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Comparison of rain rate models for equatorial climate in South East Asia

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Statistics of 1 minute rain rate has a major impact in the design of satellite communication systems at frequencies above 10 GHz. The effect of rain causes serious degradation of radio signals at frequencies above about 10 GHz; therefore, models for the prediction of statistics of excess path attenuation needed for the design of communication propagation paths requires a statistical description of rain-rate occurrences. In this paper, the tasks are tackled by processing 3 years rain rate data for selected sites in the equatorial region. A comparison between rain rate data set with a sampling period of 1 minute and existing rain rate prediction models is presented.

Keywords: rain rate, rain attenuation, satellite communication, radiowave propagation

1. Introduction

With increasing demands of telecommunication networks, the use of greater bandwidth and higher data speeds are required. Prediction of rain rate models has become main concern due to the introduction of the Ku-band satellite communication services in tropical country (ITU-R, 2009b; Moupfouma, 1984). The accurate prediction of rain rate in line-of sight terrestrial links is essential for planning and designing high capacity point-to-point and point-to-multipoint radio systems for frequency bands above 10 GHz (Mandeep, 2010; Mandeep, 2009; Mandeep and Allnutt, 2007).

Even though the structure of rainfall of the location of interest known, It would obviously be an impossible task to collect experimental data for all the frequencies, locations, and elevation angles under consideration for operational satellite systems (Ajayi and Ofoche, 1984). Therefore, a more reasonable approach is to use a predictive model based on and in agreement with, data from a variety of experiments (Ong and Zhu, 1997).

Prediction models are used to provide the best possible estimates given the available information. Using these models, the rainfall rate can be known and thus, the attenuation due to rain can be predicted. There are several rainfall rate and attenuation models that are developed by many researchers.

Many researchers have developed models that can be used to estimate one-minute rainfall attenuation distribution; there is still some confusion with regard to choosing the right model to predict attenuation for the location of interest. Thus, the existing prediction models need to be tested against the measured results from tropical regions, by this it can be known that these existing prediction models are applicable to the tropical climates. Therefore, it is very important to need to know the measured data from tropical regions to choose the right model and to propose new prediction models for these regions.

The work published by Mandeep and Hassan (2004) has some relevance with this paper in terms of ITU-R, Moupfouma and Rice & Holmberg models comparison with the measured data. Even though 1 year of rain rate measurements were conducted by Mandeep and Hassan (2004) compared to the 3 years data for this paper, the ITU-R, Moupfouma and Rice & Holmberg models produces almost the same prediction results. Besides of direct rainfall rate measurement, predictions model for rainfall rate are required for locations different from the limited number of stations or locations with sufficient long-term data for the preparation of a statistically reliable distribution estimate (Zhou et al., 2000).

Even though there is still shortage of rainfall rate of 1-minute integration time necessary for the study of rain induced impairment to telecommunication especially in the tropical region (da Silva Mello et al., 2001; da Silva Mello et al., 2007), many researchers have venture into this region to help engineers in developing telecommunication systems at higher frequencies. Cerqueira et al (2005) described some preliminary results and the activities in progress of a research program on rain attenuation in the Amazon region. Cerqueira et al. (2005) combined use of precipitation and radar data, Köppen climate classification and Salonen-Baptista mathematical model for the prediction of rainfall rate cumulative distribution in Brazil. Sharma et al. (2009) conducted rain attenuation measurements at 28.75 GHz over a terrestrial path link in Amritsar, India. Sharma et al. (2009) made comparison of the measured data against ITU-R model and found that the model underestimates the attenuation at lower rain rates and overestimates at higher rain rate. Omotosho and Oluwafemi (2009a) obtained data from the Tropical Rainfall Measuring Mission (TRMM) satellite sensors, the Microwave Imager (TMI, 3A12 V6) and other satellite sources (3B43 V6) to derive 1-min rainfall rates for 37 stations in Nigeria. Omotosho and Oluwafemi (2009b) also investigated the effect of rainfall on horizontally polarized radio waves for fixed satellite service at Ku, Ka and

V bands for links by Nigeria Communication Satellite One (NigComSat-1), for 37 stations in Nigeria. The results reveal the regional patterns of rain impairment in Nigeria.

