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Performance analysis of rain attenuation on earth-to-satellite microwave links design in Libya

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Abstract. Performances of earth-to-satellite microwave links operating in Ku, Ka, and V-bands are degraded by the environment and strongly attenuated by rain. Rain attenuation is the most significant consideration and challenge to design a reliable earth-to-satellite microwave links for these frequency bands. Hence, it is essential for satellite link designer to take into account rain fade margin accurately before system implementation. Rain rate is the main measured parameter to predict of rain attenuation. Rainfall statistical data measured and recorded in Libya for the period of 30 years are collected from 5 locations. The prediction methods require one minute integration time rain intensity. Therefore, collected data were analyzed and processed to convert into one–minute rain rate cumulative distribution in Libya. The model proposed by ITU-R is used to predict and investigate rain fade based on converted 1-minute rain rate data. Rain fade predicted at two locations are used for performance analysis in terms of link spectral efficiency and throughput. V-band downlink shows that 99.99% availability is possible in all the Southern part stations in Libya at 0.29 bps/Hz spectral efficiency and 20.74 Mbps throughput when 72 MHz transponder band width is used which is not feasible in Northern part. Results of this paper will be a very useful resource to design highly reliable earth-to-satellite communication links in Libya.

1. Introduction

Future satellite communication systems are demanding towards the use of higher frequency bands in order to achieve larger bandwidth[1]. These bands offer many advantages to satellite communication services and applications, in terms of spectrum availability, reduced interference potential and minimized equipment size[2]. However, rain attenuation is an important factor that limits the use of frequency above C-band in tropical and sub-tropical regions. Atmospheric hydrometer affects the characteristic of the satellite signals[3]. It causes the reduction in the power density of an electromagnetic wave as it propagates through the rainy path[4]. It is directly responsible for link outages and causes link performance degradation. Rain attenuates the signal, disturbs the polarization and increases system temperature. Thus, accurate prediction of rain attenuation is very significant to design reliable microwave link at higher frequencies. The prediction methods require rain intensity at one- minute integration time. According to Owolawi [6-7] the high integration time may not respond to rapid changes in the rainfall rate CD.

In this paper, one-minute integration time rain rate cumulative distribution (CD) is derived from rainfall measured at 5 meteorological stations in Libya for 30 years in order to investigate the link performance in terms of spectral efficiency and, throughput. The Rainfall rate R (mm/h is the most significant parameter to predict rain attenuation in radio wave propagation. Rain fade is directly responsible for link outages at Ku, Ka and future V-bands.

In Şen & Eljadid [5] represented Mediterranean climate region such as Libya, whereas the temperate rain is mostly stratiform and widespread. Therefore, the conditions of the electromagnetic wave propagation absolutely different in Libya because of rain intensities vary significantly over large areas in the country. The highest and the lowest rain rate in the study of interested locations are considered and analyzed in terms of link spectral efficiency and throughput. The model proposed by International Telecommunication Union-Radio wave Propagation (ITU-R) is used to predict and investigate rain fade based on 1-minute rain rate data. Rain fade predicted at five locations are used for performance analysis in terms of link spectral efficiency and throughput.

2. Collection and Processing of Data

Libya lies approximately within the latitude 34°~33°N and longitude 10°-23°E. Libya's coastline is the longest of any African country bordering the Mediterranean. Therefore, Libya influenced directly and strongly by the Mediterranean climate, which is characterized by hot, dry, sunny summers and a winter rainy season [13]. A long- term cumulative rainfall data measured and recorded at the Libyan National Meteorological Center (LNMC) were collected. This study utilizes the data from a climatic period of (1981-2010). Readings of rain gauge are recorded 3 hourly or 8 readings per day at five stations. Hence, 2880 of rainfall readings per year have been considered in rain rate estimation. In this work rain rate in mm/h for each year have been calculated in these stations. The values of R obtained by averaging the data of rain rates calculated from 1981 to 2010. The average value of rain rate $R_{0.01\%}$ expressed in mm/h was obtained [6,13] and shown in Table 1.

