SAKARYA UNIVERSITY JOURNAL OF COMPUTER AND INFORMATION SCIENCES
VOL. 4, NO. 3, DECEMBER 2021
DOI: 10.35377/saucis.04.03.978803

Research Article

Rain Rate and Rain Attenuation Prediction for Satellite Communication in Ku Band Beacon over TURKSAT Golbasi

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Received 4 August 2021; Revised 04 December 2021; Accepted 13 December 2021; Published online 31 December 2021

Abstract

The most effective technique used to measure rain attenuation is experimentally monitoring the received signal strength of satellite beacon. A satellite beacon is a signal which does not modulated and sends to the ground in constant frequency with a specifically designed power. Beacon signals are used by ground station antenna users to track the satellite easily. The satellite operators generally choose beacon signal at the Ku Band frequency band since this band is more resistant to rain attenuation. Ku band satellite system performance describe by the contribute of rainfall rate and rain attenuation. This paper includes the comparison of rain attenuation in Ku band beacon and takes as a reference ITU – 838 model caused by rain fall rate in TURKSAT premises. It is compared by calculating that how signals affected from rain between 2012 and 2019 observations for a TURKSAT satellite and in this measurement, both theoretical formula and data are used.

Keywords: TURKSAT, rain attenuation, ku band beacon signal, ITU-838

1. Introduction

The most dominant sources of attenuation in satellite communication systems come from atmospheric losses. These losses arise from rain, snow and dense clouds individually or as a combined effect. Rain attenuation becomes more dominant loss for carrier frequencies above 10 GHz. Precipitation rates (determining the amount of rain) and cumulative precipitations show differences from region to region on earth. Calculating and predicting path losses are therefore not accurate without comprehensive meteorological information obtained locally. In ITU-R proposal [1], earth is divided into regions according to precipitation rates. However, precipitation rates vary because of geographical locations of countries and climate conditions [2]. There might be some discrepancies on precipitations between ITU-R proposals and real case, considering that the ITU-R should have been used more conservative approach. That's why, the operators are motivated to revisit the rain attenuation models on their region. Rain precipitation model of ITU-R designated Turkey region 'K'. The main motivation for this work is to analyze whether there is differences between region K values versus long term rain statics maintained under all local weather conditions. The data used in this study belongs to the Golbasi /Ankara /Turkey for the dates starting from June 2012 up to September 2019 at yearly basis. Ku band beacon signals coming from an operational TURKSAT GEO satellite are used. They are examined according to weather conditions, space propagation (or path) losses, cable losses and atmospheric losses. This paper is organized as follows. In section 2, link budget of path losses of the TURKSAT Ku band beacon signal is provided. Section 3 presents rain losses comparing ITU-R-838 and TURKSAT data. In section 4, results are summarized, and a solution method is proposed to compensate for the differential errors that might endanger the reliability and even the continuity of communication.

2. Link Budget of TURKSAT Satellite Ku Band Beacon

Satellite operators broadcast at high frequencies such as C, Ku or Ka band. Ku band used most commonly to minimize such attenuations. Frequency of the C-band is small compared to the Ku and Ka bands, and the antenna diameter is quite large compared to the other frequencies used. In C-band, more power is required to transmit the signal to the satellite. This is not a preferred frequency. As the frequency increases, the antenna diameters will decrease proportionally. For satellite operations, larger antennas with tracking capabilities are used in Ku and Ka band and this kind of antennas cost more comparing the others [3], [4], [5], [6]. One of the biggest motivation for calculating satellite losses due rain as accurate as possible is financial gain especially on the uplink side. For this study, two different antennas were selected and their parameters are given in Table 1.

Table 1 Türksat Satellite Beacon link budget information for Two Antennas [6]

Parameter	**Symbol**	**Antenna-A**	**Antenna-B**
Frequency:	f	11.120 GHz	11.120 GHz
Diameter:	d	7.2 m	13.2 m
Efficiency	η	0.6	0.6
Satellite EIRP	EIRP	15 dBW	15 dBW
Free Space Loss Downlink	LS	204.88 dB	204.88 dB
Receiver Gain	Gr	56.26 dBW	61.53 dBW
Receiver System Temp	Ts	127K	125.8 K
Receiver G/T	G/T	35.26 (dB/K)	40.30 (dB/K)
Received power	Pr	-103.62 dBm	-98.152 dBm
Received Power LNA	Pr (LNA)	-43.62 dBm	-68.152 dBm
Gain of LNA	GLNA	60 dBm	30 dBm
Bandwidth	BW	2 kHz	2 kHz
Gas Absorption Losses	Lg	1 dB	1 dB
Pol. and Misalign losses	Lp	1 dB	1 dB
Rain Rate	R0.01	16.35 mm/h	15.36 mm/h
Carrier to Noise Ratio	C/N0	70.28 (dB/Hz)	75.70 (dB/Hz)

