

CHAPTER IV: RESULTS AND ANALYSIS

4.1 Introduction

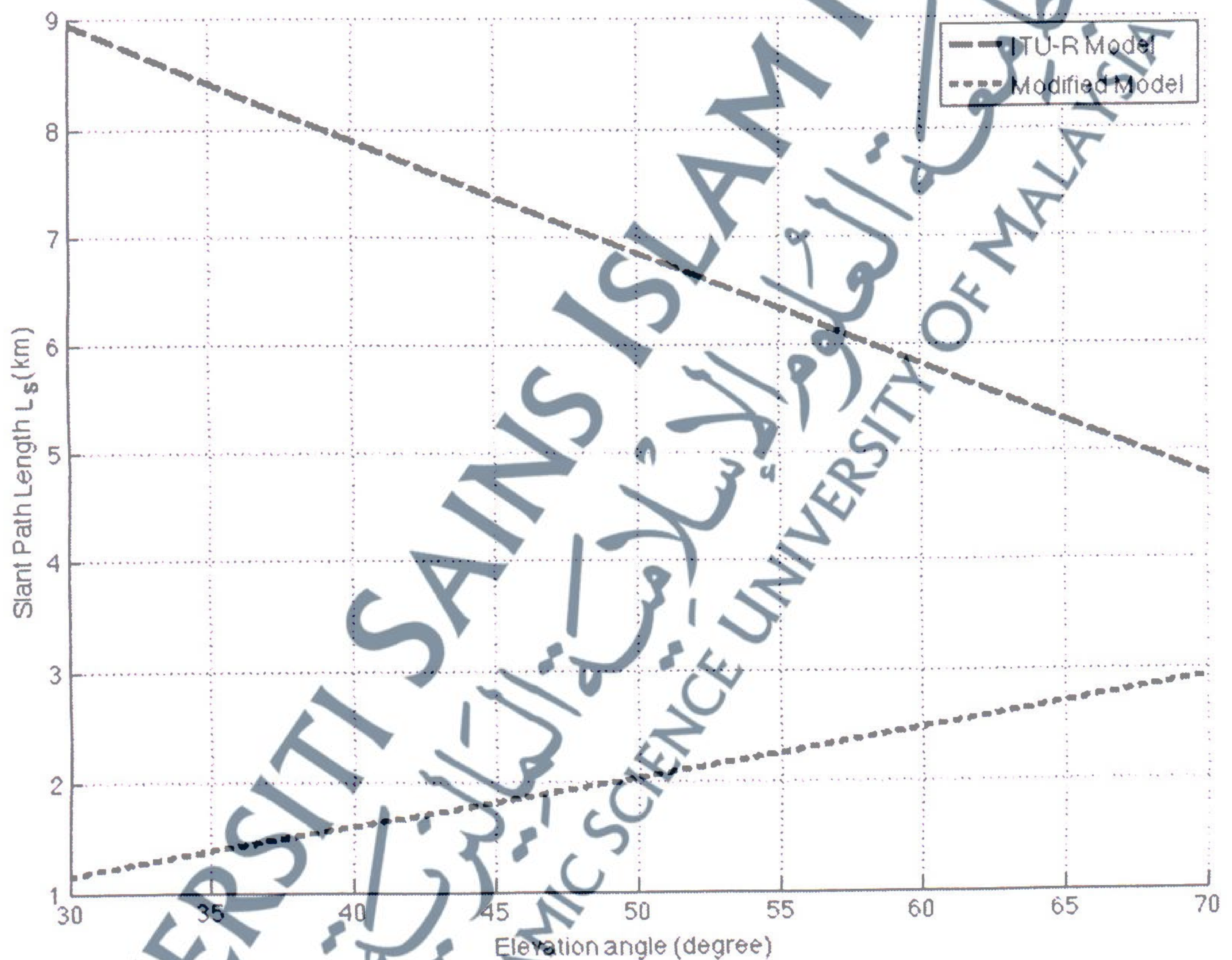
This chapter shows the results of rain attenuation prediction at the ten selected sites, which are listed from the most north to the least south respectively. The earth stations targeted are Kampung Sungai Tong, Batu Kurau, Taiping, Kampar, Bidor, Tanjung Malim, Kepong, Endau, Jln Kluang Mersing and Kahang Kluang. The attenuation was predicted based on the geographical characteristics such as the stations coordinates, rainfall rate that affecting each location. The attenuation was calculated referring to the rainfall data that can introduce an outage time percentage of 0.001, 0.01, 0.1 and 1 of average a year. The analysis of the result will also be employed to identify the best location of the HAPS stratospheric segment.

4.2 Comparison Between Modified HAPS-GEO Model and ITU-R Model

To predict precisely the rain attenuation for a certain location, accurate environment characteristics estimation is required, because the rain attenuation is geographically dependent. This section presents a comparison between the modified model versus the model which is recommended by the ITU-R. One of the advantages of the modified model is the ability to predict the earth-space rain attenuation when the signal path is either completely or partially affected by rain. The frequency of the predicted signal that has been used in this study is 28 GHz and the specific attenuation was evaluated using power law approximation.

For validating the ITU-R modified model, Figure 4.1 shows the calculated signal path length (km) affected by rain at two different elevation angles (30 to 70), and the rain cell size was assumed to be 1.25 km (Khamis et al., 2004). The path length calculated based on the ITU-R model is proportional indirectly with the angle of elevation, while it is seen that the path affected by rain based on the modified model is in direct relation with the elevation angle.

Figure 4.1: Relationship between the elevation angle and slant path length



Based on the scenario shown in Figure 4.2, it is clearly noticeable that the path length obtained based on the modified model is much more valid than the path which is calculated by the ITU-R model, because as the signal elevation angle decreases, the path length penetrated in the rain will also decrease and vice-versa. Where $h_r - h_s$ is

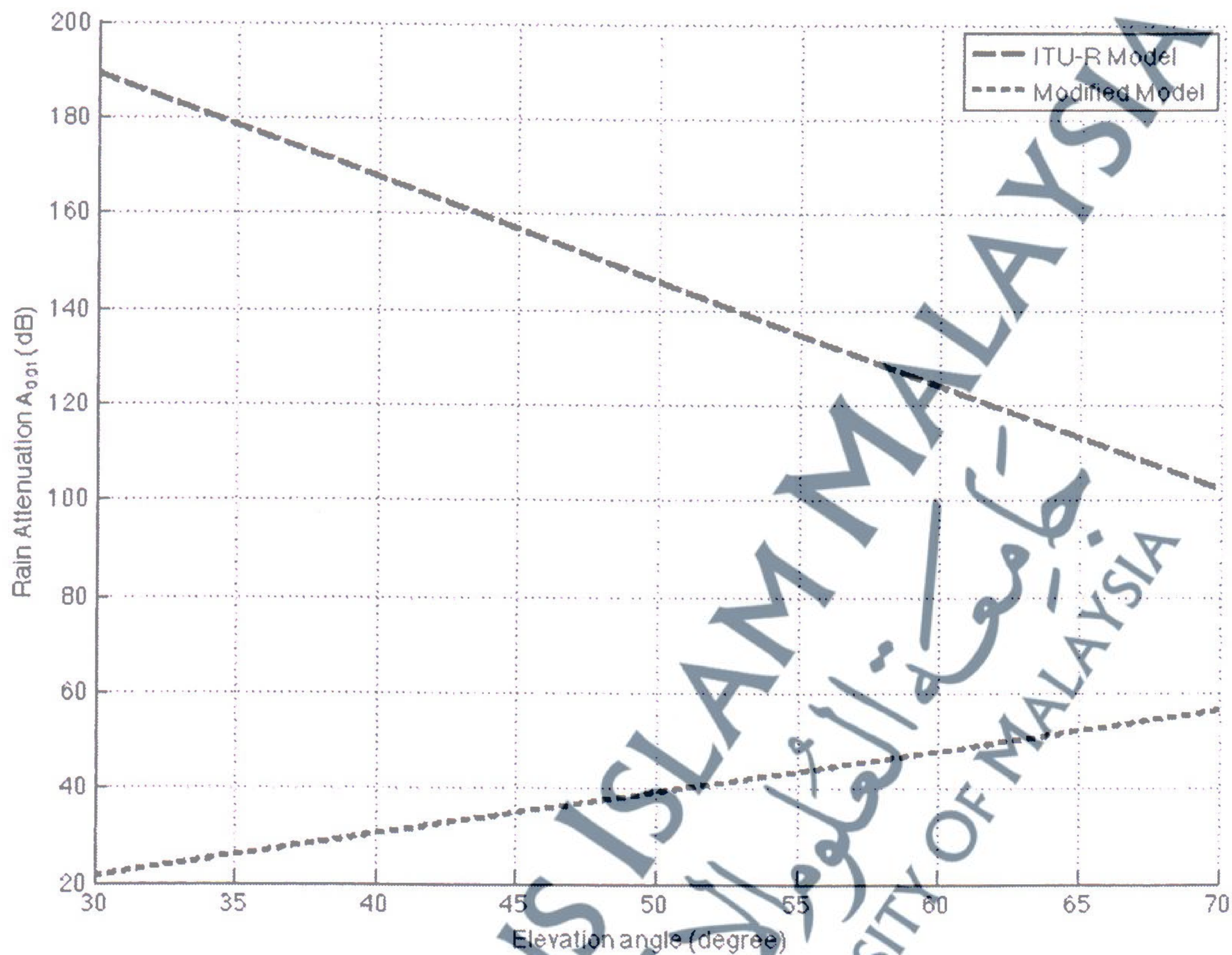
the distance between the rain and the earth station which equals 4.475 km, A and B are the signal path lengths when the elevation angles equal 30° and 70° respectively, and L_G is the rain cell size.

Figure 4.2: Path length estimated by the modified model for different angles



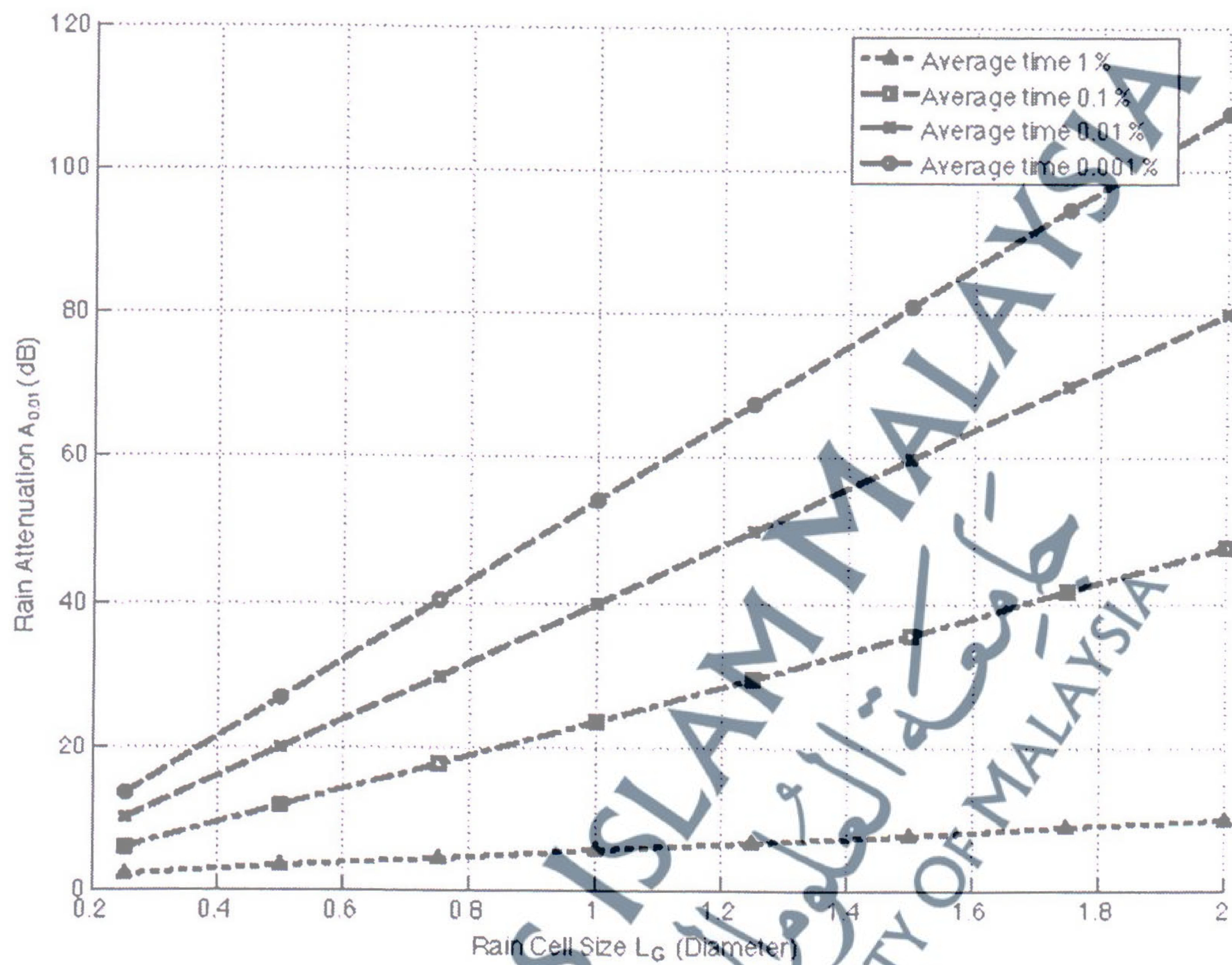
Based on the two different models of path length evaluation, Figure 4.3 shows the predicted rain attenuation of both models. It is observed that the HAPS signal level varies as a function of the angle of elevation. For the signal predicted by the ITU-R model, it is seen that the attenuation is very high compared to the modified model, especially at the low elevation angles.

Figure 4.3: Comparison of rain attenuation obtained by ITU-R model and the modified model based on the elevation angle



One of the features of the modified ITU-R model presented in this thesis is that it takes into account the size of the rain cell, while the rain cell size is neglected in the ITU-R model. The rain attenuation relationship with cell size for different average times is illustrated in Figure 4.4.

Figure 4.4. Variation of the rain attenuation with the rain cell size

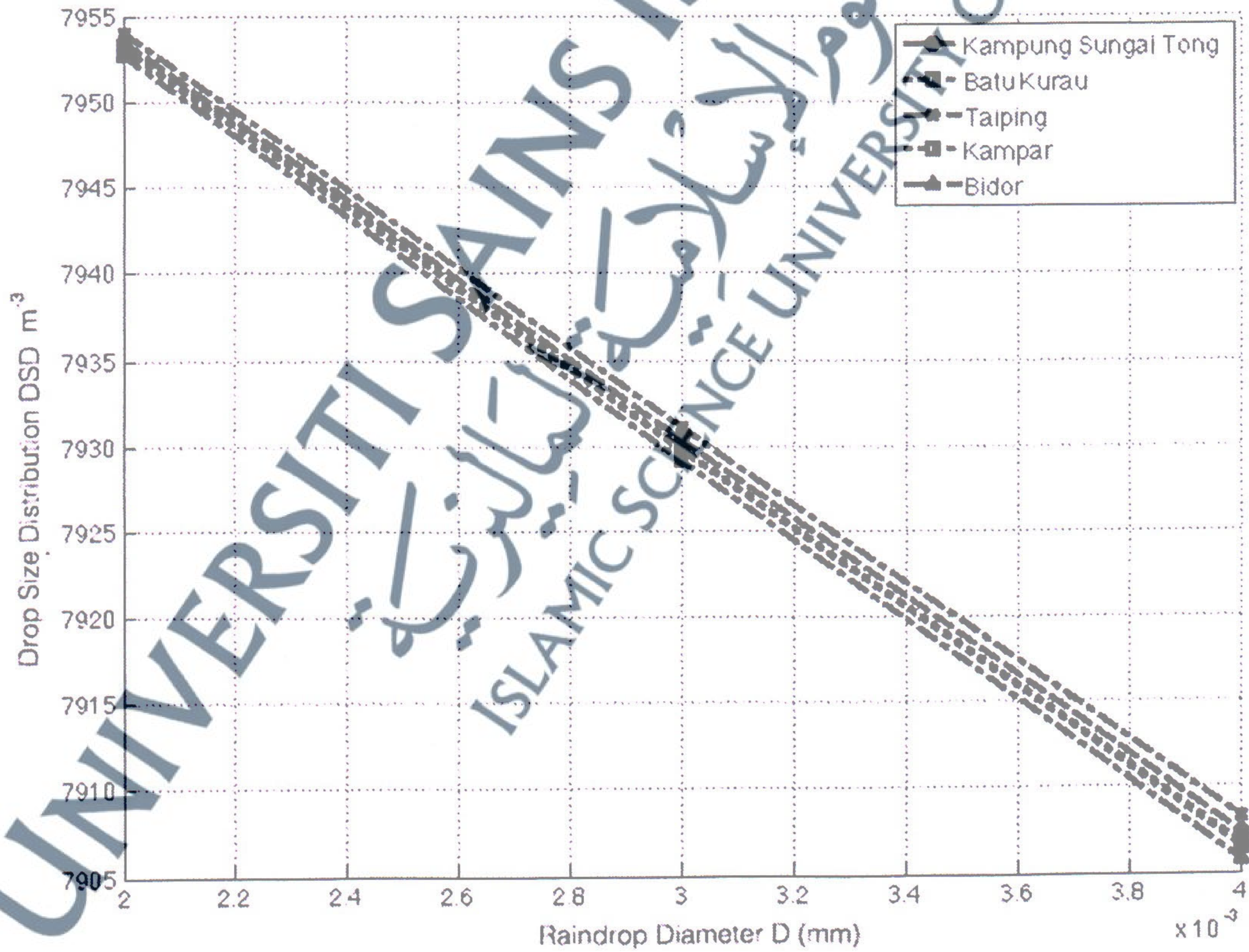


It is seen that the size of the rain cell (L_G) has a high impact on the rain attenuation. The rain attenuation is directly related to the size of the rain cell where it varies from 0.25 to 2.5 km. This variation of cell size causes more rain attenuation in the signal. Thus, the affected signal path becomes longer, doubling the attenuation each time the cell size increases. The figure also shows that the rain attenuation increases as the rainfall time in average increases and it is much higher in the case of 0.001%. The average time is related to the system service availability (SSA), where the rainfall rate is 0.001 of average time implies the SSA equals 99.999%.

