INVESTIGATION OF KA-BAND SATELLITE COMMUNICATION PROPAGATION IN EQUATORIAL REGIONS

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INTRODUCTION

Satellite communication (SatCom) systems are moving to higher operating frequencies owing to the increasing demand for high-data-rate multimedia services, typically to the Ka-band and above. However, at such frequencies, they are susceptible to tropospheric impairments mainly due to rain, which can severely degrade their quality of service (QoS) and availability. This effect is particularly drastic in tropical/equatorial climates with heavy precipitation characteristics (Lam *et al.* 2012).

Therefore, the design of modern SatCom systems in these regions requires a good understanding of radio channel characteristics that reflect the peculiarities of tropical precipitation. To this end, propagation experiments are of great importance, not only to collect actual propagation design parameters such as fade duration and fade slope, but also to allow direct evaluation of the application of propagation impairment mitigation techniques (PIMTs) such as site diversity and time diversity. However, reliable measurement data of Ka-band signals are not diffusely available in these regions, except Yeo *et al.* (2014) from Singapore who carried out Ka-band propagation measurement campaign which only focuses on first-order statistic of rain attenuation. Up to date, only few researchers performed the analysis of fade dynamics in tropical/equatorial regions, but they concentrated on Ku-band satellite communication systems. For instance, Singh (2013) presented only one year of measured fade duration statistics collected in North of Peninsular Malaysia, Penang; Dao *et al.* (2013) focused only on fade slope statistics in Kuala Lumpur, Malaysia and improvement factor was proposed to improve the ITU-R P.1623-1 model by fitting the measured fade slope statistic. Even though both of the local researchers have investigated fade duration and fade slope respectively, they did not provide a detailed analysis on rain fade characteristics. In addition, Pan and Allnutt (2004) analysed on the characteristics of diurnal fade duration and fade interval in Lae, Papua New Guinea. It was found that strong convective events frequently occurs from 9 pm to 4 am in Lae, but this might not be similar to the climate in equatorial Johor Bahru. Therefore the European Space Agency (ESA) and Joanneum Research (Austria), in close collaboration with partners from Malaysia (Universiti Teknologi Malaysia, UTM, and Universiti Tun Hussein Onn, UTHM) and Italy (Politecnico di Milano), have recently proposed an experimental propagation campaign over Peninsular Malaysia.

This work briefly describes the planning and design details of the Ka-band propagation experiment. In addition, it presents some propagation results of the first- and second-order rain attenuation statistics based on simulations on weather radar data and local rain rate time series data from this particular area. Stratiform Convective-Synthetic Storm Technique (SC-SST) and ITU-R models are used for the estimation of Ka-band rain fade characteristics, and measured statistics from other regions are also included for the purpose of comparison. In fact, SC-SST is a model that only considers the melting layer effects in stratiform rain but not in convective rain. This is particularly suitable for equatorial regions (Lam *et al.* 2012). Hence, it is interesting to note that SST model has the ability to preserve the local climatic peculiarities while transforming the rain rate time series into rain attenuation time series. Such an outcome can be ascribed to the usage of local time series of rain rate as the main input to the model, therefore, it has been used worldwide (Matricciani, 1996).

PROPAGATION EXPERIMENT DETAILS

The experimental campaign has been planned for collecting propagation measurements of Ka-band signals from the Syracuse-3A satellite (47°E), whose beacon frequency is 20.245 GHz. The main site of the campaign is located at the UTM campus (1.56°N, 103.65°E), and the remote diversity site is located at the UTHM campus (1.86°N, 103.09°E), approximately 70 km away (Figure-1). The elevation angles of the receiver antennas at UTM and UTHM are 25.24° and 26.15°, respectively. Both sites are equipped with meteorological stations and provided with the auxiliary data such as 2D video disdrometer data (main site), weather radar data and radiosonde data.

The main objective of this propagation campaign is to improve the characterization of radio channel modeling and ground system requirements for the development of a Ka-band SatCom system covering tropical regions. It will focus on the statistical analysis of rain fade dynamics (i.e., fade slope and fade duration) in tropical/equatorial regions as well as the evaluation of the performance of both site diversity and time diversity techniques. In addition, the experimental results will be submitted to radio regulatory bodies (e.g., International Telecommunication Union-Radio, ITU-R) for the standardization of models.

