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Initial study of rainfall rates distribution and simulation of terrestrial microwave links using EUMETSAT's Multi-Sensor Precipitation Estimate in Malaysia

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Abstract: Radio links operating at high frequency level are likely to suffer scattering and absorption losses due to hydrometeors. The largest hydrometeor fade mechanism is rain fade and it is widely recognized to trigger outages on microwave links. Radio engineers and planners often use rain rate as a parameter to calculate and predict attenuation/fade on microwave links. Typically, rain rate distribution with 1 minute integration time is needed for predicting rain fade statistic. This paper presents the initial study of rainfall rates distribution obtained from EUMETSAT's Multi-Sensor Precipitation Estimate (MPE) and attempts to simulate them with microwave links. Rainfall rate distributions collected from EUMETSAT's MPE are compared with the ITU-R model and rain gauge data for corroboration purposes. Additionally, terrestrial microwave links are simulated from rainfall rates obtained from MPE and compared with ITU-R terrestrial fade model.

Keywords: Rain Fade, Rain Rate, Microwave Links, MPE

1.0 INTRODUCTION

Wireless transmission has become a major backbone in telecommunication industry. Compared to cables, wireless systems are cheaper and easier to deploy. Hence, wireless systems have become an attraction for developing nations. However, wireless transmission, particularly microwave links suffer scattering and absorption losses due to hydrometeor particles (rain, sleet and fog) in the atmosphere. Wireless links with frequencies below 5 GHz have insignificant atmospheric losses. Conversely, wireless links operating at 10 GHz or above, losses due to rain can cause outages and it is the factor that limits availability of these links[1]. Among the largest and most dynamic hydrometeor fade is rain fade.

International Telecommunication Union-Radio section or ITU-R offers recommendations for engineers to calculate and predict hydrometeor fade on wireless links. These models and recommendations however, are limited to individual links and not sufficient for the design and optimization of radio networks, even as simple as two links in route diverse or multi-hop configuration network, which need a joint channel model with a short temporal resolution. For this reason, it is preferable to predict hydrometeor fade using meteorological dataset such as rain maps[1].

Rainfall rate (in mm/hr) is one of the fundamental factors for radio engineers and planners to calculate and predict attenuation on radio links due to rain. Rain rate at 0.1% or 0.01% of the time in a year is often used to design a communication system with 99.9% or 99.99% availability. Annual fade distribution due to rain for microwave links requires rain rates statistics with 1 minute integration time [2]. In this paper, the EUMETSAT' MPE weather satellite product is selected and studied for its potential use for rain fade simulation on microwave links.

2.0 EUMETSAT's Multi Precipitation Estimate

An intergovernmental organization called The European Organization for the Exploitation of Meteorological Satellites or EUMETSAT manages several METEOSAT observation satellites and produces range of meteorological datasets including rain maps with rain rates parameter in mm/hr. The dataset from MPE produces global rain rates with 5 to 30 minutes sample period and

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fine spatial resolution from few to tenths of kilometers. Figure 1 shows a sample rain map from MPE.

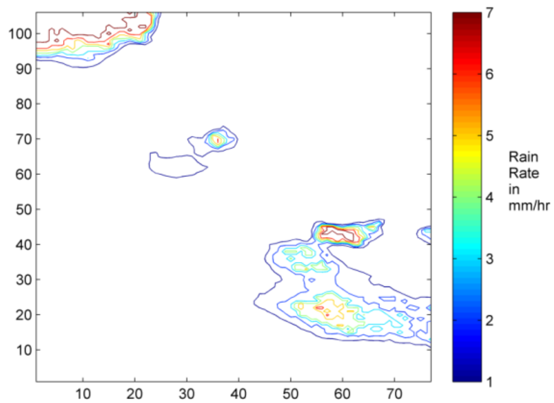

Figure 1: A sample of estimated rain map from MPE in contour lines

Typically, weather satellites estimate rainfall rates by measuring the cloud top temperature. This is an indirect approach and as such, measurements from regular weather satellites may not be as accurate as rain gauges and weather radars. Hence, measurements from weather satellites should be treated as a complement and not a replacement to other sources of meteorological measurements [6]. In spite of this, weather satellites offer global coverage of rain rates and thus more economical than other form of measurements. To increase its accuracy and applications, MPE employs a process known as "blending" by merging both the microwave-based and IR (infrared) from satellite instruments. EUMETSAT's MPE integrates the IR channel data from METEOSAT satellites and Special Sensor Microwave/Imager (SSM/I) microwave data from US-DMP satellites in the re-processing branch of its Meteorological Product Extraction Facility (MPEF) to estimate precipitation rate. MPE regularly uses rain gauge or radars for validation purposes [7].