4.3 Drop Size Distribution

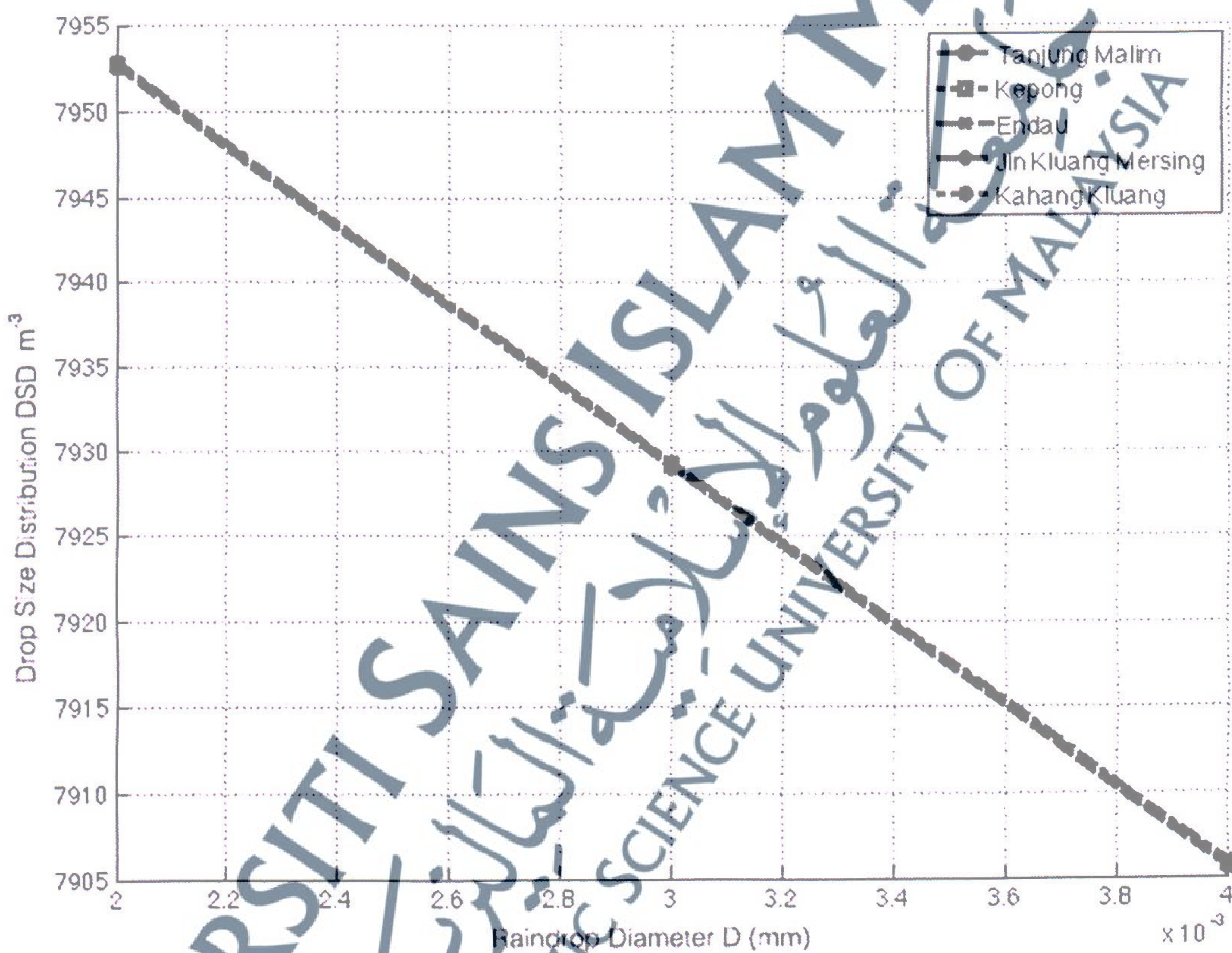
The evaluation of rain attenuation in this task was based on the knowledge of rain microstructure including the raindrop size distribution, rain drop diameter scale which varies from 2 mm to 4 mm. The comparison was made to obtain the raindrops number for different raindrop sizes. Additionally, it will be noticed the reason of why the rain attenuation of the stations covered via that the HAPS platform are suffering almost the same attenuation amount, especially in the southern part of the Malaysian peninsular. Figures 4.5 and 4.6 show the relationship between the drop size distribution and raindrop diameter for the 10 locations.

Figure 4.5: Relationship between DSD and raindrop diameter for northern HAPS



The rainfall rate is the amount of rain that will fall at a certain time, regardless of the raindrops size. Therefore, inside the rain spatial, there must be an inverse relation between the raindrop size and the number of raindrops. Therefore, the result for all stations of interest show that the number of the drops in a cubic meter decrease as the drop size of the rain spatial increases.

Figure 4.6: Relationship between DSD and raindrop diameter for southern HAPS



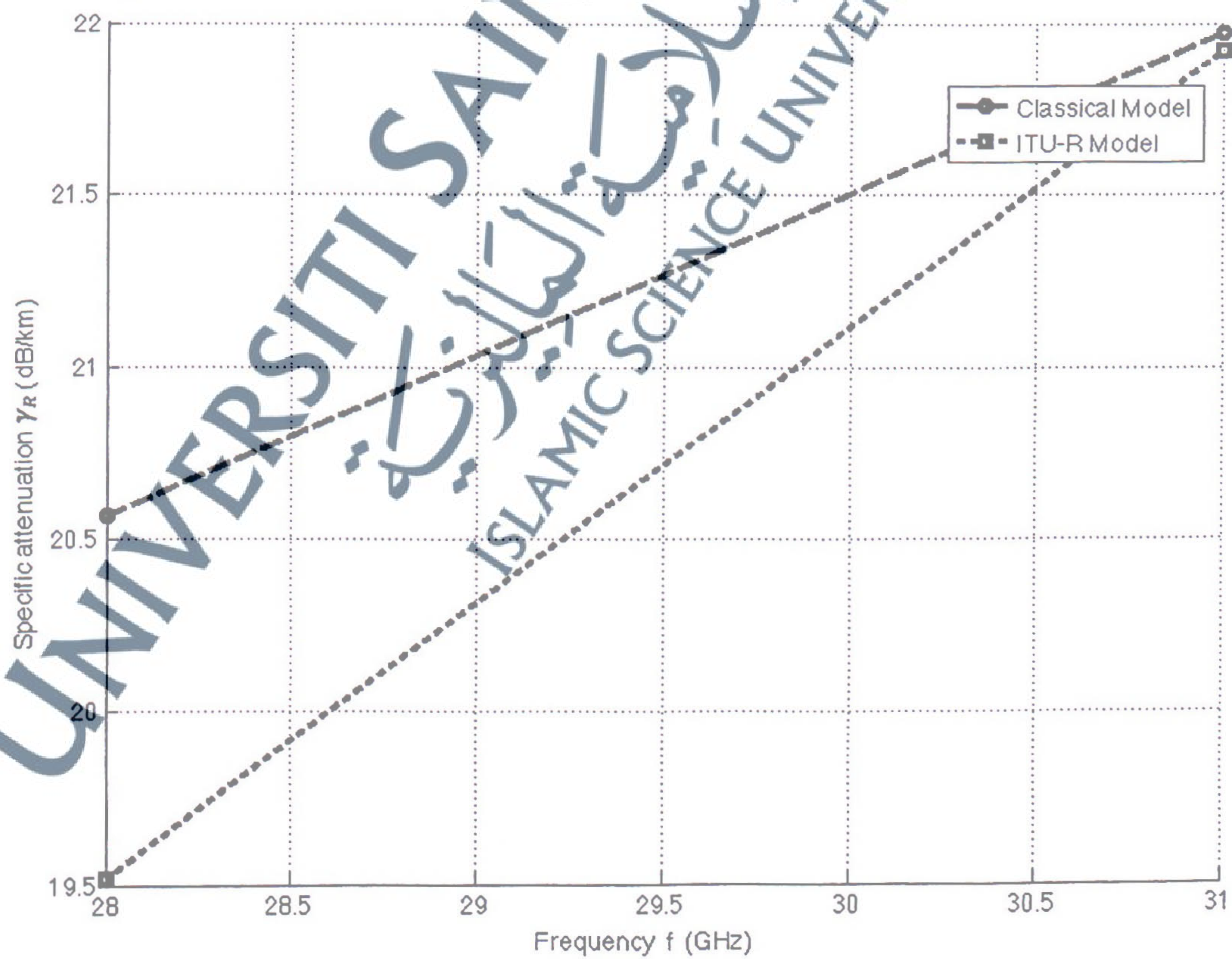
The distribution approach of the stations that located in the south part is almost overlaying for all locations. Since the one of the main parameters which must be taken into consideration for the DSD is the rainfall rate, it can be seen that the stations covered by the southern HAPS platform almost have the same rain drops number.

Therefore, the reason of why those stations are suffering almost same amount of the rain attenuation is because the rainfall rate affecting those stations is relatively same.

4.4 Specific Attenuation

The specific rain attenuation (dB/km) is the fundamental parameter in the prediction of the rain attenuation statistics for terrestrial and earth-space links. The ITU-R model and the classical model that demonstrated in Sections 2.17.2 and 2.17.3 were used to predict the HAPS signal. It can be noted from Figure 4.7 that the attenuation predicted using the classical model is about 1 dB higher for the downlink signal (28 GHz, C polarization), while the difference will decrease to be about 0.1 dB for the uplink signal.

Figure 4.7: Variation of the specific attenuation with the signal frequency

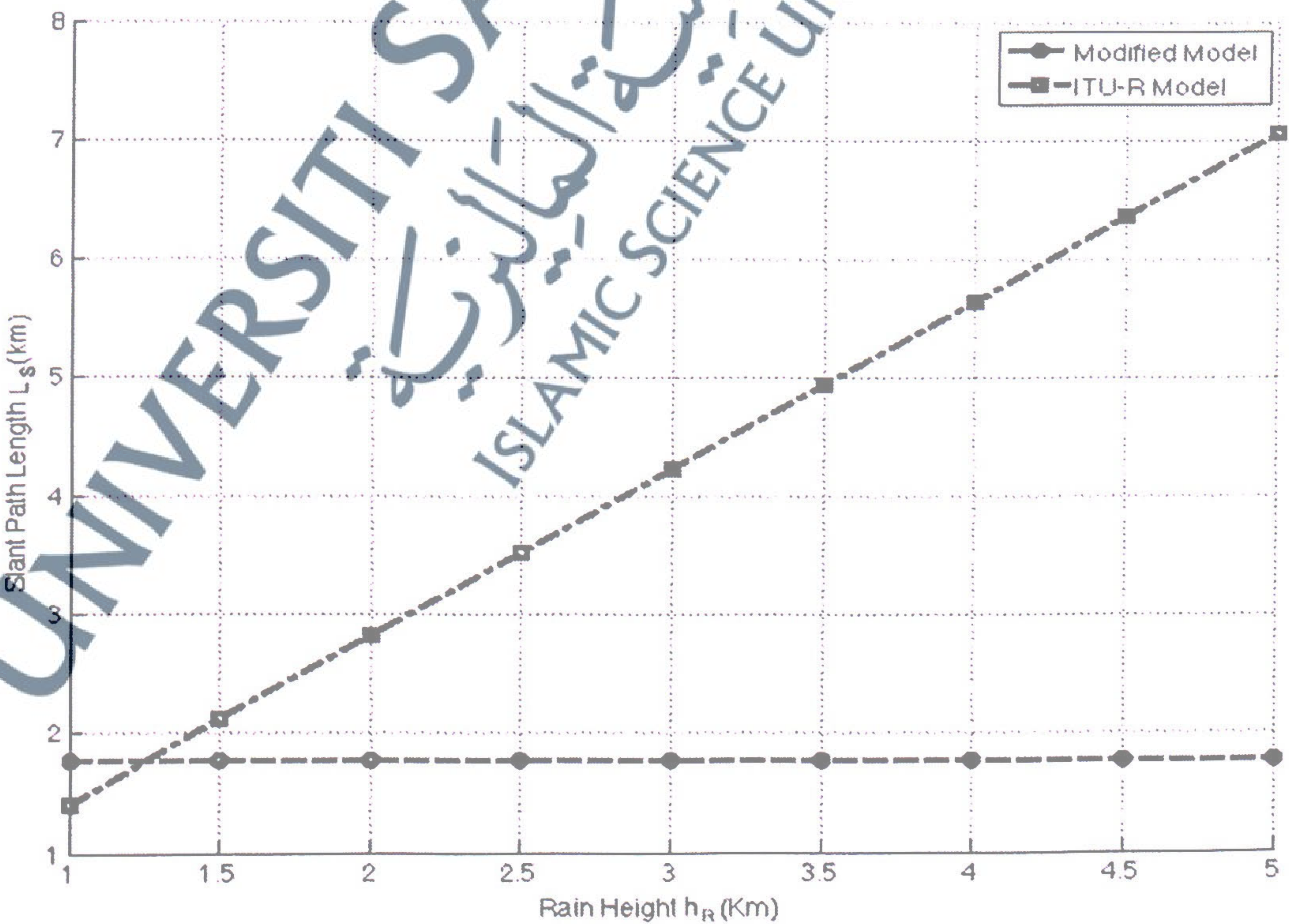


The variation is because of both models are using different methods of predicting the specific attenuation. The ITU-R model is utilizes the power law relationship, while the classical model is predicting the specific attenuation based on the knowledge of the rain microstructure.

4.5 Rain Height Dependence

The melting cloud layer can be formed at a certain height above the mean sea level. The rain height is the distance from the mean sea level to the melting layer. The altitude of the effective rain height is dependent on the geographical region. Based on the modified model which proposed in this thesis, the slant path length does not vary in proportion to the rain height when the signal is partially affected by rain, as shown in Figure 4.8.