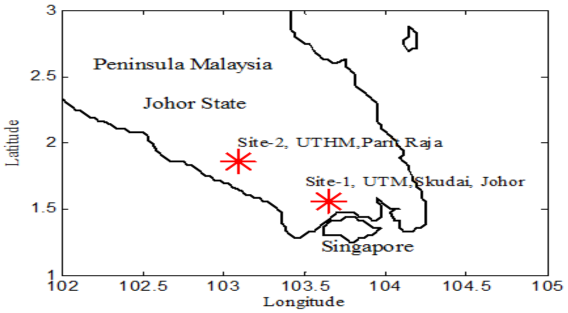

Figure-1. Map of equatorial Malaysia showing locations of ground stations for both experimental sites.

RESULTS AND DISCUSSIONS

This work involved analysis of rain rate and some preliminary evaluation of the first- and second-order statistics of rain attenuation suffered by an earth-space link at the main site by means of the weather radar data (Lam *et al.* 2013), SC-SST model (Lam *et al.* 2012), ITU-R P.618-11 Recommendation (2013) and ITU-R P.1623-1 (2005) according to the planned experimental radio link parameters.

Rainfall rate measurement results

The complementary cumulative distribution functions (CCDFs) of rain intensity for 2001 (Jong *et al.* 2014) and 2013 which were collected in Johor Bahru-UTM are investigated. Figure-2 depicts the measured mean CCDFs of precipitation rate for three locations and two climatic regions. Johor Bahru and Singapore (Ong and Zhu, 1997) are catogoried as tropical/equatorial region and Spino d'Adda, Italy (D'Amico *et al.* 2013) represents temperate region. It can be observed that considerable differences of rain rate between both regions are found at 0.01% of time. For instance, Johor Bahru-UTM experiences annual rain rate of 137.5 mm/h, Singapore encounters 119 mm/h whereas Spino d'Adda, Italy experiences significantly lower rain rate at 50 mm/h. This indicates that equatorial regions suffer considerably higher precipitation rate (e.g. more than 100%) than temperate regions and this has a huge impact to earth-space propagation link, particularly at frequencies above 10 GHz. In addition, as expected in heavy rain region, the CCDF of precipitation rate derived from ITU-R P.837-6 (2012) in Johor Bahru underestimates the measured statistics of rainfall rate (Jong *et al.* 2014). In fact, the local measured rain rate at 0.01% of time will be used as an input parameter to predict rain attenuation by means of ITU-R P.618-11 model in the latter section. Table-1 gives the comparison of rain rate exceeded for 0.01% as well as 0.1% of times.

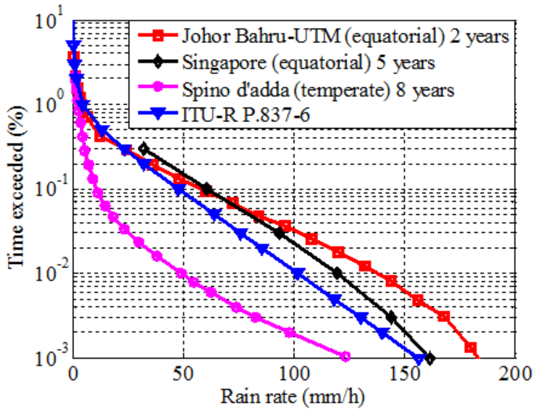

Figure-2. Cumulative distributions of rainfall rate obtained from measured rain intensity in Johor Bahru compared with ITU-R model and measured rain intensity from Singapore as well as Spino d'Adda.

Table-1. Comparison of cumulative statistics of rain intensity.

Site	**Rain rate exceeded for specific % of times**	
	0.1%	**0.01%**
Johor Bahru-UTM	58.0 mm/h	137.5 mm/h
Singapore	60.5 mm/h	119.0 mm/h
Spino d'Adda, Italy	10.5 mm/h	50.0 mm/h
ITU-R P.837-6	47.5 mm/h	102.0 mm/h

Rain attenuation

Signal quality perceived by end users is very much dependent on the operating frequency. As can be observed in Figure-3, statistics of rain attenuation estimated from ITU-R P.618-11 (2013) model show that Ka-band (20.2 GHz) experiences more than double attenuation than Ku-band (12.2 GHz) at 0.01% of time. Unfortunately, the vast majority of rain attenuation studies in tropical/equatorial regions concentrate on Ku-band, e.g. Ismail and Watson (2000) and Singh (2007). To the best knowledge of the authors, only Yeo *et al.* (2014) performed an analysis at Ka-band, which only focuses on first-order statistic of rain attenuation. Therefore, a Ka-band propagation measurement campaign carried out in equatorial Malaysia will be extremely useful to precisely characterise the first- and second-order statistics of rain attenuation, as far as PIMTs are concerned.