3.0 DATA COLLECTION

Three years of EUMETSAT's MPE data starting from 2010 to 2012 were collected to ensure statistical stability as rainfall rate distributions tend to vary widely from year to year. ITU-R P.837-6 in [3] suggests three or more years of rain rate data collected from local measurements to produce more accurate results.

The MPE satellite product consists of rainfall maps with 30 minutes sample period. The map covers from -8.0° West to 122.0° East bound longitude and 65.0° North to -65.0° South bound latitude. For this study, the Peninsular Malaysia (1.4° to 6.3° North latitude, 99.5° to 104.47° East longitude) and East Malaysia (Sabah and Sarawak, 0.79° to 7.2° North latitude, 109.4° to 119.5° East longitude) regions in MPE product are selected.

For validation with rain gauge, one year of rain gauge data in 2012 with 1 hour integration time is selected and obtained from Malaysia Meteorological Department. The rain gauge is located in Petaling Jaya, Malaysia (3° 06' North and 101° 39' East).

4.0 CONVERSION METHODS

ITU-R P. 837-5 in [2] provides a regression model based on the principle of direct power-law fit for conversion between different integration times of rain rates distribution. For a fair comparison with the ITU-R rain rate distribution model, rain rates distribution from MPE has to be converted from 30 minute to 1 minute integration or sampling time.

$$R_1(p) = a[R_\tau(p)]^b \quad \text{mm/hr} \qquad (1)$$

Figure 1: Rainfall rate distribution with different conversion methods comparison in East Malaysia

Equation (1) shows the equation where R_1 and R_τ are rain rates at 1 minute and τ integration time respectively and exceeded with equal probability, $p\%$ while a and b are regression coefficients. From ITU-R P.837-5, the conversion from 30 minutes to 1 minute integration time requires the coefficients of a and b to be 0.564 and 1.288 respectively. The use of regression model for conversion from longer to shorter integration time is expected to increase the exceedance probability of higher rain rates and decrease the exceedance probability for lower rain rates.

5.0 RESULTS

Rainfall rates distribution with exceedance probability derived from EUMETSAT's MPE are studied and compared to a rain rate distribution model from ITU-R P.837-6 and a rain gauge data for corroboration. In addition, the rain rates from MPE will be converted to fade loss via a specific attenuation model from ITU-R P.838-3 in [4] for terrestrial microwave link simulation and compared with the model from ITU-R P.530-13 in [5].

5.1 Rain rates distributions from EUMETSAT's MPE

Rain rates distribution from EUMETSAT's MPE in Peninsular Malaysia and East Malaysia from year 2010, 2011 and 2012 are shown in Figure 2 and 3. The figures show the rainfall rates distribution from MPE is capped at approximately 37 mm/hr. This could be due to the algorithms and models employed to estimate rain rates.

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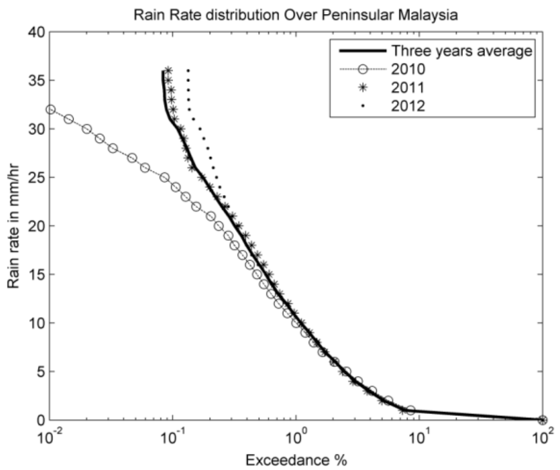

Figure 2: Rain rates distribution over Peninsular Malaysia from EUMETSAT's MPE.

