

RAIN EFFECT ON KU-BAND SATELLITE SYSTEM

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ABSTRACT

Satellite system has many frequency bands, Ku-band is the most used bands in satellite services like DVB, DAB, Internet, the ionosphere influences specially, rain has the direct effect on the satellite signal and causes decrease in the received signal, this paper is an attempt to study, calculation of rain effect in Iraqi Kurdistan region, some results presented and finally, some solutions and recommendations presented to reduce the rain effect hope be useful for any satellite system users in any locations to minimize this effect, improvement and increase in the received signal.

KEYWORDS

Ku-Band satellite system, rain effect, rain attenuation calculation

1. INTRODUCTION

Satellite communication system like other systems has some impairments for example, the transmitting and receiving equipment, polarization mismatch losses, di-pointing losses and free-space losses, the first three impairments can be improved and overcome their effects is not impossible, but the last one needs some technical and special methods to reduce not to overcome but to reduce its effects, free space losses in clear sky exists and affects the signal, and this loss increases in case of rain, snow, heavy clouds, specially, the regions with heavy rain suffering from the disconnecting the received signal during rains, this paper is an attempt how to calculate the free space losses and then the received signal during rain and clear sky, comparing the two results to see the amount of losses, then how to compensate these losses, then, finally, giving the signal continuity without interruption of the received signal.

After the introduction section, there will be a brief discussion about the satellite system, the impairments, then, the free space losses in more details, calculation of the rain effect, as an example in Iraqi Kurdistan region for the four seasons, the methods to compensate these losses, results and some conclusions.

2. KU-BAND DIFFICULTIES

When frequencies higher than 10 GHz are transmitted and received in a heavy rain fall area, a noticeable degradation occurs, due to the problems caused by and proportional to the amount of rain fall (commonly known as known as “rain fade”).

This problem can be combated, however, by deploying an appropriate link budget strategy when designing the satellite network and allocating a higher power consumption to overcome rain fade loss. In terms of end-viewer TV reception, it takes heavy rainfalls in excess of 100 mm per hour to have a noticeable effect, Figure 1 is for the rain effect in satellite system in up-link and Figure 2 for down –link respectively.

A similar phenomena called “snow fade” (when snow accumulation significantly alters the dish’s focal point) can also occur during Winter Season.

Also, the Ku band satellites typically require considerably more power to transmit than the C band satellites. However, both Ku and Ka band satellite dishes are smaller (varying in size from 2’ to 5’ in diameter.) but, larger dish will causes in increase for the received signal and better quality of the system.

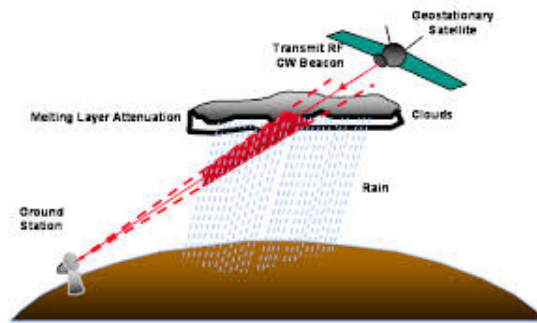


Figure. 1 Rain Effect on Satellite System (up-link)

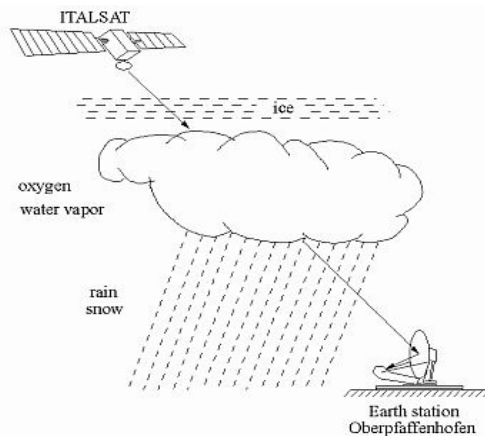


Figure. 2 Rain Effect on Satellite System (down-link)

Advantages of Ku-band compared with C-band, this band is not similarly restricted in power to avoid interference with terrestrial microwave systems, and the power of its uplinks and downlinks can be increased. This higher power also translates into smaller receiving dishes and points out a generalization between a satellite's transmission and a dish's size. As the power increases, the dish's size can decrease. This is because the purpose of the dish element of the antenna is to collect the incident waves over an area and focus them all onto the antenna's actual receiving element, mounted in front of the dish (and pointed back towards its face); if the waves are more intense, fewer of them need to be collected to achieve the same intensity at the receiving element.

