COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION FOR RAIN RATE AND RAIN ATTENUATION FOR TROPICAL REGION: MALAYSIA

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Abstract- Millimetre wave (mm Wave) is today's breakthrough frontier for emerging wireless mobile cellular networks, wireless local area networks, personal area networks, and vehicular communications. In the near future, mm Wave products, systems, theories, and devices will come together to deliver mobile data rates thousands of times faster than today's existing cellular and Wi-Fi networks for an example from the era of 3G towards 5G mobile communication near future.. However for tropical region the data link reliability is effected during rain. A comparison studies has been conducted for lower and upper band frequency for the complementary cumulative distribution function (CCDF) on rain rate and rain attenuation. The research was divided into two categories, firstly the rain rate CCDF and secondly the rain attenuation CCDF. For the rain rate CCDF, it had a common rate for both the 5.8 GHz and 26 GHz link. The recorded data was analysed using the Mat lab tools and plotted the necessary graphs to identify the rain rate at $R_{0.01\% \text{ of}}$ time which is the unavailability of a link in the microwave system. The same was done in the rain attenuation at particular links to identify the links unavailability at $A_{0.01\% \text{ of}}$ time. It was found that at $R_{0.01\%}$, the rain rate was 120 mm/h. On the other hand, at $A_{0.01\% \text{ for}}$ 5.8 GHz and 26 GHz, the rain attenuation was recorded at 3.5 dB and 34 dB. This study will provide useful information for researchers by understanding and good considerations in rain attenuation predictions for a terrestrial link operating frequency at 5.8 GHz and 26 GHz in a tropical region.

Keywords- Rain Rate, Rain Attenuation, CCDF, link Reliability, Unavailability

I. INTRODUCTION

In 1935, a rain attenuation study was carried out by Wolff and Linder [1] to measure the attenuation of 9 cm waves over 2 mile path length using a rain rate of 75 mm/hr. Unfortunately, no database attenuation had been observed. In 1942, the first positive measurement was obtained by Clarendan Laboratory group at Oxford and this was followed by the research of The Bell group [2]. Research on radio wave propagation is a new field in Malaysia. It started in the early 1990's at Universiti Sains Malaysia (USM) and Universiti Teknologi Malaysia (UTM) [3][4].
The approach followed by both of these universities in their early studies were to collect one-minute rain rate and drop size distribution data in order to predict rain attenuation statistics. Since then, several rain attenuation measurements campaigns had been carried out in Malaysia for both terrestrial and satellite links. Data analysis provided for cumulative distributions of point rain fall rate, rain attenuation and differential rain attenuation in terrestrial links, fade durations in terrestrial links, fade durations and fade slope in slant path links.

Based on experimental data, models for predicting rain attenuation in slant path and terrestrial links in tropical regions and differential rain attenuation prediction model had been developed. For terrestrial microwave links operating at frequencies higher than 5 GHz [5], rain induced degradations are significant. Major degradations caused by rain that effect the reliability and availability of terrestrial links are rain attenuation and rain fade.

II. EXPERIMENTAL SET-UP

A link of path length 1.30 km was set up in UTM campus at Johor Bahru, Malaysia. Both the transmitter and receiver operate at two frequency bands: lower 5.8 GHz and higher 26 GHz. The received signal levels were sampled every minute. One year precipitation data with 95% of validity of all time, were collected from the tipping bucket rain gauge model TB 3 installed at the measurement site (June 2011 – May 2012). These data have been used to investigate the link.

The precipitation data and rain attenuation data was recorded at the same period of time. The rain gauge used is a tipping bucket type and it has sensitivity of 0.2mm. It records the total rainfall occurring in each minute without recording non rainy events; therefore the rain rate is recorded as an integral multiple of 12 mm/h or 0.2mm/min. Figure 1 shows the actual test bed and experimental test bed for rain rate measurement.

Rain rate data collected from the years 1996 to 1999 and from June 2011 – May 2012 at UTM, Skudai, Johore was analysed for rain rate distribution. Rain attenuation data 5.8 GHz and 26 GHz for June 2011 – May 2012 had also been analysed.

