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OPTIMUM TERRESTRIAL KA MICROWAVE LINK FOR MALAYSIA BASED ON RAIN DISTRIBUTION PROFILE EXTRACTED FROM RADAR DATA

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ABSTRACT

This paper aims to identify the optimum link required for radio communication at different rain rates, and also to estimate rain attenuation for various path lengths at different time percentages for 28 GHz terrestrial link. The obtained cumulative rainfall rate, and rain attenuation path lengths had been achieved using radar reflectivity from Malaysian Meteorological Department. The radar data had been compared with rain gauge networks and ITUR Study Group 3. The result achieved in providing 99.99% of time percentage of availability, which leads to better Ka microwave link design in tropical region. Thus, proper implementation of mitigation technique for microwave link could be identified.

Keywords: *Rain intensity, Rain length distribution, Rain attenuation, and terrestrial path*

1. INTRODUCTION

Adequate knowledge of attenuation for different path length is vital to design any high frequency radio communication system. However, rain attenuation is the major limitation factor to the high frequency bands for terrestrial point-to-point microwave links and satellite communications [1-4]. According to International Telecommunication Union for Radio (ITUR), the microwave engineers should design a desired availability of microwave link at 99.99% of the time that determines the required amount of link margin to counter the extreme rain attenuation condition. Therefore, the link is only allowed to experience outage of 0.01% of the time throughout the year. When predicting the attenuation by rain, it is required to consider the non-uniformity distribution of rainfall rate along the entire path length [5]. In most cases, employing direct measurements such as rain gauge or microwave link are not convenient, can be costly and time consuming. In addition, it is difficult to apply the results to other sites. Thus, there is growing demand for using indirect measurement techniques such as radar system.

The reason for utilizing radar is the ability of this instrument to provide a true representation of the local climatology rain field distributions. It is able to detect with great spatial detail of precipitation over large area in real time and with single installation. The drawback is that radar reflectivity (Z), which is basic measurement to the meteorological target, cannot be directly used, it's conversion to rain intensity (or attenuation) is not unique, depending mostly on Drop Size Distribution (DSD) [6].

In this article, rain rate and rain attenuation at different time percentages have been derived from radar reflectivity to be used for terrestrial link application. The rain length had been defined as number of consecutive range bin that had detected reflectivity. Based on the obtained results, rain attenuation for different path lengths has been predicted for 28 GHz. The results have been tested against the ITUR predictions model.

2. RADAR DESCRIPTION

S-band polarization meteorological radar had been considered for this study. The radar station located at latitude 2.020° and longitude 103.320° in Kluang, Johor, Malaysia. The radar specification is shown in Table 1.

The plan position indicator (PPI) scan reads 15 elevation angles measured upward from the local horizontal at the earth station. The selected PPI scan was at 0.5° elevation angle, which is appropriate for terrestrial study. The PPI scan range of 360° in the horizontal plane for each elevation angle for range size resolution of 500 m range bin. These scans are repeated every 10 minutes.

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Table1 : Radar Specifications.

Meteorological Radar EEC-WSR8500S	
Station Position	Latitude: 2.020°, Longitude: 103.320°, Altitude 113 meter. Height: 88.1meter above MSL
Reflector	12 Feet parabolic (3.66 m)
Frequency	2.8 GHz
Polarization	Vertical
Gain	38 dB
Coverage	Elevation: -2° to +90°, Azimuth: 360°
Beam width	2.0°
Pulse duration	2.2µs
PRF	250pps
Peak power	600 kW
STC range	480 km

3. METHODOLOGY

The study area from Kluang radar includes an area from 40 to 65 km radial distance and azimuth angles between 140° to 174°, as shown in Figure 1. This area encompasses the UTM, Johor Bahru campus.