Also, as frequencies increase, parabolic reflectors become more efficient at focusing them. The focusing is equivalent given the size of the reflector is the same with respect to the wavelength. At 12 GHz a 1-meter dish is capable of focusing on one satellite while sufficiently rejecting the signal from another satellite only 2 degrees away. This is important because satellites in FSS (Fixed Satellite Service) service (11.7-12.2 GHz in the U.S.) are only 2 degrees apart. At 4 GHz (C-band) a 3-meter dish is required to achieve this narrow of a focus beam. Note the inverse

linear correlation between dish size and frequency. For Ku satellites in DBS (Direct Broadcast Satellite) service (12.2-12.7 GHz in the U.S.) dishes much smaller than 1-meter can be used because those satellites are spaced 9 degrees apart. As power levels on both C and Ku band satellites have increased over the years, dish beam-width has become much more critical than gain. The Ku band also offers a user more flexibility. A smaller dish size and a Ku band system's freedom from terrestrial operations simplifies finding a suitable dish site. For the end users Ku band is generally cheaper and enables smaller antennas (both because of the higher frequency and a more focused beam). Ku band is also less vulnerable to rain fade than the Ka band frequency spectrum. The satellite operator's Earth Station antenna does require more accurate position control when operating at Ku band due to its much narrower focus beam compared to C band for a dish of a given size. Position feedback accuracies are higher and the antenna may require a closed loop control system to maintain position under wind loading of the dish surface.

However, as a disadvantage of Ku band system especially at frequencies higher than 10 GHz in heavy rainfall areas, a noticeable degradation occurs, due to the problems caused by and proportional to the amount of rainfall (commonly known as "rain fade"). This problem can be mitigated, however, by deploying an appropriate link budget strategy when designing the satellite network, and allocating a higher power consumption to compensate rain fade loss. The Ku band is not only used for television transmission, which some sources imply, but also very much for digital data transmission via satellites, and for voice/audio transmissions.

The higher frequency spectrum of the Ku band is particularly susceptible to signal degradation, considerably more so than C-band satellite frequency spectrum. A similar phenomenon, called "snow fade" (where snow or ice accumulation significantly alters the focal point of a dish) can also occur during winter precipitation. Also, the Ku band satellites typically require considerably more power to transmit than the C-band satellites. Under both "rain fade" and "snow fade" conditions, Ka and Ku band losses can be marginally reduced using super-hydrophobic Lotus effect coatings.

3. Influence of the atmosphere

On both the up- and downlinks, the carrier passes through the atmosphere. Recall that the range of frequencies concerned is from 1 to 30 GHz. From the point of view of wave propagation at these frequencies, only two regions of the atmosphere have an influence the troposphere and the ionosphere. The troposphere extends practically from the ground to an altitude of 15 km. the ionosphere is situated between around 70 and 1000 km, the regions where their influence is maximum are in the vicinity of the ground for the troposphere and an altitude of the order of 400 km for the ionosphere. The influence of the atmosphere has been mentioned previously in order to introduce the losses LA due to atmosphere attenuation and in connection with antenna noise temperature. Figure 3 is the relation between the free space losses versus frequency for clear sky. However, other phenomena can occur. The predominant effects are those caused by absorption and depolarization due to tropospheric precipitation (rain and snow), dry snow has little effect. Although wet snowfalls can cause greater attenuation than the equivalent rainfall rate, this situation is rate and little effect on attenuation statistics. Effects are particularly significant for frequencies greater than 10 GHz. The occurrence of rain is defined by the percentage of time during which a given rainfall rate is exceeded, low rainfall rates with negligible effects correspond to high percentage of time (typically 20%); these are described as clear sky conditions. High rainfall rate with significant effects, correspond to small percentage of time (typically 0.01%); these are described as rain conditions. These effects can degrade the quality of the link below an acceptable threshold. The availability of a link is thus directly related to the rainfall rate time statistics. In view of their importance, the effects of precipitation are presented first. There are several of main problems of propagation using Ku-band satellite links :