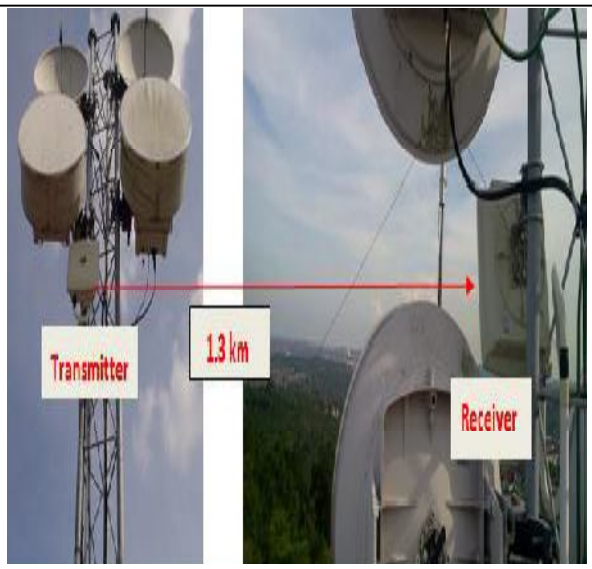


Figure 1: Test Bed for measurement

III. RAIN RATE DISTRIBUTION FROM 1996 - 1999

The ITU-R rain rate distribution model was investigated based on nine years one minute rainfall, measured at three locations in Peninsular Malaysia [4]. According to ITU-R classification Malaysia falls in rain zone P, but it is found that Malaysia has a rain climate which falls between the ITU-R rain zone N and zone P. The cumulative distributions of rain rate R (mm/h) exceeded for a percentage of time P (%) measured at three locations in Malaysia for a 3 to 4 year period (1996-1999) with corresponding time availability was also given in the same table. From the observation of Table 1 it seems that the yearly distributions for the three locations followed almost the same trend. The percentage of time from 0.03% to 0.3% shows that the measurements are closes to those recommended by ITU-R for zone P. Figure 2 presents the cumulative distribution of rain intensity measured at three locations. All the measurements follow the zone P distribution for all time percentages. Most of the time (P > 0.01%), the measurement at the three locations were very close to those of ITU-R predictions for zone P. There are discrepancies between them at other lower fractions of time (P < 0.01%) for all locations. For 0.001% of time, no measured average value reached 200 mm/H but the predicted value was 250 mm/h. Therefore, the rain rate data in Malaysia shows that the ITU-R model for zone P is close to the measured data at lower rain rates, but overestimates the measurement at higher rain rates. At the same time, higher rain rate measurement (P < 0.05%) at all three locations are much higher than those for zones N and Q prediction. For 0.001% of time, all the measured data point to the value for zone N. Therefore, the results of several years one minute rainfall rate measurements at three locations show that Malaysia has a rain climate which falls between the ITU-R rain zones of N and P.

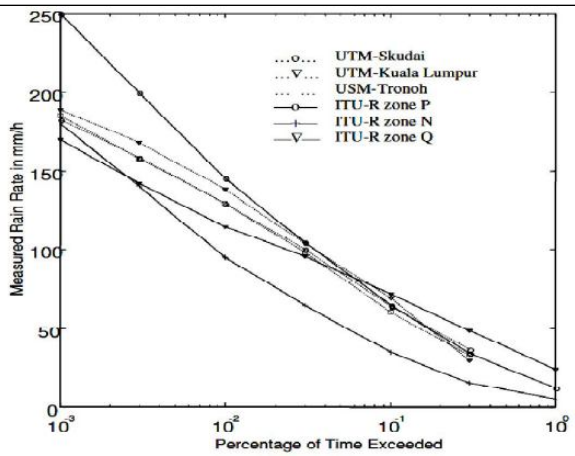


Figure 2. Cumulative distribution of rain intensity measured at three locations [9].

Figure 2. Cumulative distribution of rain intensity measured at three locations [9].

Table 1: Rain Climate Zones N,P and Q together with measured rainfall intensity for 3 locations, 2 to 4 years in Malaysia [9].

Sites	Availability	Percentage of Time (%)					
		0.3	0.1	0.03	0.01	0.003	0.001
Skudai 1996	86.6%	40	69	102	131	160	182
Skudai 1997	100%	38	71	111	138	163	184
Skudai 1998	98.6%	35	51	86	117	142	158
Skudai 1999	98.4%	25	53	93	127	159	185
Kuala Lumpur'92	88%	29	66	99	129	156	180
Kuala Lumpur'93	93.4%	29	62	96	128	173	212
Kuala Lumpur'94	93.4%	35	79	116	150	171	191
Tronoh'92	-	30	45	83	110	138	159
Tronoh'93	100%	35	59	99	143	175	206
Tronoh 1998-99	-	33	77	113	136	161	191
Skudai 1996-99	Average Rainfall Intensity	37	64	100	129	159	183
KL 1992 -94		30	69	104	138	168	189
Tronoh 92-93,98-99		33	60	98	130	158	185
ITU-R Zone N		15	35	65	95	140	180
ITU-R Zone P		34	65	105	145	200	250
ITU-R Zone Q		49	72	96	115	142	170

