Rain Fade Analysis on Earth–to-Satellite Microwave Link Operating in Comoros

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Abstract. Microwave link operates at high frequency approximately 10 GHz and above, and it suffers from high attenuation in the tropical region due to high rain intensity. Therefore, a microwave designer should consider this effect in the design so that the link can be operated with good quality of service, high availability and reliability. This study is about analysis of rain fade in a tropical country, Comoros, where the rain intensity was considered from ITU-R Recommendation. This rain intensity was used to determine the rain fade for earth-to-satellite of links operating in this country at L, C, Ka, Ku and V bands in horizontal, vertical and circular for 0.001% to 1% of exceeded per year. From the analysis, it was found that the link has availability to work from 99.999% to 99% with least effects in all frequency bands at vertical polarization, except in V-band. At 99% of availability, it shows that B-PSK is the best technique for modulation to make the proposed link more reliable. To attain 10dB fade margin which allows the antenna to reach certain quality of services, the gain receiver, diameter and figure of merit were increased while the footprint was maximized. The outcome of this study will be useful resources to upgrade the availability and reliability of earth to satellite microwave link in Comoros.

1. Introduction
Microwave link system for the earth to a satellite is designed to be operated at high frequency approximately 10 GHz and above. To operate up to 10 GHz [1][2][3], it suffers from high rain rate attenuation which may affect the signal transmission due to heavy rain in the tropical countries. This effect is the main problem of microwave link faces when operating in such countries. Comoros is one of the tropical countries and therefore the microwave link operated is entirely influenced by the high rain intensity especially during the period of heavy rainfall. Therefore, to evaluate this effect on the signal and the performance of the microwave link operating in Comoros, the in-depth analyses have been done to evaluate the range of availability and unavailability of this link at all frequency bands such as L-band (2 GHz), C-band (4 GHz), Ku-band (12 GHz), Ka-band (20 GHz) and V-band (40 GHz) in three polarizations; horizontal (PL_h), vertical (PL_v) and circular (PL_c). The prediction attenuation was derived from ITU-R Recommendation of rain attenuation and the ones obtained from

simulation has been analysed to identify the overall availability and the outage time of this proposed link operated under the rain effects at all microwave's frequency bands with their respective polarizations. Also, this study intends to analyse the performance of the microwave link budget to transmit high data rate of the signal with a minimum loss. Moreover, the modulations technique (B-PSK, Q-PSK and 8-PSK) were used to estimate the carrier to noise ratio (CNR) under two environment conditions such as in clear air and during rain with their respective bits errors rate (BER) at outage of year percentage (0.01%).The evaluations will determine the required frequency band for backup from optical link with 100Gbps capacity (5G wireless) to the proposed microwave link without failure of signal and much loss. Hence, the achievement of these evaluations is the goal of this study. The prediction attenuation model based on the ITU-R of rain attenuation has been used by other researchers in the same field of study and therefore this study proposed to use the same model.

2. Rain Fade Prediction

The downlink microwave satellite communication system is almost influenced by the high attenuation effects in all tropical regions especially when it is operating at high frequency band. For this reason, many researchers have conducted their research in this area [1-4] to predict the effect of rain attenuation. It is obtained by having the specific attenuation in dB/km times the effective slant path length of the antenna. Many methods have been proposed to analyse this model of attenuation as in [1][3][5].

However, most of the researchers have been following the ITU-R method applied in [6-8] to analyse the prediction attenuation which will be performed on their microwave link in the long run. The procedure of ITU-R (P.618-13[8]) is more accurate and contains all the necessary conditions applicable for any microwave link location in anywhere around the world, in such way, once it is applied, it will bring a good solution on any microwave link selected to be operated at any frequency band. Therefore, this method has been proposed to be used to analyse rain fade of the earth to satellite microwave link operating in Comoros.

The information on microwave link operating in Comoros has been considered to follow ITU_R model of rain attenuation (ITU-R P.618-13). The estimated attenuation to be exceeded for other percentages of an average year, in the range 0.001% to 1% was determined from the attenuation to be exceeded for 0.01% for an average year in step 10 of this model where the rain intensity exceeded for 0.01% of average year of time and was retrieved from ITU-R of rain intensity (ITU-R P.389-3/4 [9]) according to geographical location of the proposed link information.

