–66.8	–80.3	
	5			133.6	28.5	40.9	56.5	–61.7	–74.12	–89.7	
26	1	+18.0	41.0	120.7	8.9	13.9	19.1	–29.6	–34.6	–39.8	–82.0 dBm
	2			126.7	16.5	25.11	34.4	–43.2	–51.8	–61.1	
	3			130.2	23.1	34.18	49.9	–53.3	–64.3	–77.1	
	4			132.7	28.8	41.7	57.2	–61.5	–74.4	–89.9	
	5			134.7	33.8	48.0	66.0	–68.5	–82.7	–100.7	
38	1	+15.0	44.90	124	14.1	21.1	28.2	–33.3	–40.3	–47.4	–79.0 dBm
	2			130	26.2	38.0	50.7	–51.4	–63.2	–75.9	
	3			133.5	36.6	51.7	69.0	–65.3	–80.4	–97.7	
	4			136	45.6	63.1	84.2	–76.8	–94.3	–115.4	
	5			138	53.5	72.7	97.0	–86.8	–105.9	–130.2	

is also varied with antenna size, radomes materials, etc. Hence this loss has not been considered during calculation. Therefore the receive signal level (RSL) can be calculated as follows.

$$\text{Unfaded } RSL = P_t + G_t + G_r - 32.4 - 20\log_{10}(d_{\text{km}}) - 20\log_{10}(F_{\text{MHz}}) \quad (4)$$

$$\text{Faded } RSL \text{ due to Rain} = \text{Unfaded } RSL - \alpha R^{k}_{\%P} r_{\%P} d_{\text{km}} \quad (5)$$

Predicted Receive Signal Level (RSL) for frequencies 23, 26 and 38 GHz with path lengths of 1, 2, 3, 4 and 5 km and vertical polarization are calculated using (5) and compared with the receive threshold level for 10^{-6} BER. The same for 15 GHz link are calculated for 1 to 10 km path lengths. Fade margins for excess attenuation due to rain at three percentages of time and corresponding RSL are presented in Table 3 for 15 GHz and in Table 4 for 23, 26 and 38 GHz.

From Fig. 2, the outage of the MINI-LINK 15E will occur for 0.001% of time the year at the path length of 8 km or higher. From Fig. 3(a), the outage of MINI-LINK 23E will occur at 5.0 km or higher for 0.001% time of the year. The outage of MINI-LINK 26E will occur at 5 km or higher and 4 km or higher for 0.01% and 0.001% time of the year respectively as shown in Fig. 3(b). From Fig. 3(c), the outage of MINI-LINK 38E will occur at 5 km or higher for 0.1% and 3 km or higher for 0.01% and 0.001% time of the year respectively.

All the fade margins which are predicted here are based on free space loss and rain induced attenuation only. The wet antenna losses are not considered here. It could be 2 dB to 5 dB depending on the links. Therefore, it would be worsen in practical case. It is obvious that 38 GHz link is the most sensitive to rain whereas 15 GHz is the least [16, 17].

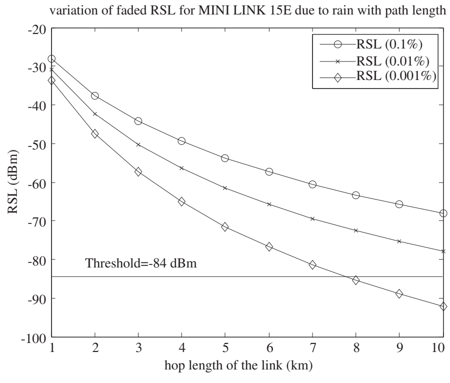


Figure 2. Rain fade margins for different path lengths at MINI-LINK 15E.