Rain attenuation - The attenuation of the signal due rain is the most remarkable propagation effect of the signal in the Ku-band frequency, this kind of loss occurs due to the previous thing, can be greater than 15 dB for a small amount of time.

Gaseous absorption - The loss of approximately 1dB happens due to the steam absorption of oxygen and water.

Cloud attenuation - The clouds that are in the propagation trajectory can attenuate the signal at the frequency of the Ku-band, the amount of attenuation that happens is of approximately of 1 dB or more.

Scintillation - This term is indicative of fast fluctuations in the amplitude of the signal, this is caused by the changes that happen by the variation of the time in the refractive index of the atmosphere, it can also be caused by rainstorms.

Depolarization - The transference of energy from a state of polarization in its orthogonal state can be caused by the atmosphere, mainly in clouds and the rain.

Atmospheric noise - The atmosphere has a temperature equivalent of a black body, in the frequency of Ku-band, this temperature varies from about 10K to close to the temperature of the ambient.

Wet antenna - The condensation in the antennas causes additional loss of the signal. In this paper, we just concern about the concurrent Ku-band rain attenuation and tropospheric scintillation issues.

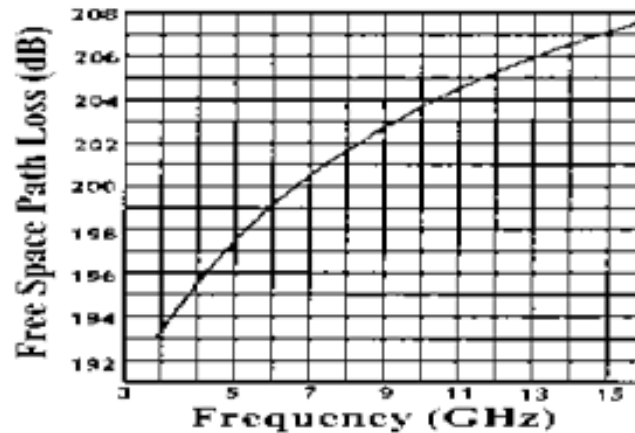


Figure. 3 Free-space path loss vs. frequency in clear sky[1]

4. Calculation of rain attenuation

Rain effect attenuation can be calculated in several steps commonly for any location in the world, the data will be different from location to other depending the weather, in this paper, the calculation is for Iraqi Kurdistan region for the five cities : Erbil, Sulaimanyia, Duhok, Kirkuk and Halabja, where has four seasons Winter, Spring, Summer and Autumn.

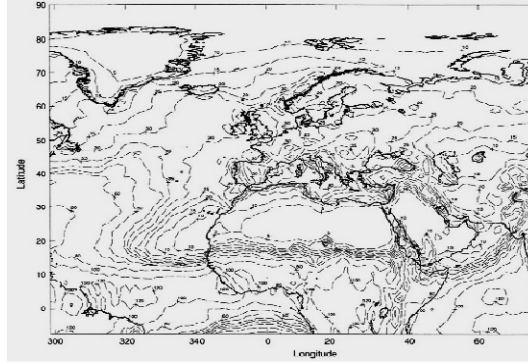


Figure. 4 Longitude and Latitude for overall earth zones[1]

Rain starts from October and ends from April or sometimes on May, temperature decreases and rain fall will be maximum after November until April, the value of attenuation due to rain A_{rain} is given the product of specific attenuation γ_R (dB/km) and the effective path length of the wave in the L_e (km), that is the overall rain attenuation is given by :

$$A_{rain} = \gamma_R L_e \quad (1)$$

The value of γ_R depends on the frequency and intensity R_p (mm/h) of the rain. The result is a value of attenuation which is exceeded during the percentage of time p . The calculation of A_{rain} done in several steps according to the location mentioned above in this paper.