The microwave link operating in Comoros from Intelsat satellite to earth base station located in VOLO-VOLO, Moroni with 43.247° of longitude and -11.717° of latitude. The elevation (*EL= θ*) is 62° which is provided by microwave station operator of Comoros Telecom. The height of the antenna from the ground to slant path (hs) is assumed to be 56 m from sea level. Figure 1 shows the presentation of an Earth –Space path giving the parameters to be input into the attenuation prediction process.
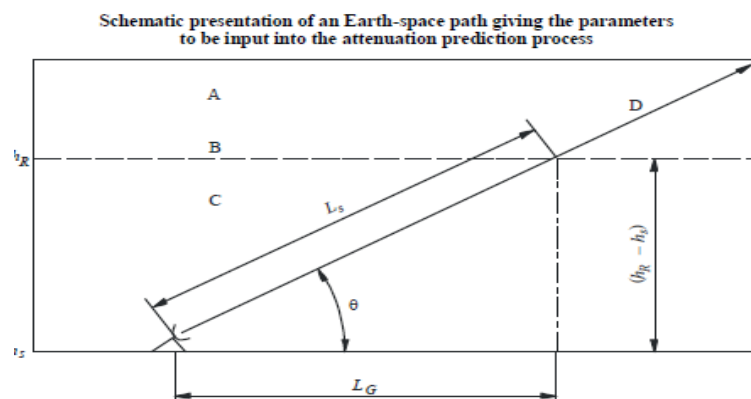

Figure 1. Rain height structure [4][9].

Where A: Frozen precipitation, B: Rain height, C: Liquid precipitation and D: Earth space path. The rain height was selected on ITU-R of rain height model for prediction methods (ITU-R839-4[9]). This model of ITU-R state that,

Step 1: the mean annual rain height above mean sea level, h_R, may be obtained from 0° isotherms as follow:

$$h_R = h0 + 0.36 \text{ km} \qquad (1)$$

Hence, according to the microwave link information of Comoros, the longitude (*Lo*) is 43.247° belongs to 0° to 360° longitudes and the latitude (*La*) is -11.717° which belongs to +90° to –90° of latitudes provided. Since the condition is satisfied, height rain (*hR*) is determined as in equation (1). Where $h0$ is height above mean sea level determined in ITU-R P.839-3 [9] as follow: the intersection point between longitude as X and latitude as Y that determines the height above the mean sea level through the geographical picture of yearly average 0° isotherm height above mean sea level (km). So, the height corresponding to the characteristics of this link is 4.5 km.

Step 2: Calculate the slant length, *Ls* below the rain height, h_R

$$\text{For } EL >= 5^0, Ls = \frac{hr - hs}{\sin(El)} \qquad (2)$$

Step 3: Calculate the horizontal projection, *LG* of the slant length
$$LG = Ls * cos(EL) \qquad (3)$$

Step 4: Obtain Rainfall Rate, $R_{0.01\%}$, exceeded for 0.01% of an average year in figure 2 (ITU-R P.837-7) [10]. The rain rate geographical area of Comoros is found in ITU-R P.837 -7.
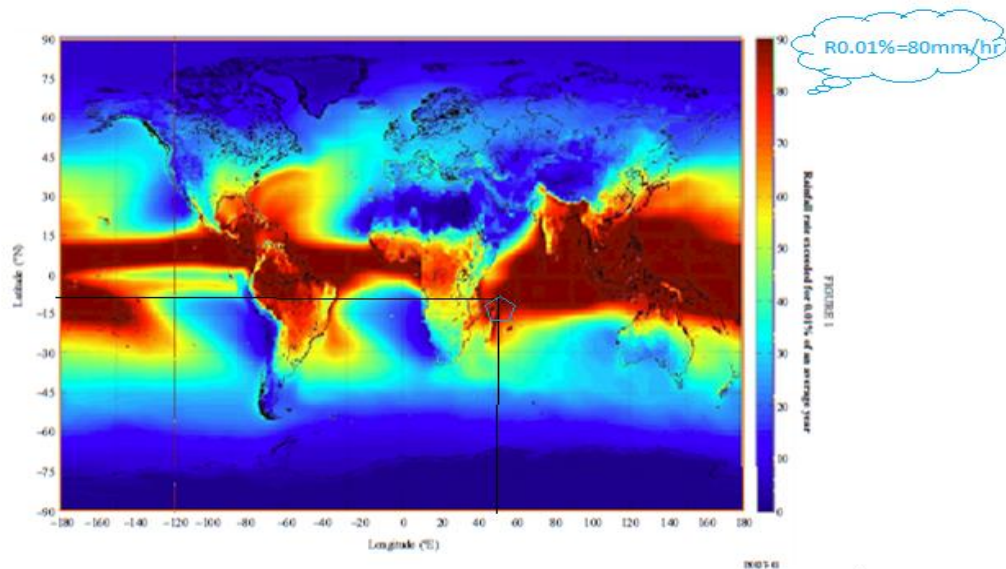

