# CHAPTER V: CONCLUSION AND FUTURE WORK

## 5.1 Conclusion

The attenuation of the radio waves caused by the rain is the main source of impairment to the systems operating at frequencies above 10 GHz. The accurate estimation of the rain induced attenuation is an essential part of the HAPS system calculations. However, due to the attenuation issues, one of the challenges is to identify the most efficient location for the HAPS platform segment.

An evaluation of predicting the rain attenuation was conducted for Malaysian peninsular region to identify the best location for placing the HAPS stratospheric segment. The peninsular was divided into two parts, where one HAPS segment dedicated to each part. The best HAPS location has been investigated using a matrix of 10*10. Based on the annual rainfall data used, the best locations for the northern and the southern platform were found to be at **Sungai Lembing** (4.11° N, 102.88° E), and **Tanjung Kling** (2.23° N, 102.02° E) respectively. However, the identification of the best HAPS location based on the monthly rainfall data shows that the best location of HAPS is changed based on the climatic annual quart.

Two different models have been presented to predict the rain attenuation. The first model is dedicated for the Geo-stationary satellites. It is used to predict the rain attenuation when the signal path is either completely or partially affected by the rain.

The second model is able to predict the rain attenuation for non-stationary satellites, such as LEO and MEO, where the model takes into account the movement of the satellites as well as the clouds

Additionally, a review of the basic concepts of the propagation modeling was presented. The review included the relationships of the rainfall intensity with: the attenuation (specific attenuation), drop size distribution, and raindrop velocity. A summary of many currently used attenuation models was given.

One of the advantages of the proposed models is the simplicity. The models are easy to apply because they are mathematical models made up of a few simple formulas. The frequency, elevation angle, earth station latitude and altitude, rainfall intensity, and rain cell size are the only required parameters. Thus, no interpolated values from tables or graphs are needed.

The second feature that the models have is the physical sound since both models are based primarily upon directly measured rainfall behavior. The vertical adjustment factor and horizontal reduction factor of the rain were determined based on the ITU-R model. The rain profile data used was obtained from the Malaysian Meteorological Department.

Both models are in agreement in terms of the attenuation prediction versus the rainfall rate data for the 10 different locations (see Figure 4.10 and Figures 4.18, 4.19).

The results of the north and the south HAPS signals were analyzed in terms of the attenuation exceeded at 0.01% of the time in average year. The mean deviation was found to be approximately 1 dB and 0.25 dB for north and south parts respectively, while the standard deviation about the mean was about 1.25 dB and 0.3 dB (see Figures A.5 and A.6, Appendix-A). The best agreement occurred as the percentage of time increased. An important feature of both models is that the attenuation depends on the rainfall rate, not upon the percentage of time that the rain rate is exceeded in the average year.

Among the 10 locations that selected, it is can be noticed that the earth station located in Taiping experiences the highest rain attenuation reaching 30.7 dB for the circular polarized signal. By contrast, the downlink signal received at the Tanjung Malim station has experienced the least attenuation reaching 27.3 dB for the same signal polarity. The HAPS downlink signal will be available even during the rainfall events. As a result, the service will not be interrupted. The best fade margin can be obtained when the receiver threshold equals -100 dB. For the other two receivers, the fade margin still maintains the acceptable signal strength.

The rain attenuation predicted using the ITU-R model is reduced about 90 dB when the elevation angle varies from 30° to 70° degrees. In the meantime, the rain attenuation predicted by the modified ITU-R model, increases about 40 dB, as shown in Figure 4.3.

Several mitigation techniques such as site diversity were used to improve the received signal, where the results show that the signal can be improved about 9.4 dB. Some other parameters such as the received power can adjusted to receive more efficient signals.

A new method used to calculate the effective rain cell size has been presented. The effective rain cell size method is utilize four parameters ($v_s$, $v_c$, $RCS$, and $d_R$) that can be adjusted depend on the velocity of both the satellite and clouds, the touching point distance of the signal to the rain cell, and the rain cell size.

## 5.2 Future works

While there were many significant and interesting results taken from this study, there were some aspects must be refined to guarantee an accurate rain attenuation prediction as well as to enhance the overall work presented. The recommendations that should be taken into the considerations are

1- The weather radar data should be employed to estimate the slant path reduction factors. Thus, the physical behavior behind the impact of the rain cell sizes variation upon the effective path length can be accurately obtained. Radar data can also be used to refine the models in terms of proposing new formulas to obtain the vertical reduction factor and the horizontal adjustment factor.

2- Estimating and analysis of the HAPS link in the peninsular of Malaysia is the main goal for this study. Therefore, for future studies, it is advisable to take into the consideration other sources of the signal degradation such as, cloud attenuation, fog, scintillation, etc.

3- There are many obstacles facing the HAPS technology, especially in a tropical region like Malaysia, because it is operates at high frequency bands. Thus, a combination of the mitigation techniques must be used together to compensate for the signal impairments.

4- Site diversity is one of the effective solutions to improve the link availability by relaying the signal from the diverse site to the main site. In some cases, the remote site may also suffer from a certain amount of rain, which sometimes equals to the main site. Therefore, developing a new technique that relays the signal to other platforms is advisable.

5- The rain attenuation models presented are considering a constant rain spatial structure for all geographical areas. Therefore, an extensive estimation to evaluate the rain behavior based on the geographical area is recommended to ensure an accurate prediction.