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Preliminary Study of Hydro-Estimator Product for Microwave Links in Malaysia

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Abstract:

Radio links operating at 20 GHz or above tend to suffer losses, mainly due to hydrometeor particles in the atmosphere. This phenomenon also known as hydrometeor fades. The largest and most dynamic of these fading is rain. Rain fade can cause massive loss of signal for high frequency links. Optimal solution would be to use meteorological data that contains rain rate and convert it to rain fade for better network planning, simulation and deployment. This paper studies the possibility of exploiting Hydro-estimator product from NOAA that could be utilised for such endeavour. Rain rate distribution results from Hydro-estimator product are compared with ITU-R model and rain gauge for validation.

I. INTRODUCTION

Wireless transmission has always been one of the major backbones for communication. When compared to fixed line cables, wireless technologies are easier to be deployed and treated as a cheaper option. This is evident when deploying networks in rural or less populated areas in which wireless communication is certainly a more economical choice for network providers. The rise of population and users around the globe gives the rise of demand for telecommunication and connectivity. The rise of demand from users means the more pressing need for telco companies to utilise higher bandwidth to accommodate them. Higher bandwidth means higher frequency exploitation [1].

However, high frequency signals operating at 20 GHz or Ka and Ku band or above will suffer losses in signal strength due to hydrometeor particles in the air. These losses are also known as hydrometeor fades and the largest and most dynamic of them all is rain fade. Extreme losses due to rain fade can cause outages or complete loss of signals for radio links. A loss due to rain fade occurs when radio signal colliding with water particles and the signal lost its power through Rayleigh and Mie scattering. Typically, high frequency terrestrial backhaul and satellite links encounter this type of fading mechanism [1].

To ensure 99.99% signal availability at all times, ITU (International Telecommunication Union) publishes series of recommendations and models for radio engineers to plan and deploy radio networks. Typically, radio engineers utilise information from ITU such as rain rate in mm/hr unit and its distribution annually when dealing with rain fade issue. Annual fade distribution due to rain for satellite and point to point terrestrial links require rain rates statistics with 1 minute integration time which can be obtained from ITU [2].

Conversely, the theoretical models from ITU lack vital information necessary for a more complex analysis and simulation of radio links. The models only provided statistics for annual distribution and results but lack the information on the exact when and where for rain events to occur. This may complicate the effort for FMTs (Fade Mitigation Techniques) applications including automatic power control and route diversity control to mitigate rain fade. For a more optimal solution, meteorological data that contains rain rate data can be used for rain

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fade simulation on radio links in which FMTs could be applied more effectively [1]. In addition, rain rate data from meteorological dataset provides updated information on rain rate distribution yearly when compared to static models from ITU. For this research, Hydro-estimator product is used to provide global rain rate coverage for the purpose of simulating rain fade on millimetre wave links.

II. Rainfall Measurements

Measuring rain rate in mm/hr in terms of both spatial and temporal properties can be challenging. Few methods available to measure rain rate directly and indirectly including rain gauges, weather radar and weather satellites.

Rain gauges provide rain rate measurement directly by collecting rain drops over certain period of time and calculated into rain rate in mm/hr. Rain gauges are often used as "ground truth" to compare with other types of measurements since rain gauge is the most reliable source of rain rate measurement. However, it has poor spatial coverage and would require a great number of rain gauges to cover a wide area such as a city [1][8].

Weather radars or rain radars also provide rain rate measurement through measuring signal reflection in S or C band frequencies. Typically, weather radars are operated by national meteorological agencies around the globe, with spatial resolution ranging from few hundreds of meters to few kilometres and temporal resolution between scans in 5 minutes to 15 minutes long. Each radar could cover an area from dozens to hundreds of kilometres. Despite this, a single nation with a size like Malaysia would require at least several of these radars for complete coverage and can be expensive to maintain. [1][8]

Weather satellites are another method to measure rain rates and typically these satellites are more economical to estimate rainfall rates compared to other methods since satellites are able to cover globally, despite being less accurate when compared to rain gauges. Typical weather satellites employ microwave and/or infrared (IR) channel to measure rain rate indirectly by measuring the cloud top temperature, such as employed by Geostationary Operational Environmental Satellite (GOES) and METEOSAT satellites [4]. The temporal sampling time between scans can range from 30 minutes to 1 hour long. Meteorologists typically rely on weather satellites to estimate rainfall in areas where rain gauges and rain radars are unavailable such as over oceans and less populated areas.