Figure 2. Rainfall Rate from ITU-R P.837 [10].

Step 5: Obtain the specific attenuation from ITU-P.838-3[11].

Specific attenuation model for rain for use in prediction methods,

$$Y_{0.01\%} = k\ (R_{0.01\%})^{\alpha} \qquad dB\ /km \tag{4}$$

To determine this attenuation in all polarizations, especially horizontal and vertical polarizations depend on the coefficient of frequency in table 1. The circular polarization was calculated using these following equations (5) and (6):

$$k_C = [k_H + k_V + (k_H - k_V)\cos^2 \Theta * \cos 2\tau]/2 \tag{5}$$

$$\alpha_C = [k_H * \alpha_H + k_V * \alpha_V + (k_H * \alpha_H - k_V * \alpha_V) \cos 2\Theta \cos 2\tau] / 2k \tag{6}$$

Where θ is elevation angle and $\tau = 45$.

Table 1. Coefficient frequency of polarization [ITUR.P.838 [11]].

Frequency bands (GHz)		Horizontal Polarization (LP-H)		Vertical Polarization (LP-V)		Circular Polarization (LP-C)	
		K_H	α_H	K_V	α_V	K_C	α_C
L-Band	2	0.0001	1.0664	0.0001	0.9490	0.00001	1.003
C-Band	4	0.0001	1.6009	0.0002	1.2476	0.00018	1.355
Ku-Band	12	0.0239	1.1825	0.0246	1.1216	0.02421	1.152
Ka- Band	20	0.0916	1.0568	0.0961	0.9847	0.09388	1.020
V- Band	40	0.4431	0.8673	0.4274	0.8421	0.43525	0.855

Step 6: Calculate the horizontal reduction factor, $r_{0.01}$ for 0.01% of the time:

$$r_{0.01\%} = \frac{1}{1 + 0.78 * \left(\frac{LG*YR}{f}\right)^{\frac{1}{2}} - 0.38(1 - e^{-2}*LG)} \tag{7}$$

Step 7: Calculate Vertical Adjustment, $V_{0.01\%}$, for 0.01%:

$\Psi = -11.7\ 17degree,$

$\|\Psi\| < 36^0 \cdot X = 36^0 - |\Psi|$

$$V_{0.01\%} = \frac{1}{1 + \sqrt{sin\theta}\ \left(31\left(1 - e^{-\left(\frac{\theta}{1+X}\right)}\right)\sqrt{LG*\gamma R}/f^\wedge 2 - 0.45\right)} \tag{8}$$

Step 8: Calculate the effective path length, *km:*

$$LE = LR * V_{0.01\%} \tag{9}$$

Step 9: Predict attenuation exceeded for 0.01% of an average year:

$$A_{0.01\%} = Y_{0.01\%} * LE \tag{10}$$

Steps 1-4: Calculation of rain height, h_R, slant length, *Ls*, horizontal projection, *LG* and rain rate $(R_{0.01}\%)$.

Table 2 presents the calculation of the parameters for Step 1 to 4. Table 3 shows the calculation for Step 5 to 9 in order to identify respectively the effect of specific attenuation in dB/km as well as the prediction attenuation (dB) based on the slant path of the antenna at 0.01%.

Table 2. The calculation of the necessary elements from Step1-4.

Step1 - Step 4	ITU-R of rain attenuation
Step 1	h_R =4.86km, Rain heigh above the sea level, $h0$ = 4.5 km
Step 2	Height of antenna , Hs = 56 m = 0.05, For $EL = 62^0 > = 5^0$, $Ls = 5.547 km$
Step 3	$LG \approx$ 2.6 km, The horizontal projection,
Step 4	$R_{0.01\%}$ = 80mm/hr,Rain , intensity of comoros based on IITU-R [11]

Table 3. The required elements from step 2 and 9.

