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

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Introduction

Microwave link system for the earth to a satellite is designed to be operated at high frequency approximately 10 GHz and above10 [1][2][3], it suffers from high rain rate attenuation which may affect the transmission signal 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

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.

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%). Hence, the achievement of these evaluations is the goal of this study

Cont.

- Microwave link used in communication system, it is the beam of radio waves based on microwave frequency band to send high data rate signal between transmitter and receiver. This quality of service introduces a lot of activities in telecom Centre such as: Providing their client with high-speed internet access without using cable
- Use telephone calls between switching Centre of microwave link to ensure proper communication between severs and users.

- Although the earth -to satellite transmission link brings a lot of benefits from their companies and users, but during rainfall, the microwave spectrum is mostly unavailable for them to exchange data especially when this link is operating at higher frequency. This is because of the following reasons::
- Signal affected causes the serious failure of signal in some of frequency bands at some polarization.

- At outage, the performance of the link is getting worst and worst in such way there is degradation of transmission signal in based station system. Since, there is another alternative of transmission signal such fiber, the transmission signal is wisely transmitted without losing data.
- However, the problem is when the fiber is faulty and it is needed to do backup from optical link with 100Gbps (5G wireless), there is a big loss in such way it affects the quality of the services; the outcomes of the service is too bad. So, there are the main problems that have been highlighted to find the solution in this particular link to make it more reliable.

Methodology

- Use Recommendation of rain attenuation ITU-R P.618-13 [8] for analysis the prediction attenuation from 0.001% to 1%
- Modulation Technique to analyse the performance of the proposed link

Height above mean sea level $h0$ [10]

Calculate

ITU-R Procedure P.618-13

Step1: The rain height h_R — $h_R = h0 + 0.36$ km in ITU-R839-4[9]

Step2: The slant length, Ls — For $EL>=5^0$, $Ls = \frac{hr-hs}{\sin(EL)}$

Step3: The horizontal projection, LG — $LG=Ls*\cos(EL)$

Step4: Obtain Rainfall Rate, $R_{0.01\%}$ — $R_{0.01\%}$=80mm/hr

Step5: The specific attenuation — $Y_{0.01\%} = k\,(R_{0.01\%})^{\alpha}$ dB /km

Step6: The horizontal reduction factor, $r_{0.01}$ — $r_{0.01\%}=\frac{1}{1+0.78*\left(\frac{LG*YR}{f}\right)^{\frac{1}{2}}-0.38(1-e^{-2}*LG)}$

Step8: Vertical Adjustment, $V_{0.01\%}$, — $V_{0.01\%}=\frac{1}{1+\sqrt{\sin\theta}\,\left(31\left(1-e^{-\left(\frac{\theta}{1+X}\right)}\right)\right)\sqrt{LG*\gamma R/f\text{^}2-0.45}}$

Step7: The effective path length, km — $LE=LR*V_{0.01\%}$

Step9: The Predict Attenuation $A_{0.01\%}$ — $A_{0.01\%}=Y_{0.01\%}*LE$

Cont.

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

step1- step 4	ITU-R of Rain attenuation
Step1	h_R =4.86km, Rain heigh above the sea level, $h0$=4.5km
Step2	Height of antenna , hs=56 m=0.05, For EL=62^0>=5^0,$Ls = 5.547km$
Step3	LG≈2.6km, The horizontal projection,
Step4	$R_{0.01\,\%}$=80mm/hr,Rain , intensity of comoros based on IITU-R[8]

Comoros Location
Longitude(X= -11.717°) & Latitude(Y=43.247°)

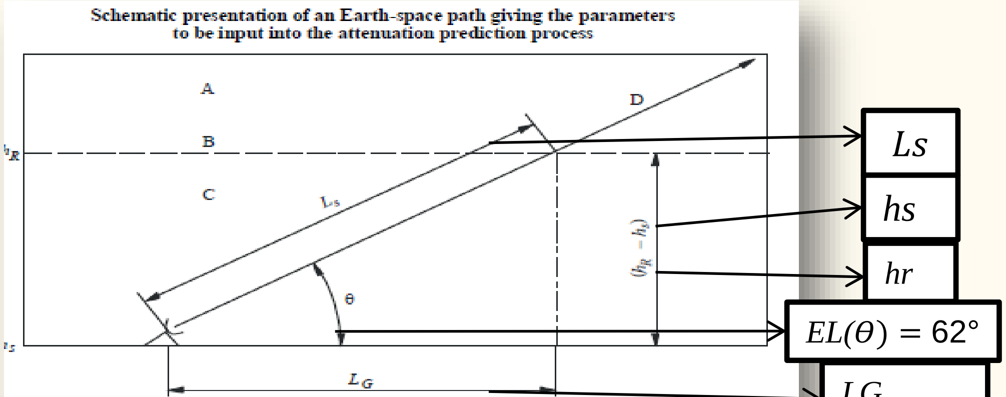
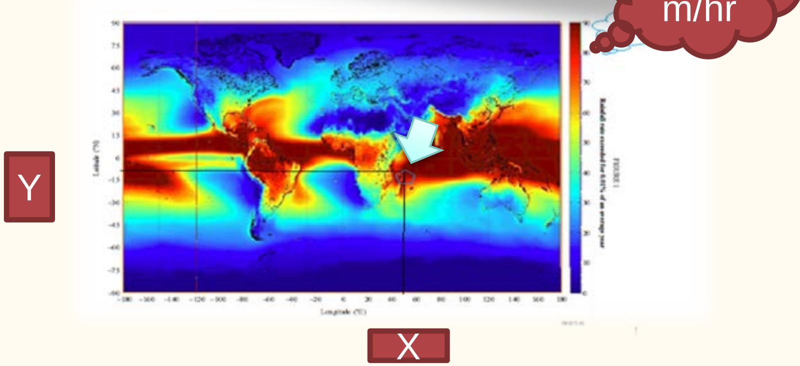