3. Rain Fade Calculations

3.1. Based on ITU-R

Rain fade which is the main source of error in path loss calculations, changes with frequency, location, polarization and rainfall rate. The amount of loss due to rain can be calculated using

$$L_{RAIN} = \gamma_R D_S \quad (1)$$

Where L_{RAIN} is the rain loss (or attenuation) in dB, γ_R is the specific attenuation in dB/km, and D_S is the path length through the troposphere in km which is measured from the freezing point (zero-degree isotherm, the level at which it is assumed that all rain originates) in the atmosphere to the receiving antenna. To calculated the rain loss, latitude (φ) and longitude of the earth station should be known. Inaddition the antenna altitude of the station; hs km, the frequency of operation, and the polarization of the signal should also be known. Schematic presentation of an Earth-space path is shown in Fig.1

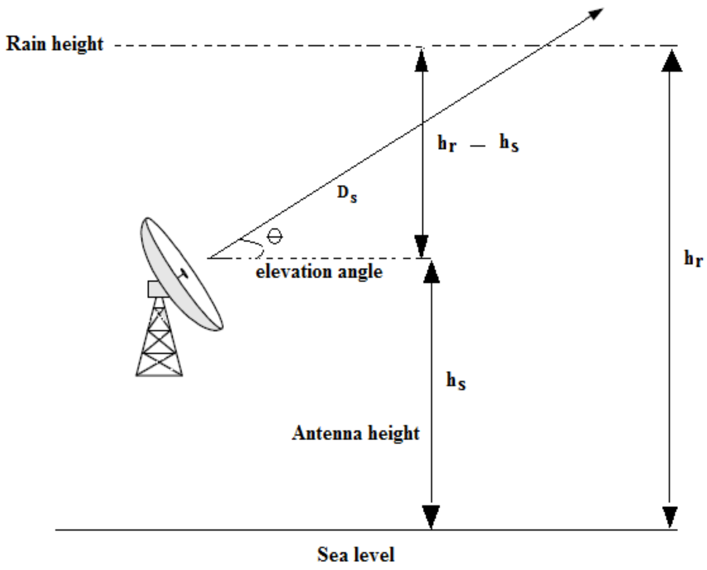

Figure 1. Schematic representation of an Earth-space path [7], [8], [9], [10]

$$D_S = \frac{(\mathbf{hr - hs})}{sin\Theta} \tag{2}$$

Where h_r is the rain height from the sea level, h_S is the distance of the satellite receiving antenna to the sea level, and Θ is the elevation angle. ITU-R Recommendation P.839 relates rain height to location which is reproduced in Table 2.

Table 2 Rain height, h_r for different regions of the Earth [11]

Latitude φ	**h_r (km)**	**Region**
φ> 23 North	5 - 0.075 (φ-23)	Northern hemisphere (except North America &
0 < φ <23 North	5	Northern hemisphere (except North America &
	3.2-0.075 (φ-35)	Northern hemisphere North America & Europe west of
0≥φ≥21 South	5	Southern hemisphere
21S ≥φ≥71	5 + 0.1(φ +21)	Southern hemisphere
71 South > φ		Southern hemisphere

The elevation angle Θ and the rain path D_S can be calculated as 43.145° and 3.8976 km respectively. Besides, Antenna-A was used between 2012-2015 whose h_S is 1086 meters, Antenna-B was used between 2016-2019 whose h_S is 1095 meters from the sea level. The elevation angle Θ and the rain path D_S can be calculated as of 43.145° and 3.885 km respectively. Using equation the specific attenuation, γ_R can be found from for each year [6].

$$\gamma_R = kR^{\alpha} \tag{3}$$

where k (either k_H or k_V), and α (either α_H or α_V) are frequency-dependent parameters given in ITU-R Recommendation P-838 [8] as shown in the first three rows of Table 3. If the beacon signal is horizontally polarized then k_H, and α_H are used in equation (3).