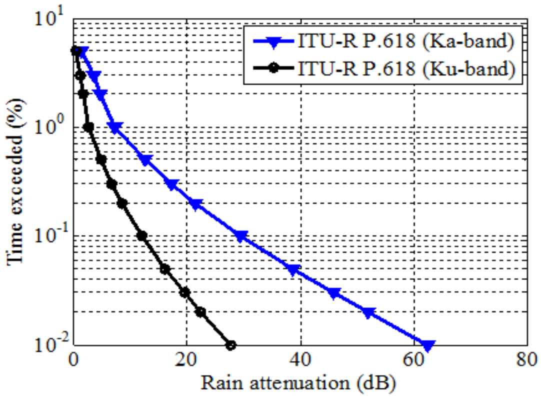

Figure-3. Comparison of Ku- and Ka-band rain attenuation CCDFs estimated from ITU-R P.618-11 model.

In addition, Figure-4 shows the comparison of cumulative distributions of rain attenuation estimated by the ITU-R model with prediction from weather radar data and SC-SST prediction model. It is found that the ITU-R model tends to underestimate the rain attenuation. However, both prediction results from weather radar and SC-SST model are very similar over the entire probability range. It should be noted that SC-SST has been proven to perform well in the prediction of CCDF of rain attenuation particularly in tropical/equatorial regions (Lam *et al.* 2012). Our results seems to point out that rain attenuation values as high as 80 dB may exits at 0.01% of time at the lower elevation angle (25.24˚), at Ka-band frequency. On the other hand, three years of measured attenuation distribution from Singapore obtained from WINDS satellite at an elevation angle of 44.5˚ does not agree with the prediction from weather radar and SC-SST model, although Singapore falls in same climatic region. The measured data show a substantially lower attenuation (e.g. 42.5 dB) with respect to prediction from radar data (e.g. 82 dB) and SC-SST (e.g. 87 dB) model. Therefore, it is of great importance to carry out a propagation measurement campaign particularly for lower elevation angles. For low elevation angles, the link can travel more than 10 km in the lower troposphere; thus, rain attenuation along the earth-space path might be owing to the combination of multiple rain cells. In this respect, the dynamic characteristics of rain attenuation at low elevation angle could be considerably different from those at high elevation angles, especially in heavy rain areas.

Furthermore, Figure-4 also clearly show that measured attenuation at Spino d'Adda for 0.01% of time is significantly lower (e.g. 12.5 dB) than that observed in tropical/equatorial regions. It is important to note that the precipitation and rain attenuation characteristics in temperate regions are not suitable to represent the characteristics in tropical/equatorial regions as they are remarkly different from those in tropical/equatorial climates.

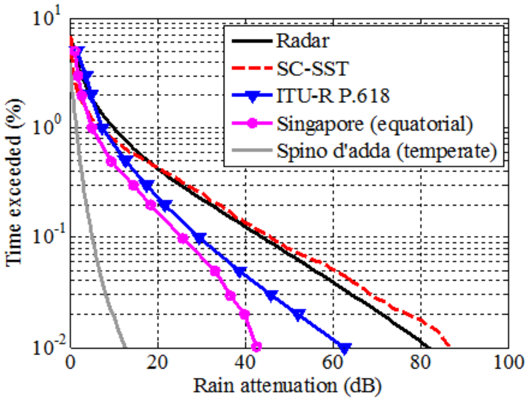

Figure-4. Comparison of first order rain attenuation CCDFs: Prediction using weather radar data, SC-SST and ITU-R models are compared with Singapore and Spino d'Adda measured data.