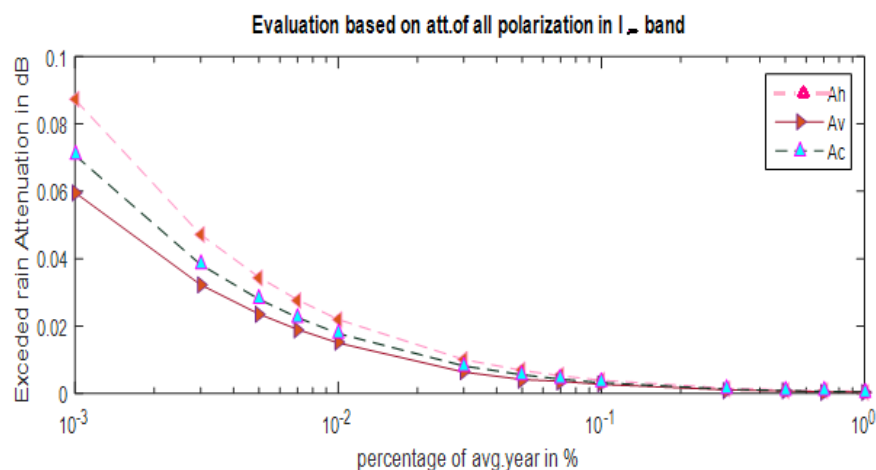| Frequency bands (*GHz*)		LP_H $\Upsilon_{0.01\%}$ (dB/km)	LP_V $\Upsilon_{0.01\%}$ (dB/km)	LP_C $\Upsilon_{0.01\%}$ (dB /km)	LP_H $A_{0.01\%}$ (dB)	LP_V $A_{0.0\%}$ (dB)	LP_C $A_{0.01\%}$ (dB)
L-Band	2	0.01	0.01	0.01	0.02	0.02	0.02
C-Band	4	0.12	0.06	0.07	0.34	0.15	0.18
Ku-Band	12	4.25	3.35	3.76	19.71	14.46	16.84
Ka- Band	20	9.40	7.19	8.19	46.15	32.55	38.56
V- Band	40	19.82	17.12	18.44	96.81	80.06	88.16

Step 10: The estimated attenuation to be exceeded for other percentages of an average year, in the range 0.001% to 1%, is determined from the attenuation to be exceeded for 0.01% for an average year using equation (9).

$$A_P = A_{0.01} \left(\frac{P}{0.01} \right)^{-(0.655 + 0.033 \ln(p) - 0.045 \ln(A0.01) - \beta(1-p) \sin\theta)} \qquad (11)$$

with if p < 1% and $| \Psi | < 36°$ and $\theta \geq 25°$: B = –0.005($|\Psi|$ – 36)

3. Rain Fade Analysis

Rain fade analysis is derived from the prediction attenuation transformed with the range of percentage of average year the attenuation will be exceeded. Therefore, the data has been processed using simulation to predict exceeded attenuation in all polarizations in each frequency band and predict the estimated attenuation. Figure 3 to 7 present the plot of rain attenuation in each frequency bands in all polarizations.

Figure 3. Prediction of rain attenuation at L-band for *LP_H, LP_V* and *LP_C* polarizations.

In the L-band as shown in figure 3, the attenuation is linearly polarized for horizontal, vertical and circular. It is clear that the attenuation based on horizontal polarization is the highest in L-band which is 0.09 dB while the vertical polarization has the lowest attenuation and circular polarization is slightly affected.
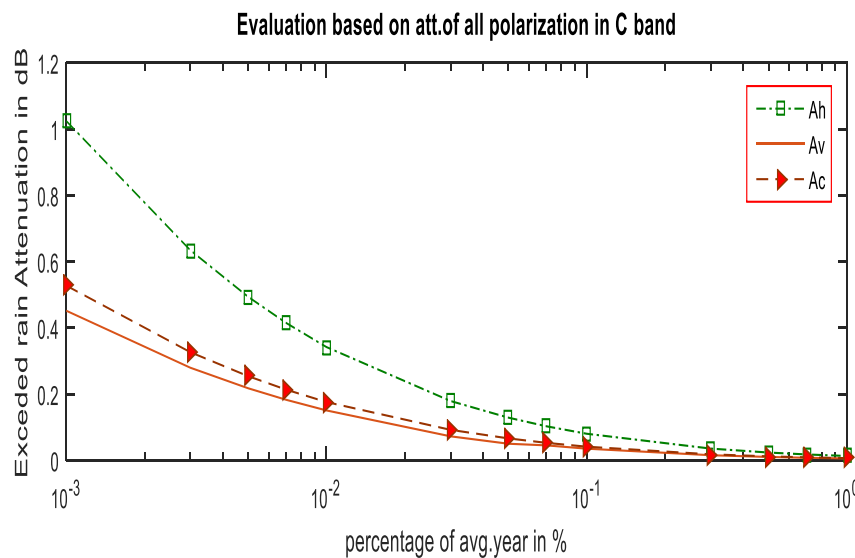