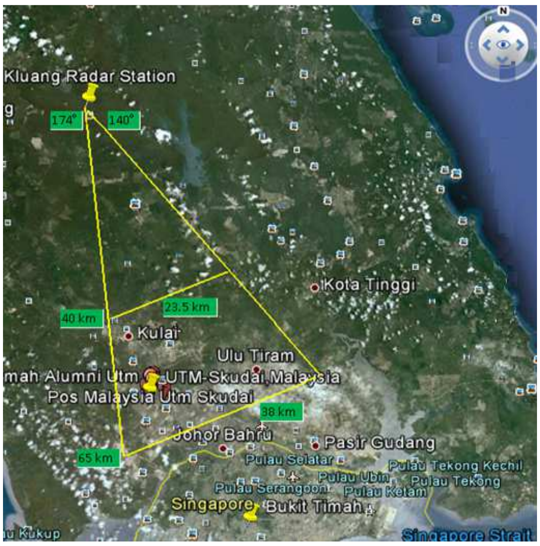

Figure 1: Site of the study area view from Kluang radar station

One year radar reflectivity data from December 2006 to November 2007 had been considered in this study. The total PPI scans was 48324 rain maps. The probability of no rain exceedance was recorded for 97% from the total radar data compared to rain-event, where minimum acceptable rain rate is 4.9 mm/hr. The radar echo test had been conducted and confirms that no sign of clutter or permanent echo were found in the studied area.

3.1 Rain Rate Inferred From Radar Data

The rain rate had been obtained from radar reflectivity using Marshall Palmer (MP) relation [7]. The rain intensity had been determined for three locations in UTM; Balai Cerap (B-C), Wireless Communication Center (WCC) and college 17 (K17). As shown in Table 2.

Table 2: The UTM selected point locations from radar data

Location	Latitude	Longitude	Distance from Kluang radar	Azimuth angle
B-C	1.34°	103.38°	52.97 km	166.95°
WCC	1.33°	103.38°	54 km	167.10°
K17	1.34°	103.37°	51.6 km	169.47°

The obtained rain rate from radar data had been compared with ITUR 837-6 [8] and rain gauges network data (RGN) located in UTM. The rain gauges were 0.5 mm Casella tipping-bucket type, which record the number of tipping in a 1-minute integration time. It also had been compared with ITUR Study Group 3, and 0.2 mm Casella tipping-bucket type rain gauge, at Bukit Timah, Singapore (Longitude 103.9° and Latitude 1.3°).

3.2 Determination of Rain Length Along Radar Azimuths

This section essentially concerned with rain clouds which influence the performance of terrestrial communication systems. A matrix had been created within the radar study sector. It contains point rain rate for each radar range bin (52 range bin x 35 azimuth angles). The study considered the cumulative distribution for the number of consecutive range bin that had detected reflectivity. Therefore, threshold values were selected based on radar levels for equivalent rain rates from 4.9 to 99.9 mm/hr and 106.2 mm/hr (99.99% of time availability), these rain rates are defined as "core" values of rain intensities [9].

3.3 Rain Attenuation Extracted from Radar data

Attenuation of radio waves through rain (A_r) in dB, over path length (L) in km, is given by [10]:

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$$A_r = \int_0^l \gamma_s(L).dL \quad (1)$$

Where $\gamma_s(L)$ is the specific attenuation of rain (dB/km). Specific attenuation depends on rain rate and regression coefficients of the frequency and the polarization [11]. The simple relationship is given as [12]

$$\gamma s = kR \quad (2)$$

Where k and α are regression coefficients which depends on drop size distribution (DSD), temperature, frequency and polarization of radio wave.

The rain attenuation had been extracted from radar data, where the rain rate in studied area for every 1 km along the azimuths. Thus, the specific attenuation had been obtained using Equation 2. Similarly, the attenuation for eight different path lengths had been obtained. The extracted rain attenuation had been compared with ITUR recommendation [13, 14]. An estimate of the path attenuation exceeded (dB) for 0.01% of the time is given by (3):

$$A_{r0.01}(dB) = \gamma_s(dB/km) * L_{eff}(km) = \gamma_s * r * L \quad (3)$$

where L_{eff} is effective path length (km), and r is the reduction factor.

According to long-term statistics of rain attenuation in ITUR P. 530-14 [13], r value could be obtained from Equation 4:

$$r = \frac{1}{0.477 d^{0.633} R_{0.01}^{0.073\alpha} f^{0.123} - 10.579(1 - \exp(-0.024d))} \quad (4)$$

where $R_{0.01}$ is rain rate exceeded 0.01% of the time, f is frequency in GHz, and α is the exponent in the specific attenuation model using Recommendation ITUR P.838-3 [15].

4. RESULTS AND DISCUSSION

This section will include rain intensity, rain length distribution, and rain attenuation for terrestrial path.