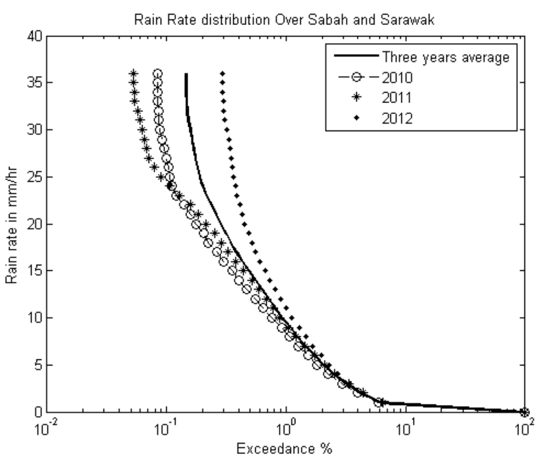

Figure 3: Rainfall rates distribution over East Malaysia from EUMETSAT's MPE.

5.2 Comparison between MPE and ITU-R Model Rain Rates Distribution

In this section, three years averaged rain rates from EUMETSAT's MPE are evaluated with ITU-R P.837-6 model as shown in Figure 4 and 5. The sampling or integration time for rain rates distribution statistic from MPE has been converted from 30 minutes to 1 minute using the previously mentioned regression model in (1).

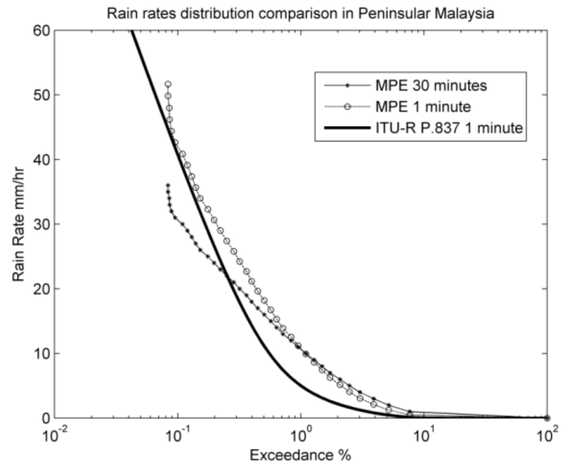

Figure 4: Rainfall rates distribution comparison between ITU-R 837 model and MPE over Peninsular Malaysia

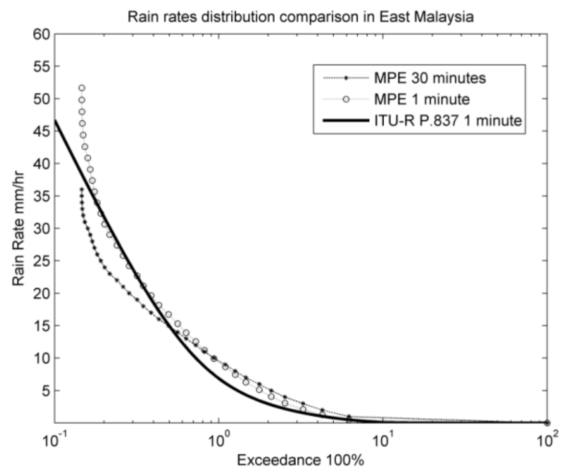

Figure 5: Rainfall rates distribution comparison between ITU-R 837 model and MPE over Sabah and Sarawak or East Malaysia

The MPE rain rates distribution for Peninsular Malaysia in Figure 3 shows agreement and disagreements with the ITU-R model at higher and lower rain rates respectively. For the disagreement part, this is probably due to the errors or miscalculations from IR to rain rates conversion algorithm in MPE product. It could also be from the ITU-R model itself since it is just a prediction model based on years of historical data.

Nevertheless, the higher rain rates data is what most radio engineers and planners require for design radio networks as higher rain rates contribute more losses to high frequency radio signals. Despite this, the comparison result between MPE and ITU-R rain rates model in Figure 5 for East Malaysia however shows promising result.

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5.3 Comparison between MPE and a Rain Gauge data

One year rain gauge data (2012) with one hour integration time in Petaling Jaya is collected and compared with MPE rain rates distribution in 2012 at the same location as shown in Figure 6. The interval time of MPE has been integrated to one hour for a fair comparison with the rain gauge data. The comparison result shows that the MPE rain rates distribution has a small agreement with the rain gauge data.

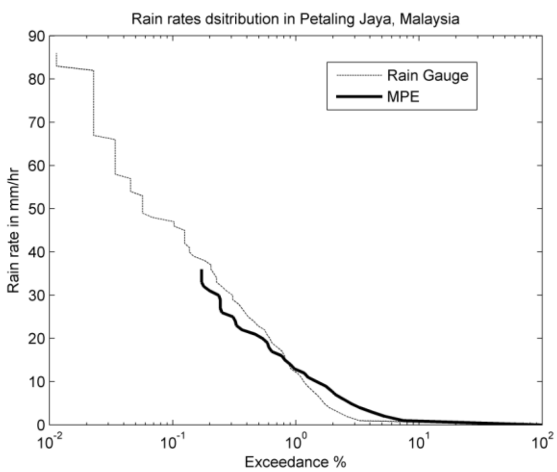

Figure 6: Rainfall rates distribution comparison between MPE and a rain gauge in Petaling Jaya, Malaysia.