2. Data and methodology

The duration of 3 years rainfall data were measured from 1st January 2006 to 31st December 2008 using rain gauge data. Rainfall rate data from selected equatorial climates sites such as Universiti Sains Malaysia (USM) located at Penang, Malaysia (φ = 5.17° N, λ = 100.4° E), Bangkok (φ = 13.45° N, λ = 100.35° E) in Thailand, Bandung (φ = 6.7° S, λ = 107.6° E) in Indonesia, Basiad (φ = 14.9° N, λ = 122.2° E) in Manila, Philippines and Suva (φ = 18.06° S, λ = 178.3° E) in Fiji were used to make a comparison of rain rate prediction in tropical climates. All the measurement sites are equipped with a 400 cm^2 aperture tipping bucket. The rain rates were plotted against percentage of time unavailability, from 0.01% to 1% which corresponds to 52.6 min to 8.76 h of exceedance of the indicated one-minute rainfall rates in an average year.

The method used for testing the prediction models has been suggested by ITU-R (2009a). For certain percentage of time (from 0.001 to 1 percent of the year), for which data are available, percentage relative error, E_{rel} (percent) between the predicted value, $A_{predicted}$ and the measured value, $A_{measured}$ are calculated

$$E_{rel} = \frac{A_{predicted} - A_{measured}}{A_{measured}} 100 \qquad (1)$$

The mean error, μ_e and standard deviation, σ_e are used to calculate the root mean square, $D_e(RMS)$. The parameter is defined as follows

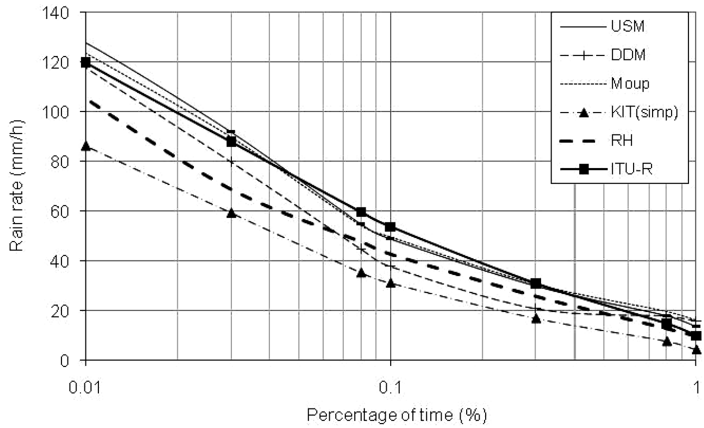
$$D_e = [(\mu_e)^2 + (\sigma_e)^2]^{1/2} \qquad (2)$$

3. Results and discussion

The existing models that applied in the prediction one minute rain rate are Moupfouma and Martin (1995) model (Moup), ITU-R (2009a,b) model, Kitami Institute of Technology (Ito and Hosoya, 1999) simplified model (KIT(simp)), Rice and Holmberg (1973) model (RH) and Dutton, Dougherty and Martin (1974) model (DDM). The comparison of one minute rain rate prediction models with measured data for the 5 tropical climates sites are shown on Figures 1a to 1e.