Figure 4. Prediction of rain attenuation at C-band *for LP_H, LP_V* and *LP_C* polarizations.

In C-band as shown in figure 4, the attenuation is linearly polarized and again horizontal shows the highest attenuation that attains to 1 dB, whereas the attenuation for vertical has the lowest attenuation and the circular is slightly affected. Finally, for Ku, Ka and V-bands, the attenuation in horizontal polarization remains the highest which attains 40, 82 and 160 dB, respectively and the vertical has the lowest and circular in between as shown in figure 5, 6 and 7, respectively.
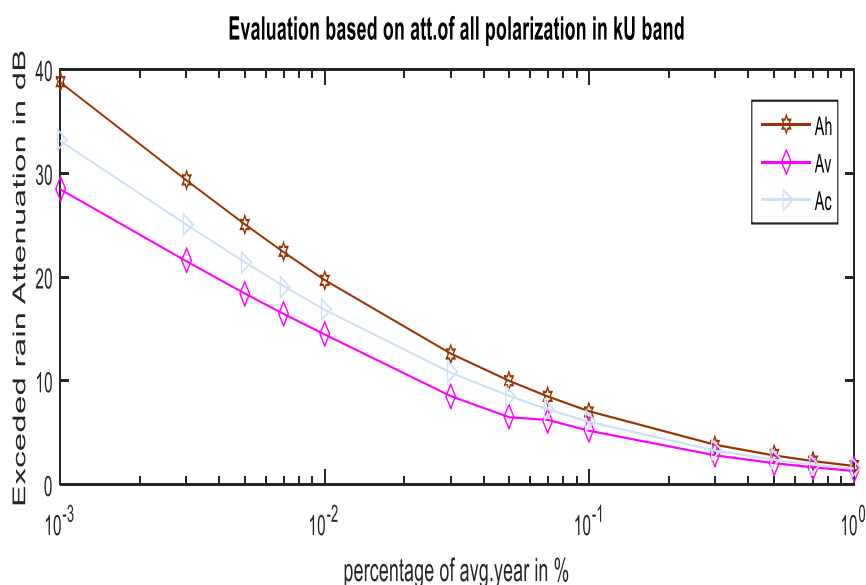