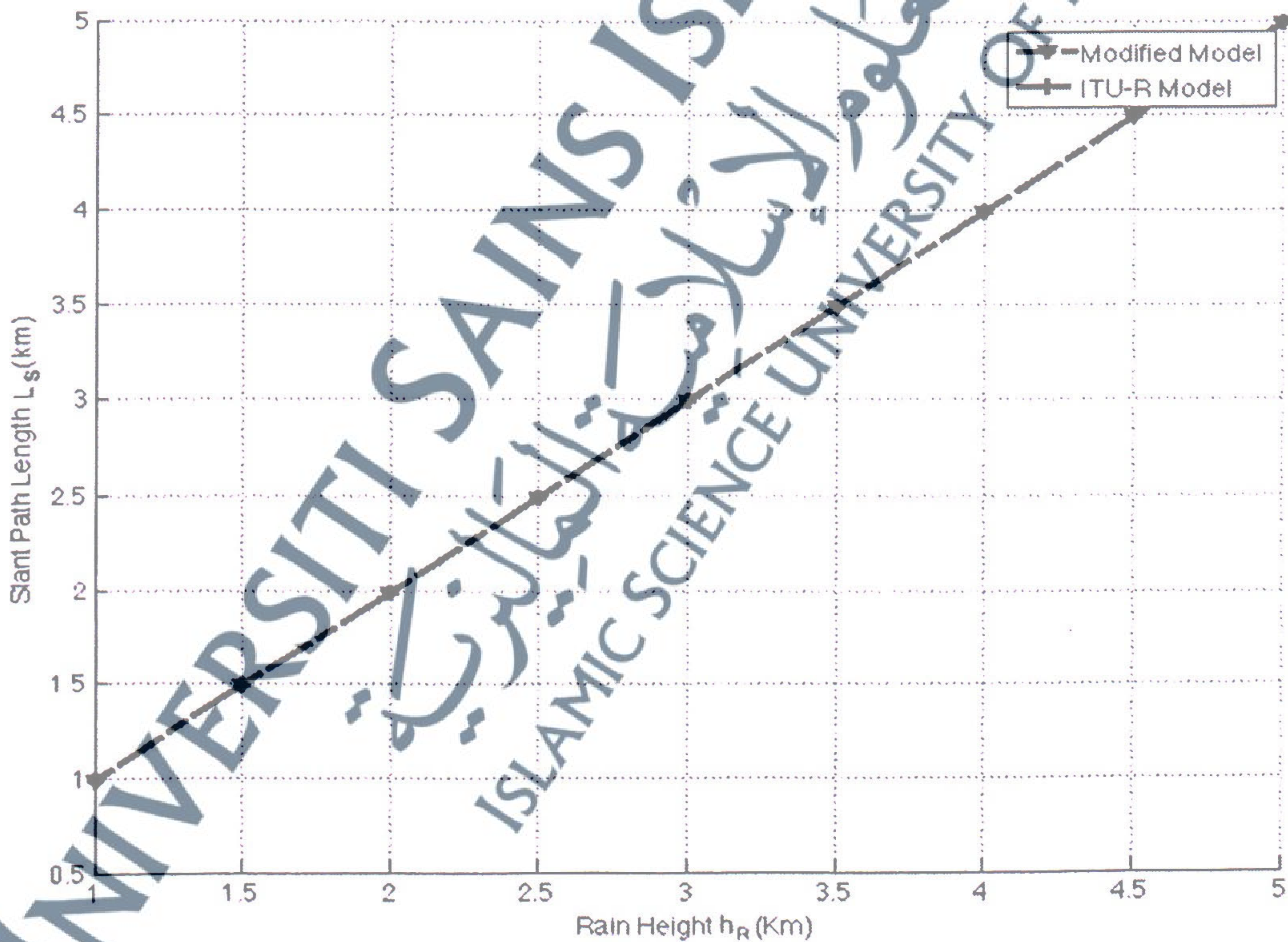
Figure 4.8: Relationship between slant path length and rain height when $\theta = 45^\circ$



The stability in the slant path is because the value of the elevation angle will not change as the rain height increases. It is totally contrast to the ITU-R model, where the slant path length is obtained based on the rain height. Thus, the slant path will vary as the rain height changes. The path length is linearly proportional to the rain height. Thus any increment in the rain height will lead to an increase in the slant path length. The slant path can be doubled when the rain height is duplicated.

Figure 4.9 shows the relationship between the slant path length and the rain height at 90° elevation angle. The path length can be obtaining by subtracting the earth station altitude from the height of the rain.

Figure 4.9: Relationship between slant path length and rain height when $\theta = 90^\circ$



At this elevation angle, the path length will be entirely penetrated by the rain volume, regardless of the rain cell diameter. Therefore, the rain and the earth stations heights are the only factors that may affect the path length of the propagation path. Therefore

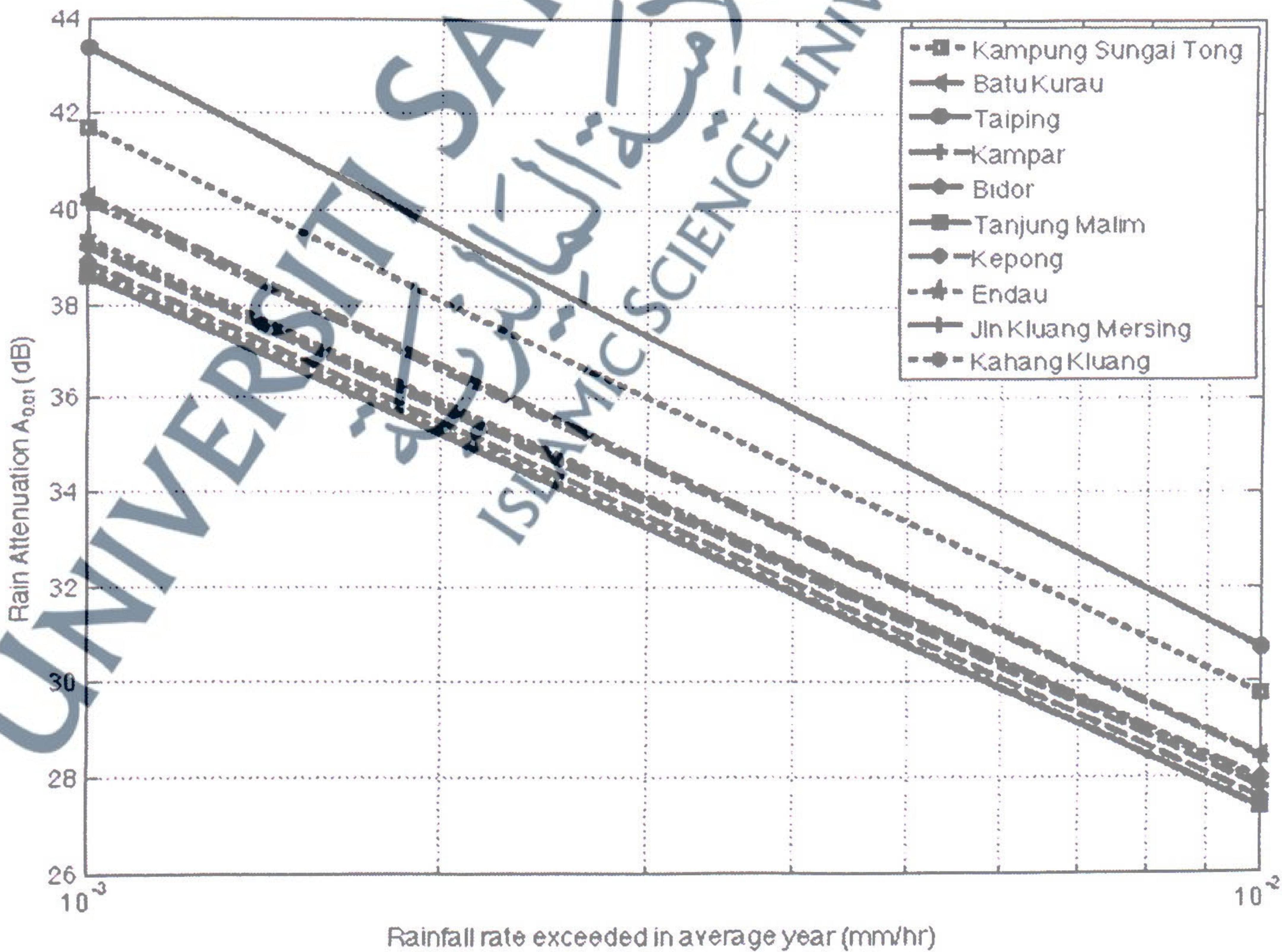
any increase of decrease of those parameters will affect on the signal path length.

4.6 Rain attenuation prediction results

The rain attenuation predicted for HAPS signals in vertical, horizontal and circular polarization is illustrated in this task. The frequency of the predicted signal carried out in this study is 28 GHz.

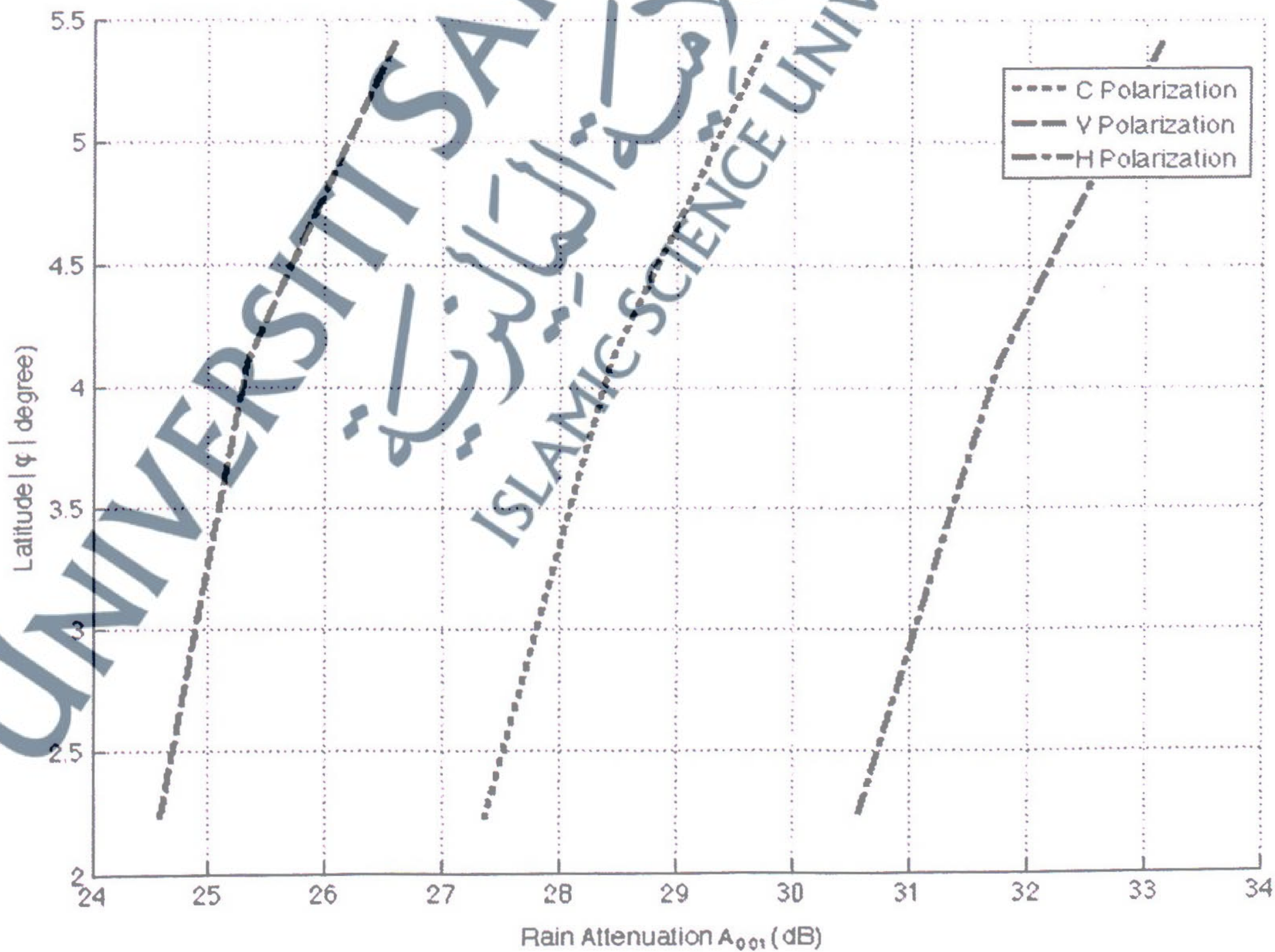
The result in Figure 4.10 illustrates the relationship between the rain attenuation ($A_{0.01}$) and the rainfall rate exceeded in average year ($R_{0.01}$). The attenuation was predicted in case of circular polarization. It can be observed that all locations are suffering different rain attenuation since each site has it is distinct parameters in term of the rainfall rate and the elevation angle.

Figure 4.10: Rain attenuation behavior based on rainfall average time for the selected earth stations (C polarization)



It is also can be seen that the attenuation is linearly decreases as the time percentage increases, where the difference between the attenuation of the 10 earth stations is decreases as the time percentage increases. The rain attenuation is much higher in case of the rainfall average time is 0.001% (see Figure A.1 through Figure A.6 in appendix A). The average time is related to the system service availability (SSA), where 0.001% of rainfall average time implies 99.999% system service availability. The amount of the rain attenuation is relatively the same for the stations which located in the southern part of Malaysian peninsular (Tanjung Malim, Kepong, Endau, Jln Kluang Mersing, and Kahang Kluang). The reason of the similarity in the attenuation is because of all stations are suffering almost the same rainfall rates. The relation of the rain attenuation with the latitude of the earth stations for different polarizations is illustrated in Figure 4.11.

Figure 4.11: Variation of the rain attenuation against the earth stations latitude



Three different stations which are Kampung Sungai Tong, Bidor, and Kahang Kluang were selected based on the latitude. It can be seen that the attenuation increases gradually as the latitude of the earth station increases.

The rain attenuation is at the maximum when the signal polarization is horizontal. In the rain event, the shape of the raindrop can be formed based on two forces, which are the earth gravity and the air pressure. The airflow on the bottom of the raindrop will be higher than the airflow on the top. Therefore, these forces will squeeze the shape of the raindrop. Thus, the signal cross-section with raindrop will be higher in case of horizontal polarization.

The attenuation of the circular polarity signal is laying between the values of the attenuation predicted for the vertical and horizontal polarized signals. The lowest amount of the rain attenuation is when the signal is polarized vertically, where a smaller cross-section between the signal and the raindrop. Thus, lower rain attenuation will be induced.

4.7 Free Space Loss

Free space loss is a loss in the signal strength of an electromagnetic wave propagates in line of sight path through free space. The calculation of the path loss is intended to find the ratio of the transmitted power to the received power between antenna pairs. Table 4.1 illustrates the free space loss amount for the 10 stations selected in this study. The loss was calculated for the uplink and downlink signals.

Table 4.1: Free Space loss for circular polarization

Station	Up-FSL (dB) 31 GHz	Down-FSL (dB) 28 GHz	Elevation Angle (degree)
K. Sungai Tong	165.7	164.4	10.2
Batu Kurau	170.4	169.5	5.7
Taiping	170.4	169.5	5.7
Kampar	168.1	167.2	7.4
Bidor	167.4	166.5	8.0
Tanjung Malim	170.3	169.4	5.7
Kepong	168.8	167.9	6.8
Endau	158.9	158.0	21.7
Jln Kluang Mersing	155.7	154.8	32.3
Kahang Kluang	157.9	157.0	24.6

Figure 4.12 and Figure 4.13 show the impact of the free space loss on the HAPS link versus the elevation angles. This task aimed to calculate the loss of the free space for the 10 stations which are covered by two different HAPS segments.