Kurdistan region located in region K as shown in Figure 5, this means that the rain rate will be between 2 – 100 mm/Hr depending on the rain rates 1% - 0.001% according to the Table I for the rain rate chart CCIR Rain Zones.

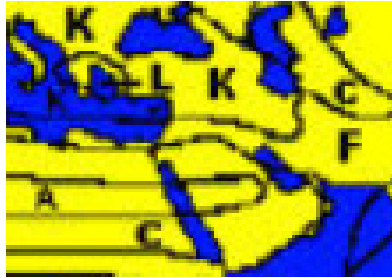
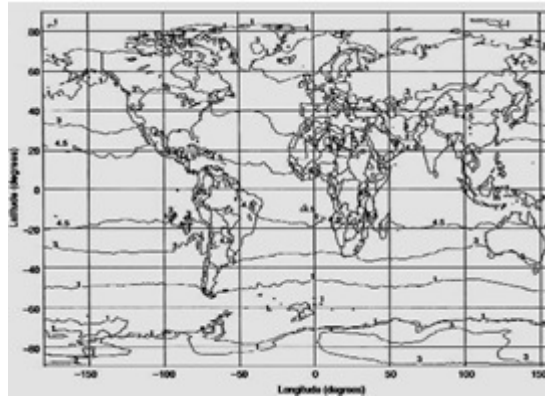


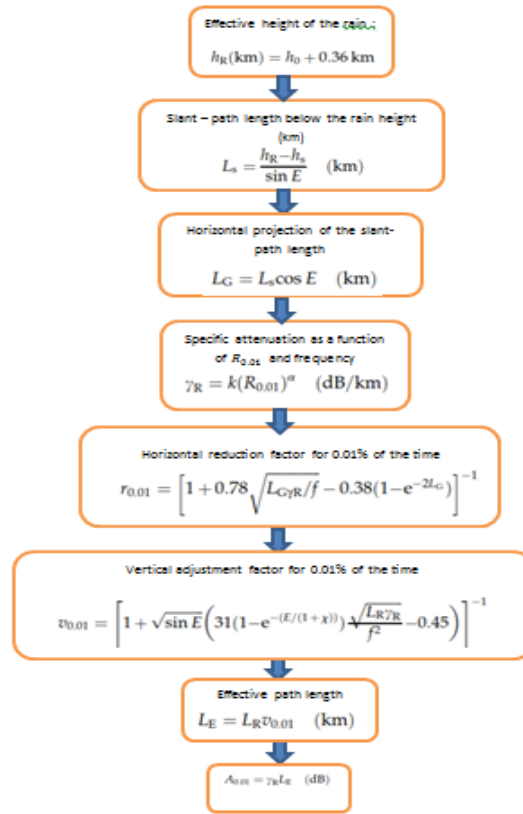
Figure. 5 Rain rate region sections

Table 1. CCIR rain zone rain rates in mm/Hr for different zones

Rainzone	CCIR Rain Zone Rain Rates in mm/h						% Time at Rate	
	1%	0.30%	0.10%	0.03%	0.01%	0.003%	0.001%	
A	0	1	2	5	8	14	22	
B	1	2	3	6	12	21	32	
C	0	3	5	9	15	26	42	
D	3	5	8	13	19	29	42	
E	1	3	6	12	22	41	70	
F	2	4	8	15	28	54	78	
G	0	7	12	20	30	45	65	
H	0	4	10	18	32	55	83	
J	0	13	20	28	35	45	55	
K	2	6	12	23	42	70	100	
L	0	7	15	33	60	105	150	
M	4	11	22	40	63	95	120	
N	5	15	35	65	95	140	180	
P	12	34	65	105	145	200	250	
Hr/Yr	87.6	26.28	8.76	2.628	0.876	0.2628	0.0876	
Availability	99%	99.7%	99.9%	99.97%	99.99%	99.997%	99.999%	
1 Year	8760	Hours						