A summary of the information of the result obtained from the measured data is as show in Table 1 and 2. Table 1 shows that for 0.01% of time the Moupfouma model gave the lowest error for all of the measurement sites except for Bangkok whereby at this location the ITU-R gave the lowest error of 1.6%. Most of the existing prediction models did not perform well in the equatorial region whereby comparison between the predicted and experimental data has led to high prediction errors. There is a high correlation between the rain rate and attenuation exceeded values in average years that would be useful in determining the link fade margin. For the equatorial region, it was found out that Moupfouma model revealed a close fit to the measured data for low, medium and high rain rates. The Moupfouma model is judged suitable for use in predicting rates in tropical climates. This is because the model has a probability law behavior that underlines the complexity of the rain rate distribution according to the climate of the zone of interest. The Moupfouma model was developed based on intensity cumulative distributions for most of the

a)



b)

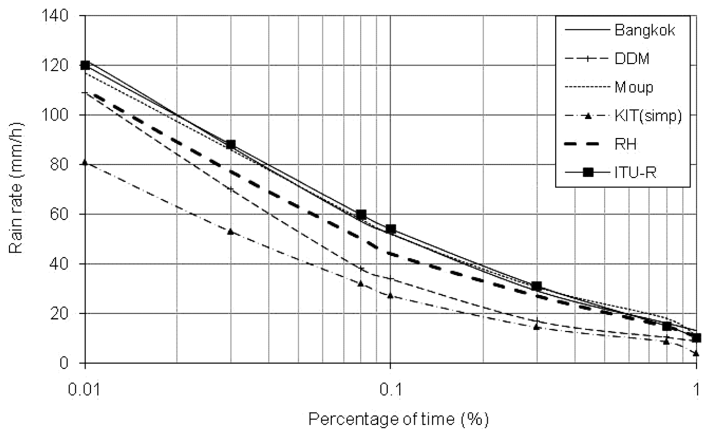
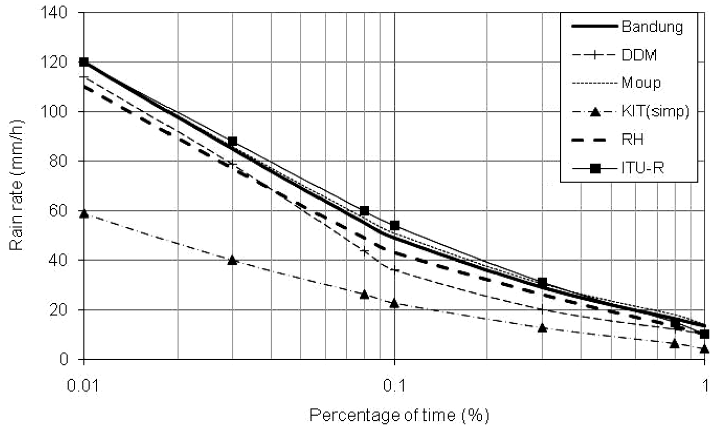
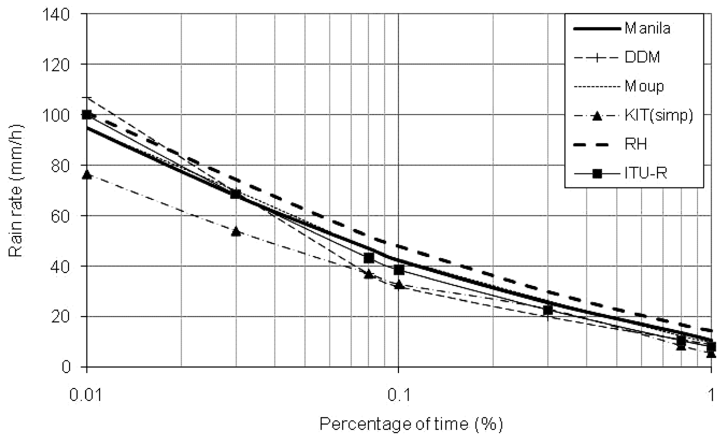


Figure 1. Comparison of one minute rain rate prediction models: (- + -) DDM (Dutton, Dougherty and Martin, 1974); (- - -) Moup (Moupfouma and Martin, 1995); (-▲-) KIT(simp) (Kitami Institute of Technology simplified; Ito and Hosoya, 1999), (– –) RH (Rice and Holmberg, 1983) and (-■-) ITU-R (International Telecommunication Union-Radiocommision Sector, 2009a,b) with measured data for: a) USM, b) Bangkok, c) Bandung, d) Manila and e) Fiji site.