4.1 Rain Intensity

The rain rate was obtained from the cumulative distribution radar reflectivity data for the three locations inside UTM. Similar information could also be obtained form ITUR 837-6 [15] to the required area using Study Group 3 Database. These outcomes had been compared with UTM-RGN and Singaporean rain gauge as shown in Figure 2.

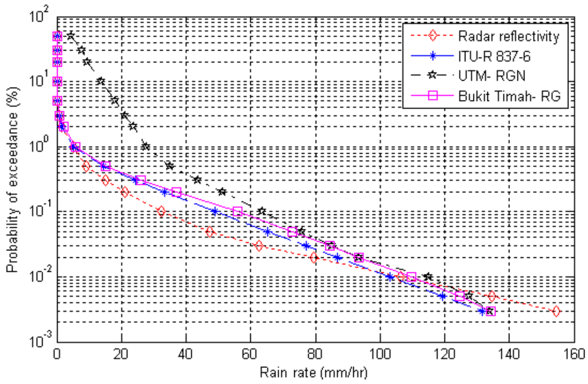

Figure 2: CDF rain rate obtained from radar data compared with UTM-RGN along with Singaporean RG and ITUR 837-6.

Figure 2 shows that, the radar reflectivity rain rate exhibit similar curve trend with other measurements. It observed that, the rain intensity obtained by radar reflectivity underestimated ITUR when rain rate lower than 100 mm/hr. However, it overestimated ITUR when rain rate exceed 100 mm/hr. This could be easily anticipated since tropical areas experience higher rain rate intensity compared to ITUR data bank. Also, the results from Singaporean RG had similar behavior. It also showed that, the 0.01% probability of exceedance detected by radar reflectivity were equivalent to 106.2 mm/hr.

4.2 Rain Length Distribution

Rain distribution was obtained for the rain path ranges which exceed the selected core intensity threshold values R_{th}, where R_{th} is the minimum acceptable detectable rain rate. The CDF of rain length for different rain rates in the study area at various time percentages is given in Figure 3.

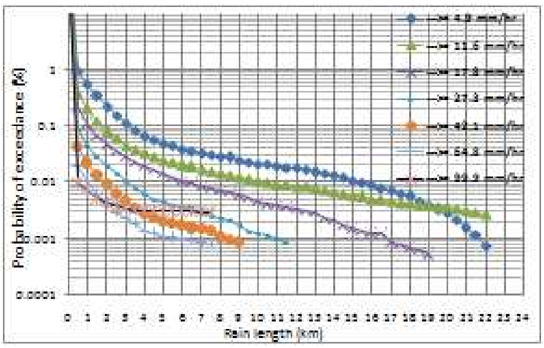

Figure 3: CDF of rain length probability corresponding to different core intensity.

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From Figure 3, considering the 99.99 % of time availability, it is summarized as shown in Table 3.

Table 3: Different rain rate at 99.99% time availability of rain length in study area.

Rain rate (mm/hr)	4.9	11.6	17.8	27.3	42.1	64.8	99.9
99.99% availability of rain length (km)	15.8	10.3	6.4	3.1	1.9	1.1	0.46

According to Table 3, to establish microwave link with 99.99% availability it is required to have maximum distance of about 0.5 km. Thus, for 2 km microwave link with 99.99% availability, requires three repeaters for every 0.5 km distance. To have longer microwave link with 99.99% availability, it is recommended to use fade mitigation techniques such as site diversity.

4.3 Rain Attenuation for Terrestrial Path Length

The terrestrial specific rain attenuation for horizontal polarization was estimated from radar data at 28 GHz for the study area. The specific attenuation had been determined as shown in Figure 4.

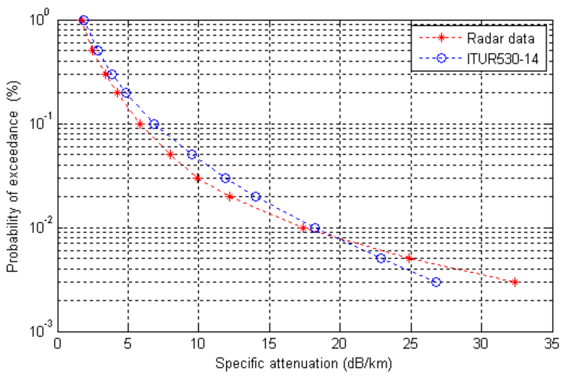

Figure 4: Specific Attenuation From Radar Data Compare With ITUR Data At 28 Ghz For Horizontal Polarization.