III. Hydro-Estimator Product

Hydro-Estimator product (H-E) is a set of meteorological data that contains rainfall rate information and currently operated by NOAA (National Oceanic and Atmospheric Administration) and NESDIS (National Environmental Satellite, Data, and Information Service) in United States. Rainfall rates are estimated using infrared data on board of GOES satellites. The infrared channel is used to measure cloud top temperature to indirectly estimate rainfall rates. The method has long been developed since the late 1970's, from Flash Flood Analyzer (IFFA) to the fully automated Auto-Estimator. The current generation of operational algorithm for rain rate estimation is Hydro-Estimator and has been used since 2002. [9, hydro estimator website].

The rainfall rate estimates are produced every 15 minutes for the continental United States and 1 hour for global scale. For global map product, NOAA and NESDIS collaborating with other national agencies such as EUMETSAT (European Organization for the Exploitation of Meteorological Satellites) with its METEOSAT satellites and Japanese meteorological agency with its MTSAT satellites. This is to ensure full global coverage for estimating rainfall rates [9, hydro estimator website]. In terms of spatial resolution of the product, each pixel ranges from few kilometers to 10 kilometers. Fig. 1 shows sample of rain events over Malaysia in 2016.

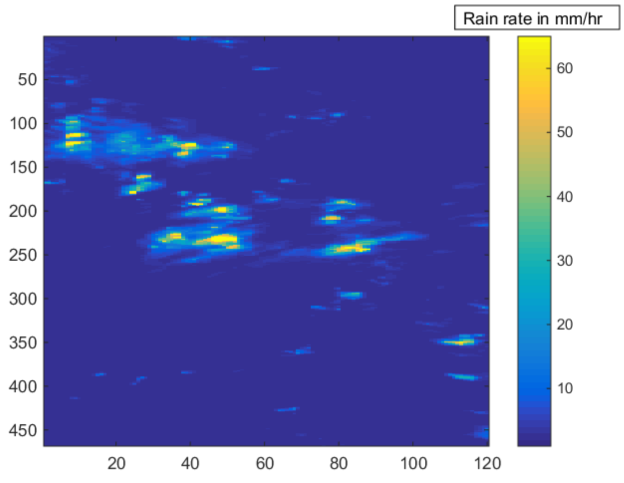

Fig. 1. A sample of Hydro-Estimator's estimated rainfall rates map in over Malaysia.

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IV. Data Collection

A year worth of collected Hydro-Estimator data was performed. The data was in 2016, from January till December. For this study, only Malaysian region are considered to be studied. The coverage area that has been selected is from 0.8 to 7.7 degrees in North bound latitude and 99 to 120 degrees in East bound longitude. The area covers all Malaysia which includes the Peninsular, Sabah and Sarawak regions. The selected product has one hour long sampling time between scans.

The data is to be compared with ITU-R 837 model in terms of rain rate distribution. For further validation, a one year worth of rain gauge was supplied by Malaysia Meteorological Department or MMD and to be compared with the result from Hydro-Estimator product. The rain gauge is located in Petaling Jaya, Malaysia (3° 06' North and 101° 39' East).

V. Results and Analysis

The rain rate's exceedance probability distribution over a year from Hydro-Estimator and ITU-R 837 model is compared. Rain rates distribution from the Hydro-Estimator product has 1 hour sampling time while ITU-R 837 model produces 1 minute integration time for rain rates distribution. To make a fair comparison, the rain rate exceedance probability distribution from Hydro-Estimator product is converted to 1 minute integration time by using a mathematical regression model, provided by ITU-R 837 [2][3].