Table 1. Measured and converted rainfall data at 5 selected sites

Station Name	Maximum rainfall in a day (mm)	Average number of rainy days/year	Maximum rainfall in a month (mm)	Average $R_{0.01\%}$ (mm/h)	ITU-R $R_{0.01\%}$ (mm/h)
Tripoli city	120.5	52.8	330	45	30
Shahat	86.5	70	434.8	51.7	50
Tripoliairport	130.2	46	173.4	35.8	30
Sebha	29	3.63	29	4.18	10
Benini	53.4	57.72	234.7	21.3	25

3. Rain Attenuation Prediction

The estimation of the long-term statistics of attenuation due to rain for maximum and minimum $R_{0.01}$ in Libya has been calculated by ITU-R procedure. Based on rainfall rate exceeded in 0.01% of the time of the year, the rain rate has been derived from long-term measured data [8-10]. Table.3 presents some of the local geometry parameters used for ITU-R 2012 methodology on the 30.5-E ◦ARABSAT - 5A links at different elevation angles to each of the stations at C - Ku- Ka- V -band downlink with horizontal (H), vertical (V) ,and circular (C) polarization. For the different percentage of time of the year (P %). For estimating of rain fade at a given location, the following two components need to be predicted [11-12]

- Specific attenuation – attenuation due to the rain per unit length of signal path
- Effective path length.

Table 2. Specifications which are considered to predict rain attenuations at 2 locations

Point of rainfall rate for the location R0.01% mm/h	Shahat	Sebha
Point of rainfall rate for the location R0.01% mm/h	51.7	4.2
Height of ES above MSL in m	621	432
Latitude of ES	32.48°	27.01°
Satellite elevation	51.12◦	53.83°
Effective Earth radius	8500	
Polarization	LP-H, LP-V, CP	
Percentage % of time of the year	0.001,0.01,0.1,1	

Table 3. Estimated rain fades based on measured rain rate

Downlink Frequency band	Rain Attenuation $A_{0.01\%}$ (dB) at Maximum $R_{0.01\%}$ 51.7 mm/h			Rain Attenuation $A_{0.01\%}$ (dB) at Minimum $R_{0.01\%}$ 4.2 mm/h		
	LP-H	LP-V	CP	LP-H	LP-V	CP
4GHz	0.19	0.12	0.13	0.01	0.01	0.01
12GHz	8.09	7.16	7.61	0.91	0.86	0.88
20GHz	22.62	19.55	21.01	3.14	2.99	2.43
40GHz	63.49	57.98	60.73	12.56	11.71	12.13

Both rain rates are used to predict rain fades at C, Ku, Ka and V-bands with Vertical, Horizontal and Circular polarized waves for two stations in Libya namely, Shahad and Sebha. It has been observed that rain fade is not significant at C and Ku-bands. The maximum rain attenuation corresponding to these frequencies is 0.19dB and 8.09dB respectively. However, it was observed 22.63 dB at Ka-band and 63.5 dB at V-band which can be considered as a challenge to keep link working with 99.99% of reliability. Figures 1 and 2 represent rain attenuation for C, Ku, Ka, V-band down-link frequency at horizontal polarization using measured $R_{0.01}$. For 99.99% of reliability. Figure 3 shows the rain attenuation when the signal is horizontally polarized at 40 GHz for major zones in Libya at different percentage of time and various on rain intensity obtained from long-term measured data. It's clear that rain effect increases with increase of frequency, R and decrease of elevation angle.