Figure shows the presentation of an Earth –Space path giving the parameters to be input into the attenuation prediction process.



- 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%.

Frequency f 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	0.009	0.006	0.007	0.02	0.015	0.018
C-Band	4	0.119	0.058	0.066	0.34	0.15	0.176
Ku-Band	12	4.246	3.346	3.762	19.71	14.46	16.841
Ka- Band	20	9.403	7.190	8.193	46.15	32.55	38.56
V- Band	40	19.817	17.116	18.439	96.81	80.06	88.156

- The data has been processed using simulation to predict exceeded attenuation in all polarization in each band frequency and predict the estimated attenuation.

Rain Fade Analysis

Step10

The prediction 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

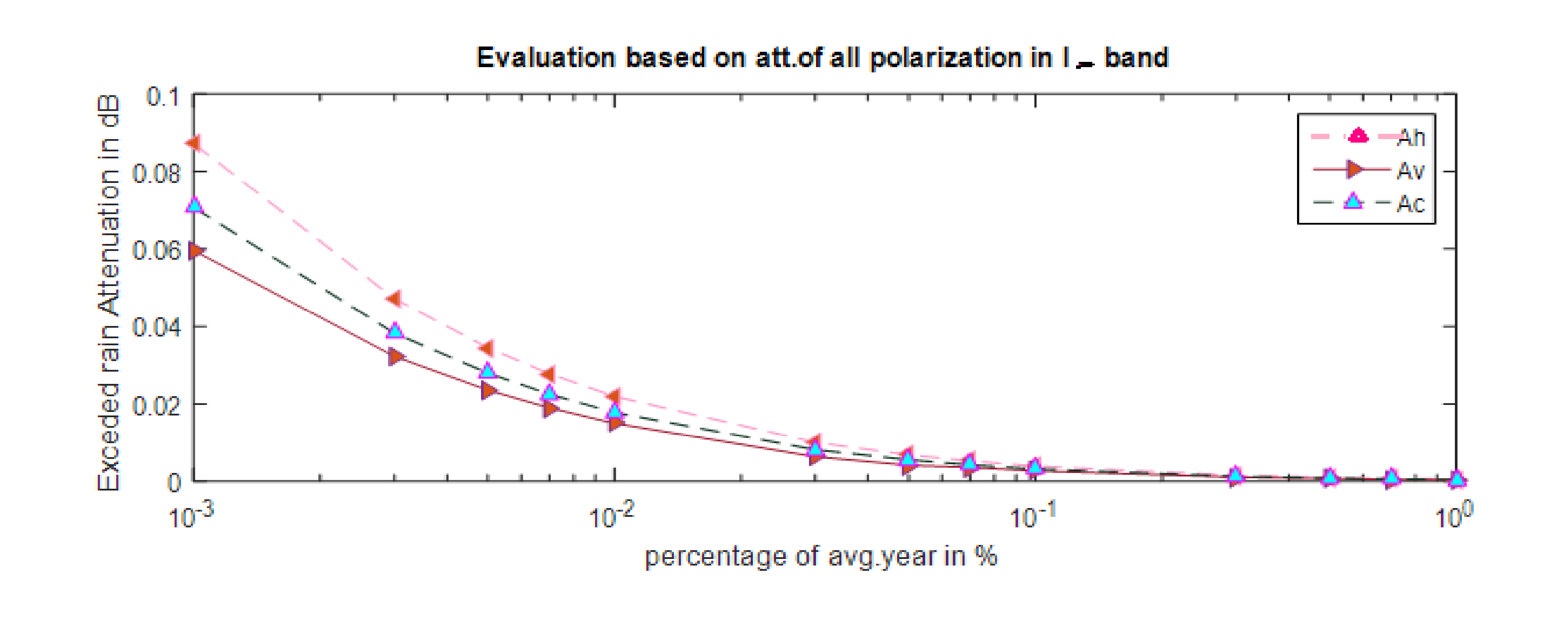
$$A_P = A_{0.01}\left(\frac{P}{0.01}\right)^{-(0.655+0.033\ln(p)-0.045\ln(A_{0.01})-\beta(1-p)\sin\theta)}$$