A. *Regression model for conversion between different integration times*

Using the regression model provided by ITU-R 837 [3], the hour 1 sampling or integration time of rainfall rate maps from Hydro-Estimator was converted to 1 minute. The regression model is as follows:

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

From the regression model, $R1$ (p) is the variable for rain rates in mm/hr with 1 minute integration time while $R\tau$ (p) refers to rain rates with τ-min integration times. The symbol (p) refers to equal exceedance probability in p%. The symbols a and b are regression coefficients and can change depending on which τ-min integration time to be converted to 1 minute. According to the table of extension of ITU-R method for conversion rain rate statistics integration times in [10], the coefficients of a and b to be 0.509 and 1.394 respectively for 1 hour to 1 minute. The regression model has transformed the exceedance distribution of rain rates and extended it from roughly 30 mm/hr to more than 50 mm/hr at 0.01% probability for Hydro-Estimator rainfall rate meteorological product as demonstrated in Fig. 2.

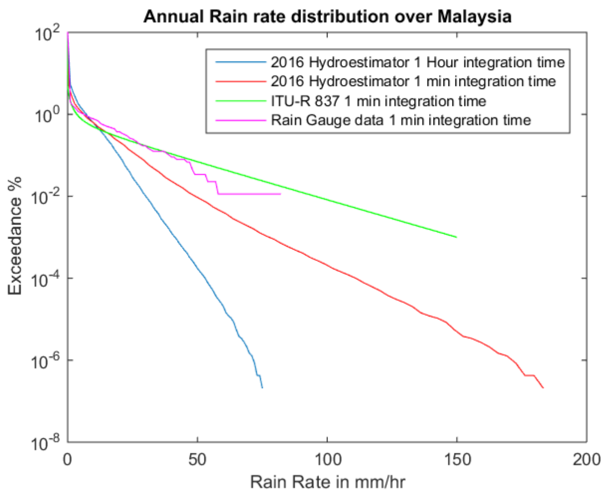

Fig. 2. Comparison of rainfall rates distribution over Malaysia from Hydro-Estimator, rain gauge and ITU-R 837 model.

B. *Comparison of rainfall rates distribution from Hydro-Estimator*

Fig. 2 shows the rain rates distribution from Hydro-Estimator with 1 hour and 1 minute integration times compared to rain gauge and ITU-R 837 model for whole of Malaysia. The regression model provided by ITU-R 837 has expanded the rain rate distribution of Hydro-Estimator when converting from 1 hour to 1 minute integration time. The lower rain rate regions were decreased in terms of probability while the higher regions of rain rates increased when utilizing the regression model. From the comparison of results, the rainfall rates exceedance distribution results from Hydro-Estimator underestimated ITU-R 837 model but the results are more plausible when compared to rain gauge data. It should be noted that ITU-R 837 models are based on historical data and it may not represent current distribution. ITU itself stated that any meteorologist should use their own data whenever possible and only rely on ITU-R models when those data are not available. Nevertheless, the results show potentiality of utilising rain rates data from Hydro-Estimator product for rain fade simulation on millimeter wave frequencies.

C. *Comparison of rain fade distribution from Hydro-Estimator*

For this comparison, rain rates from extracted Hydro-Estimator data has been converted to rain fade in dB using specific attenuation equation provided by ITU-R 838-3 [11] as shown below:

$$\gamma = kR^{a}$$

Where γ is the specific attenuation, R is the rain rate in mm/hr, k and *a* are the constants that depends on the frequency operation of a link. For the purpose of this simulation, 38 GHz frequency terrestrial links with vertical polarisation was simulated. For such configuration of frequency and polarisation, the value of k and *a* are 0.2801 and 0.9426 respectively. The rain fade distribution from Hydro-Estimator product was compared to ITU-R 530 rain fade distribution model for terrestrial radio links with the same frequency and polarisation [7]. For ITU-R 530 model, two distributions were plotted, one with 95 mm/hr at 0.01% probability according to ITU-R 837 for Malaysian region, another one at 49 mm/hr at 0.01% probability, based on rain rates exceedance distribution from Hydro-Estimator product as shown in Fig. 3.