5.4 Terrestrial microwave links simulation

In this section, the rain rates from MPE for Peninsular and East Malaysia are converted to attenuation in dB for terrestrial microwave links with 1 km and 500 meters lengths. The attenuation results from MPE are compared with ITU-R P.530-13 fade model.

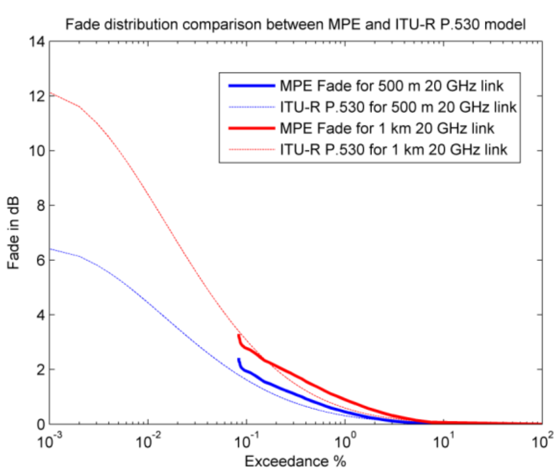

Figure 7: Fade distribution comparison between MPE and ITU-R P.530 model for Peninsular Malaysia

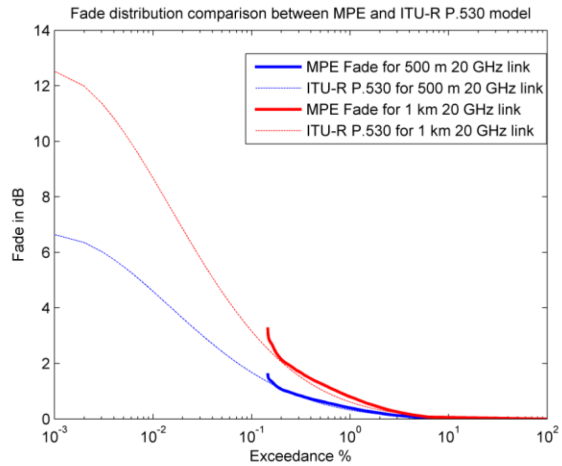

Figure 8: Fade distribution comparison between MPE and ITU-R P.530 model for East Malaysia

For Peninsular Malaysia region, the MPE results slightly overestimate the ITU-R models at lower rain rates for both 500 m and 1 km terrestrial links as shown in Figure 7. This is most probably due to the rain rates distribution from MPE that overestimates the ITU-R model as demonstrates in Figure 4. However, for East Malaysia, the MPE fade distributions show plausible result with the ITU-R model for both lengths of the terrestrial links as shown in Figure 8.

6.0 CONCLUSION

The MPE rain rates and fade distribution have been successfully compared with the ITU-R models and the rain gauge data. The results are plausible and promising especially for East Malaysia region. This could lead to the exploitation of MPE to provide essential rain rates and fade statistics for radio planners and engineers. However, the research on utilizing MPE for microwave fades simulation is still in early stage and requires additional validations, possibly with more real fade and rain gauges statistics.

A number of improvements could be employed to this research. The rain rates distribution statistic from MPE could be extrapolated further than the capped rain rate threshold but this would definitely requires more analysis and corroboration with rain gauges and rain radars. The regression model in (1) could be replaced with other more reliable models such as Segal's model [8] to provide more accurate conversion between different integration times for rain rates distribution. In addition, this MPE could be compared with actual measurement of radio link at high frequency bands for stronger validation. Also for future works, the EUMETSAT's MPE could be used for different regions of the world, which requires more analysis and results.

Ultimately, the rain maps from MPE could be downscaled into finer spatial and temporal scales by a downscaling tool such as GINSIM in [1]. The rain maps from MPE could be downscaled to hundreds of meters in spatial and ten of seconds in time resolution. The downscaled rain maps would be extremely useful for radio engineers to perform more advanced analysis, such as fade slope and duration and implement fade mitigation techniques, including power control and switching in microwave networks to mitigate rain fade [9].

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