Figure 6, Kurdistan region average 0°C isotherm height above mean sea level h_o is 3 km.Figure. 6 Yearly average 0°C isotherm height above mean sea level(km)[1]

The steps to calculate the attenuation caused by rain given in the flow chart below, it starts by calculation of mean rain height above mean sea level and ends by calculating specific attenuation γ_R (dB/km) and the effective path length of the wave in the L_e (km), finally, the overall rain attenuation A_{rain} .



Where,

h_0 is the mean 0°C isotherm height above mean sea level

where h_s (km) is the earth station height above mean sea level and E is the satellite elevation angle. This is valid for $E \geq 5^\circ$.

$$k = [k_H + k_V + (k_H - k_V) \cos^2 E \cos 2\tau] / 2$$

$$\alpha = [k_H \alpha_H + k_V \alpha_V + (k_H \alpha_H - k_V \alpha_V) \cos^2 E \cos 2\tau] / 2k$$

E is the elevation angle and τ is the polarisation tilt angle relative to the horizontal

L_G in km, γ_R in dB/km, f in GHz

$$\zeta = \tan^{-1} \left(\frac{h_R - h_s}{L_G r_{0.01}} \right) \text{ (degrees)}$$

$$L_R(\text{km}) = \begin{cases} L_G r_{0.01} / \cos E & \text{for } \zeta > E \\ (h_R - h_s) / \sin E & \text{otherwise} \end{cases}$$

$$\chi = \begin{cases} 36 - |\text{latitude}| & \text{if } |\text{latitude}| < 36^\circ \\ 0 & \text{otherwise} \end{cases}$$

5. Results

In this paper, the attenuation causes by rain calculated for the five cities in Iraqi Kurdistan region, the longitude and latitude are given in Table 2, also, the calculated parameters needed are given in the Table for the Ku-band in the frequency range from 10 GHz to 12 GHz ($10 \text{ GHz} \leq f \leq 12 \text{ GHz}$) :

$$0.0101 \leq k_H \leq 0.0188, 0.00887 \leq k_v \leq 0.0168$$

$$1.276 \leq \alpha_H \leq 1.217, 1.264 \leq \alpha_v \leq 1.200$$

Height above sea level for Erbil, Sulaimanyiah, Kirkuk, Duhok, and Halabjah (h_s) are 0.428km, 0.807km, 0.308km, 0.553km and 0.718km respectively, elevation angles (E) = 90 – Zenith angle

where, Zenith angle is the angle between the sun and the vertical.

Therefore from the longitude and latitude locations for the five cities, the zenith angles are $30.47^\circ, 31.11^\circ, 31.19^\circ, 29.77^\circ, 31.48^\circ$, as a result, the elevations (E) will be respectively : $59.53^\circ, 58.89^\circ, 58.81^\circ, 60.23^\circ$ and 58.52° .

Table 2. Locations characteristics and results for Kurdistan region

Location	Lat.	Long.	RainRateat0.01 % (mm/hr)	E°	L_s (km)	L_G (km)
Erbil	36.27	44.08	43 mm/hr	59.53	3.41	1.72
Sulaimanyia	35.63	45.44	40 mm/hr	58.89	2.98	1.54
Duhok	36.85	43.13	41 mm/hr	58.81	3.56	1.87
Kirkuk	35.63	44.32	37 mm/hr	60.23	3.23	1.60
Halabjah	35.23	45.93	39 mm/hr	58.52	3.09	1.61

For Ku-band, the specific attenuation is about 5 dB for 50mm/hr as average, also, k and α for the band which has the following calculated parameters Will be :

$$0.0101 \leq k_H \leq 0.0188, 0.00887 \leq k_v \leq 0.0168$$

$$1.276 \leq \alpha_H \leq 1.217, 1.264 \leq \alpha_v \leq 1.200$$

Where, $f = 10\text{GHz}$, $k = 0.0096$, $\alpha = 0.0123$, therefore, $y_R = 0.0097\text{dB/km}$ for vertical polarization, $k = 0.0189$, $\alpha = 0.0238$, therefore, $y_R = 0.0194\text{dB/km}$ for horizontal polarization.