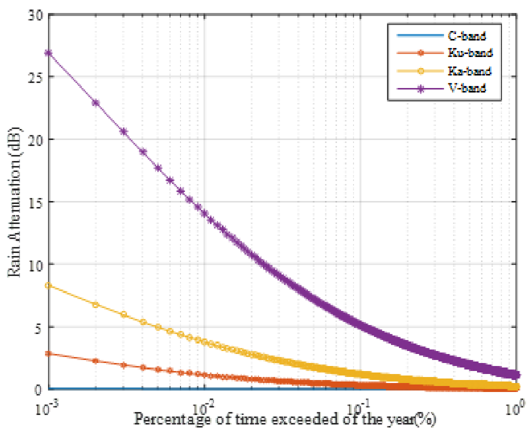

Figure 1. Rain attenuation distribution at Sebha

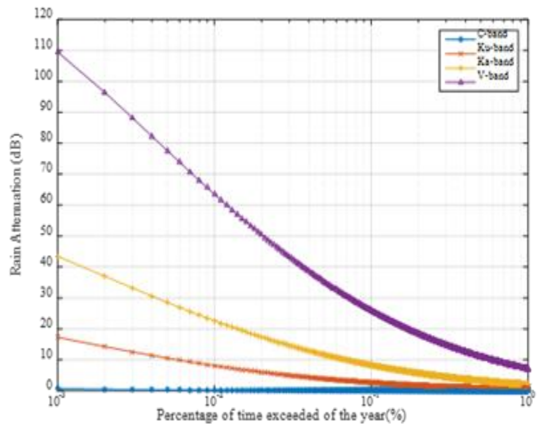

Figure 2. Rain attenuation distribution at Shahat

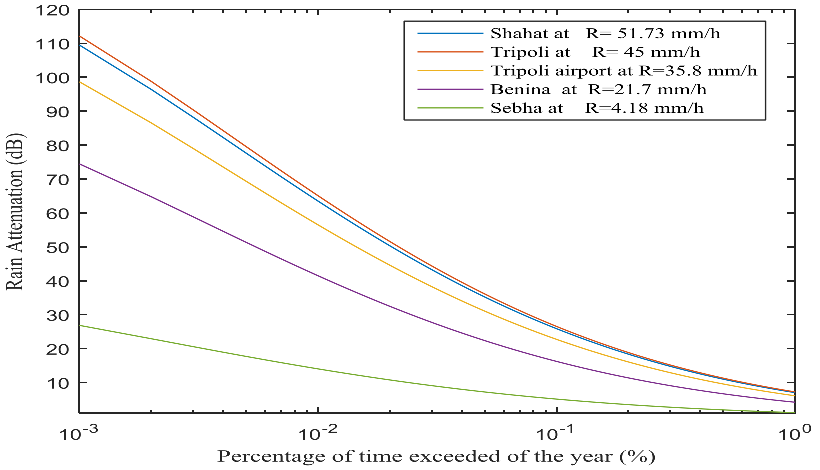

Figure 3. Comparison of Rain Attenuation for Horizontal Polarization in 5 different locations at V- Downlink Frequencies Band

4. Performance Analysis

Performance analysis was performed based on link efficiency in bps/Hz and throughput in Mbps. If the system designed to work at average 7 dB SNR means (BER $=10^{-6}$, 1 dB implementation) at clear air condition at particular reliability. This value of SNR would be decreased by Fade Margin. The spectral efficiency and throughput of downlink satellite- to- earth microwave links changed with transponders bandwidth respectively. The following steps represent the approach of calculation the efficiency and throughput at some vital locations in Libya. By using equation1 and 2 at horizontal polarization. The results of this analysis would assessment the performance of satellite microwave links operating at different frequencies band according to the peculiarity of the calamite condition of the study area of interest during the rainy season.

$$\textit{Spectral Efficiency} = \log(1+SNR/FM)/\log_2 \quad (1)$$

$$\textit{Throughput} = \textit{Spectral efficiency} \times \textit{Transponder BW} \quad (2)$$

In this section, the frequency band utilization efficiency and performance issues of earth-to-satellite communications link would be analytically investigated at Shahat and Sebha. Considering C, Ku, Ka and V- down-link frequency band during rainy events at selected locations, and 4 PSK resource access model. With 7 dB SNR threshold is considered at transponder bandwidths of 36, 54 and 72 MHz respectively. If the link is designed for 99.99% of reliability, a fade margin is introduced to compensate the effects of rain at a given level of availability. The other parameters and values used for the estimation are presented in Tables 5 and 6.