* - Not Available

3.1 Rain Rate Distribution from 2011 – 2012

Every rain fall rate at various times in a day was recorded monthly for only rainy events. The daily data obtained for one month can be converted to CCDF at time and the monthly CCDF can be converted to an annual CCDF at time in percentage. The Matlab software was used to plot the CCDF graph. Figure 3, shows the measured monthly and average annually complementary cumulative distribution function (CCDF) graph for the rain rate from June 2011 to May 2012.The rain rate was collected each month for the rainy events. An average graph was plotted for the whole year.

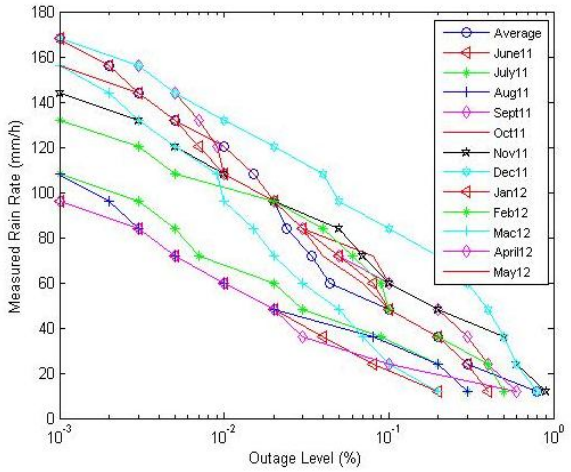


Figure 3. Measured monthly and average annually rain rate CCDF from June 2011 – May 2012

From the CCDF graph for the rain rate, a table for rain rate against percentage of time or outage level can be drawn. From table 2, the measured rain rate for the 0.01% of time ($R_{0.01}$) have been determined.

Table 2: Measured cumulative distributions of rain rate

Outage level (%)	0.5	0.3	0.1	0.05	0.03	0.01	0.005	0.003	0.001
Measured Rain Rate (mm/h)	15	24	48	62	83	120	132	144	168

From Table 2 it was observed that, when the rain fall rate increases, the percentage of time or the outage level decreases. In other words, the link unavailability period is shorter when the rain rate is higher. At 0.01% of time, the recorded rain rate from the CCDF graph was 120 mm/h. This rain rate is a very important factor used to calculate the rain attenuation at $R_{0.01}$ for a link at particular location. It was observed from the previous research [9] conducted in the same location at Universiti Teknologi Malaysia way back in 1999-2000, the recorded rain rate $R_{0.01}$ was 125 mm/h. From
the CCDF graph in figure 2 at $R_{0.01}$, it was observed that the measured rain rate is almost similar at Universiti Teknologi Malaysia location in 2000 (120 mm/h) and 2012 (125 mm/h). However, referring to the latest ITU-R P837 [6] the proposed rain rate, $R_{0.01}$ for Malaysia was in the region of 100 mm/h. This is an interesting aspect that needs to be investigated and analysed by future researches.

IV. RAIN ATTENUATION DISTRIBUTION

Besides the rain rate distribution, the rain attenuation distribution was recorded using the CCDF. The link distance or the path distance is 1.3 km. The same procedure as the rain rate measurement mentioned in section 3.0 was followed using the tipping bucket rain gauge at 0.5mm bucket size and the data was logged to data taker model DT80. Data was recorded for each day, each month and annually for a period of one year with 95% of link availability for all times. The fade duration during the rain was recorded for each rainy event as above. The daily data for one month can be converted to CCDF at time in percentage and the monthly CCDF can be converted to annual CCDF at time in percentage. Matlab software was used to plot the CCDF graph. From the CCDF graph, the measured rain attenuation at 0.01% in time, $A_{0.01}$ was determined.

4.1 Complementary Cumulative Distribution Function at 5.8 GHz

Figure 4, shows the measured monthly and average annually Complementary Cumulative Distribution Function (CCDF) graph for rain attenuation from June 2011 – May 2012. The measurements were taken during rainy events. The fade duration, unavailability during the rain was recorded for each rainy event for a day, a month and a year.