The influence of rain attenuation (dB) on coverage area for terrestrial links had been applied to estimate surface rainfall rates to different path length. The horizontal terrestrial path length rain attenuation extracted from radar data for 28 GHz, rain attenuation to different path length is shown in Figure 5.

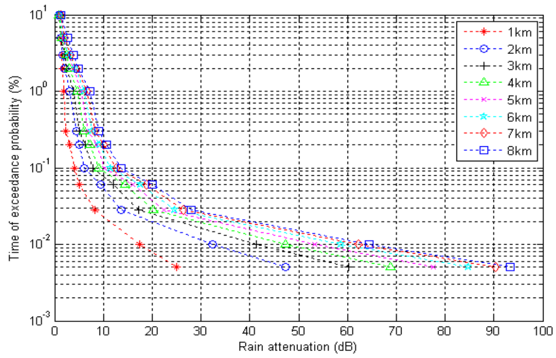

Figure 5: CDF of rain attenuation from radar data at different path lengths at 28 GHz for horizontal polarization.

From Figure 2, the time percentage for selected core values is shown in Table 4.

Table 4: Equivalent time percentage to the selected core values.

Core values from radar data (mm/hr)	4.9	11.6	17.8	27.3	42.1	64.8	99.9	106.2
Time percentage (%)	1	0.4	0.25	0.15	0.06	0.023	0.017	0.01
Equivalent ITUR value (mm/hr)	4.9	18.8	29.4	41.3	60	79.4	99.9	103

From Figures 2 and 5, the horizontal polarization rain attenuation conducted from radar reflectivity at different rain rate to various path lengths could be obtained. The results had been compared with ITUR data as shown in Figure 6.

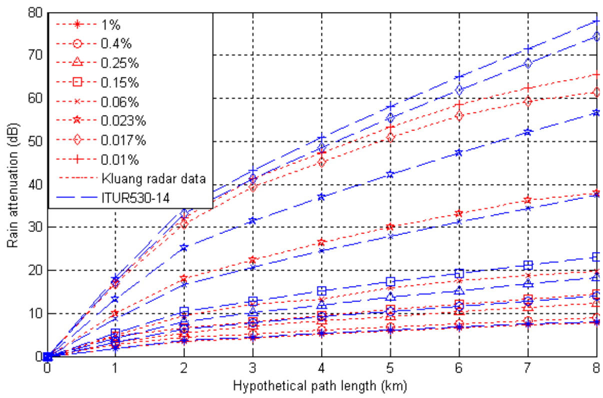

Figure 6: The Horizontal Rain Attenuation At 28 Ghz To Different Time Percentage Based On ITUR530-14 And Radar Versus Different Path Lengths

In wireless communications studies are concern about providing at least 99.99% reliability. Thus, comparison between ITUR data and radar data had been conducted at $R_{0.01}$ for 28 GHz at horizontal polarization, where the rain rates are 103.058 and 106.25 mm/hr, respectively. Rain

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attenuation at different path lengths at 99.99 % of rain availability was also shown in Figure 6.

Figure 6 shows that, rain attenuation estimated from radar data were lower than ITUR 530-14, especially at rain rate between 27.3 and 64.8 mm/hr. It also reveal that, for shorter path length (up to 2 km), rain attenuation obtained by radar data agreed with estimated rain attenuation using ITUR 530-14. However, radar reflectivity results were underestimated rain attenuation that estimated by ITUR when path length exceeded 2 km of range.

5. CONCLUSIONS

The work was conducted using reflectivity of weather radar data collected from the Meteorological Department of Malaysia. The rain intensity and rain attenuation for different path length were derived from radar reflectivity and compared with ITUR model, which tends to underestimate the ITUR models when rain rate lower than 100 mm/hr.

The optimum microwave link for different time percentage availability had been identified. Thus, proper implementation of mitigation technique could be proposed to improve the link availability.

The path attenuation was estimated for different path length at different time percentage, employing ITUR model and radar reflectivity at 28 GHz. Thus, using radar reflectivity to estimate the attenuation in tropical region has advantage for presenting operation of localized rain events. These results could be very supportive to implement Ka-band terrestrial link such as local multipoint distribution service (LMDS).

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