Figure 4.12: Relationship between the FSL and the elevation angle for northern part (C polarization)

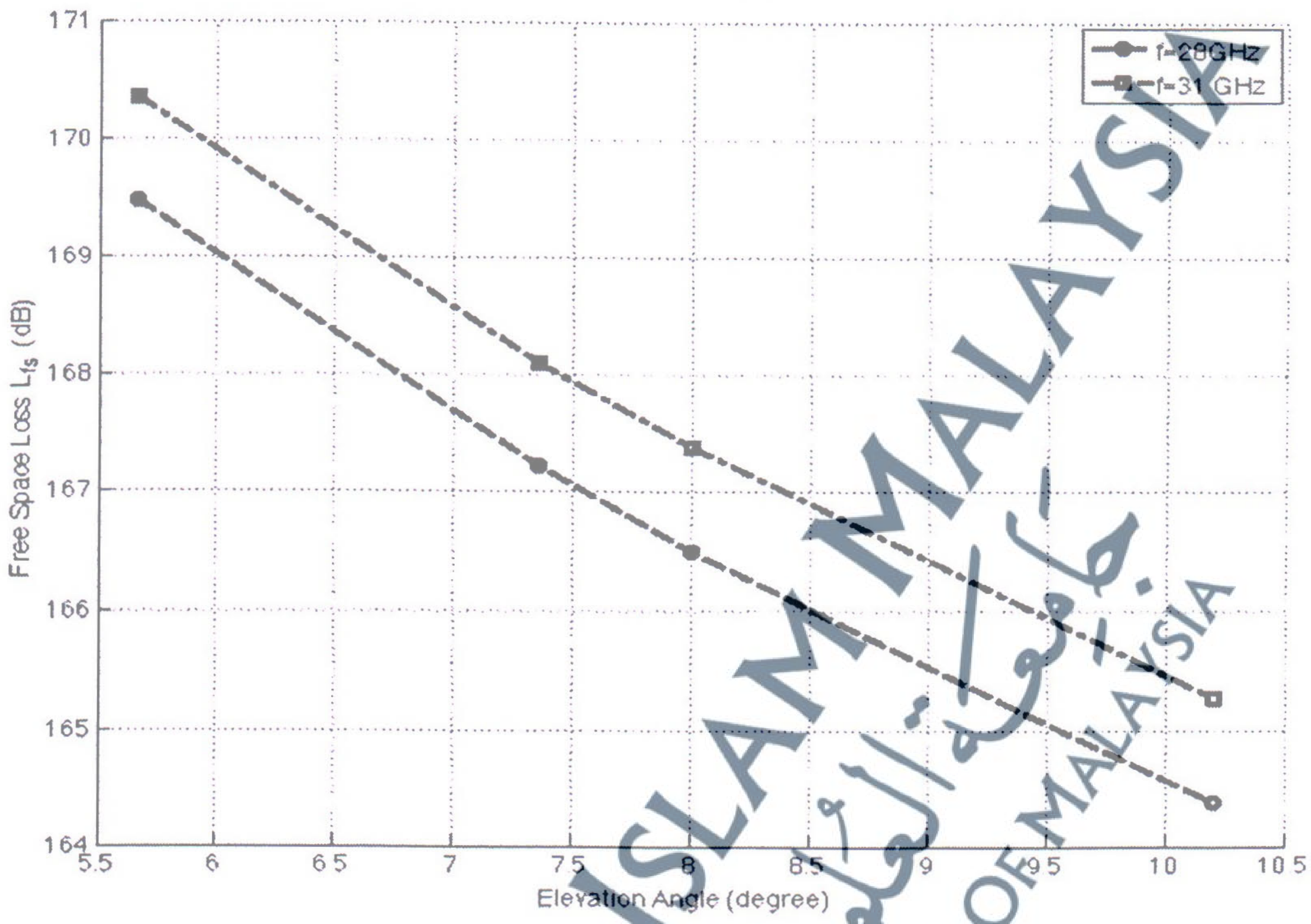


Figure 4.13: Relationship between the FSL and the elevation angle for southern part (C Polarization)

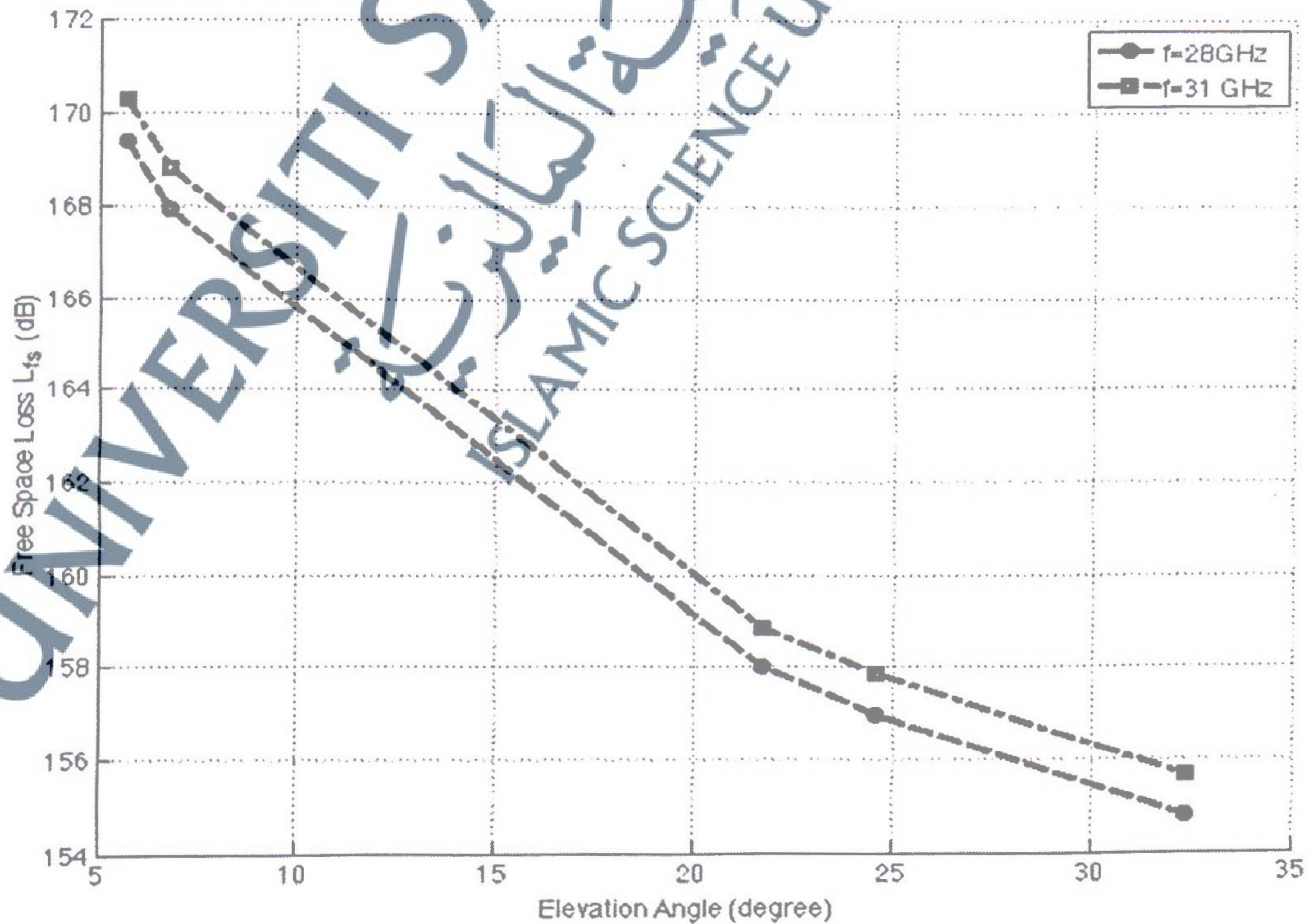


Table 4.1 reflects the impact of two important propagation characteristics. First, for a given frequency, the path loss increases with the increase of the elevation angle which leads to the propagation path length between the HAPS segment and the earth station. From Figures 4.12, at 28 GHz frequency, the free space loss in the northern part decreases from 169.47 dB at 5.66° elevation angle to 164.38 dB at 10.2° elevation angle. For the southern part which is illustrated in Figure 4.13, the free space loss is also decreases from 169.41 dB at 5.69° elevation angle to 154.78 dB at 32.33° elevation angle. The difference in the fade margin caused by the free space loss is up to 14.63 dB in the southern part, while it is about 5 dB in the northern part. The second factor which is very important to observe is the frequency. For a given elevation angle, it can be seen that the path loss increases as the frequency increases. This difference in the operating frequency could have a detrimental impact on the signal quality especially when the gap between the up and downlink signals is much higher.

4.8 Link budget

By referring to the results of the predicted attenuation, Table 4.2 illustrates the link budget which calculated by using the received signal equation with the assumption that $P_t = 50$ dB, $G_t = 55$ dB, and $G_r = 55$ dB. The link budget for all locations is obtained by using Equation 4.1, where in the case of the ground station located in Kampung Sungai Tong, the link budget is calculated as follows:

$$P_r = 50 + 55 + 55 - 164.4 - 29.8 = -34.1 \text{ dB} \quad (4.1)$$

The same equation was used to calculate the power received to the other locations, where the results are listed below:

Table 4.2: Result for link budget calculation for $A_{0.01}$

Location	Elevation angle (Degree)	Rainfall Rate (mm/h)	Rain Attenuation $A_{0.01}$ (dB)	P_r (dB)
K. Sungai Tong	10.2	138.2	29.8	-34.1
Batu Kurau	5.7	133.9	28.5	-37.9
Taiping	5.7	145.5	30.7	-40.2
Kampar	7.4	132.5	28.4	-35.6
Bidor	8.0	127.5	27.5	-34.0
Tanjung Malim	8.3	126.2	27.3	-36.8
Kepong	11.9	127.1	28.0	-35.9
Endau	7.7	129.0	27.9	-25.9
Jln Kluang Mersing	8.1	128.0	27.8	-22.5
Kahang Kluang	7.5	126.4	27.4	-24.4

The HAPS link budget is an important issue to guarantee that the service system will be available under any climatic condition. The relation between received signal power versus the total attenuation for the 10 proposed locations in different power transmission is shown in Figure 4.14.

Figure 4.14: Behavior of the received signal for different total loss

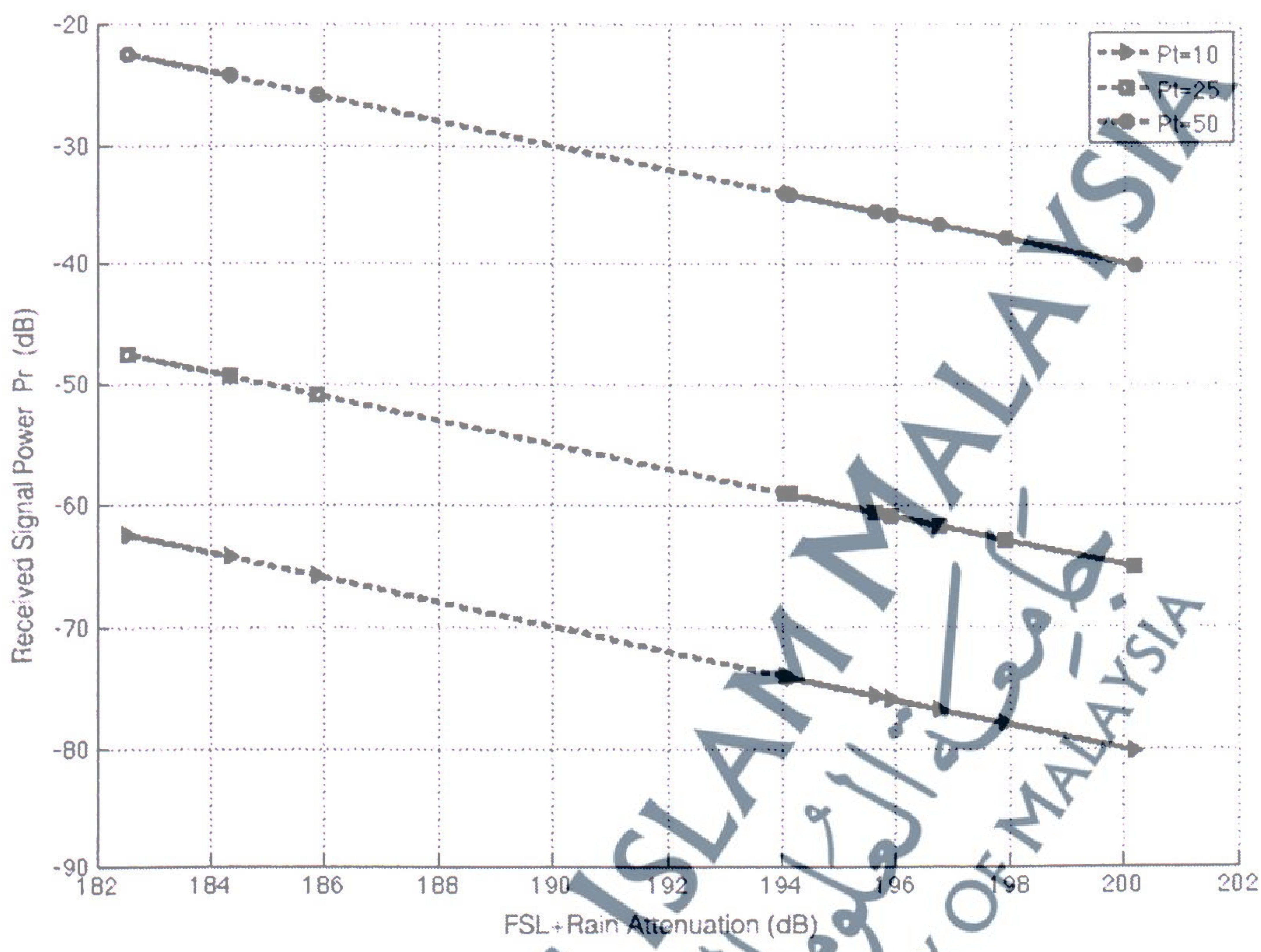


Figure 4.14 shows the relation between the signal attenuation and the received signal of the HAPS. It is seen that the power of the received signal varies according to the environment in which the ground station is located, since each earth station has its distinct parameters. It is shown that the received signal is indirectly proportional to the attenuation while it is directly proportional to the transmitted power. Therefore, the received signal for all ground stations can be accepted at all receivers only when the transmitted power equals 50 dB.

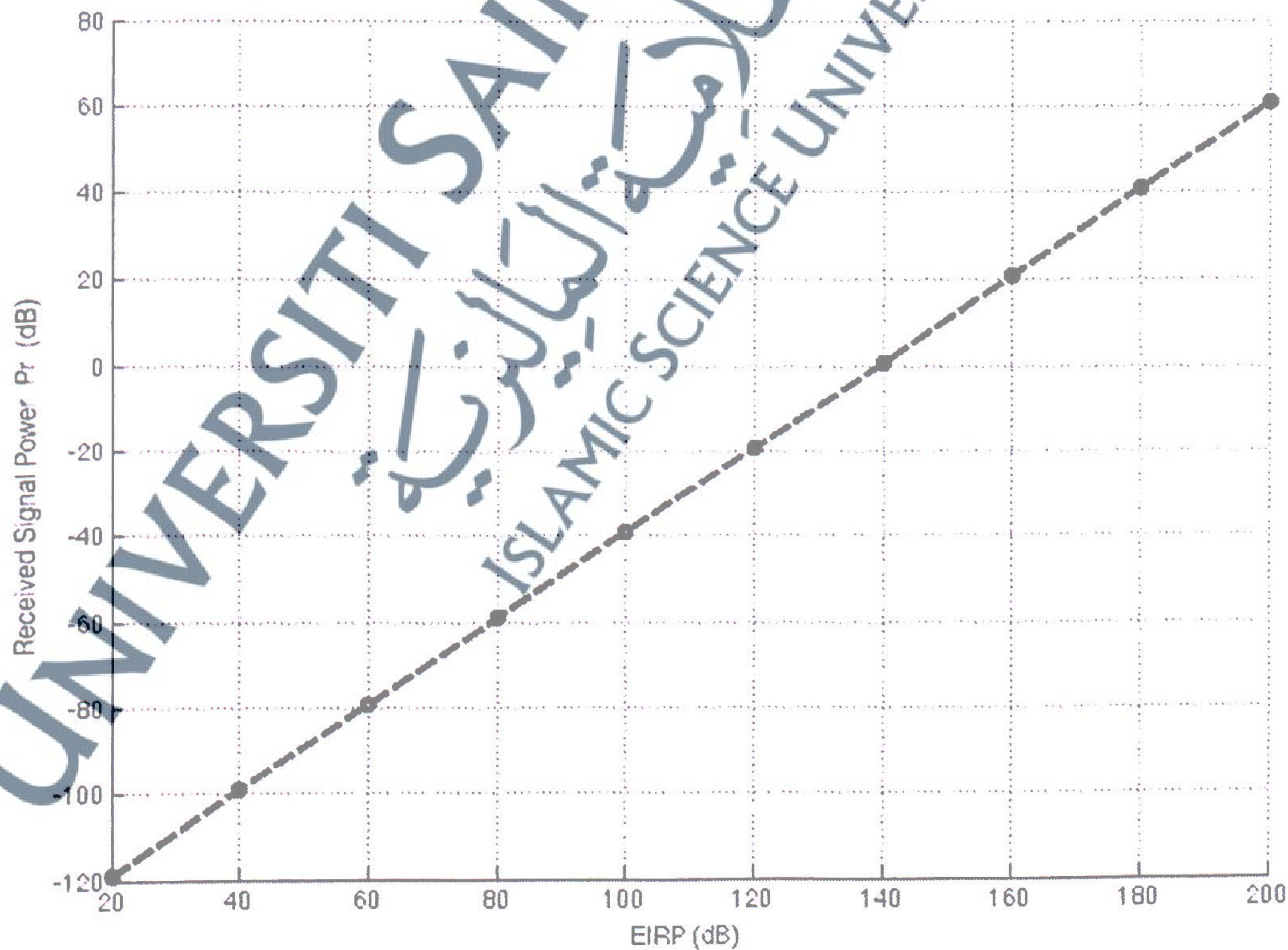
The received signal is qualified for the three proposed receivers only when the transmitted power equals to 50 dB, because the receiver thresholds are assumed to equal -45 dB, -75 dB and -100 dB.

4.9 HAPS Down-Link Signal

To estimate the received signal level which is affected by a particular attenuator, the received power level (P_r) is a very important factor. For good system performance, the amount of P_r must be maintained as higher as possible at the receiver input. Some parameters can be engaged and manipulated to improve or achieve the desired received signal power such as transmitted signal power, transmitted signal gain and the received signal gain.

A simulation scenario was conducted to evaluate the impact of the equivalent isotropic radiated power (EIRP) to improve the received signal. Figure 4.15 shows the relationship between the received signal and the EIRP that varies on a scale between 20 to 200 dB, and the corresponding received power was estimated for each case.