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

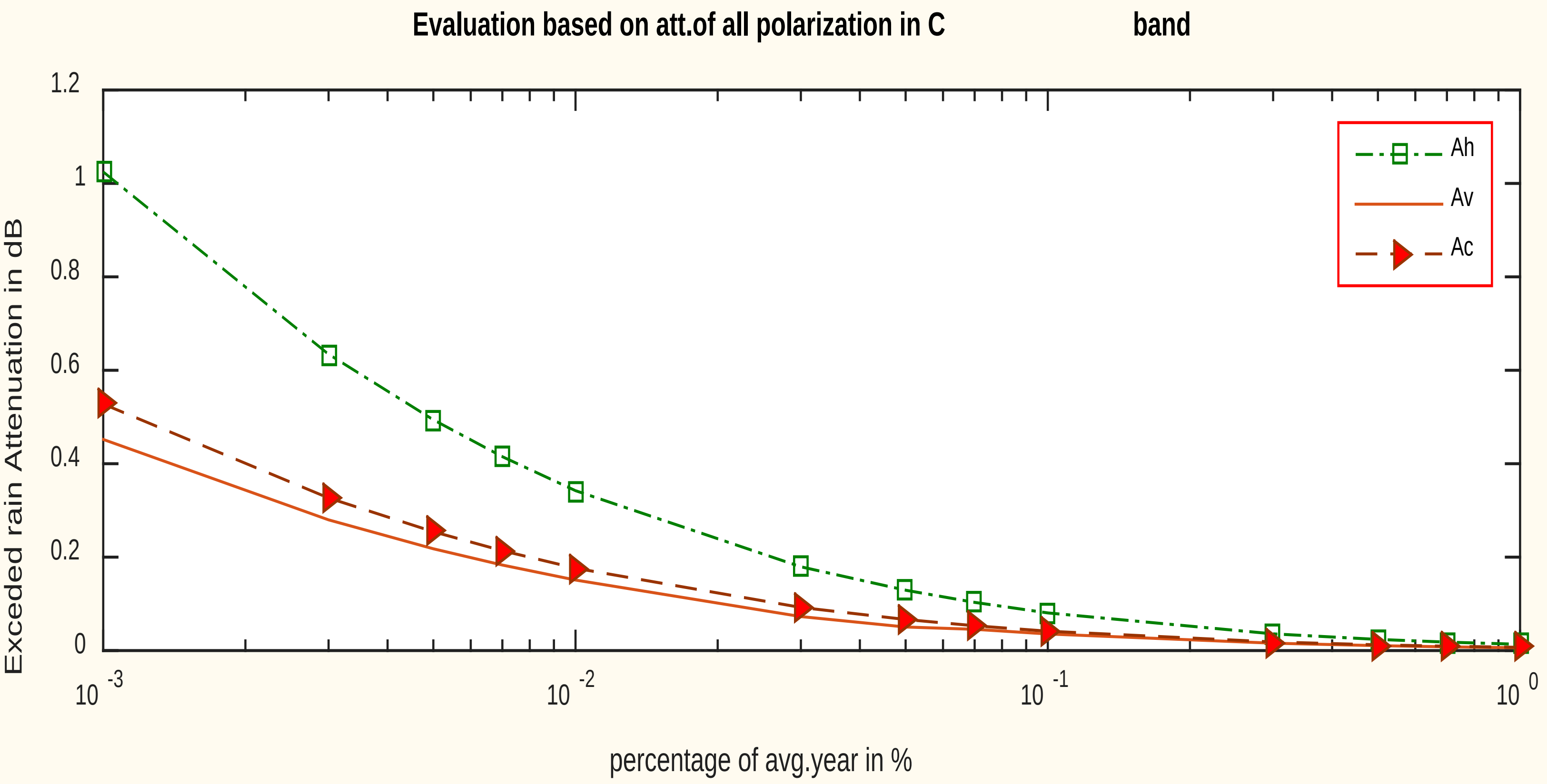
Results

Four figures present the plot of prediction of rain attenuation in each frequency bands at all polarizations.