c)



d)



e)

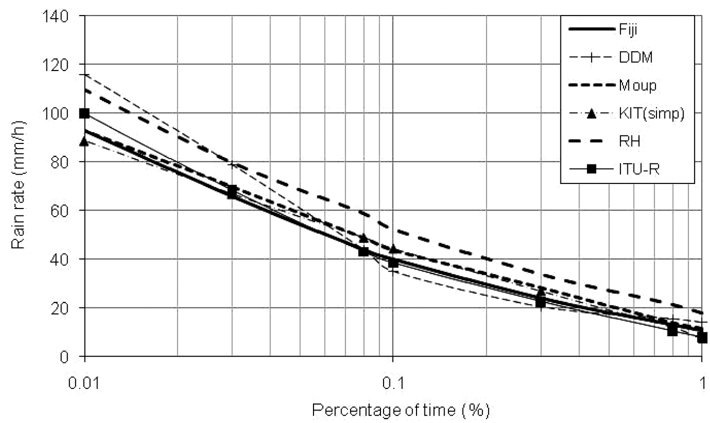


Figure 1. Continued.

Table 1. Comparison of rain rate models with measured data at 0.01% of time.

Measurement site	Rain rate [mm/h] 0.01%	Rain rate models at 0.01% of time [mm/h]									
		DDM	% error	Moup	% error	KIT (simp)	% error	ITU-R	% error	RH	% error
USM	128	118	7.8	123.8	3.3	86.3	32.6	120	6.3	105.6	17.6
Bangkok	122	109	10.7	117.0	4.1	80.9	33.7	120	1.6	110	9.7
Bandung	117.5	114	3.0	120.0	2.1	58.7	50	120	2.1	110	6.4
Manila	95	107	12.6	95.0	0	76.6	19.4	100	9.3	101	6.3
Suva	93	116	24.7	93.0	0	88.8	–4.5	100	7.5	110	18.3

Table 2. Comparison of rain rate prediction models.

Measurement site	Annual rainfall [mm]	RMS value [%]					Conclusion	
		DDM	Moup	KIT (simp)	ITU-R	RH	Best model	Worst model
USM	2088.0	29.04	8.64	36.56	20.72	29.65	Moup	KIT(simp)
Bangkok	1565.0	16.03	4.35	41.59	13.18	8.59	Moup	KIT(simp)
Bandung	1956.0	14.86	2.33	42.72	11.75	7.58	Moup	KIT(simp)
Manila	2300.0	7.73	1.69	25.59	13.65	14.49	Moup	KIT(simp)
Suva	3087.5	28.10	6.22	15.62	17.90	42.16	Moup	RH

hydrometeorological zones of the world classified by the Consultative Committee on International Radio, CCIR. Moupfouma and Martin's model is based on approximation of log-normal distribution at the low rates, and a gamma distribution at high rain rate. To estimate rain rate (R) at 0.01% of time, $R_{0.01}$, the use of Chebil and Rahman's model (1999) appears suitable, it allows the usage of long-time mean annual accumulation, M, at the location of interest. Thus, using the refined Moupfouma model and Chebil and Rahman's model, the 1 min rain-rate cumulative distribution is fully determined from the long-term mean annual rainfall data. Another element for consideration is the development of attenuation prediction models that make use of the full rainfall distribution, rather than just of the 0.01% point. As such models improve, the importance of an accurate prediction of the $P(R)1$ distribution increases (Emiliani et al., 2010).