Where, $f = 12\text{GHz}$, $k = 0.0181$, $\alpha = 0.0219$, therefore, $y_R = 0.0187\text{dB/km}$ for vertical polarization, $k = 0.0356$, $\alpha = 0.0429$, therefore, $y_R = 0.0381\text{dB/km}$ for horizontal polarization, as a result, for the range of ku-band : $10\text{GHz} \leq f \leq 12 \text{ GHz}$

$0.0097 \leq y_R \leq 0.0187$ for vertical polarization and $0.0194 \leq y_R \leq 0.0381$ for horizontal polarization.

And the effective path length L_e is approximately the slant path length L_s because $E > \zeta$, agiven in Table 3 : 3.41, 2.98, 3.56, 3.23 and 3.09 for the five locations, as a result the rain attenuation A_{rain} which is the multiplication of L_e and y_R given in equation (1) will be as given in Table IV

Table 3. Predicted rain attenuation for the five locations

Location	A_{rain} (dB)	
	Vertical Pol.	Horizontal Pol.
Erbil	0.033 – 0.063	0.066 – 0.129
Sulaimanyiah	0.028 – 0.055	0.057 – 0.113
Kirkuk	0.034 – 0.066	0.069 – 0.135
Duhok	0.031 – 0.060	0.062 – 0.123
Halabjah	0.029 – 0.057	0.059 – 0.117

Figures 7-11 are the path losses comparison in clear sky and rain situation for horizontal and vertical polarization signals predicted for the five cities in Iraqi Kurdistan region Erbil, Sulaimanyiah, Kirkuk, Duhok and Halabjah respectively.

It is shown that horizontal polarized signals affected by the rain and causes higher rain attenuation and then higher decrease in the received signal than the vertical polarized signals.