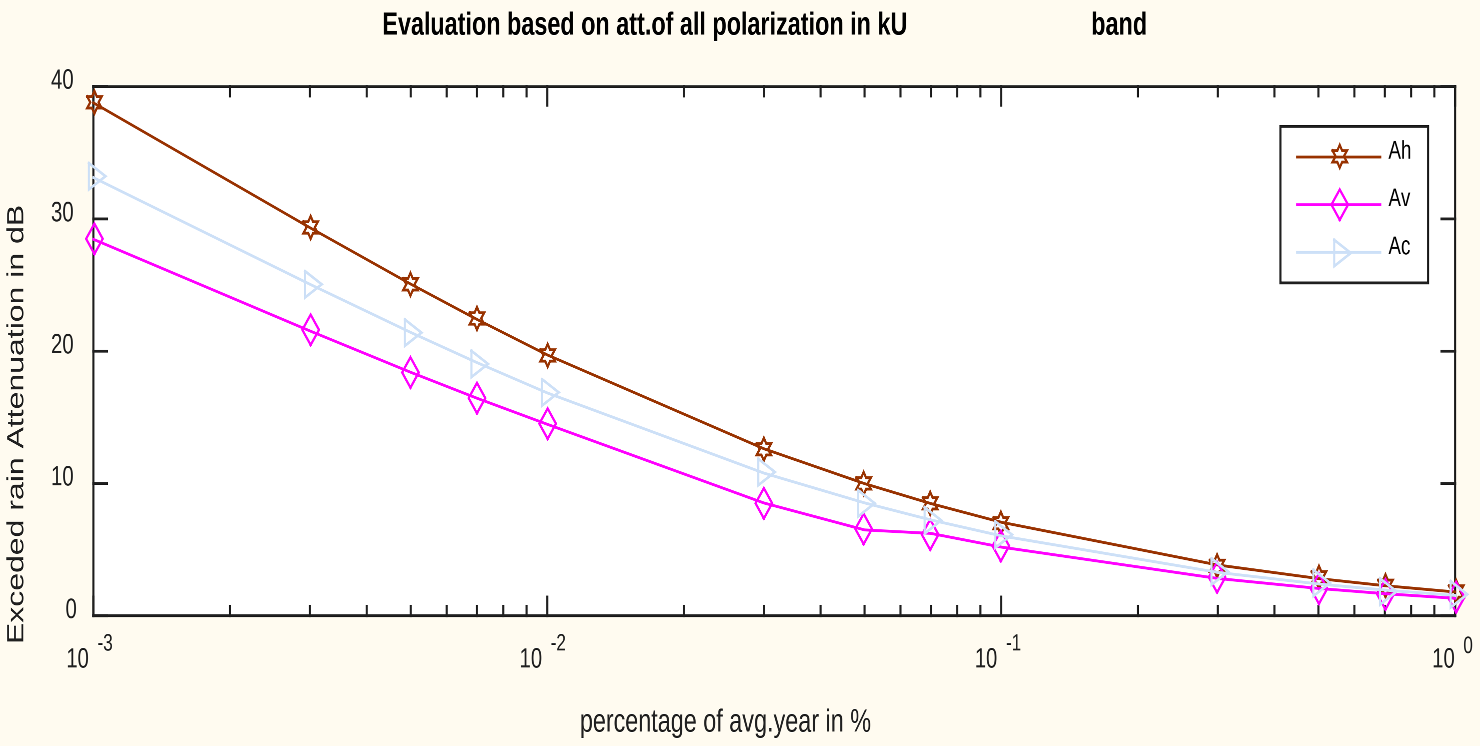
- L-band



C-band


Evaluation based on att.of all polarization in C band
1.2
1
0.8
0.6
0.4
0.2
0
Exceded rain Attenuation in dB
10 -3
10 -2
10 -1
10 0
percentage of avg.year in %
Ah
Av
Ac