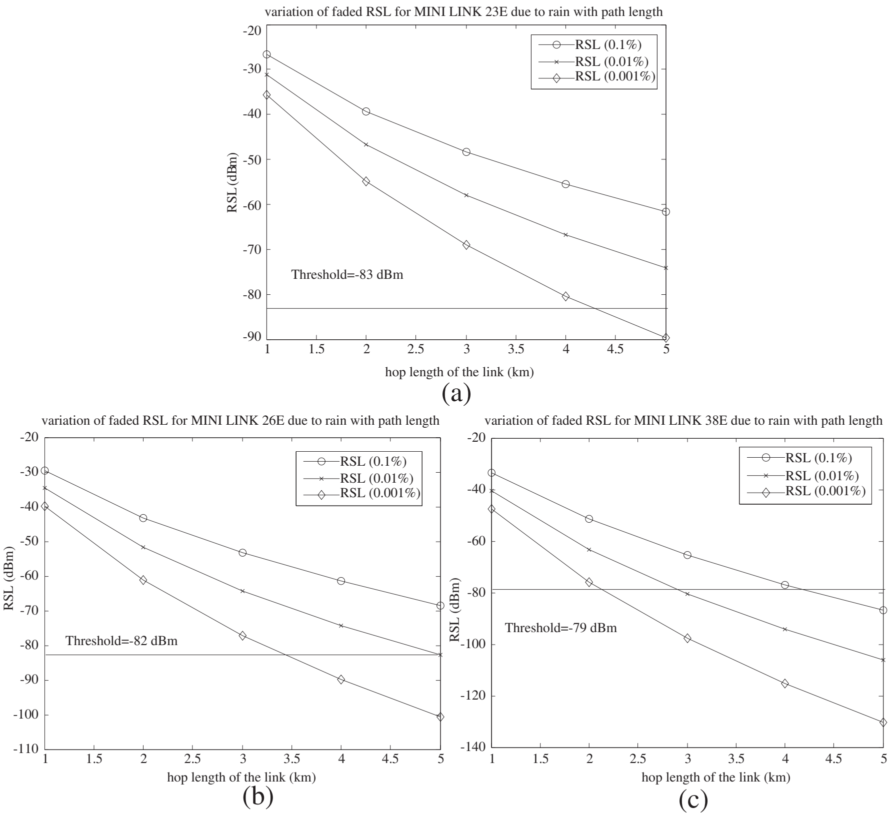


Figure 3. Rain fade margins for different path lengths at (a) MINI-LINK 23E, (b) MINI-LINK 26E, and (c) MINI-LINK 38E.

3. PREDICTION OF FADE MARGINS FOR MINI-LINKS C

3.1. Locations & Specifications of the MINI-LINKS C

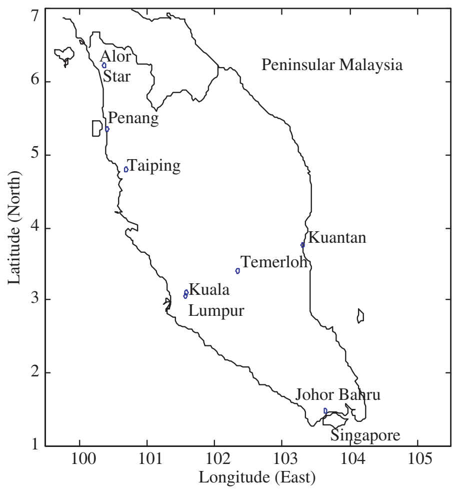
These links are located over Peninsular Malaysia and their locations are shown in Fig. 4. The specific frequencies, hop lengths, polarizations and the duration of rain attenuation data collection are given below.

