CHAPTER 10

CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

Long-term and short term analysis of measured rain attenuation and rain intensity data over a four year period at five locations in Southeast Asia were performed. In addition the new models (Fade-duration model and diurnal attenuation model) developed from analytical results were presented to be a useful tool for the design of the Ku-band satellite communication system in Southeast Asia. Results analysis in this dissertation can be summarized as follows:

1) Rain Attenuation Analysis

The measured cumulative rain intensity distributions in Southeast Asia are well fitted with a single exponential or a Gamma distribution. Year-to-year variation of the measured distribution shows a large variation in a tropical moderate climate (ITU-R zone-N), but small variation in a tropical wet climate (ITU-R Zone-P). The Diurnal variation of rainfall distribution is highly dependent on a geographical location. The rain intensity distribution in the ITU-R zone N relies on the seasonal variation, whereas the rain intensity distribution in the ITU-R zone P has no seasonal variation. The statistics of rain intensity duration in the ITU-R zone N are longer than those in the ITU-R zone-P.

2) Rain Attenuation Analysis

Rain attenuation at 12 GHz along the earth-satellite path in Southeast Asia is relatively severe compared with other temperate regions. No available statistical distributions well represent the cumulative distribution of rain attenuation in Southeast Asia. The log-normal distribution presents some reasonable fits to the attenuation lower than 10 dB, but it overestimates attenuation higher than 10 dB. The power-law distribution is found to be a reasonable fit to the annual cumulative distribution in Si-racha and Songkla at deep rain fade from 3 dB to 30 dB. There is relatively small year to year variation on the annual attenuation distributions. The attenuation distribution in the ITU-R zone N varies with the season whereas the attenuation distribution in the ITU-R zone-P does not change with seasons. The worst month distribution in the ITU-R zone N is higher than those in the ITU-R zone P. Various rain attenuation prediction models are tested with all measured distributions and all models disagree with the measured distribution.

3) Site Diversity Analysis

For a site diversity experiment at relatively low elevation angle, analytical result indicates that for system link availabilities of 99.9%, only system margins of less than 3 dB would be necessary for the diversity configuration. At the 99.99% level, margins of 5 dB

shall be provided. A comparison of measured diversity improvement factors with those predicted by the ITU-R indicates that the measured diversity performance exceeds the predicated values. Given the restrictions on the prediction model, quite reasonable agreement was obtained. In addition, the measured diversity gain shows the excellent performance compared with the ITU-R model.

4) Fade Duration Analysis

For fade-duration analysis, It is found that the event fade duration statistic can be well represented by a double exponential distribution over the range from 2 seconds to 4000 seconds. The events fade duration in ITU-R zone N show longer attenuation time than those in ITU-R zone-P.

5) Fade-Duration Model

Data analysis over a three year period at four locations can be developed the fade-duration model using the three fitted parameters (a,b,d) to the double exponential distribution. The shape parameter (a) may have some relations with the ratio of thunderstorm (β) of Rice & Holmberg model.

6) Diurnal variation Analysis

Results of a diurnal variation analysis are found that the diurnal variation pattern of attenuation and rainfall are highly dependent on the environmental conditions i.e., buildings, geographical locations. Rain attenuation and rainfall frequently occur in the afternoon to evening having the peak between 1300LT - 1800LT. The diurnal variation patterns of rain attenuation and rainfall are high correlation. There is significant different of the diurnal variation pattern between the coastal area and the mountainous area due to the influence of geographical location. The diurnal variation pattern of attenuation and rainfall show distance insensitivity.

7) Diurnal Variation of Rain Attenuation Model

The statistical model is introduced to predict the amount of attenuation that fall in each hour interval (1-24hours) using the knowledge of measured 1-hour rainfall statistic and the log-normal distribution. The proposed model was tested with the measured data between the percent probability of 0.1% - 1% and attenuation up to 12 dB. It is found that the model is found to be reasonably fitted with all measured data especially at high elevation angle experiment. This prediction model is useful for the satellite system design above 10 GHz.

10.2 Recommendations

Results analysis indicate that rainfall and rain attenuation on 12 GHz frequencies are relatively more severe than other regions. To operate more cost-effective Ku-band satellite links in Southeast Asia some recommendations are:

1) The satellite links operated in the ITU-R zone N (sub-tropical climate) can operate lower link margin in the cold and dry season (November - April) than the rainy season (May - October), but no benefits of the seasonal variation in the ITU-R zone P (equatorial climate).

2) The satellite links that operate in the ITU-R zone N having small number of rain fade and rainfall events and longer fade duration than those in the ITU-R zone P, system operated in the ITU-R zone N must be able to support longer fade durations.

3) Site-diversity in the most powerful and the most applicable for relatively high link availability (>99.99%) to compensate rain attenuation in the heavy rainfall of Southeast Asia.

4) The fixed satellite service (e.g., point-to-point), the diurnal attenuation statistics are highly useful for the design of a satellite link to avoid high attenuation period in a particular area. For the broadcasting satellite service, i.e., Direct-to-Home (DTH) service, that serves a relatively large area, the knowledge of diurnal variation of rain attenuation and rainfall may not be high profitable to compensate high attenuation duration period due to different diurnal pattern in each small area.

10.3 Other Suggestions

1) Rainfall and rain attenuation prediction models suitable for Southeast Asia shall be further developed.

2) Study of rain attenuation especially in other frequencies band such as Ka-Band (30/20 GHz), 40 GHz band, etc. must be performed.

3) Intensive studies of both rain intensity and rain attenuation in many particular places in Southeast Asia shall be conducted.

4) Due to a large year-to-year variation of rainfall and rain attenuation statistics especially in ITU-R zone N, studies of rain attenuation shall be continuously performed for more longer period (at least 10 years).

5) To improve the accuracy of rain attenuation measurement, both radiometer and beacon receiver shall be cooperated at the same place and time.

6) Further study of rain affects on radiowave propagation i.e., depolarization, scintillation, clear-air effects in Southeast Asia shall be performed.