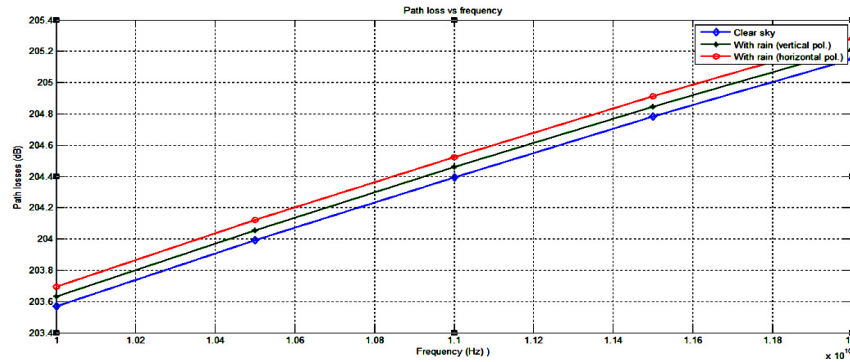


Figure. 7 Path loss vs. frequency for Erbil city

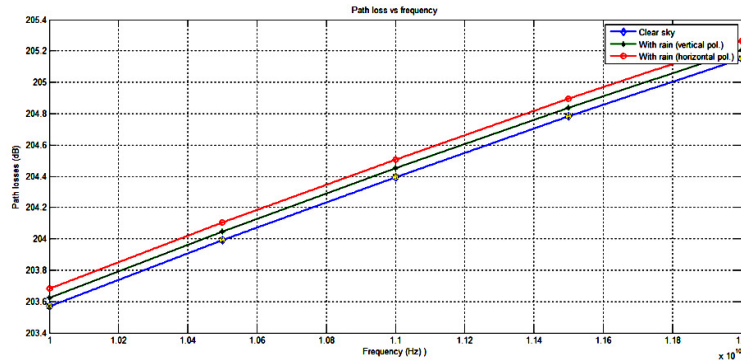


Figure. 8 Path loss vs. frequency for Sulaimanyiah city

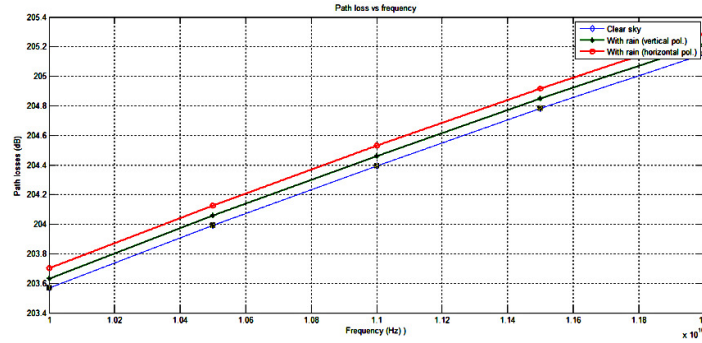


Figure. 9 Path loss vs. frequency for Kirkuk city

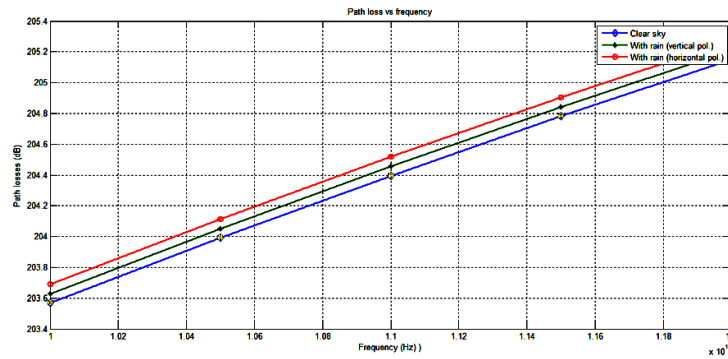


Figure. 10 Path loss vs. frequency for Duhok city

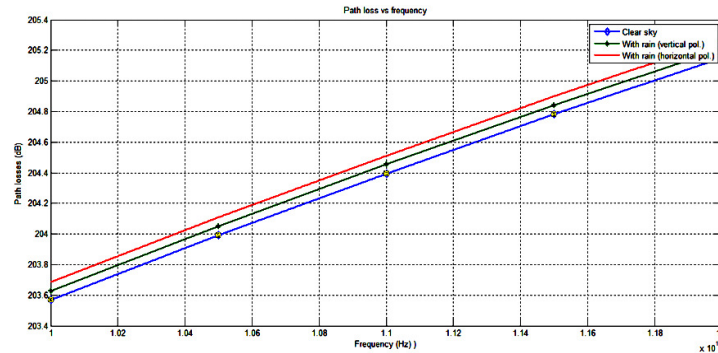


Figure. 11 Path loss vs. frequency for Halabjah city

After the calculations and shown results, it is clear that the rain has the effect on the received signal and causes decrease in the received signal, as a technical recommendations for the user how to decrease this effect, there will be for the two sides up-link side and down-link side, for the up-link side :

1. Greater antenna reflector diameter with higher gain.
2. Tracking the weather situations for the four seasons specially the months rain starts as mentioned in section IV in this paper to increase the transmitting power for heavy rain in order to compensate the loss causes by rain attenuation.

3. Because for the vertical polarized signals, the rain effect is less than that for horizontal, vertical polarization is preferred.

For the down-link side, using antenna reflectors with greater diameter and higher gain, also the distance between the LNB and the reflector preferred that must be prevented from the rain.

6. Conclusions

Satellite signal affected by the atmosphere situations, like snow, rain, and clouds, in this paper, the attenuation causes with rain which increased the path loss has been predicted for Iraqi Kurdistan region main cities Erbil, Sulaimanyiah, Kirkuk, Duhok and Halabjah, it is shown from the results that the horizontal polarized signals affected greater than that with vertical polarized, also, the approximately predicted amount of attenuation causes by rain presented, finally, some useful recommendations to minimize this attenuation and then improve the received signal has been presented.

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