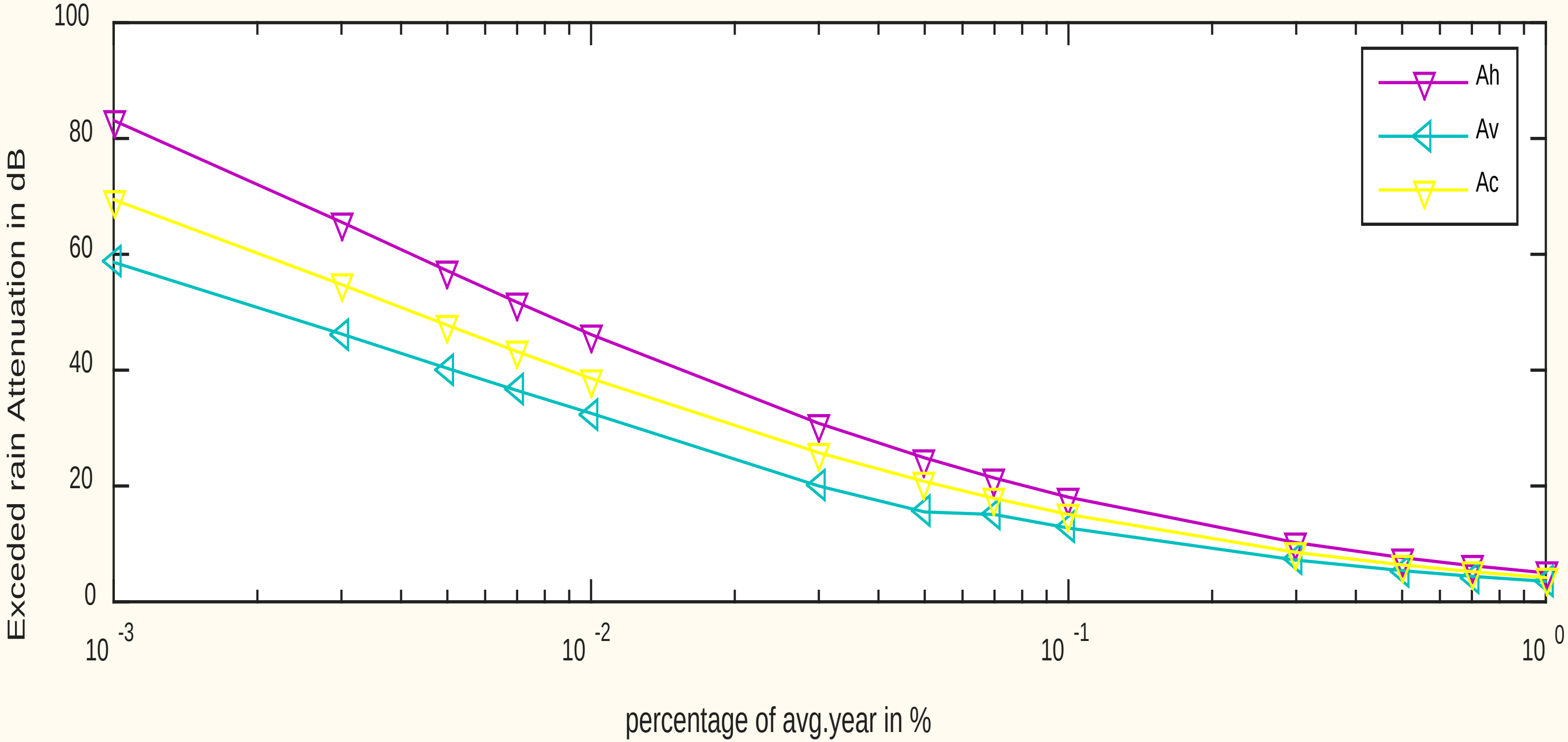
Ku-band



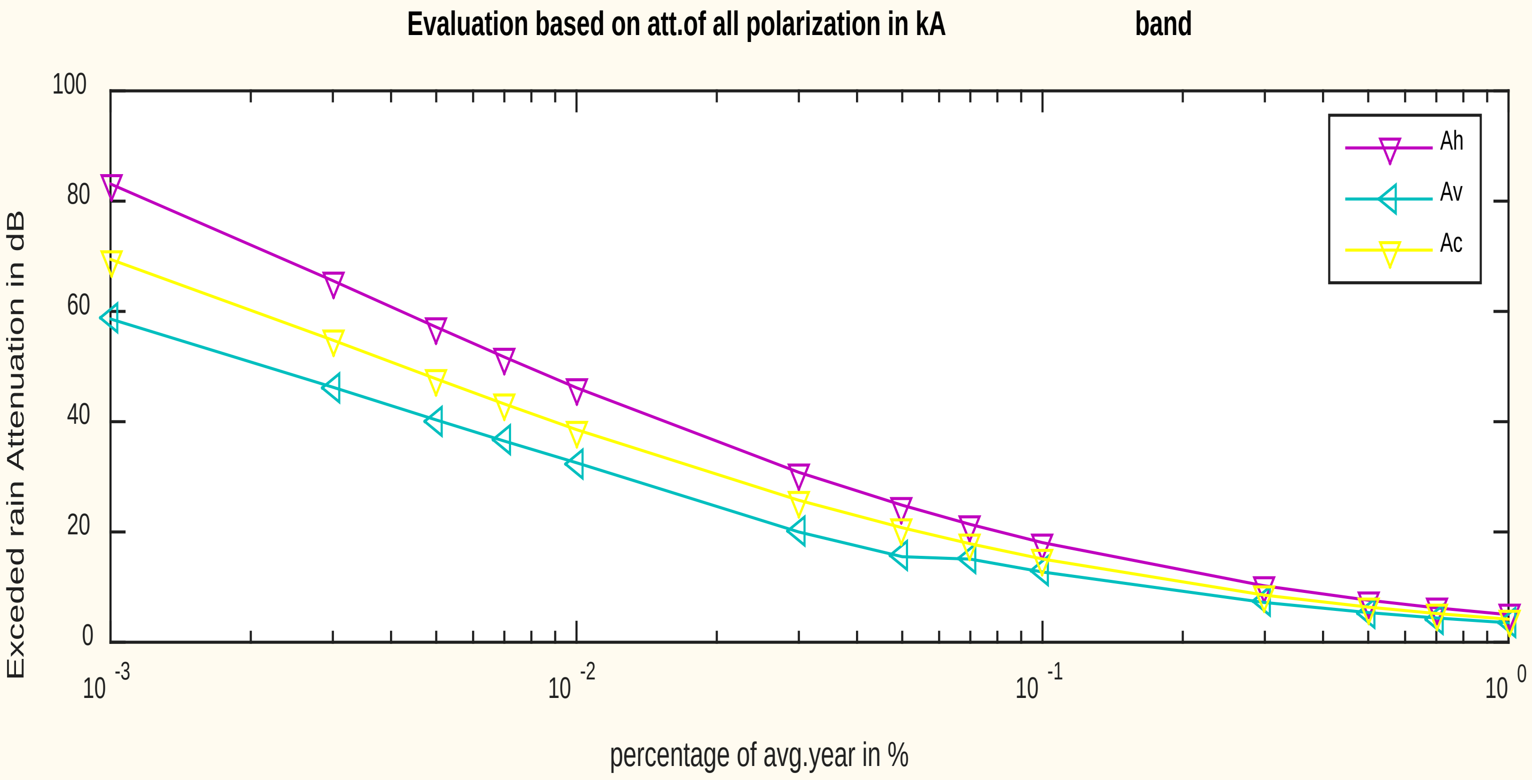
Evaluation based on att.of all polarization in kU band
40
30
20
10
0
Exceded rain Attenuation in dB
10 -3
10 -2
10 -1
10 0
percentage of avg.year in %
Ah
Av
Ac