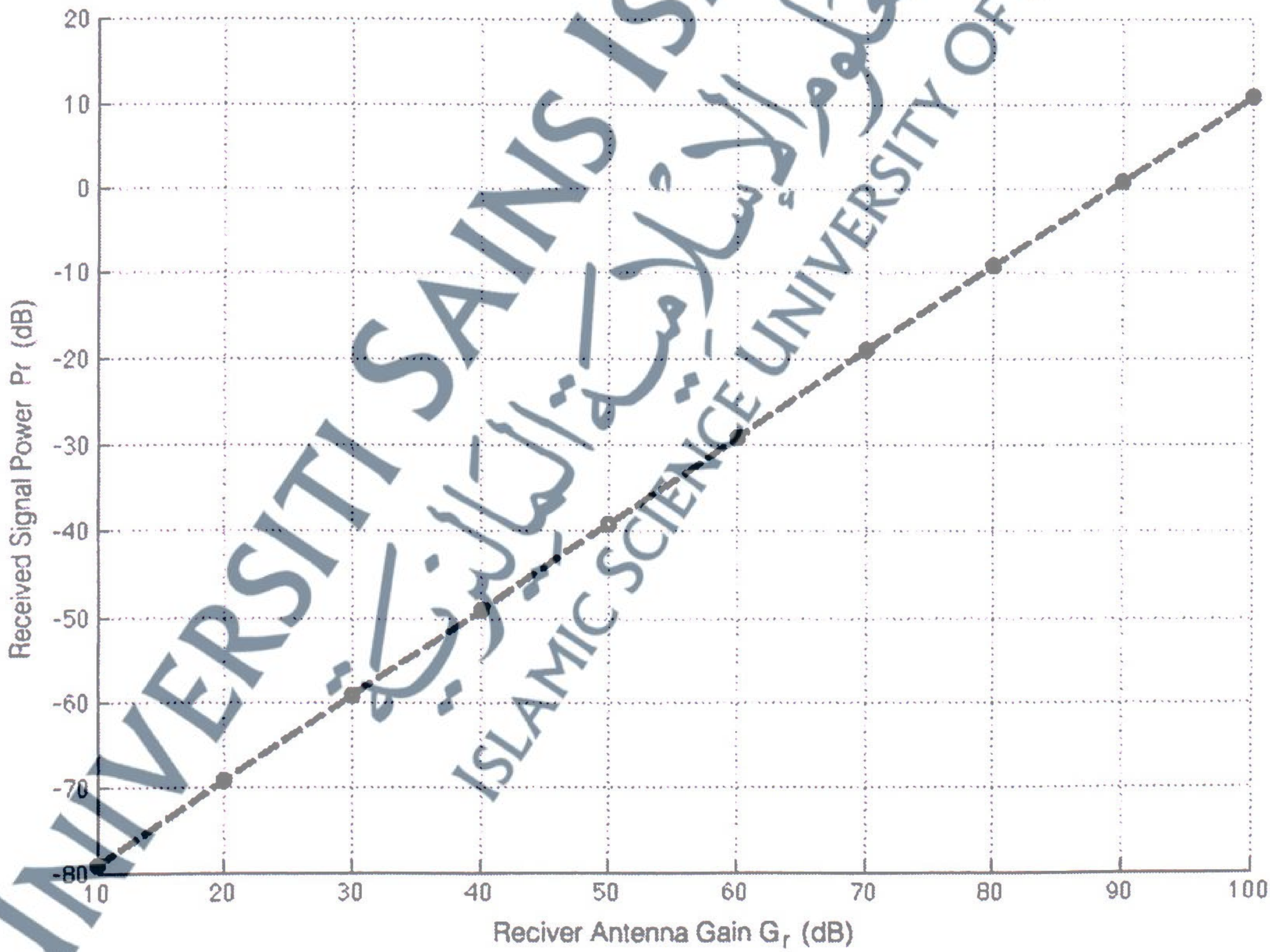
Figure 4.15: Received signal power variation due to EIRP



From Figure 4.15, it can be deduced that the received power increases gradually as the amount of the EIRP increases. The highest received power can be obtained when the EIRP is at the maximum. This is because they are directly related since the EIRP is the summation of the transmitted antenna power (dB) and the gain of the transmitted antenna (dB).

Based on the concept which has been understood from the relationship between the received power and the EIRP, another important factor can be also manipulated to achieve the desired signal strength. The power of the received signal was simulated over different gains of the receiver antenna. The result is shown in Figure 4.16.

Figure 4.16: Relationship between received signal power and receiver antenna gain



Based on Figure 4.16, it is clearly seen that the received signal strength goes higher as the gain increases. This happens because the received signal is dependent on the gain

of the receiver antenna. Therefore, as the antenna gains are increased, the received signal will become stronger.

Those parameters (EIRP and Gain) can be the key elements to compensate the HAPS signal which impaired by the rain and/or the free space loss, especially when the attenuation exceeds the wanted fade margin.

4.10 Fade Margin

For selected receiver thresholds, the fade margin is calculated by referring to three different receiver thresholds that were set to equal -45 dB, -75 dB and -100 dB. The result is calculated based on Equation 4.2, which is applied to calculate the fade margins for all receivers.

$$\text{Fade margin (Rx} = -45) = \text{Received signal strength} - \text{Receiver threshold} \quad (4.2)$$

The fade margin of Kampung Sungai Tong station is calculated as

$$= -34,1 - (-45) = 10.9 \text{ dB}$$

Same equation was used to calculate the power received to the other locations, where the results are listed in Table 4.3:

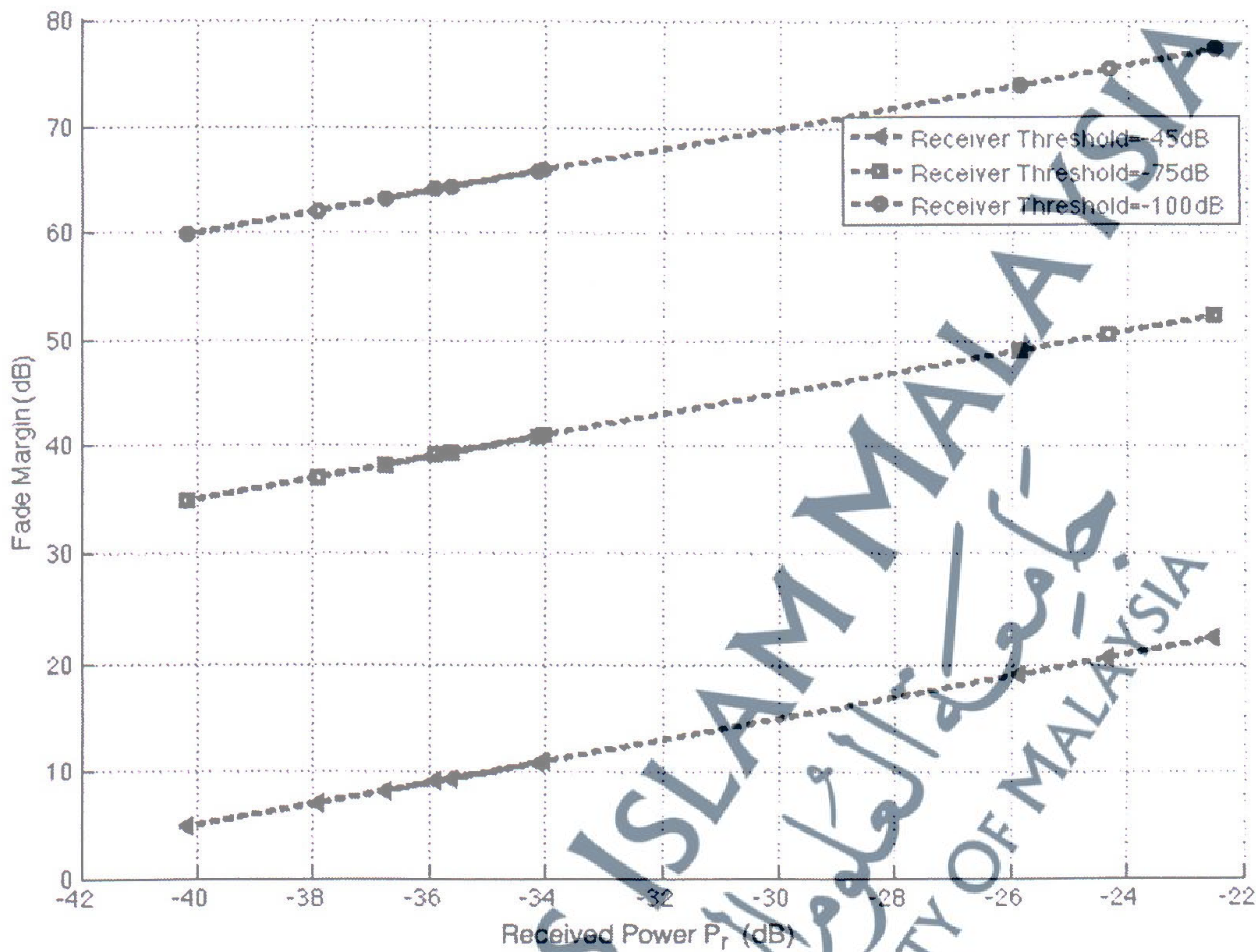
Table 4.3: Result for Calculated Fade Margin

Location	Attenuation A _{0.01} (dB)	P _r (dB)	Receiver Threshold(dB)		
			-45	-75	-100
			Fade Margin		
Kampung Sungai Tong	29.8	-34.1	10.9	40.9	65.9
Batu Kurau	28.5	-37.9	7.1	37.1	62.1
Taiping	30.7	-40.2	4.8	34.8	59.8
Kampar	28.4	-35.6	9.4	39.4	64.4
Bidor	27.5	-34.0	11.0	41.0	66.0
Tanjung Malim	27.3	-36.8	8.2	38.2	63.2
Kepong	28.0	-35.9	9.1	39.1	64.1
Endau	27.9	-25.9	19.1	49.1	74.1
Jln Kluang Mersing	27.8	-22.5	22.5	52.5	77.5
Kahang Kluang	27.4	-24.4	20.7	50.7	75.7

The careful selection of power transmission and the antenna gain can efficiently enhance the fade margin of a HAPS link. Increasing transmitter power output or increase the elevation angle can also increase the fade margin. The fade margin enhancement can also be done by increasing the EIRP. However, increasing the transmitter power output may be illegally, because the radio channels are limited to certain power outputs.

Figure 4.17 shows the fade margin approach versus the received signal power for the 10 earth stations, where 3 different receiver thresholds were used to evaluate the fade margin.

Figure 4.17: Relationship between fade margin and received power for different receiver thresholds



The best fade margin can be obtained when the receiver threshold is equal to -100 dB. For the other thresholds, the fade margin still maintains the acceptable signal strength. Since each station is suffering different attenuation, the best fade margin can be achieved at Jln Kluang Mersing station because it suffers the lowest amount of the free space loss as well as low rain attenuation.

In order to improve the link availability, higher fade margins are very important, especially in the tropical areas where the rainfall rates in sometimes could not be expected and the thunderstorms are suddenly happen.

4.11 Rain Attenuation Prediction Model for Non- Stationary Satellites

The relation between the rain attenuation in dB versus the distance of the horizontal projection of the signal is penetrated in the rain is illustrated in Figure 4.18 and Figure 4.19. It is seen that the rain attenuation increases in the linear approach as the satellite moves gradually toward the rain cell. Therefore, the attenuation will increase gradually until the signal path reaches the edge of the rain cell (L_G), where the rain cell radius is assumed to be 1.25 km (Khamis et al., 2004). At a certain length, the signal path (which is denoted by the red lines in Figure 3.5) will suffer the same amount of attenuation as the satellite moves. The stability of the penetrated path length depends on two factors which are the elevation angle and the rain cell size. When the elevation angle is higher and/or the rain cell size is large, the rain attenuation will stay equal for certain distance. This phenomena takes place because the signal path is suffering from the same length in the rain spatial. However, when the elevation angle decreases, the stability of the affected path length will not be noted as shown in Figures 4.18 and Figure 4.19. As the signal exceeds the rain cell edge, the attenuation will decrease linearly until the penetrated signal length equals zero.

Figure 4.18: Relationship between rain attenuation and the number of the intersections between the signal and the rain cell for northern part of peninsular Malaysia, when $\theta = 40^\circ$ (C Polarization)

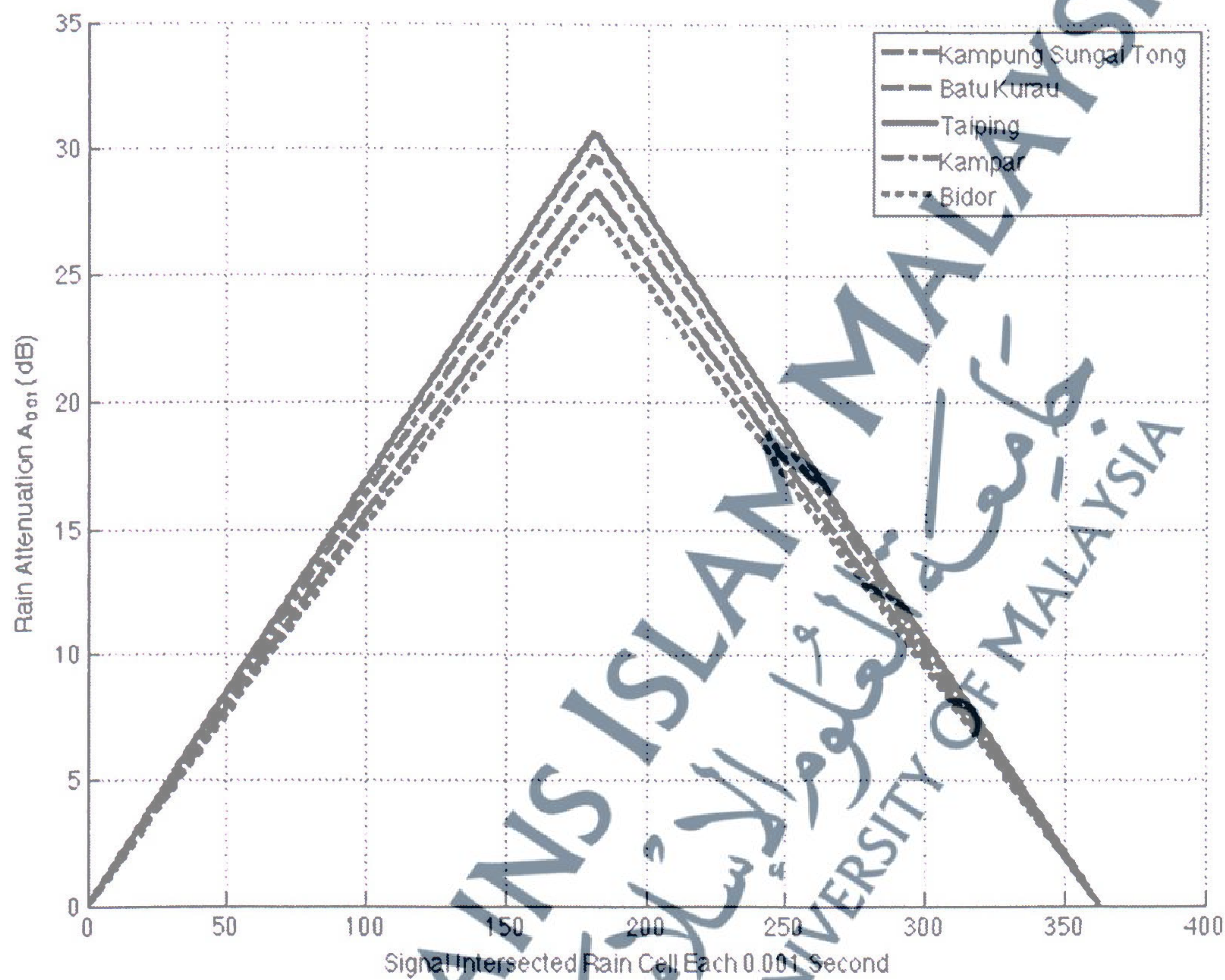
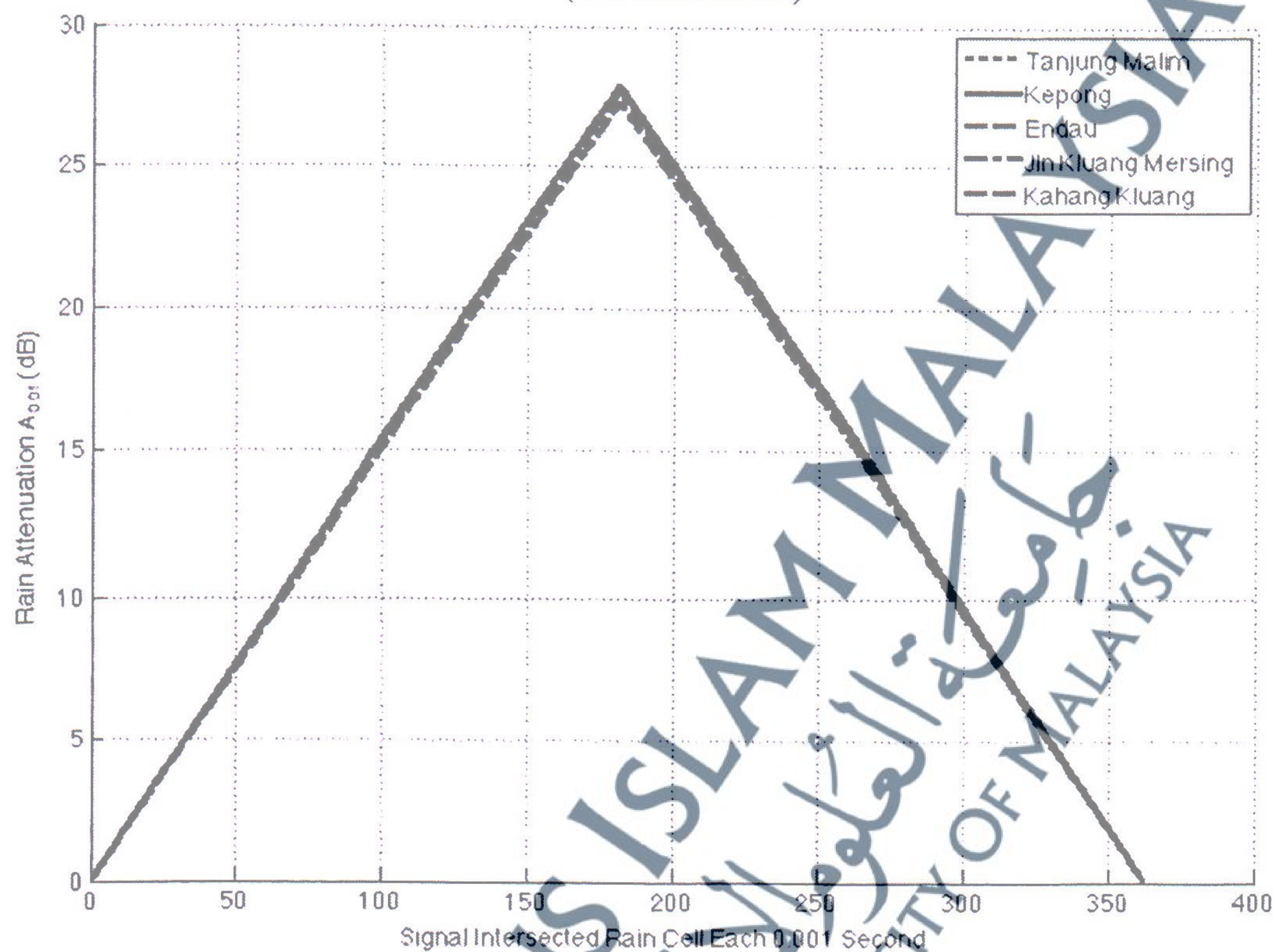