Johor Bahru (5.83 km, 14.8 GHz, V-Pol., Two Years)
Kuala Lumpur-1 (3.96 km, 14.8 GHz, V-Pol., One Year)
Kuala Lumpur-2 (0.91 km, 23.02 GHz, V-Pol., One Year)
Taiping (3.48 km, 14.8 GHz, V-Pol., One Year)
Penang (11.33 km, 14.8 GHz, V-Pol., Two Year)
Alor Star (4.85 km, 15.3 GHz, V-Pol., Two Year)

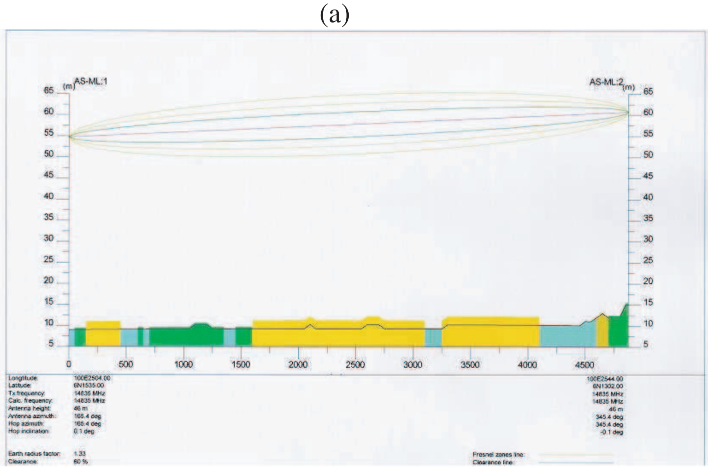
Temerloh (5.36 km, 14.8 GHz, V-Pol., One Year)
Kuantan (1.45 km, 14.8 GHz, H-Pol., One Year)

3.2. Measurements of Links Availability

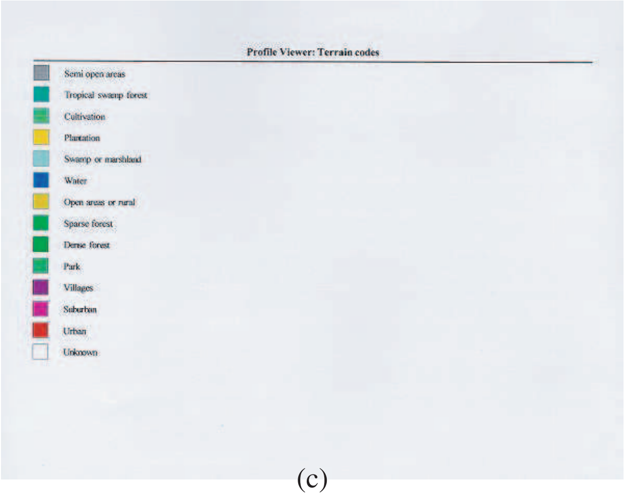
The rain attenuation data were collected at eight locations over Peninsular Malaysia for a period of one year except at Johor Bahru, Penang and Alor Star where data collection period were two years. All links are vertically polarized except Kuantan which is polarized horizontally. The hop lengths vary from 1.45 km to 11.33 km. All



(a)



(b)



(c)

Figure 4. (a) Locations of microwave links in Peninsular Malaysia. (b) Path profile for Alor star link.

operational links has been setup either on top of the condominium or in open rural areas without any obstacles between two points. The antenna heights differ from 12 m to 61 m. As an example, the path profile and the fresnel zone clearances for Alor Star link is shown in Fig. 4(b). The measured rain attenuation distributions are plotted from Fig. 5 to Fig. 7 for eight different locations in Malaysia. The percentage of time that a given attenuation is equaled or exceeded is on the ordinate, and the attenuation is on the abscissa.

The percentage of time represents the outage time for a given link budget. For example, if 15.0 dB is allocated for losses due to rain in a link budget, the 15 GHz link in Penang with 11.33 km hop length, Johor Bahru with 5.83 km hop length, Kuala Lumpur with 3.96 km hop length and Kuantan with 1.45 km hop length will be out for 0.42%, 0.2%, 0.14% and 0.003% of time of a year. This corresponds to an availability of 99.68%, 99.80%, 99.86% and 99.997% respectively. In Advanced Communication Technology Satellite (ACTS) propagation experiment, it was found that attenuation lower than 3% of time of the year caused mainly due to rain [18].