Ka-band

Evaluation based on att.of all polarization in kA band

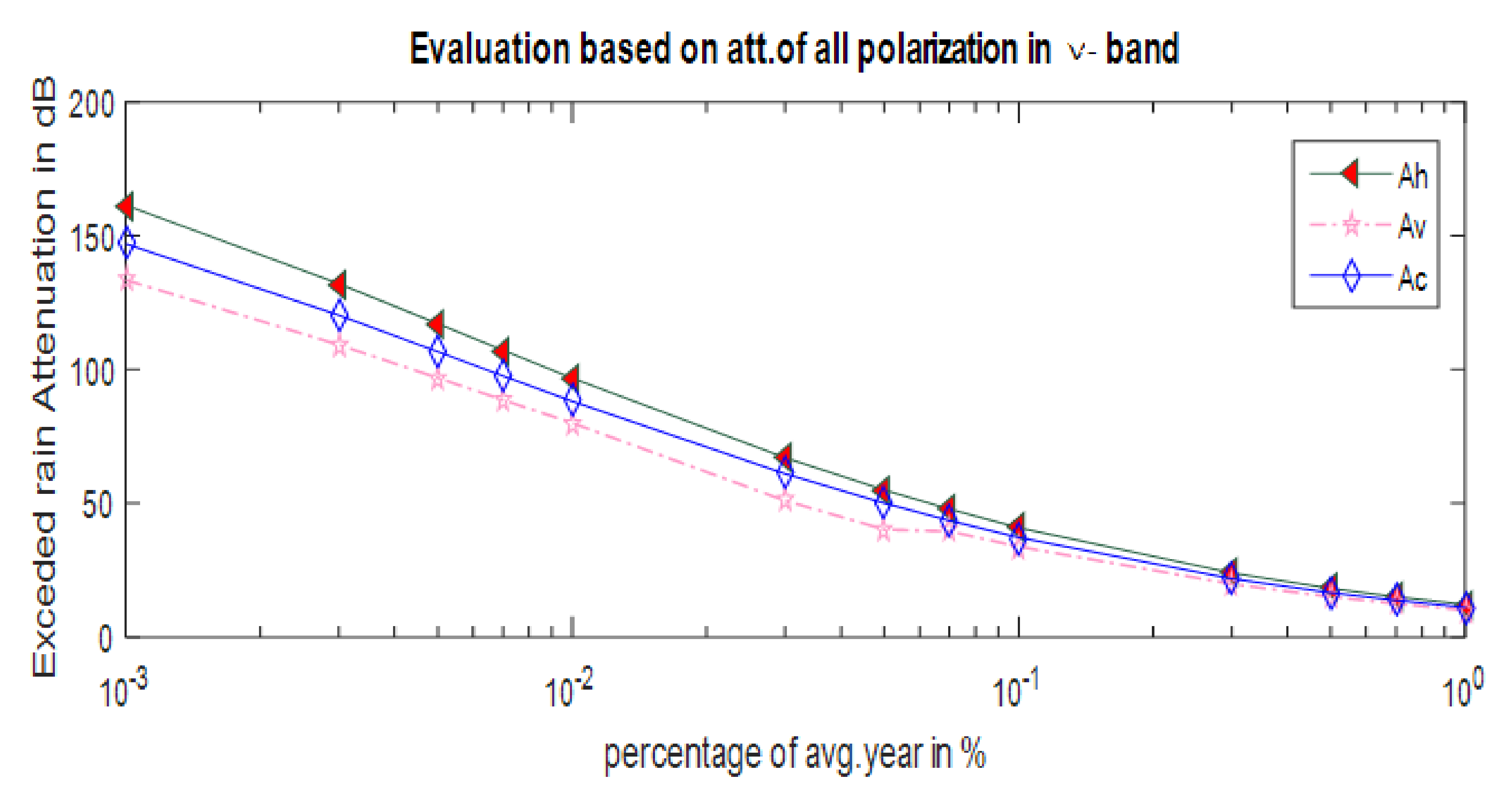


Ka-band

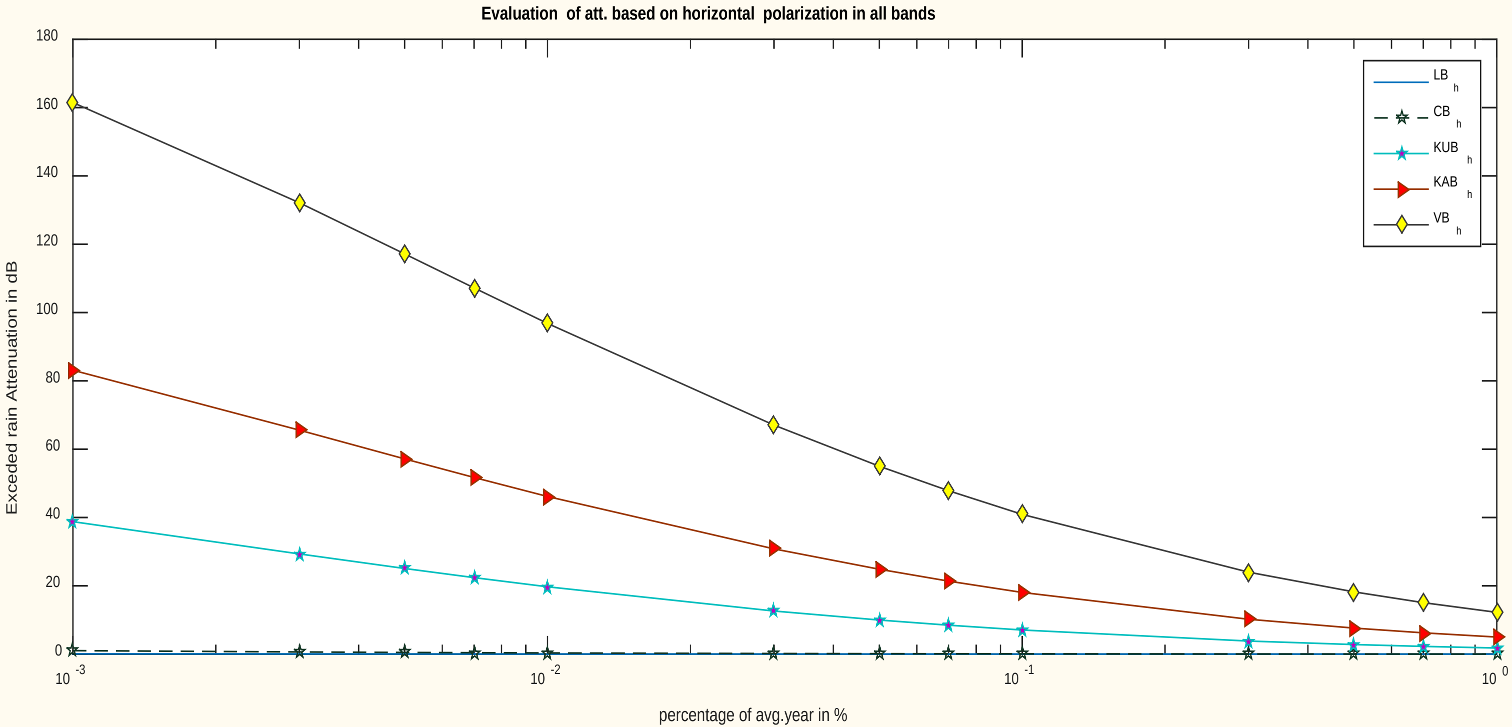


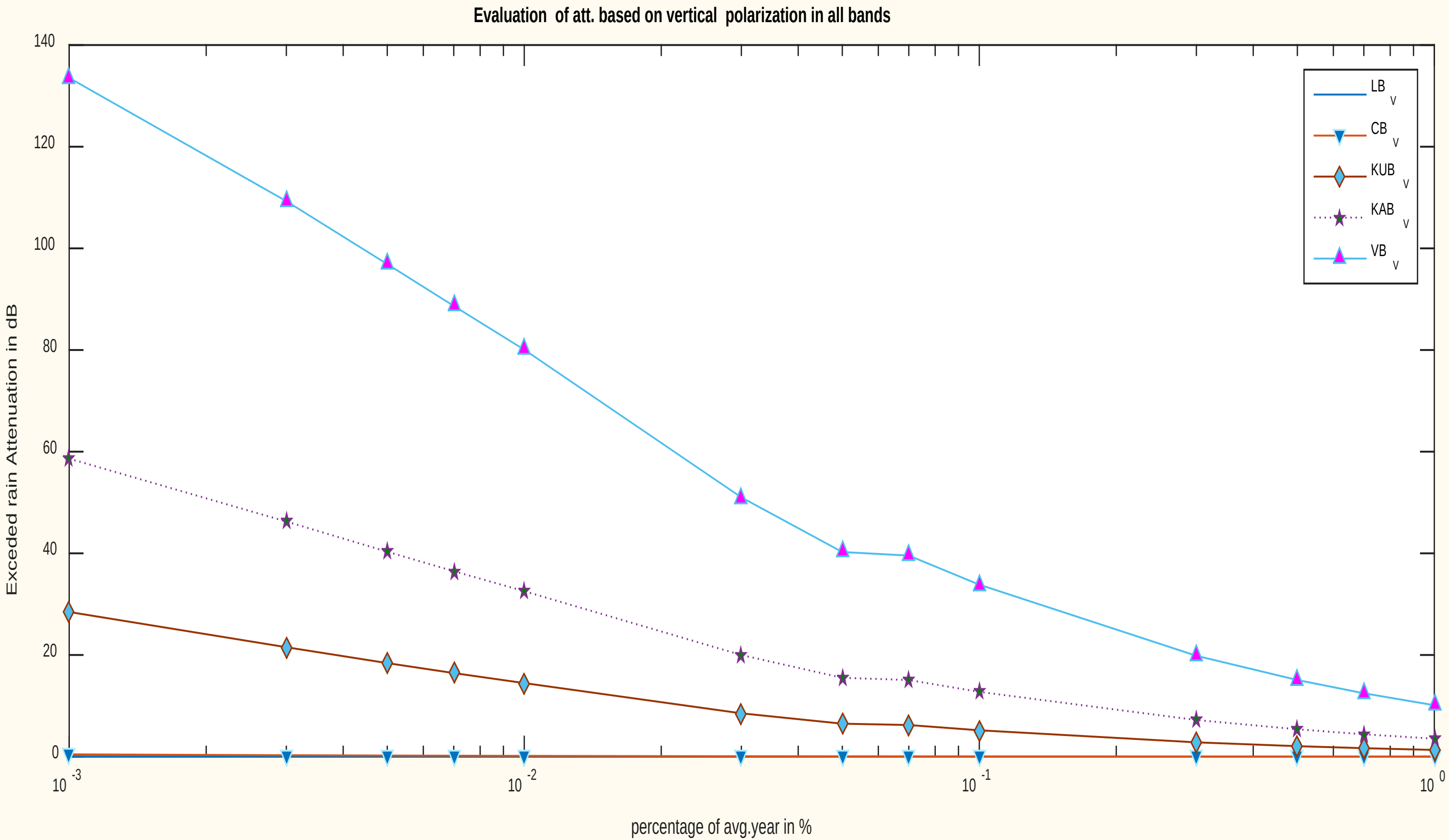
Evaluation based on att.of all polarization in kA band
Exceded rain Attenuation in dB
percentage of avg.year in %
Ah
Av
Ac
0
20
40
60
80
100
10^{-3}
10^{-2}
10^{-1}
10^{0}