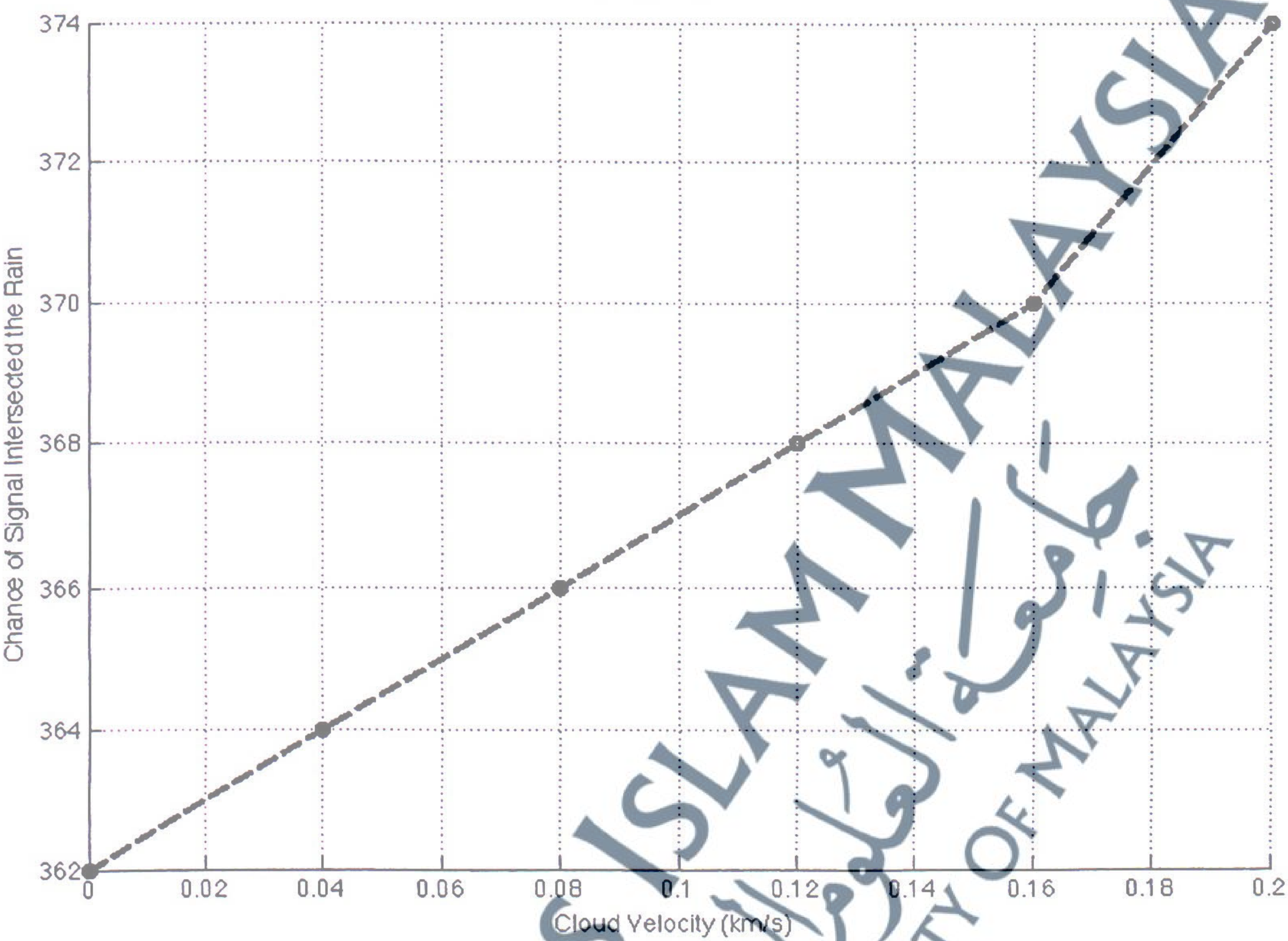
Figure 4.18 depicts the predicted rain attenuation for the stations located in the northern part of peninsular Malaysia, while Figure 4.19 is related to those stations which are located in the southern part. The reason that the attenuation varies for all locations is because each station has their characteristics such as the elevation angle, rainfall rate, etc. The attenuation variation can reach up to 4 dB for the northern part, while the attenuation in the southern part is relatively equal for all stations because the rainfall rate and the elevation angles are almost same for all locations.

Figure 4.19: Relationship between rain attenuation and number of the intersections between the signal and the rain cell for southern part of peninsular Malaysia, when $\theta=40^\circ$ (C Polarization)



When the satellite and the clouds are moving in the same direction, the satellite will take a longer time to cross the rain cell. Figure 4.20 shows how many times the satellite signal will intersect the rain cell for different cloud's velocities, where the interval time equals 0.001 second.

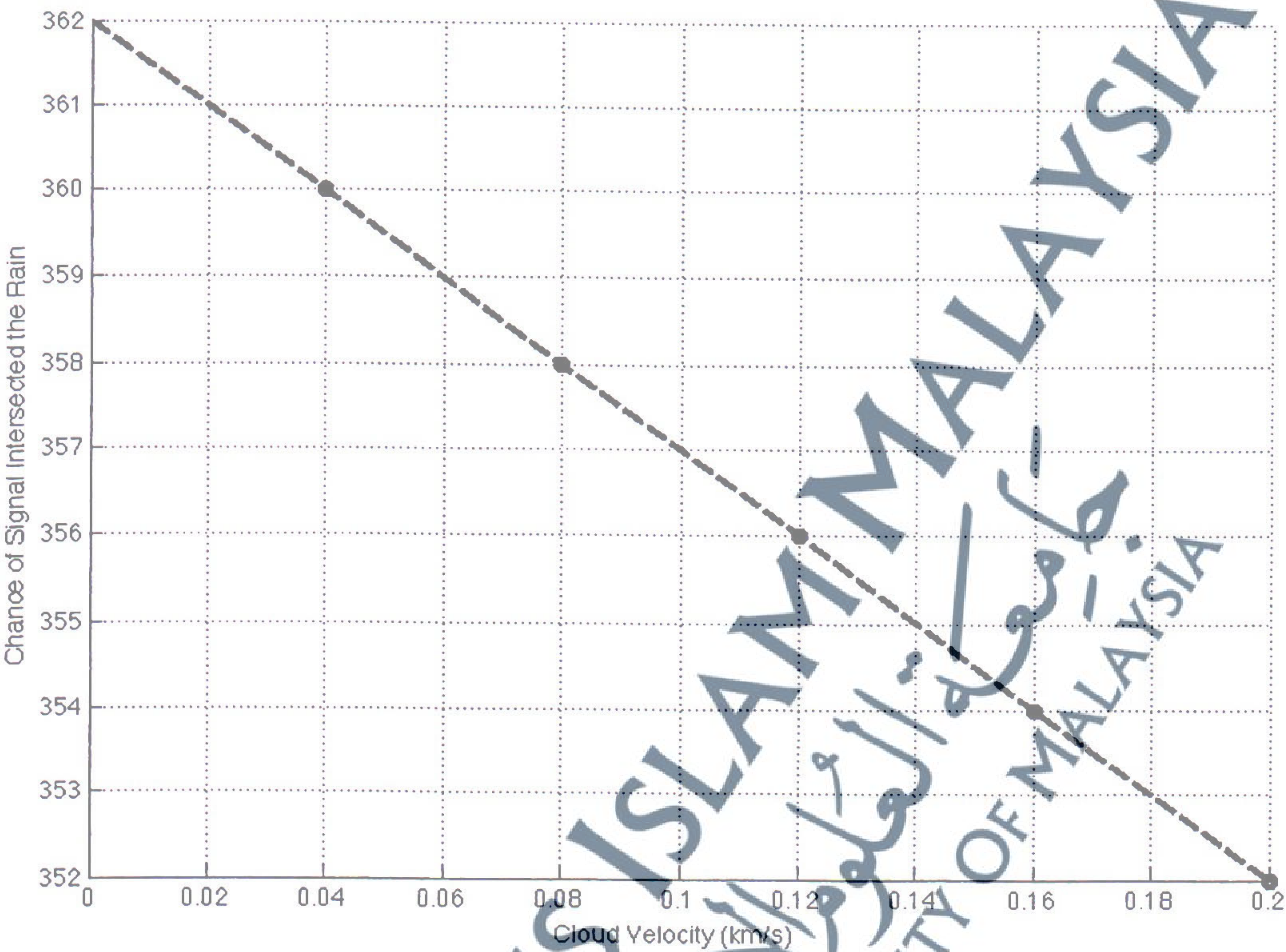
Figure 4.20: Relationship between the number of the intersections of the signal with the rain cell and cloud velocity, when the satellite and clouds are moving in same direction



It can be seen that as the cloud moves faster, the chance of the intersection will increase. When the clouds velocity being equal to the satellite, the intersection period between the signal and the rain will equal to infinity until the rain stops.

Figure 4.21 illustrates the relationship between the cloud velocity and the number of the intersections between the signal and the rain.

Figure 4.21: Relationship between the number of the intersections of the signal with the rain cell and cloud velocity, when the satellite and clouds are moving in opposite direction

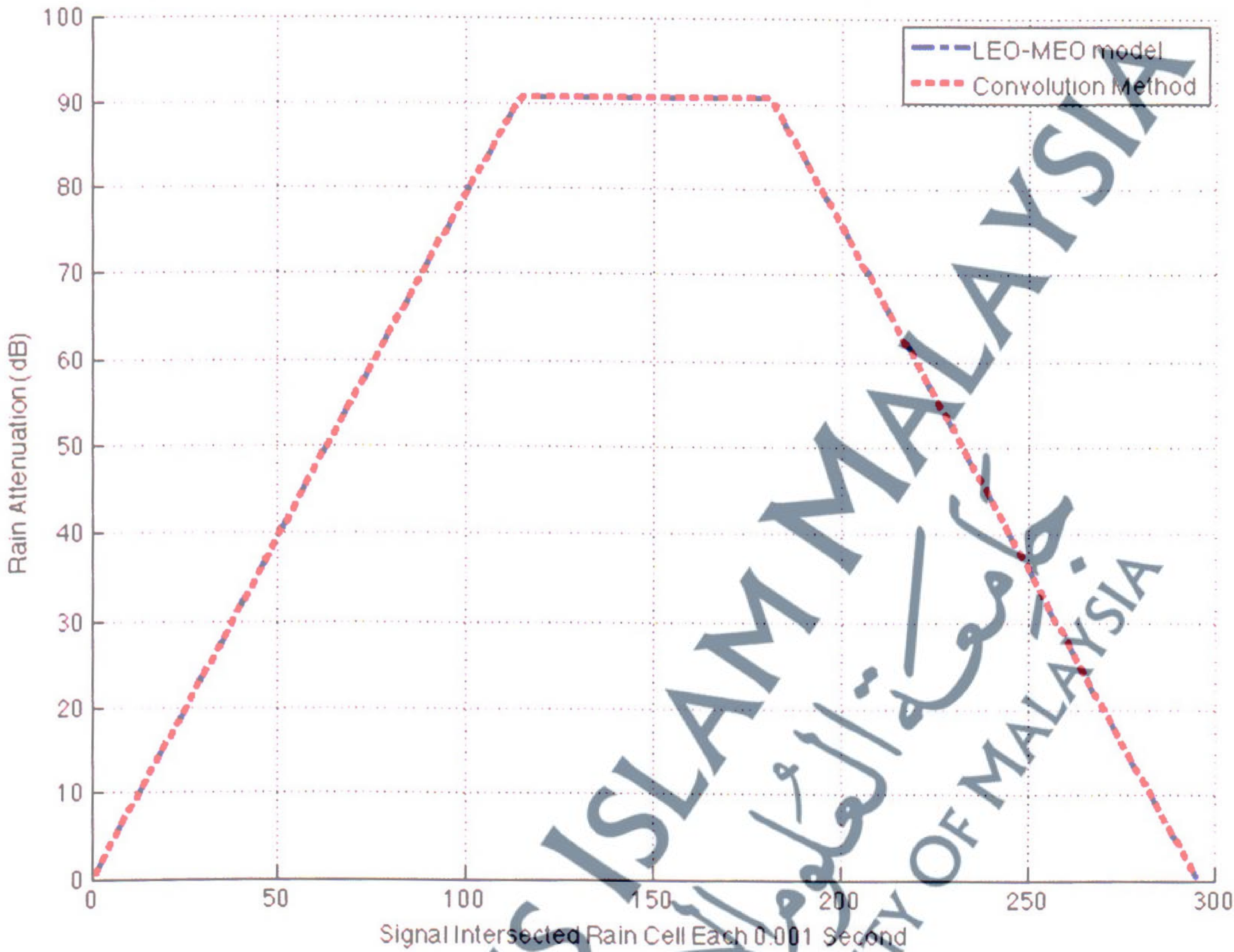


When the cloud moves against the satellite, by contrast, the intersection duration time will decrease as the speed of the cloud increases. Therefore, the number of intersections between the signal and the rain will decrease.

4.12 Rain Attenuation Prediction Using Convolution Method

An important consideration in the evaluation of the attenuation model is whether or not the model is in agreement with other models. With this in mind, the performance of the convolution model presented in this study was compared to model that dedicated to the non-stationary satellites (LEO and MEO as shown in Figure 4.22).

Figure 4.22: Comparison between rain attenuation obtained by the model of the non-geostationary satellites and the convolution method, when $\theta=80^\circ$



Both models were coded in MATLAB and used to predict the rain attenuation at any time percentage exceeded during a year. From the result shown in Figure 4.22, it can be seen that the attenuation approach of both models is totally identical. The attenuation is increases as the signal path goes deeper into the rain, until it reaches the maximum amount (about 90 dB). Since the elevation angle used is higher (where it equals 80° degrees), the affected path length will be the same for certain distance, therefore the rain attenuation will be stable for some time.