The total amount of power needed to overcome rain effects for a given availability varies significantly with propagation path length and frequency of the links as well as its location. It also varies from year to year for the same link. Table 5 compares the attenuation values at 99.9% and 99.99% availability for each of eight locations

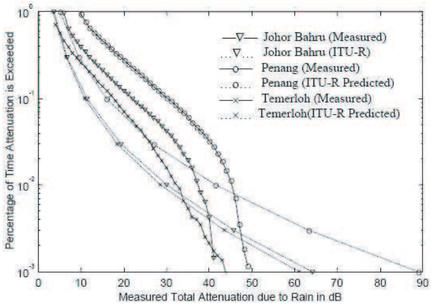


Figure 5. Rain attenuation distribution measured at 15 GHz frequency over microwave links at Johor Bahru, Penang and Temerloh and those predicted by ITU-R.

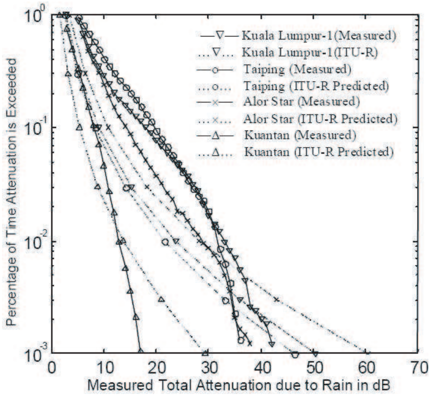


Figure 6. Rain attenuation distribution measured at 15 GHz frequency over microwave links at Kuala Lumpur −1, Taiping, Alor star and Kuantan and those predicted by ITU-R.

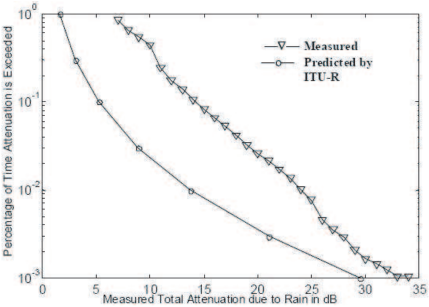


Figure 7. Rain attenuation distribution measured at 23 GHz frequency over microwave links at Kuala Lumpur −2 and those predicted by ITU-R.

in Malaysia with different lengths of propagation path and 15 GHz and 23 GHz operating frequency. This corresponds to outage of the link due to rainfall for 0.1% and 0.01% of the time of the year. The rain attenuations for the same % of time are also calculated using prediction method proposed by ITU-R for each of link and presented for comparison. Most of the cases the measured attenuation is much higher than that proposed by ITU-R. The differences between measurements and predictions are because of most of the prediction

Table 5. Rain attenuation measured at 15 GHz and 23 GHz with 99.9% and 99.99% of availability at various locations in Peninsular Malaysia and those predicted by ITU-R.

	Freq in GHz	Hop Length in km	Measured		Predicted by ITU-R	
% Availability			99.9	99.99	99.9	99.99
% Outage Time			0.1	0.01	0.1	0.01
Location of Links			**Attenuation Due to Rain**			
Johor Bahru	14.8	5.83	22.0 dB	37.3 dB	11.8 dB	30.0 dB
Kuala Lumpur-I	14.8	3.96	18.0 dB	32.8 dB	9.30 dB	23.6 dB
Kuala Lumpur -II	23.02	0.91	13.8 dB	23.7 dB	5.30 dB	13.8 dB
Taiping	14.8	3.48	19.5 dB	31.8 dB	8.30 dB	21.7 dB
Penang	14.8	11.33	29.7 dB	45.4 dB	15.8 dB	41.3 dB
Alor Star	15.3	4.85	14.0 dB	29.0 dB	10.8 dB	28.7 dB
Temerloh	14.8	5.36	17.5 dB	32.5 dB	10.9 dB	28.5 dB
Kuantan	14.8	1.45	8.10 dB	12.9 dB	5.30 dB	14.0 dB

models developed are based on the measurement data obtained from temperate regions and do not give proper results when applied in high rainfall regions. Many researchers shown that, ITU-R model underestimates the measured rain attenuation cumulative distribution when applied to tropical regions, leading to a poor prediction [19]. Besides, other effects such as gaseous absorption, cloud, scintillation, wet antenna etc. also plays a role in the differences. The attenuation values represent the amount of power in decibels needed to obtain the specified availability for that particular link.