Figure 5. Prediction of rain attenuation at Ku-band for *LP_H, LP_V* and *LP_C* polarizations.
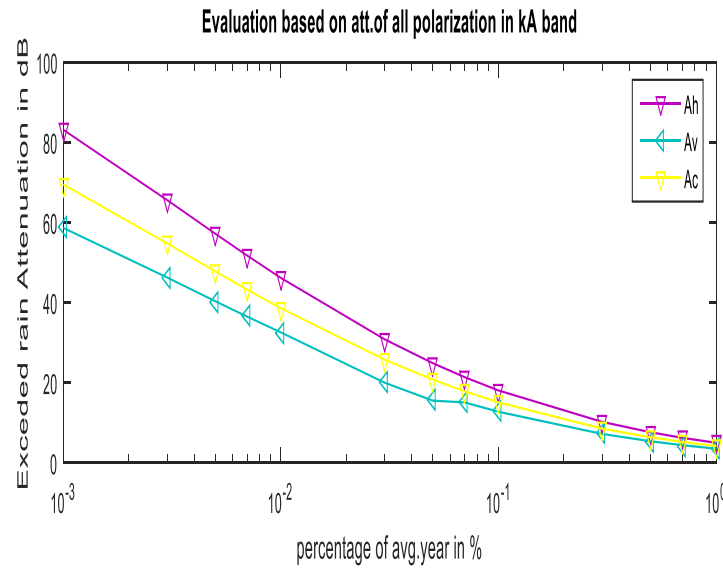
Figure 6. Prediction of rain attenuation at Ka-band for *LP_H, LP_V* and *LP_C* polarizations.
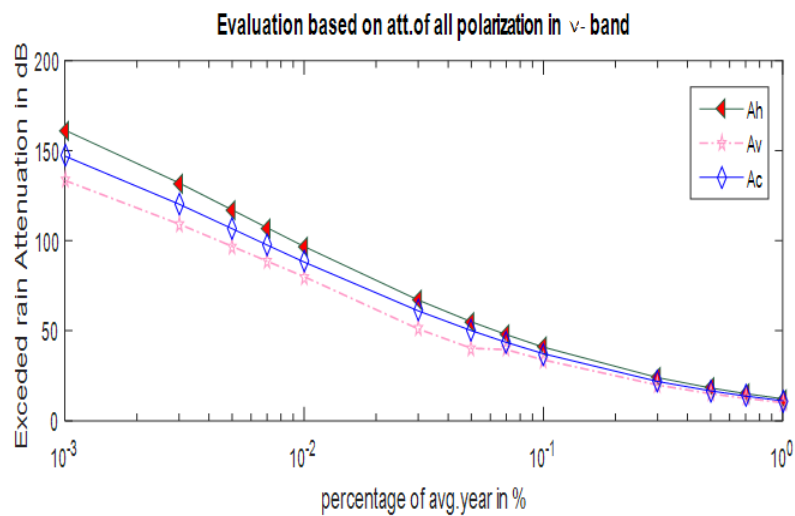

Figure 7. Prediction of rain attenuation at V-band for *LP_H, LP_V* and *LP_C* polarizations.

Table 4 tabulated the results obtained from prediction of attenuation based on horizontal and vertical polarizations in all frequency bands as in figure 8 and 9.

Table 4.Evaluation of the result of simulation in each polarization.

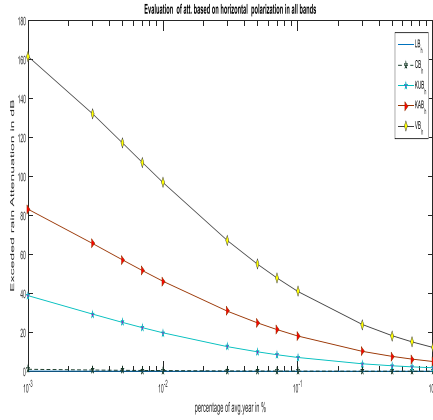| Frequency bands (Ghz)		LP_H A0.1 (dB)	LP_V A0.1 (dB)	LP_H A0.01 (dB)	LP_V A0.01 (dB)	LP_H A0.001 (dB)	LP_y A0.001 (dB)
L-Band	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
C-Band	4	<1	<1	<1	<1	1	0.5
Ku-Band	12	8	6	22	17	38	28
Ka-Band	20	25	22	46	38	82	60
V-Band	40	35	28	100	84	160	140

Figure 8. Prediction of attenuation based on horizontal polarization for L,C, Ku, Ka and V-bands.
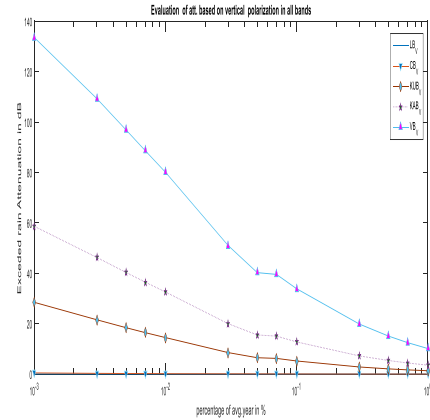

Figure 9. Prediction of rain attenuation based on vertical polarization at L, C, Ku, Ka and V- bands.

