Analysis of Raindrop Size Distribution Characteristics in Malaysia for Rain Attenuation Prediction

H.Y. Lam[1] , Din.J[2], L Luini [3], A. D.Panagopoulos[4] , C.Capsoni[5]

[1,2]Department of Radio Communication Engineering, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Skudai 81310 Johor, Malaysia. lamhongyin@ieee.org, jafri@fke.utm.my

[3,5]Dipartimento di Elettronica e Informazione, Politecnico di Milano, Piazza L.da Vinci 32, 20133 Milano, Italy. luini@elet.polimi.it, capsoni@elet.polimi.it

[4]Mobile Radio Communications Laboratory, School of Electrical and Computer Engineering, National Technical University of Athens, GR-15780, Athens, Greece. thpanag@cc.ece.ntua.gr

Abstract

The assessment of the variability of rainfall characteristics in the equatorial regions is a key problem in estimating adequate fade margin due to rain attenuation in satellite communication systems. Based on one year of disdrometer data that have been collected in Kuala Lumpur, Malaysia, this paper investigates the general characteristics of the raindrop size distribution (DSD) and the dependence of the rain attenuation on the DSD. Its diurnal variation and the role of critical diameter values on the estimation of the specific attenuation are also discussed. Preliminary results suggest that satellite links operating in the afternoon and early evening hours should be provided with an extra fade margin to compensate for rain attenuation impairments.

1. Introduction

A good understanding of the characteristics and variability of the raindrop size distribution (DSD) is extremely important in predicting rain induced propagation effects for terrestrial and Earth to space radio links operating at frequencies above 10 GHz [1]. In fact, as is well known, the specific attenuation experienced by electromagnetic waves traveling through rain is dependent on the DSD. In addition, several studies have proved that the DSD characteristics vary across different climatic regimes [1-2]; tropical and equatorial regions frequently experience higher rainfall rate compared to temperate regions, which leads to extreme attenuation events impairing the communication link. Therefore, it is worthwhile to concentrate on the local features of the DSD, specifically in equatorial and tropical regions, for the accurate modeling of rain attenuation.

Previous works carried out in the last decade have investigated the raindrop size distribution in tropical or equatorial regions such as in Singapore and Indonesia [1-4]. However, as mentioned in [5], the climate of the Malaysian equatorial region is local rather than regional; the equatorial climate of West Malaysia is characterized by high rainfall rate and uniform atmospheric temperature throughout the year. Hence, detailed analyses need to be carried out to investigate the variability and the characteristics of the DSD in this particular equatorial region.

To this aim, in this work, a Joss and Waldvogel disdrometer RD69 [6], installed in Kuala Lumpur, has been employed to collect DSD data. Details on data measured by the disdrometer are briefly discussed in the next section. General characteristics of the DSD in this particular area are presented in Section 3, followed by the analysis of the diurnal variations of the DSD. The calculation of the specific attenuation from DSD data is presented as well in Section 4. In addition to this, we also demonstrate the impact of critical diameter values on the specific attenuation. Finally, Section 5 draws some conclusions.

2. Disdrometric Data

Raindrop size spectra were collected by JW disdrometer RD69 [6] (an impact measurement device), installed at the Universiti Teknologi Malaysia − UTM − (101.42º E and 3.08º N), Kuala Lumpur, Malaysia, from January to December 1993. The disdrometer measured DSD with sampling rate of 1 sample/min by transforming the vertical momentum of the drops into electric pulses (a function of the drop diameter) and by sorting drops into 20 intervals, with diameters ranging from 0.3 mm to 5.3 mm. For brevity's sake, a comprehensive explanation on the processing of disdrometer data is not provided in this paper, but the reader may refer to [3, 6] for further details. As underlined by the results in [3], this type of instrument tends to underestimate the number of smaller drops during heavy rain events due to

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the resonance of the cone following the impact of a large drop (this is also known as “disdrometer dead time”). Moreover, environmental acoustic noise is also identified as another source of errors affecting the measurement. In the present study, the dead-time correction is however not applied due to the shortcomings associated to correction algorithms as highlighted in [3-4], but the disdrometer was installed on the rooftop of a building to minimize acoustic noise.