V-band


Evaluation based on att.of all polarization in v- band
Exceded rain Attenuation in dB
200
150
100
50
0
10-3
10-2
10-1
100
percentage of avg.year in %
Ah
Av
Ac

Two followed Figures present the plot of prediction of rain attenuation in each polarization at all frequency bands.





Evaluation of att. based on vertical polarization in all bands
Exceded rain Attenuation in dB
percentage of avg.year in %
0
20
40
60
80
100
120
140
10 -3
10 -2
10 -1
10 0
LB V
CB V
KUB V
KAB V
VB V

Cont.

This table tabulated the results obtained from prediction of attenuation based on horizontal and vertical polarizations in all frequency bands as in figure 7&8

Table 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

The signal has least rain effect in all frequency bands at Vertical polarization from 0.1,0.01 &0.001% .L & C-band are not affected in all polarization.

Link Performance

Abs.Att
(AA_b]

The performance of the proposed link: Link budget due to clear air& during Rain at 0.1,0.01 &0.001% at horizontal polarization:

Modulations Techniques

B,Q& 8-psk to digitalize the signal affected and transmit it with low loss

$G_r = 0.68((\pi * dia)/\lambda)^2$

$P_{r(ca)}(dB) = EIRP + G_r - Lp - Abs.loss$

$Lp = 92.45 + 20log\,freq.(Ghz) + 20\log(d)$

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

$N(dB) = Ts + k + Bn$

$P(e) = e^{-C/N(clear\ air)\sin^2(\frac{\pi}{M})}$

Rain effects

$P_{r(rain)}(dB) = P_{r(ca)} - A_{0.1\%}$

$C/N_{(Rain)} = C/N_{(Ca)} - \Delta T_{Sr} - L_{rain}$

$\Delta T_{Sr} = 10\log(T_{Sr}/T_{Sca}),\ T_{Sr} = T_{Ar} + T_r$

$T_{Ar} = \eta T_{Sky(r)},\ T_{Sky(r)} = T_0(1 - 10^{-A/10})$

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

dia=3.8m, T_0=270
(r), T_0=290°(ca)

Q-psk is the best modulation technique used to transmit the signal at all polarization with lower BER

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

The result shows in this figure the C/N in clear air which is almost 19 to 20 dB at all frequency bands with lower BER.

Evaluation of the result *CNR* during rain in *dB* at Vertical polarization

Frequency bands	f(GHz)	$C/N_{0.1\%}$	$C/N_{0.01\%}$	$C/N_{0.001}$
	dB	dB	dB	dB
L-Band	2	>18	>18	>18
C-Band	4	>15	>15	>15
Ku-Band	12	10	-3	-13
Ka- Band	20	-7	-23	-45
V- Band	40	-11	-69	-124

Ku not extremely affected during rain at 0.1% and the C/N is 10 dB. The BER does not affect the transmission signal

Cont.

- Solution

Link is not working in *Ku* and *V*-band 0.1,0.01 &0.001% at Vertical polarization. CNR are 0 or lower for 0.1%, 0.01% and 0.001% of outages.

Increase the bandwidth: The availability should be increased to 99.99%.

At this availability the system transmits a good signal. To transmit a better signal at 99.99% of high availability, the additional loss is required in fade margin to attain 10dB.

- At 99.99% of Availability:

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.

Link will operate in *Ku* and *V*-band in Vertical polarization at 99.99% of Availability

This is how the link should be designed.

Conclusion

Earth-to-satellite microwave links 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 be achieved 99.99% availability. Both Ka and V-band, CNR 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 used to upgrade the availability and reliability of earth to satellite microwave link in Comoros.

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Thank you

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