4.13 The Effective Rain Cell Size

The method presented is dedicated to the non-geostationary satellites (LEO and MEO). It can be noted that the effective size of the rain cell is not equal to the rain cell

size due to the movement of both clouds and the satellite. However, the effective cell size is dependent on the initial position of where the signal touched the cloud at the first moment of the penetration. Figure 4.23 shows the relationship between the effective rain cell size versus the signal cross section point (between the signal and the rain cell) away from the rain cell edge. It is noted that as the cross section takes place away from the cell edge, the effective rain cell size will increase. Thus, when the signal touches the rain cell 0.4 km or above away from the edge of the rain cell it corresponds to approximately 4 km rain cell size, while at 0 km away from the rain cell edge, the effective rain cell size will equals to 3 km.

Figure 4.23: Relationship between the effective rain cell size and the signal cross section distance, when satellite velocity is 3km/s, cloud velocity is 1km/s, and rain cell diameter is 4km

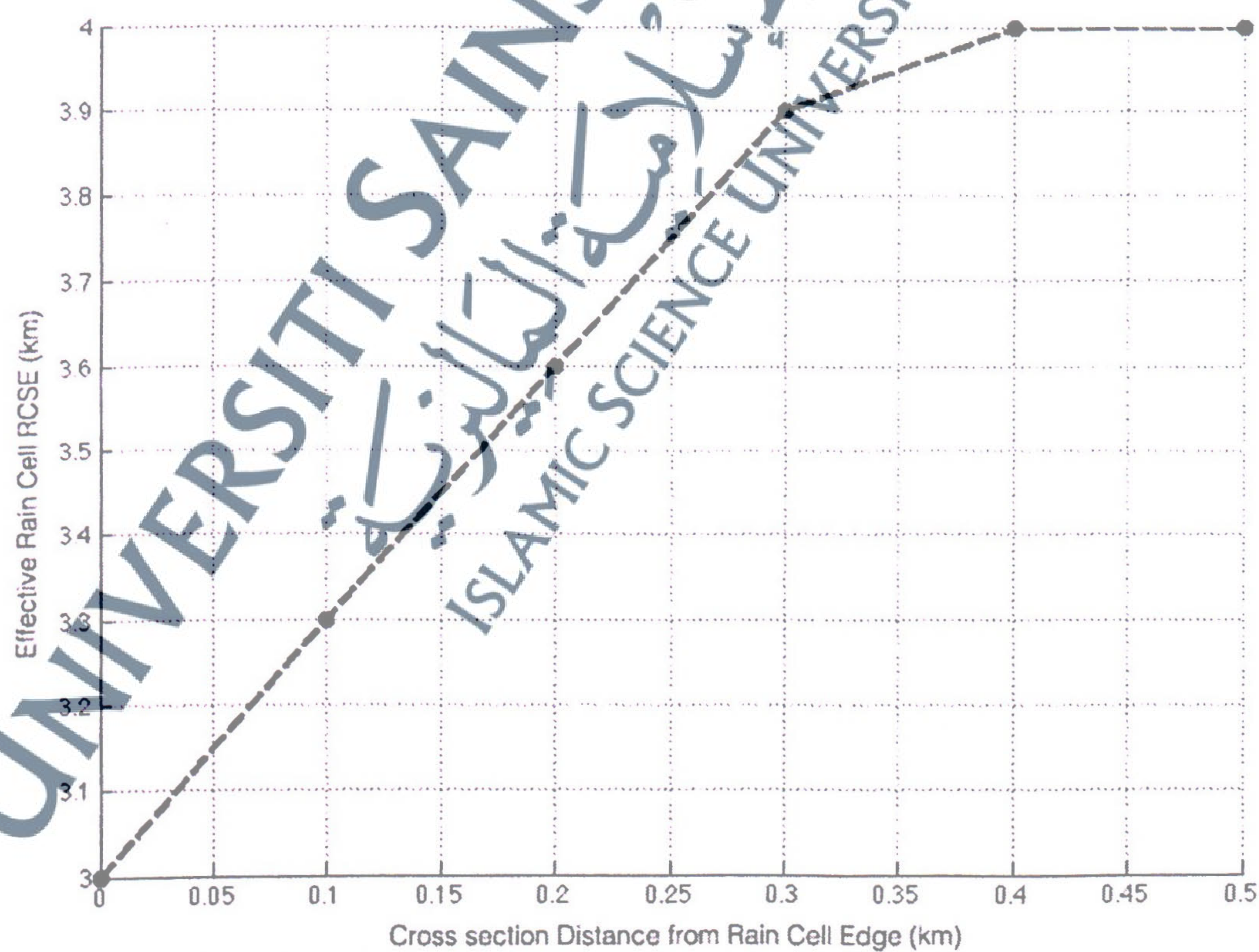
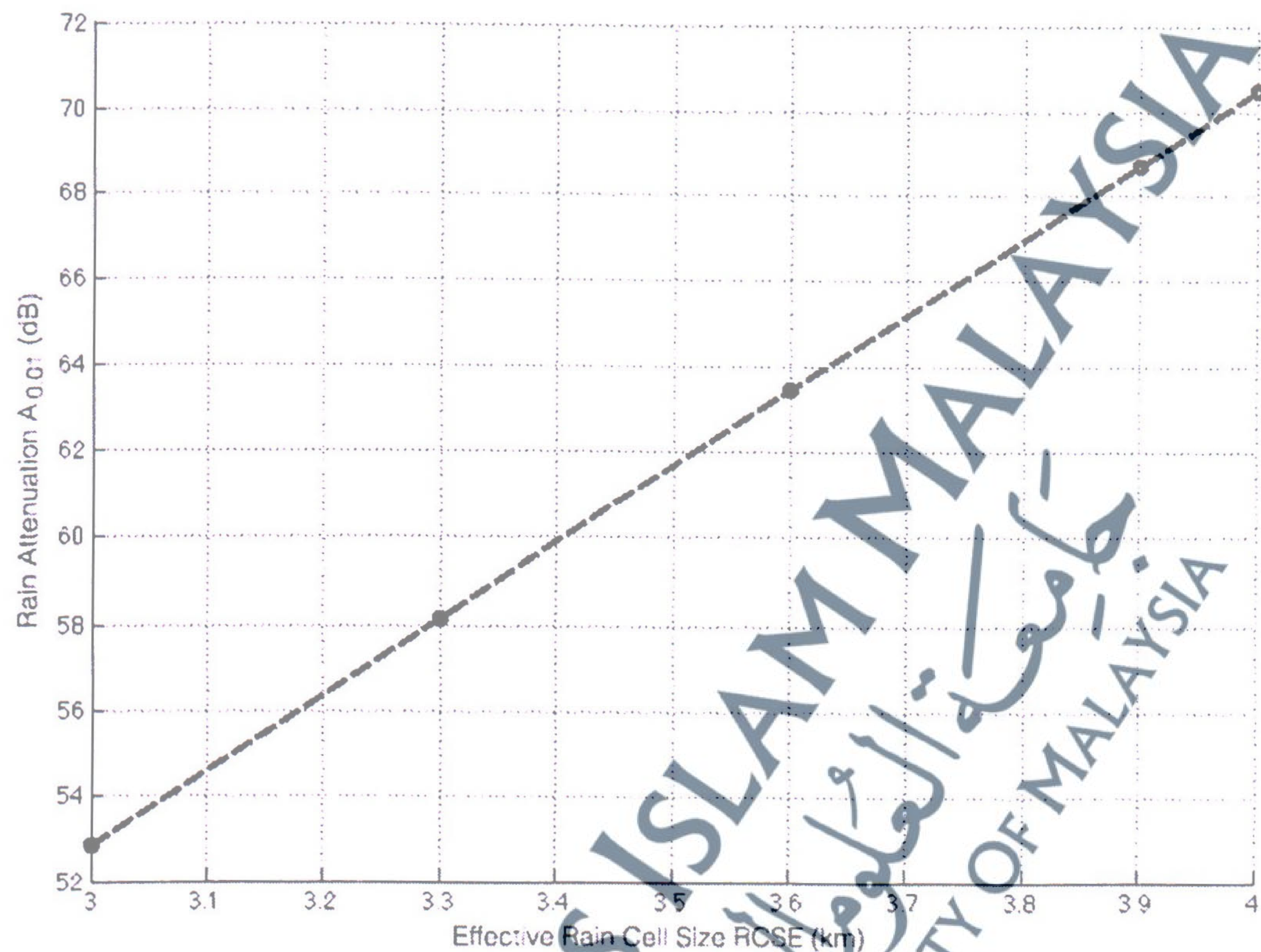


Figure 4.24: Variation of the rain attenuation due to effective rain cell



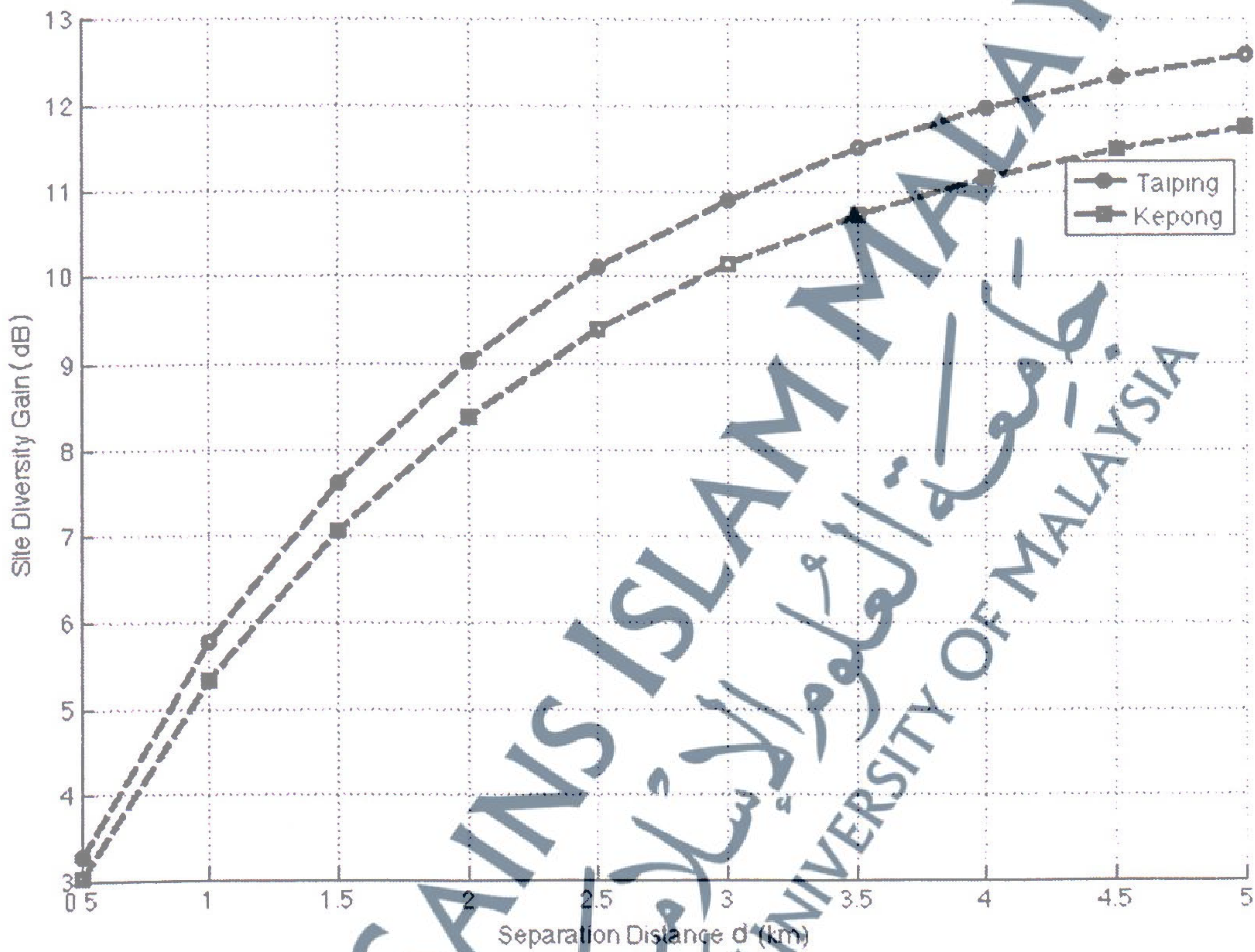
The result shown in Figure 4.24 shows that the size of the effective rain cell has a high impact on the rain attenuation. The rain attenuation is directly related to the size of the rain cell on a scale from 3 to 4 km. This variation of cell size causes more rain attenuation to the signal. Thus, the affected signal path becomes longer, causing more attenuation each time the effective cell size increases.

4.14 Site Diversity

The result shown in Figure 4.25, has been carried out for a downlink signal with an operation frequency equals 28 GHz. It can be noted that the power gained gradually increases as the separation distance between the joint site and the master site is increased. The amount of the power gained is up to 9.4 dB in Taiping while it is about

8.8 dB for the Kepong station. The power gained is significant for the HAPS link where high service availability is required.

Figure 4.25: Site diversity behavior at different separation distances



As discussed above, the benefit that can be obtained by applying the site diversity is to reduce the power consumed of the HAPS signal in the rainy events. The diversity gain was tested in Taiping and Kepong station because these stations are suffering the highest rain attenuation amounts.

4.15 Rain Attenuation Topographic Maps of Malaysian Peninsular

To estimate the rain attenuation contour maps, the modified model has been used to predict the rain attenuation at 1.25 km rain cell size for all locations. Figure 4.26 presents the map of the peninsular Malaysia with the contour lines for the rainfall rate intensity of the stations of interest selected in this study.

The figure depicts that the rainfall intensity varies in accordance with the geographical location. It can be seen that the station located in Taiping suffers the highest rainfall intensity ($R_{0.01}$ is 145.5 mm/h), while it is decreases gradually to around 126.2 mm/h at Tanjung Malim station. The figure also shows that the stations located in the southern part of the peninsula are suffering from a greater relative amount of the total rainfall accumulation than those located in the northern part.

Figure 4.26: Rainfall rate contour lines in peninsular Malaysia

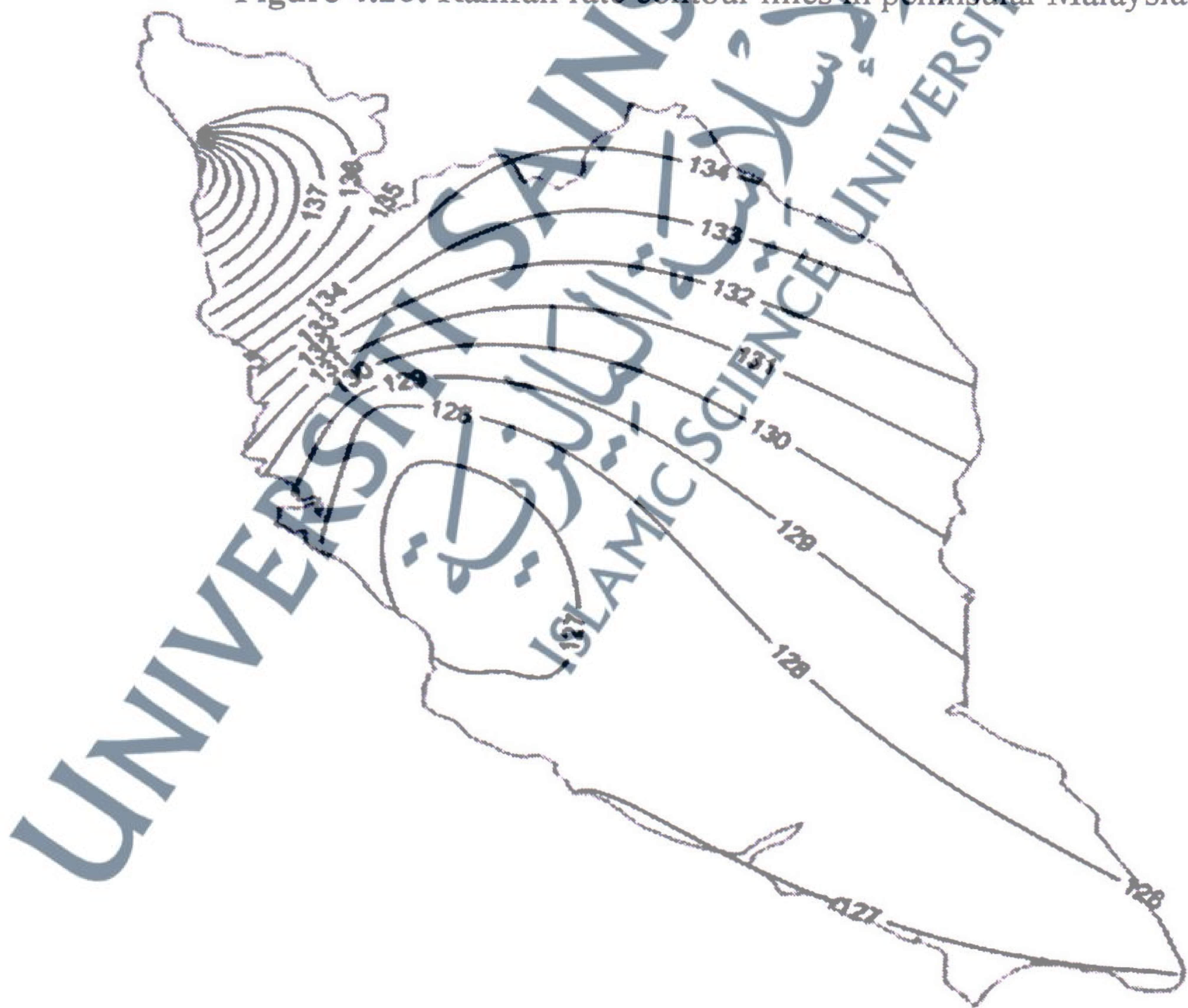


Figure 4.27 shows the contour map which was developed for the HAPS system to represent the main areas of the attenuation in Malaysian peninsular. To develop the rain attenuation for 0.01% percentage of average time, the rain attenuation has been predicted based on the modified model of the ITU-R described in Section 3.5, where the rainfall rate for each station is obtained from Table 4.2. The frequency that has been used for this mapping is 28 GHz which is classified as Ka-band, where this frequency is dedicated for the downlink HAPS signal.