3. Drop Size Distribution Characteristics in Kuala Lumpur

In this section, the DSD characteristics in Kuala Lumpur are presented. The rainfall rate observed by the JW disdrometer (expressed in mm/hr) can be calculated with (1), which involves a simple summation over various drop size classes:

$$R = \frac{3600\pi}{6ST}\sum_{i}^{20} {D_i}^3\, n_i \tag{1}$$

where n_i is the number of drops, with mean diameters D_i collected over a sample area of S = 5000 mm^2, with an integration time T = 60 sec. Moreover, the DSD, $N(D_i)$ (m^{-3} mm^{-1}), can be computed as:

$$N(D_i) = \frac{n_i \times 10^6}{\upsilon(D_i) \times S \times T \times \Delta D_i} \tag{2}$$

where $\upsilon(D_i)$ is the fall speed (m/s), in still air, of a drop of diameter D_i from Gunn and Kinzer [7] and ΔD_i is the bin-width of each drop-size class. In order to compare the characteristics of the DSD measured in Kuala Lumpur with those presented in a previous study in the same climatic region, Fig.1 depicts the average DSD for two rain rates collected from a disdrometer installed in Singapore (data are extracted from [3]) and from the one used in this study, namely R = 4 mm/hr (low rain rate) and 120 mm/hr (high rain rate). The DSD data in Singapore have been collected from August 1994 to September 1994 using the same type of instrument. A fairly good agreement between the datasets measured by the two instruments can be observed.

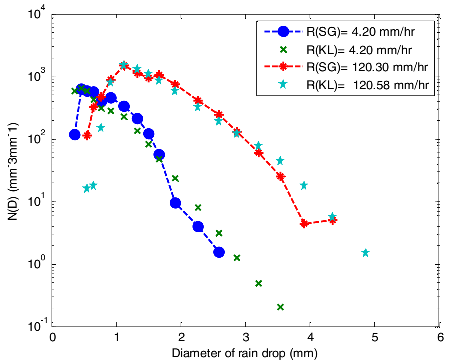

Fig.1: Comparison between raindrop size distributions measured in Kuala Lumpur and Singapore.

3.1 Diurnal Variations of the DSD

As shown in [2], the DSD presents different features, especially if its diurnal variation is concerned, even in sites which are all characterized by the same Asian monsoon climate. In order to evidence the variability of the DSD in Kuala Lumpur, we have first calculated the average DSD (from 1-minute integrated samples) relative to 8 non-overlapping time intervals of 3 hours each: 0:00-3:00, 3:00-6:00, 6:00-9:00, 9:00-12:00, 12:00-15:00, 15:00-18:00, 18:00-21:00 and 21:00-24:00. Fig.2a shows the diurnal variation of the rain rate cumulative complementary distribution function (CCDF) computed for year 1993; Fig.2b and Fig.2c report the diurnal variation of the average (over rain rate) DSD, respectively for low and high rain rates. Figures indicate a marked variability on the rain rate CCDF and also on DSD for diameters larger than approximately 3 mm. To further investigate the impact of the DSD variations on Earth-space communication links, the following section presents the analysis on the specific attenuation due to rain as estimated from disdrometer data.

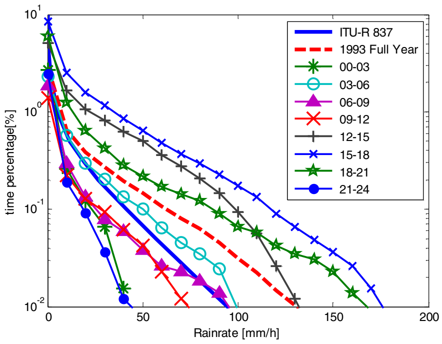

Fig.2a: Diurnal variation of the rain rate CCDF in Kuala Lumpur

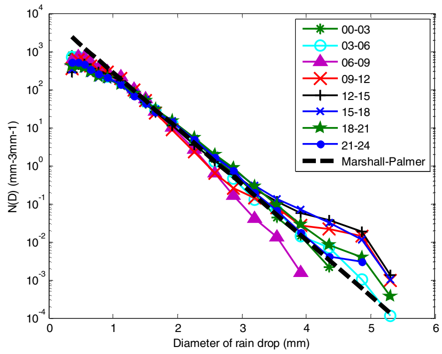

Fig.2b: Diurnal variations of the average DSD (R between 1 and 5 mm/hr) and Marshall Palmer DSD

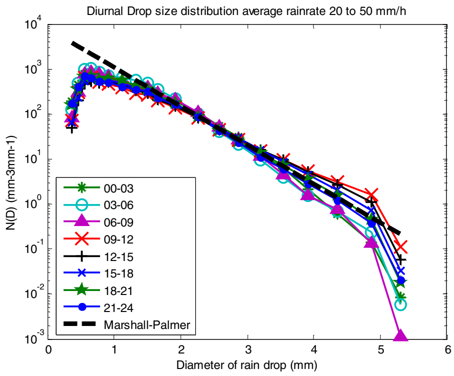

Fig.2c: Diurnal variations of the average DSD (R between 20 and 50 mm/hr) and Marshall Palmer DSD