Table 4. Spectral Efficiency and Throughput in Satellite- to- Earth Microwave Links operating at Shahat (Maximum $R_{0.01\%}$)

Parameters	4 GHz	12 GHz	20GHz	40GHz
Average SNR	7 dB	7 dB	7 dB	10 dB
Rain fade margin	0.19 dB	8.09 dB	22.63 dB	63.50 dB
Link Efficiency	2.54 bps/Hz	0.83 bps/Hz	0.04 bps/Hz	0
Transponder BW	Throughput	Throughput	Throughput	Throughput
36MHz	91.32 Mbps	29.88 Mbps	1.40 Mbps	0
54MHz	136.98 Mbps	44.82 Mbps	2.10 Mbps	0
72MHz	182.64 Mbps	59.76 Mbps	2.80 Mbps	0

Table 5. Spectral Efficiency and Throughput in Satellite-to-Earth Microwave Links operating in Sebha (Minimum Measured $R_{0.01\%}$).

Parameters	4 GHz	12 GHz	20GHz	40GHz
Average SNR	6 dB	6 dB	6 dB	6 dB
Rain fade margin dB	0.01 dB	0.91 dB	3.14dB	12.56dB
Link Efficiency bps/Hz	2.31 bps/Hz	2.08 bps/Hz	1.55bps/Hz	0.29 bps/Hz
Transponder Bandwidth	Throughput Mbps	Throughput Mbps	Throughput Mbps	Throughput
36MHz	83.32 Mbps	74.92 Mbps	55.85 Mbps	10.37 Mbps
54MHz	124.98 Mbps	112.37 Mbps	83.77 Mbps	15.56 Mbps
72MHz	166.64 Mbps	149.83 Mbps	111.69 Mbps	20.74 Mbps

The performance of the links is analyzed at two locations, namely Shahat, and Sebha. In (Maximum $R_{0.01}$) the spectral efficiency was 0.04 bps/Hz and 2.08 Mbps throughput. This is the highest efficiency that obtained at Ka –band. When transponder bandwidth is 72 MHz with 7dB SNR. However, at V-band satellite communication link will shut down even if the average value of SNR has been increased to more than 10dB in the northwest and northeast along the Libyan coast. Whereas it can still operate at V-band in the middle of the Libyan coast with an efficiency of 0.25 bps/Hz and 17.48 Mbps throughput at 7dB SNR. In Sebha, V- band satellite communication link may operate even the average of SNR have been reduced to 6 dB with efficiency of 0.29 bps/Hz and 20.74 Mbps throughput with transponder BW is 72 MHz while transponders BW of 72, 54 and 36 MHz are all shut down in Shahat.

5. Conclusions

Rain attenuation is the most significant consideration and challenge to design a reliable earth-to-satellite microwave links for Ku, Ka and V-bands frequencies. Hence, it is essential for satellite link designer to take into account rain fade margin accurately before system implementation. Rainfall statistical data measured and recorded in Libya for the period of 30 years are collected from five locations. Rain attenuation prediction methods require one minute integration time rain intensity. Therefore, collected data were analyzed and processed to convert into one–minute rain rate cumulative distribution in Libya. The model proposed by ITU-R is used to predict and investigate rain fade based on converted 1-minute rain rate data. Rain fade predicted at two locations are used for performance analysis in terms of link spectral efficiency and throughput. V-band downlink shows that 99.99% availability is possible in all the Sothern part stations in Libya at 0.29 bps/Hz spectral efficiency and 20.74 Mbps Throughput when 72 MHz transponder band width. Results of this paper will be a very useful resource to design highly reliable earth-to-satellite communication links in Libya.

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