4. Link performance

The link budget is an important factor to analyse the link performance because it contains all gains and losses which can affect the transmission signal across the link [1]. These losses could be a path loss (Lp), attenuation loss due to Rain attenuation, atmospheric loss in the Clear air (ca) as well during rain. All these losses are introducing during the propagation signal from the satellite to the slant path of the receiver antenna based on earth station. Therefore, the link budget equation   is presented as follow:

$$P_{r(ca)}(dB) = EIRP + G_r - Lp - Att.loss - other\ losses \qquad (12)$$

Where Other losses=(L_m=0.5dB+L_{ant}(2)), L_{ant} is transponder output back off that is estimated to -2 dB, Att. Absorption loss [AA_b] in clear air in this proposed link is found from this following equation [5]:

$$[AA\_b] = [AA\_b]\ 90^0 * cosec\ (El) \qquad (13)$$

Where EL (Θ) is elevation angle shown in figure1.

$EIRP = P_t + G_t = 41.8dB$, maximum footprint that covers large area of Comoros Island as in figure 10 where the satellite provider services of Comoros is INTELSAT 902 at 62^0.

Path loss, Lp is:

$$Lp = 92.45 + 20 log freq.(Ghz) + 20 \log d\ \ (in\ km) \qquad (14)$$

$$G_r = 0.68 * \left(\frac{(\pi * dia)}{\lambda} \right)^2 \qquad (15)$$

d=36000 km from the satellite to slant path of the VOLO VOLO's base station in figure 11, $\lambda = c\ /\ f$, where c is the speed of light (3.10^8 m/s) and f is the frequency band, and the overall efficiency in the telecommunication system is always belonged from this following range; from 55 to 68% and dia=3.8 m is the diameter of the Comoros base station antenna. However, in this proposed link, the efficiency of 68% is assumed to be used to get a good receiver gain.

Figure 10. The maximum footprint in Comoros Island (taken from Google).
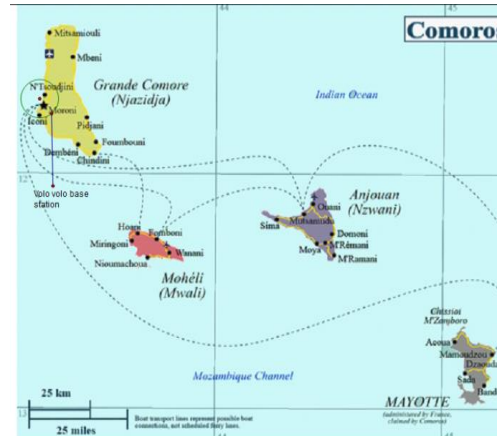

Figure 11. Comoros base station configured in Comoros map (taken from Google).

Link budget performance due to Carrier Noise Ratio (CNR) with its respective BER was derived through modulations technique such as B-PSK, Q-PSK and 8-PSK in clear air as well as during rain. In clear air, the CNR and BER are expressed respectively as follow:

$$C/N_{(in\ clear\ Air)} = P_r - N(dB) \tag{16}$$

Where, P_r is the power receiver, N is receiver noise

$$P(e) = e^{-C/N(Clear\ air)\sin^2\left(\frac{\pi}{M}\right)} \tag{17}$$

M is the number of arrays based on the types of modulation.
During rain,

$$CNR_{(during\ Rain)} = CNR_{(Clear\ air)} - \Delta T_S - L_{rain} \tag{18}$$

$$P(e) = e^{-C/N(duiring\ rain)\sin^2\left(\frac{\pi}{M}\right)} \tag{19}$$

During rain, the microwave link suffers from high rain attenuation in such way it needs an additional loss to mitigate these effects.

Table 5 and 6 show the evaluation of link performance due to CNR in clear air for all polarizations at 0.01% of time and CNR during rain for vertical polarization in *L, C, Ku, Ka,* and *V*-bands at 0.1%,0.01% and 0.001% of time, respectively.

Table 5. Carrier-to-noise ratio (CNR) in clear air for *LP_H, LP_V* and *LP_C* polarizations

Frequency bands	f (GHz)	C/N in clear air (dB)
L-Band	2	19.9
C-Band	4	19.7
Ku-Band	12	19.4
Ka- Band	20	19.2
V-Band	40	19.0

Table 6. Evaluation of the result *CNR* during rain in *dB* at vertical polarization.