Fade dynamics

In general, fade countermeasures which is generally based on first order statistics of rain attenuation, need to be introduced to counteract rain attenuation. However, first-order statistics alone are not sufficient for the proper design of adaptive PIMTs. Therefore, the knowledge of second-order statistics which describe the dynamic characteristics of rain-induced fades is of great importance to the system designers as far as fade countermeasures are concerned to optimize system capacity and reduce the probability of system outages. In fact, the second order statistics are not derivable from first-order rain fade statistics and must be extracted from the time series of signal attenuation. Such fade dynamics include fade duration, fade slope, interfade interval and inter-event interval. The features that characterise the dynamic of fade events are presented Figure-5.

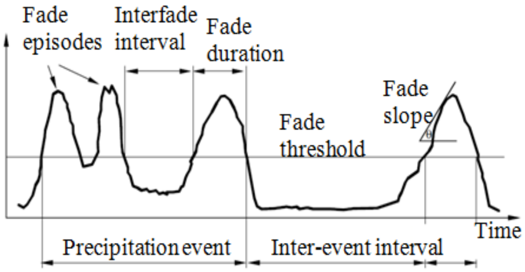

Figure-5. Dynamic features of fade events (ITU-R P.1623-1, 2005).

Among these fade dynamics, only fade duration and fade slope characteristic are of interest in the design and implementation of PIMTs. Although fade dynamics have been discussed in details in previous literature, most of the results from heavy rain region are relative to Ku-band only, such as Pan and Allnutt (2004), Dao *et al.* (2013) and Jong *et al.* (2014). Figure-6 shows the CCDFs of duration as function of threshold estimated from ITU-R P.1623-1 and SC-SST models compared with Madrid, Spain (García-Rubia *et al.* 2011) measured statistic. Significant discrepancy is found between the fraction of time estimated by ITU-R model and SC-SST model as well as measured distribution from Madrid. Similar situation is found for fade slope distributions as shown in Figure-7. Good agreement can be seen between ITU-R P.1623-1 model and Eidhoven, Netherlands measurement at an elevation angle of 26.8˚, but not with SC-SST model. Hence, such discrepancies clearly indicate the need to validate the results by using experimental data.

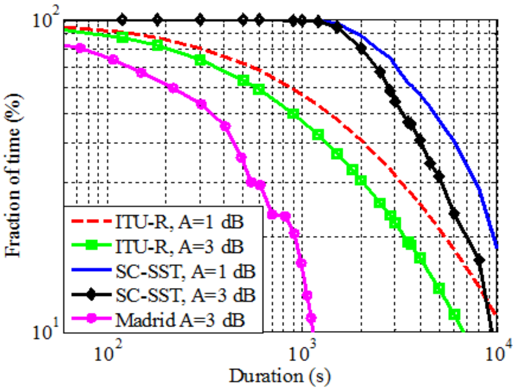

Figure-6. Comparison of fade duration statistics predicted by SC-SST and ITU-R models with respect to Madrid, Spain, for attenuation threshold of 1 dB and 3 dB.

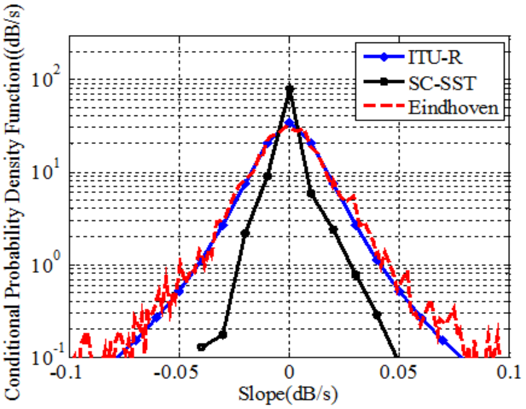

Figure-7. Conditional distribution of fade slope inferred from SC-SST and ITU-R model and compared with slope distribution measured in Eindhoven, Netherlands.

CONCLUSIONS

In this work, first- and second-order statistics of rain attenuation have been estimated exploiting weather radar data, local time series of rain rate, SC-SST and ITU-R models. The discrepancies among the predicted results obviously indicate the necessity to carry out a Ka-band propagation measurement campaign in equatorial Malaysia to validate and characterise more precisely the characteristics of rain attenuation especially in heavy rain region at lower elevation angle. The knowledge of such characteristics of benefit to system designers for the effective implementation of suitable PIMTs, to improve the link availability during severe rain periods as well as for the submission to ITU-R for standardization of models.

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