The ITU-R model overestimates the one minute rain rate from 0.01% to 1% of time and underestimates the rain rate from 0.001% to 0.01% at USM. The model gave a RMS value of 20.72% for USM whereas for measurement sites such as Bangkok, Bandung, Manila and Fiji sites, the model followed closely to the measured rain rate values up to 0.01% of time. The ITU-R method for rain rate is basically a graphical method. This is probably due in part to the higher variability observed among CDFs from stations belonging to the tropical region, while distributions from temperate stations tend to be more similar between them. The higher variability observed in the tropical region could be ascribed to the choice of the first level climate subdivision defined in Peel et al. (2007) and Emiliani et al. (2008).

At USM, Bangkok, Bandung and Manila, the KIT(simp) model underestimates the measured rain rate throughout the entire percentage of time where the rain rate is exceeded. The model gave a high RMS value for these sites because the annual rainfall amount at these sites were not more than 2300 mm. The KIT model prediction at Fiji, gave a low RMS value of 15.62%. The model follows closely the measured rain rate values at the entire percentage of time that the rain rate is exceeded. The model is based on empirical and analytical approach and cannot be considered as globally applicable, even when global coefficients are given. This is usually because the coefficients are average values derived from a given database and are therefore optimized to give the best performance within that dataset. In some cases, the database itself might be biased towards a particular climatic sub-region, or it might fail to capture the variations introduced by the local topography (Emiliani et al., 2010).

The RH model underestimates the measured rain rate at USM, Bangkok and Bandung throughout the entire percentage of time that the rain rate is exceeded. The model gave a RMS value of 29.65% at USM, 8.59% at Bangkok and 7.58% at Bandung. The RH model overestimates the measured rain rate at Manila and Fiji throughout the entire percentage of time that the rain rate is exceeded. The model gave a RMS value of 14.49% at Manila and 42.16% at Fiji. The RH considered the convective rain activity and stratiform rain activity was neglected. The thunderstorm ratio, β was based on thunderstorm rain but on the convective rain activity days to total rain days. The model gave a high RMS value at Fiji site because the β value given by RH is 0.3, however the β value calculated to be 0.75.

The DDM model underestimates the measured rain rate at USM, Bangkok and Bandung and overestimates the measured rain rate at Manila and Fiji throughout the entire percentage of time that the rain rate is exceeded. The model gave a RMS value of 29.04% at USM, 16.03% at Bangkok, 14.86% at Bandung, 7.73% at Manila and 28.10% at Fiji. The M (average annual total rainfall depth, mm) values used to calculate the coefficient constant in Europe were below 1200 mm per year, but the annual rainfall, M is above 1800 mm per year in tropical climate.

4. Conclusion

The scope of application of the 1-minute rain rate comparison included the analysis of microwave systems at frequencies above approximately 10 GHz. Among the empirical models, the Moupfouma model was found to be the best predictor for this region because of the model's log-normal asymptotic behaviour for the low rain rates, and a gamma asymptotic behaviour for the high rain rates. Nevertheless, it was clear that results were still limited by the amount of data available and research is required to ascertain with high levels of significance the actual performance of the methodologies identified in the literature search. This can only be done as more data become available.

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SAŽETAK

Usporedba modela intenziteta oborine za područja s ekvatorijalnom klimom u jugoistočnoj Aziji

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Statistika minutnih intenziteta oborine ima veliki utjecaj na modeliranje satelitskih komunikacijskih sustava koji rade na frekvencijama višim od 10 GHz. Utjecaj kiše uzrokuje jaku degradaciju radio signala na frekvencijama 10 GHz i višim; stoga modeli za predviđanje prekoračenja dozvoljenog propagacijskog gušenja, koje je potrebno za izbor komunikacijskih pravaca, zahtijevaju statistički opis intenziteta oborine na tim pravcima. U ovom su radu obrađeni trogodišnji nizovi podataka s intenzitetima oborine za odabrane postaje u ekvatorijalnom području. Uspoređeni su rezultati dobiveni s nizovima podataka intenziteta oborine koji su uzorkovani s periodom jedne minute s onima dobivenima prognostičkim modelima intenziteta oborine.

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