Frequency bands	*f(GHz)* dB	$C/N_{0.1\%}$ dB	$C/N_{0.01\%}$ dB	$C/N_{0.001}$ dB
L-Band	2	>18	>18	>18
C-Band	4	>15	>15	>15
Ku-Band	12	10	≤ 0	≤ 0
Ka- Band	20	≤ 0	≤ 0	≤ 0
V-Band	40	≤ 0	≤ 0	≤ 0

To analyse this link in both conditions, the result shows in table 5 the C/N in clear air which is almost 20 dB at all frequency bands except in V-band (19 dB) with lower BER at horizontal. During rain, L and C-bands are not affected. Table 6 shows that Ku not extremely affected during rain at 0.1% and the C/N is 10 dB. The BER does not affect the transmission signal. Hence, the link is still operated in Ku-band with availability of 99.9% at vertical polarization during rain. However, in Ka and V-bands, the link is not working even at 0.1%, with availability of 99.9% which is the lowest availability. To operate in these frequency bands, the availability will be reduced below 99.9%. Therefore, to transmit a better signal at 99.99% of high availability, the additional fade margin is required to attain 10 dB. To transmit such signal in this fade margin, the receiver gain should be increased higher than 40 dB and the diameter of antenna should be increased to 6 m and above or the maximum footprint should be increased higher than 41.8 dB in order to get high coverage in Comoros Island and the figure of merit for Comoros base station which allows the system to transmit a good signal at this availability with better performance.

5. Conclusion

Earth-to-satellite microwave link at L, C, Ku, Ka and V-bands in Comoros are analysed in clear sky and raining conditions. In clear air, C/N which is almost 20 dB with low BER in all frequency bands at all polarizations. According to the result obtained shows that the proposed link has availability to work up to 99.999% with least effects in L and C-bands frequency at all polarizations. At Ku-band at 99.9% availability, the CNR is higher than 10 dB, but it drops to 0 dB at 0.01% and 0.001% outages and cannot achieved 99.99% availability. Both Ka and V-bands, the CNRs are 0 or lower for 0.1%, 0.01% and 0.001% of outages. Hence the links cannot be designed even at 99.9% availability at these bands with current fade margins. To attain 10 dB CNR which allow the links to reach certain quality of services, the gain of receiver, diameter and figure of merit must be increased with high availability of 99.99% while the footprint also needs to be maximized. The outcome of this study will be useful resources to design the availability and reliability of earth-to-satellite microwave links in Comoros.

References

[1] Freeman R L. Radio system design for telecommunications. John Wiley & Sons; 2006 Nov 3.
[2] Islam MR, Rahman MA, Hossain SE, Azad MS. Rain fade analysis on earth-space microwave link in a subtropical region. In 2008 International Conference on Electrical and Computer Engineering 2008 Dec 20 (pp. 793-798). IEEE.
[3] Shrestha S, Choi DY. Characterization of rain specific attenuation and frequency scaling method for satellite communication in South Korea. International Journal of Antennas and Propagation. 2017;2017.
[4] Yeo JX, Lee YH, Ong JT. Rain attenuation prediction model for satellite communications in

tropical regions. IEEE Transactions on Antennas and Propagation. 2014 Sep 16;62(11):5775-81.

[5] Rashid MM, Islam MR, Alam AZ, Khan S, Khalifa OO, Rahman MA. Rain fade and it's effect analysis for earth-to-satellite microwave link based on measured rainfall statistics in Bangladesh. In 2009 IEEE 9th Malaysia International Conference on Communications (MICC) 2009 Dec 15 (pp. 244-249). IEEE.

[6] Hossain MS, Islam MA. Estimation of rain attenuation at EHF bands for earth-to-satellite links in Bangladesh. In2017 International Conference on Electrical, Computer and Communication Engineering (ECCE) 2017 Feb 16 (pp. 589-593). IEEE.

[7] Sridhar M, Raju KP, Rao CS. Estimation of rain attenuation based on ITU-R model in Guntur (AP), India. International Journal on Communication. 2012 Nov 1;3(2):6.

[8] Series P. Propagation data and prediction methods required for the design of Earth-space telecommunication systems. Recommendation ITU-R. 2015:618-12.

[9] Thurai M, Deguchi E, Okamoto K, Salonen E. Rain height variability in the tropics. IEE Proceedings-Microwaves, Antennas and Propagation. 2005 Feb 1;152(1):17-23.

[10] Series RP. Characteristics of precipitation for propagation modelling. Recommendation ITU-R. 2012:837-6.

[11] Union IT. Specific attenuation model for rain for use in prediction methods. Recommendations ITU-R. 2005:838-3.