4. Critical Diameter of DSD and the Computation of Specific Attenuation

The specific rain attenuation $\gamma_{(H,V)}$ (dB/km) is obtained from the following expression:

$$\gamma_{(H,V)} = 4.343 \times 10^3 \frac{\lambda^2}{\pi} \sum Re[S_{H,V}(0)] N(D) \Delta D \qquad (3)$$

where λ is the wavelength in meters, $S_{H,V}(0)$ are the complex forward scattering coefficients for horizontal and vertical polarization respectively, with observation angle $\emptyset = 0$ (i.e. forward scattering). It is worth mentioning that this coefficient is dependent on frequency, radius of the drop and the complex refractive index of water (which, in turn, is a function of temperature and frequency). The calculation of the complex forward scattering coefficient were performed using point matching technique deduced from [8] by assuming oblate spheroid raindrop shape at temperature T = 20ºC. $N(D)$ is the number of drops per unit volume per unit diameter in $m^{-3}mm^{-1}$, and, finally, ΔD represents drop size interval in *mm*.

Fig.3a below shows that the highest specific attenuation values obviously correspond to the most intense rain rates which are present only in some time intervals during the day. It is interesting to point out that at equal rain rate (for instance 60mm/h), the dissimilarity in the specific attenuation is clearly due to the different DSD, as evidenced for 4 time intervals, namely 15:00 to 18:00, 18:00 to 21:00, 12:00 to 15:00 and 9:00 to 12:00.

It is worth also investigating specific raindrop sizes which produce a major contribution to the total specific attenuation for each rain rate values. Fig.3b points out that the predominant contribution to the specific attenuation is produced by small and medium-size drops (in this case R = 120.4 mm/h, but the same behavior is observable for other rain rates), which is more and more true as the frequency increases. For convenience, also results derived from Singapore data [3] are depicted in Fig.3b, which indicates a similar trend of the specific attenuation contribution with raindrop diameter, although lower values are observed in Kuala Lumpur, especially for high frequencies (f = 38 GHz and 48 GHz).

5. Conclusions

The general characteristics and the diurnal variation of the DSD and of the rain rate statistics in the equatorial Malaysia have been investigated in this contribution. It was found that the DSD diurnal variation in this particular region has a significant impact on the specific attenuation, especially for rain rates higher than 30mm/hr, and that most intense and frequent rain event occur during afternoon-evening hours.

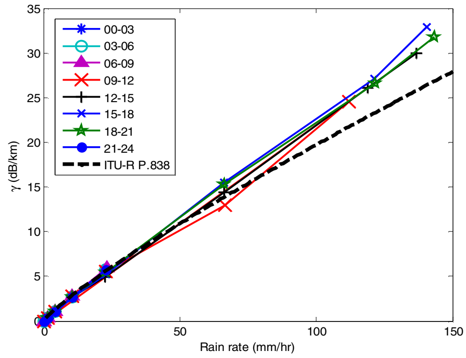

Fig.3a: Diurnal variation of the specific attenuation computed at frequency of 38 GHz for vertical polarization

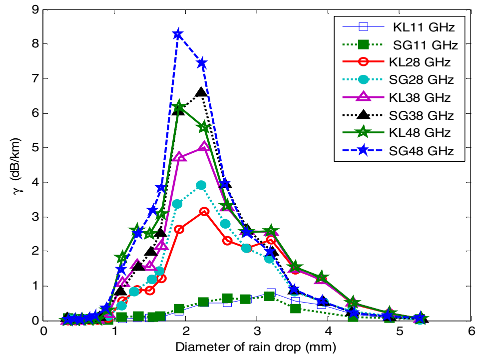

Fig.3b: Specific Attenuation (vertical polarization) as a function of raindrop size in Kuala Lumpur (KL) and Singapore (SG) at various frequencies; rain rate equal to 120.4 mm/hr

Besides this, analysis on the role of particular size of the diameter indicates that the major contribution to specific attenuation is provided by smaller and medium-sized drops, which is more and more true as frequency increases. In the future, it would be worthwhile to investigate the characteristics of the DSD in this region on event basis so as to possibly discriminate between stratiform and convective DSDs, which could improve the accuracy of rain attenuation prediction models such as SC EXCELL proposed in [9]. Finally, the preliminary results obtained in this contribution suggest that to properly design adequate fade margin levels or achieve the desired quality of service in a radio communication system operating in this particular area, one should carefully consider the diurnal variability of the DSD and of the rain rate statistics.

6. Acknowledgments

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7. References

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