4. FEASIBILITY OF OUTAGE FREE RADIO SYSTEMS DESIGN

Figures 5 to 7 show the measured rain attenuation at 15 GHz and 23 GHz over eight transmission distances. It is obvious that as the rain attenuation becomes large, the probability decreases from 0.1 to 0.001. On the other hand, when the probability becomes small, it drops quite rapidly, indicating that the rain attenuation has reached a maximum limit of that particular year; i.e., it is truncated. The maximum limits may vary each year, but in each year the rain attenuation shows the same tendency to truncate [20]. The cumulative distribution of measured rain caused attenuation shows that there are some regions in which the probability of rain attenuation decreases rapidly, and if we can increase the fade margin so that it exceeds the highest rain attenuation recorded, the links will be "outage-free" [20].

For example, from rain attenuation distribution measured at Penang which is the longest link (11.33 km) in this experiment, the

Table 6. Rainfall intensities as a threshold for the microwave links outages.

MINI-LINK	15E	23E	26E	38E
Rain Threshold for BER = 10^{-6}	165 mm/h	101 mm/h	81 mm/h	49 mm/h

highest attenuation occurred at 0.0002% of the time and the value is about 48.00 dB. This time percent is equivalent to about 1 minute of a year. Similarly, the highest attenuation happened at 0.0001% of the time and the value is about 43.00 dB for Johor Bahru link (5.83 km). This time corresponds to 1 minute in 2 years period. If the links at Penang and Johor Bahru had 48.00 dB and 43.00 dB higher margins respectively for excess attenuation due to rain, the links would have remained outage free.

Fade margins for all four MINI-LINKS E are also calculated based on rainfall intensities and the outage probabilities are analyzed hourly basis. The threshold values for four MINI-LINKS are presented in Table 6.

It is also observed from three years rain rate measurements that most of the outages occurred in between 1:00 pm to 7:00 pm. The outages of 96.8%, 85%, 82.7% and 79% will occur for MINI-LINK 15E, MINI-LINK 23E, MINI-LINK 26E and MINI-LINK 38E respectively for the above mentioned period. Therefore, MINI-LINK 15E would be outage free for 10^{-6} BER, if it is operated between 00:00 am to 13:00 pm and 7:00 pm to 12:00 pm of the day.

5. CONCLUSION

The outage probabilities of 15, 23, 26 and 38 GHz MINI-LINK E are investigated based on rainfall measurements at UTM Johor Bahru in Malaysia. The rain fade margin has been calculated in terms of receiver threshold for BER 10-6 for four MINI-LINKS. The rain attenuation data at 15 GHz collected from seven and 23 GHz from one different location in Malaysian tropical region has also been used in the investigation of link's availability. This data also has been compared with ITU-R prediction model. Based on rain attenuation data with different hop lengths, the fade margins are proposed for those links. It has been noted that, tropical region country, including Malaysia has limit the full implementation of the system in terms of installation distance and frequency usage. As the frequency increases, the rain attenuation becomes worse. So as a conclusion, we could say that, the outcomes of this study will help the system designer to employ some mitigation techniques to mitigate the rain fade for designing reliable broadband communication link. A beneficial solution could be by integrating Adaptive Transmit Power Control (ATPC) with the broadband link transceiver. The transmit power will be automatically adjusted by referring to the loss in receive signal level (RSL). The rain fading can be therefore be compensated by higher power transmission. During the clear weather, the transmit power is reduced back to a nominal lower level so that excessive interference will not be generated. By this way, the broadband service providers will be able to ensure the service availability during rain events.

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