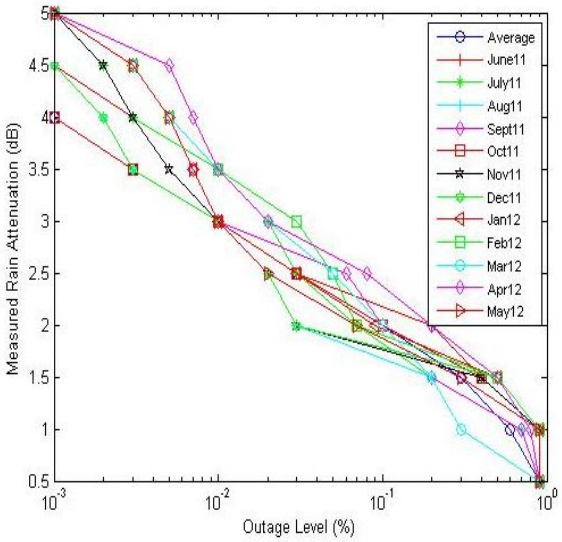


Figure 4. Measured monthly and average annually rain attenuation CCDF measured from June 2011 – May 2012 at 5.8 GHz

From the CCDF graph for rain attenuation, a table for rain attenuation against percentage of time or outage level can be drawn. From table 3, the measured rain attenuation for the 0.01% of time ($A_{0.01}$) was determined.

Table 3: Measured cumulative distributions of rain attenuation at 5.8 GHz

Outage Level (%)	0.5	0.3	0.1	0.05	0.03
Measured Rain Attenuation (dB)	0.8	1.5	2.5	2.9	3.1

Outage Level (%)	0.01	0.005	0.003	0.001
Measured Rain Attenuation (dB)	3.5	3.9	4.1	4.5

From table 3 it was observed, when rain attenuation increases, the percentage of time or the outage level decreases. In other words, the link unavailability period is shorter when the rain attenuation is higher. At 0.01% of time, the recorded rain attenuation from the CCDF graph was at 3.5 dB.

4.2 Complementary Cumulative Distribution Function at 26 GHz

Figure 5, shows the measured monthly and average annually Complementary Cumulative Distribution Function (CCDF) graph for rain attenuation from June 2011 – May 2012. The measurements were taken during rainy events. The fade duration during the rain was recorded for each rainy event for a day, a month and a year and was analysed using the Matlab software.

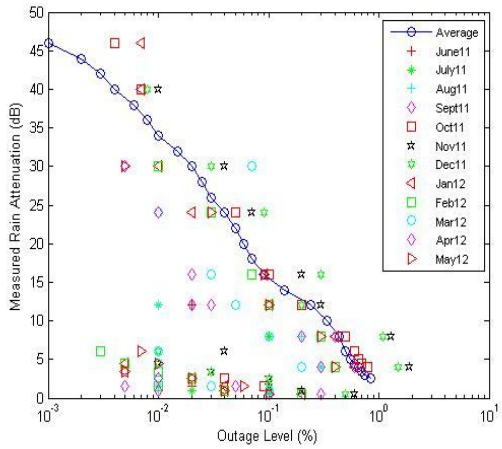


Figure 5. Measured monthly and average annually rain attenuation CCDF from June 2011 – May 2012 at 26 GHz

From the CCDF graph for rain attenuation, a table for rain attenuation against percentage of time or probability level can be drawn. From table 4, the measured rain attenuation for the 0.01% of time ($A_{0.01}$) was determined.

Table 4: Measured cumulative distributions of rain attenuation at 26 GHz

Outage Level (%)	0.5	0.3	0.1	0.05	0.03
Measured Rain Attenuation (dB)	6	10	16	22	26
Outage Level (%)	0.01	0.005	0.003	0.001	
Measured Rain Attenuation (dB)	34	39	42	46	

From table 4 it was observed, when rain attenuation increases, the percentage of time or the outage level decreases. In other words, the link unavailability period is shorter when the rain attenuation is higher. At 0.01% of time, the recorded rain attenuation from the CCDF graph was at 34 dB.

CONCLUSION

For the rain rate CCDF, it had a common rate for both the 5.8 GHz and 26 GHz link. The recorded data was analysed using the Matlab tools and we plotted the necessary graphs to identify the rain rate at $R_{0.01\% \text{ of}}$ time which is the unavailability of a link in the microwave system. The same was done in the rain attenuation at particular links to identify the links unavailability at $A_{0.01\% \text{ of}}$ time. It was found that at $R_{0.01\%}$, the rain rate was 120 mm/h. On the other hand, at $A_{0.01\% \text{ for}}$ 5.8 GHz and 26 GHz, the rain attenuation was 3.5 dB and 34 dB. This findings will be useful for the 5G application near future.

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