Table 3 Frequency-dependent coefficients for estimating specific rain attenuation [7]

Frequency (GHz)	**k_H**	**α_H**	**k_V**	**α_V**
11.000	0.01772	1.2140	0.01731	1.1617
11.120	0.01840	1.2097	0.01790	1.1563

TURKSAT carrier frequency is 11.120 GHz [6] and corresponding; k and α factors that are calculated using the ITU recommendation P 838 [7]. The rainfall rate R is another parameter necessary to calculate the attenuation coefficient, γ_R Table 4 links the rainfall rates to the percentage of the time it is exceeded in any year by rainfall regions of the world [5] as per ITU recommendation. It indicated before [5], Turkey falls in region K. For γ_R calculations, it is assumed that the rainfall rate that will only be exceeded 0.01% of the time for a satellite terminal in Turkey, Golbası (i.e. the rainfall rate that will give 99.99% availability). From that, the rain rate to be used as per ITU recommendation becomes 42 mm/h. TURKSAT is located in the central Anatolian region of Turkey, in the Gölbaşı of Ankara. It has 39°46 'N and 32°49' E values as coordinates. Since the meteorology station in the center of Gölbaşı is 20 km between TURKSAT premises, measurements is taken with the meteorology equipment (Davis Vantage Pro2) in the center of the ground station. Since meteorology equipment and antennas are in the same place, it enabled us to get more accurate results. Annual rain rate and rain attenuation are calculated according to the data obtained from the measuring device located at the ground station [6].

Table 4 Rainfall rate R to the percentage of the time it is exceeded in any year by region [11]

%R time exceeded	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q
1.0	<0.1	0.5	0.7	2.1	0.6	1.7	3	2	8	1.5	2	4	5	12	24
0.3	0.8	2	2.8	4.5	2.4	4.5	7	4	13	4.2	7	11	15	34	49
0.1	2	3	5	8	6	8	12	10	20	12	15	22	35	65	72
0.03	5	6	9	13	12	15	20	18	28	23	33	40	65	105	96
0.01	8	12	15	19	22	28	30	32	35	42	60	63	95	145	115
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200	142
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	250	170

3.2 Rain Fade Based on Long Term Meteorological Data at Golbası/Ankara

ITU-R P.618-12 recommends to use 42 mm/h rain rate for rainfall attenuation for region 'K'. Whereas, as can be seen from Table 5 and Table 6, smaller the rain rates are calculated by ITU-R-838 Model by using the measured values. The related tables show also the calculated values and actual values derived from antenna system. There are minor differences between the calculated and measured L_{RAIN} due to the differences in antenna system (i.e, diameter, rain sensor and rain blower).

Table 5 Rain rates for years Turksat Golbasi region [6], [12], [13]

Year	Rain Rate at 0.01% (mm/hr)	E° Antenna-A	D_s (km)	Calculated L_{RAIN} (dB)	Measured L_{RAIN} (dB)	Difference (dB)
2012	9.54 mm/h	43.146	3.897	1.099	0.529	0.570
2013	10.21 mm/h	43.146	3.897	1.193	0.533	0.660
2014	16.35 mm/h	43.146	3.897	2.110	0.912	1.198
2015	14.78 mm/h	43.146	3.897	1.867	0.757	1.110

Table 6 Rain rates for years Turksat Golbasi region [6], [12], [13]

Year	Rain Rate at 0.01% (mm/hr)	E° Antenna-B	D_s (km)	Calculated L_{RAIN} (dB)	Measured L_{RAIN} (dB)	Difference (dB)
2016	13.54	43.145	3.885	1.674	0.630	1.374
2017	12.06	43.145	3.885	1.455	0.589	0.866
2018	15.36	43.145	3.885	1.950	0.715	1.235
2019	14.23	43.145	3.885	1.778	0.678	1.100

4. Conclusion

While examining the losses in satellite communication link budgets, calculation of margins become very significant. Climatic conditions and rain precipitation value of Golbasi region are different from the region 'K', determined by ITU-R. Considering this region, same climatic area as South Asia and North Iraq does not always give a correct result [5]. Rain precipitation rate in tropical areas is different from continental climate. It has precipitation rate between 10-25 mm/h in accordance with data taken from meteorology and it is rarely above 25 mm/h. When precipitation rate gets higher, loss rate also gets higher according to ITU-R 838 model. According to this study, the value of 42 mm/h seem to be very conservative value comparing the long term meteorological rain data for Turkey [13], [14], [15]. Considering the region 'K' rain rate is 42 mm/h, this corresponds to about 6.6 dB rain attenuation for TURKSAT location. On the other hand, for Antenna-A case, the maximum observed value at 2014 was 16.35 mm/h which corresponds to 2.11 dB rain attenuation. In this case, the diameter of Antenna-A can be reduced from 7.2 meters to 4.5 meters as per calculations result. For Antenna-B, the maximum observed rain rate was 15.36 mm/h at 2018 which corresponds to 1.95 dB of rain loss. In that case, the diameter of Antenna-B can be reduced from 13.2 meters to 7.7 meters as per calculations. It is shown with this research that ITU-R-612 has conservative values comparing the actual results. The major gain from the study is to have opportunity of reduction of antenna diameter as well as minor profits due to the other units of the antenna systems (i.e HPA, LNA).

Acknowledgments

We would like to thank Turksat AS for its' invaluable support.

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