Figure 4.27: Rain attenuation contour lines in peninsular Malaysia



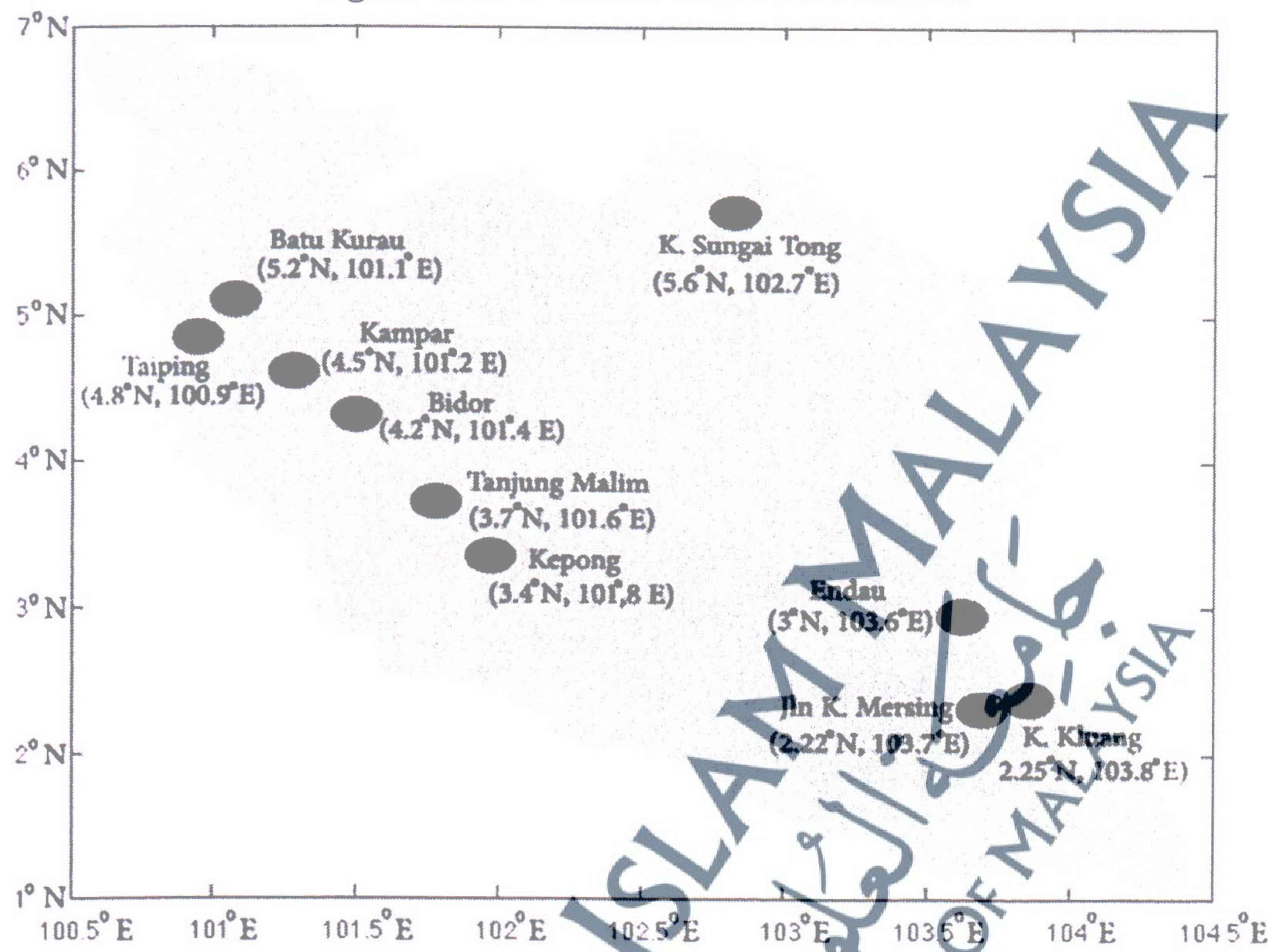
From the contour map presented in Figure 4.27 for 0.01% rainfall in peninsular of Malaysia, the variation of the predicted attenuation values for each location can be

noticed. For a station like Taiping which experiences the highest average annual rainfall, the rain attenuation is as high as ~ 3.4 dB compared to Tanjung Malim station which suffers the lowest rainfall rate as listed in Table 4.2. Since we have two distinct HAPS platforms (North and South), the difference in the rain attenuation at the same part is also varies. The results of the rain attenuation prediction in the northern part of the country has an average difference between the maximum and minimum value is about 2.5 dB higher compared to the southern region as listed in Table 4.3.

4.16 Identification of The Best HAPS Location

The HAPS network is a group of interconnected stations dedicated to providing a variety of services and applications. Various network architectures have been presented based on systems requirements, as described in Chapter 2. HAPS is able to support multi-services with high performance where it combines the advantages of terrestrial and satellite technologies. HAPS can allow operators to provide telecommunications services in rural, suburban and urban areas, since it is difficult and expensive to cover those areas with cellular and optical fiber networks. However, due to the attenuation issues, one of the challenges is to investigate the most efficient location for the HAPS platform segment to achieve higher data rates as well as to reduce the consumed power.

Figure 4.28: Locations of the earth stations



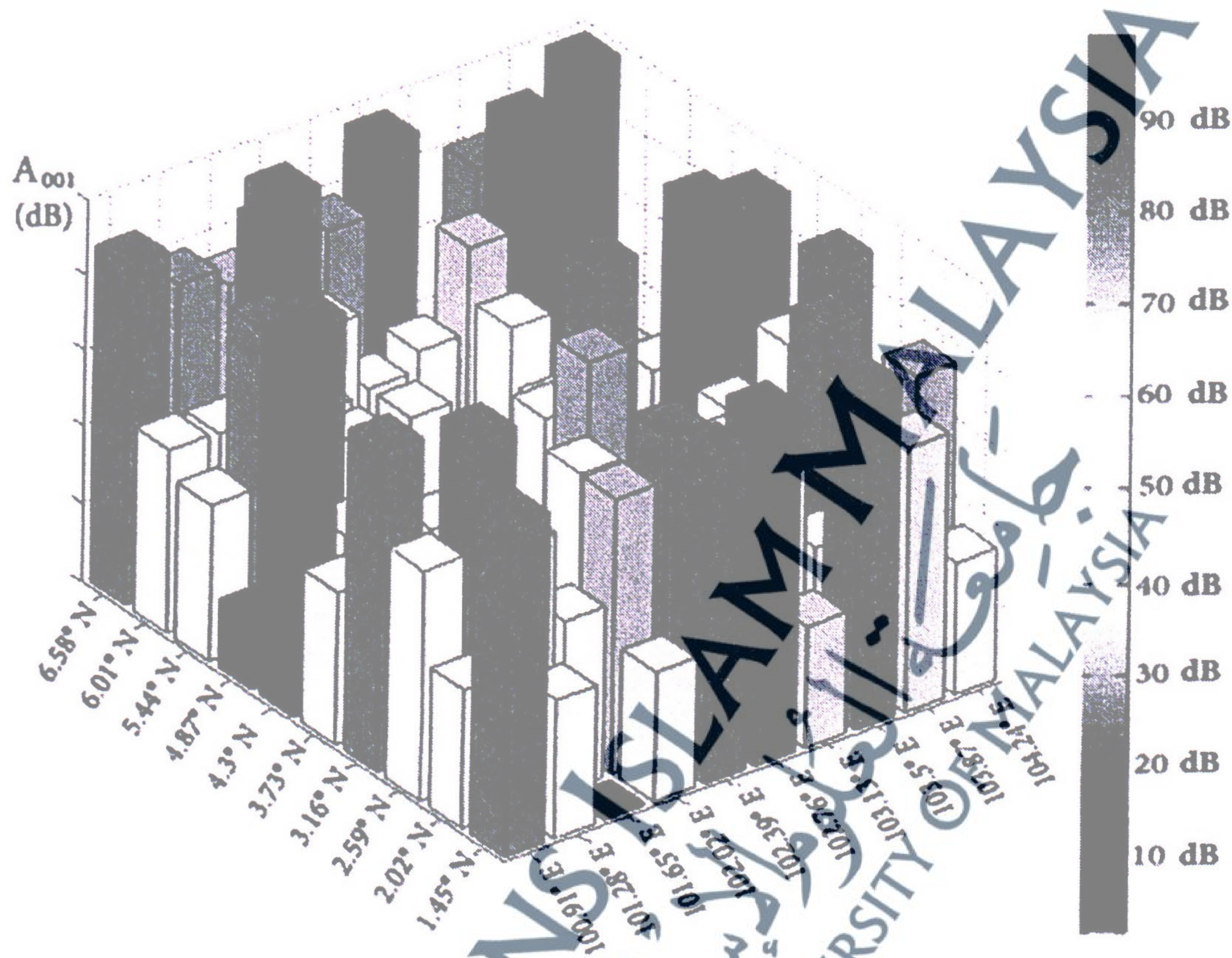
Based on the results which presented in this chapter, it was possible to identify the best location for the HAPS stratospheric segment. As mentioned in the methodology chapter, the peninsula of Malaysia has been divided into two parts, where one HAPS platform was dedicated to each part. The best HAPS location has been investigated using a matrix of 10*10 for each location. Each station will be represented by one matrix as shown in Figure 4.29. Therefore, 5 matrixes will produced in each part.

Figure 4.29: Rain attenuation matrix obtained for each part of the peninsular



The software was designed to compare each element in each matrix with the elements in the other matrixes located at the same position. The maximum value of the attenuation will be selected to achieve an accurate link budget. At the end of this step, one matrix containing all maximum values of the attenuations will be obtained as shown in Figure 4.30.

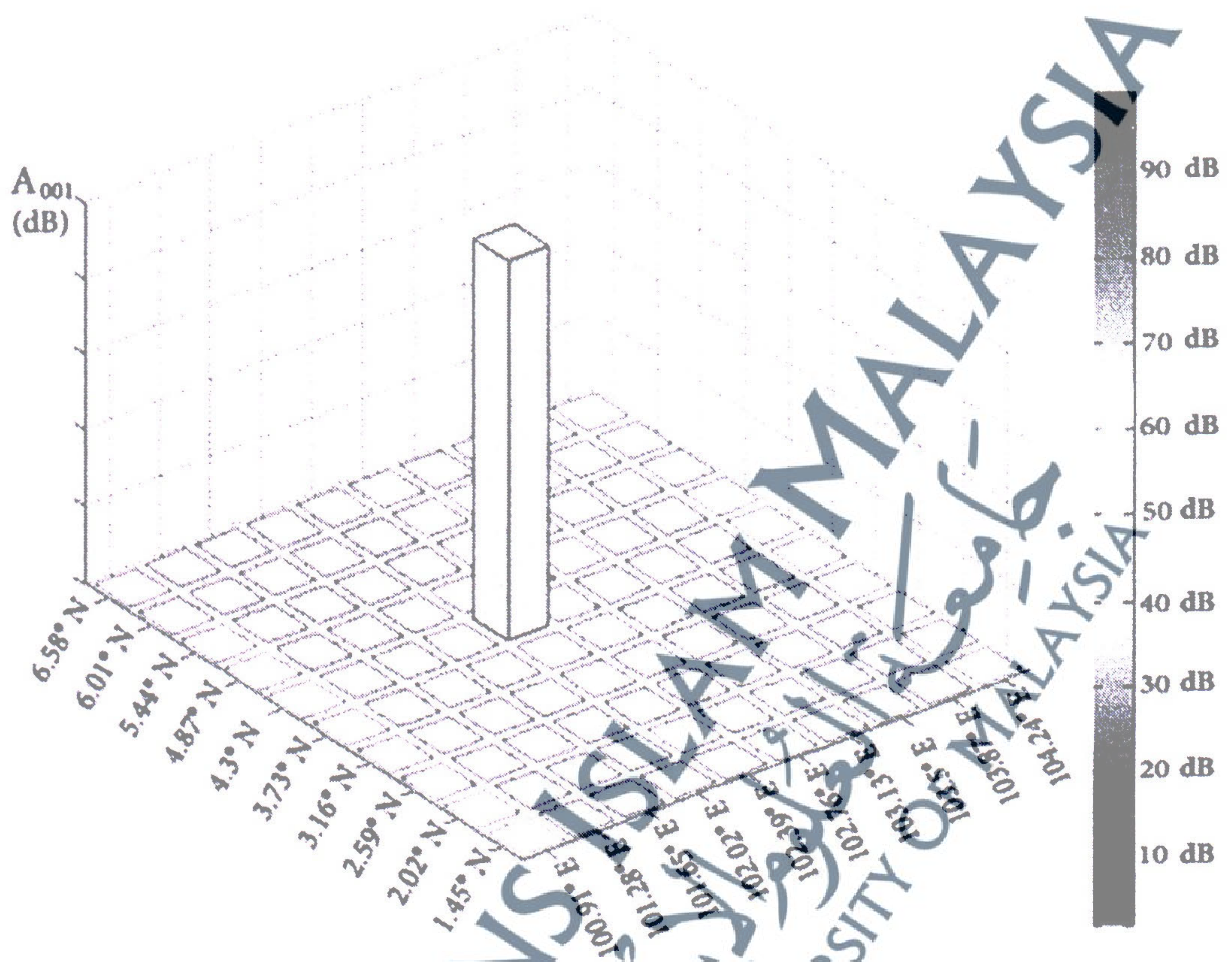
Figure 4.30: Maximum Rain attenuation matrix obtained for each part of the peninsular



Finally, as shown in Figure 4.31, the matrix element which assigned by the lowest attenuation value will be indicated as the best location for the stratospheric segment.

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.

Figure 4.31: Rain attenuation matrix indicates the best HAPS location



However, another set of rainfall data was used to identify the best location for the HAPS. The statistical rainfall data was monthly rainfall intensity for the year of 2014 for the same stations targeted in this thesis. The data was categorized into four seasons, where the average of each three months was calculated to represent different season. The aim of this process is to investigate whether the HAPS location will always be fixed or not. The result shows that the best location of the HAPS is changes based on the climatic annual quart.

For the first annual quart (January, February, and March), the best locations for the northern and the southern platforms were found at 4.94°N, 102.88°E, and 5.35°N, 101.22°E respectively. For the second annual quart (April, May, and June), the best locations for the northern platform was at 5.22°N and 100.74°E. While the best

location was at 5.36°N and 101.93°E , for the southern part. For the third annual quart (July, August, and September), the best locations for the northern and the southern platforms were found at 4.11°N , 100.74°E , and 5.36°N , 102.88°E respectively. Finally, the best HAPS locations for the fourth annual quart (October, November, and December), were found at 4.11°N , 102.88°E , and 4.11°N , 100.74°E for the northern and the southern platforms respectively.

The attenuation values of the northern part are up to 1300 dB in some points in the matrix while it is 200 dB at the most efficient location, whereas it is up to 1400 dB in the southern part but 195 dB at the most efficient location.

4.17 Summary

This chapter starts with a comparison between the modified ITU-R and the ITU-R model. This discussion is followed by a presentation of results relating to drop size distribution, specific attenuation, rain height dependence, and the link budget. Then, the chapter shows the results of rain attenuation prediction at the ten selected sites. The attenuation was calculated based to the rainfall data that can introduce an outage time percentage of 0.001, 0.01, 0.1 and 1 of average a year. The result of the new models that able to predict the LEO and MEO satellite signals is also presented.

The final section of the chapter provides an overview of mechanism that used to identify the best location of the HAPS stratospheric segment in peninsular Malaysia.

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.