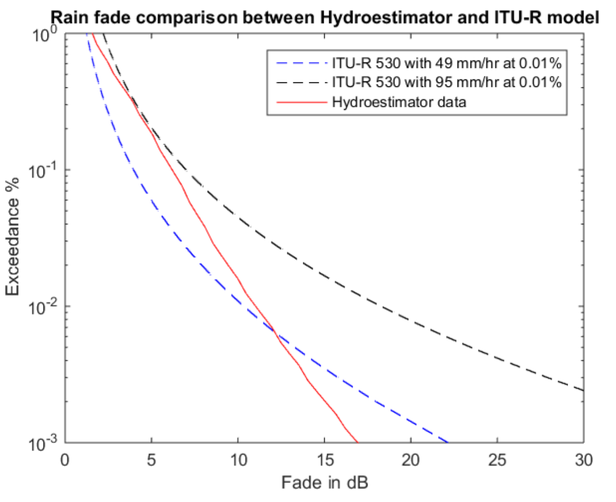

Fig. 3. Comparison of rain fades distribution over Malaysia from Hydro-Estimator and ITU-R 530 model.

From the comparison results in Fig. 3, rain fades result from Hydro-Estimator underestimate ITU-R 530 with 95 mm/hr at 0.01% probability as expected based on Fig. 2 results. However, rain fade distribution from Hydro-Estimator product performed considerably well with ITU-R 530 model that utilises 49 mm/hr at the same probability percentage.

VI. Conclusion and Future Works

Rain rate and rain fade exceedance distribution results from Hydro-Estimator were compared with ITU-R models and rain gauge. Based from the comparison results, it is plausible that Hydro-Estimator product could be utilised for rain rate and rain fade simulation for a more advanced wireless network planning and deployment.

The research in utilising Hydro-Estimator product for such endeavour is still in preliminary stage and would require more research, including more validations againts other models and measurements, and more years of rain rates data to be analysed. Future research would use at least three years worth of rain data from Hydro-Estimator to remove year to year fluctuation and ensure stability, this is crucial for verification process.

In addition, several improvements could be considered for this product, including the use of better models for rain rates integration times conversion, and possibly deploy downscaling techniques to downscale the product’s spatial and temporal resolutions, down to hundreads of meters and tens of seconds respectively. These improvements would allow the product to be used for Fade Mitigation Techniques (FMT) study that includes automatic power control, switching control and bit rate control. FMTs are tools that able to mitigate hydrometeor fades and ensure better quality for high frequency signals.

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References

[1] H. Basarudin, “Development of a Heterogeneous Microwave Network, Fade Simulation Tool

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ISSN: 0193-4120 Page No. 1941 - 1945

Applicable to Networks that Span Europe", Ph.D. Thesis, University of Hull, 2012.
[2] ITU-R P.837-6, "Characteristics of precipitation for propagation modelling", International Telecommunication Union, 2012.
[3] ITU-R P.837-5, "Characteristics of precipitation for propagation modelling", International Telecommunication Union, 2007.
[4] R. A. Scofield and R. J. Kuligowski, "Status and Outlook of Operational Satellite Precipitation Algorithms for Extreme-Precipitation Events", *Wea. Forecasting*, pp. 1037–1051, vol. 18, 2003.
[5] T. Heinemann and J. Kerényi, European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Multi sensor Precipitation Estimate (MPE): concept and validation. [Online]. Available: http://www.isac.cnr.it/~ipwg/meetings/monterey-2004/pres/Heinemann/mpef/pdf/EUMETSAT_UC2003_MPE.pdf
[6] B. Segal, "The Influence of Rain Gauge Integration Time on Measured Rainfall Intensity Distribution Functions", *J. of Atmospheric Oceanic Tech.*, pp. 662–671, vol. 3, no. 4, 1986.
[7] ITU-R P.530-16, "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems", International Telecommunication Union, 2016.
[8] H. Basarudin, T. A. Aziz, M. I. Sulaiman and A. H. Ali, "Preliminary study of EUMETSAT's Multi-Sensor Precipitation Estimate product for microwave links in Malaysia", IEEE Xplore, 2014.
[9] STAR Satellite Rainfall Estimates – Hydro-Estimator website, URL: www.star.nesdis.noaa.gov/scmd/emb/ff/HydroEst.php
[10] L. D. Emiliani, L. Luini and C. Capsoni, "Extension of ITU-R Method for conversion of rain rate statistics from various integration times to one minute", IEEE Xplore, 2008.
[11] ITU-R P.838-3, "Specific attenuation model for rain for use in prediction methods", International Telecommunication Union, 2005.