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COMPARISON OF THE OPTIMAL TRANSMISSION RANGE OF FIXED POINT TERRESTRIAL KU AND KA BANDS MICROWAVE COMMUNICATION LINKS FOR DIFFERENT CITIES ACROSS NIGERIA

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***Abstract*— In this paper, comparison of the optimal transmission range of fixed point terrestrial Ku and Ka bands microwave communication links for different cities across Nigeria is presented. The mathematical expressions for the computation of the optimal transmission range were presented. The average annual rainfall data for the selected Nigerian cities were obtained and then used in Chebil's model to estimate $R_{0.01}$, which is the point rainfall rate (mm/hr) at 0.01 % exceeded time. The computation was implemented using Mathlab software. The result of the optimal transmission range of fixed point terrestrial Ka-band frequency of 40 GHz for the selected cities showed that Calabar in Cross River State had the lowest optimal transmission range (Dopt) of 753.9 m while Katsina State had the highest optimal transmission range of 1028.5 m. Based on the results for the 40 GHz links, an empirical analytical model that related the optimal transmission range, Dopt in meters to the rainfall rate, $R_{0.01}$ in mm/hr was developed. Similarly, the result of the optimal transmission range Ku-band frequency of 18GHz for the selected cities showed that Calabar in Cross River State had the lowest optimal transmission range (Dopt) of 1662.3 m while Katsina State had the highest optimal transmission range of 2445.6 m. Based on the results for the 18 GHz links, another empirical analytical model that related the optimal transmission range, Dopt in meters to the rainfall rate, $R_{0.01}$ in mm/hr was developed. In all, the results showed that the optimal transmission range of the Ka band is smaller in all the cities than their corresponding values for the Ku-band frequency. Also, the results showed that the higher the rain fall rate, the higher the rain attenuation and also rain attenuation increases with increase in frequency.**

Keywords*— *Optimal Transmission Range, Fixed Point Terrestrial, Point Rainfall Rate, Ku Band, Communication Links Ka Band , Fixed Point Terrestrial , Microwave

1. INTRODUCTION

As the adoption of wireless communication grows, there is corresponding increase in the demand for more bandwidth by the users and there is also running increases in the user population [1,2,3,4,5,6,7,8,9,10,11,12,13]. The impact of such growth in customer base and bandwidth on line-of-sight communication systems has led to the use of higher frequency bands such as the Ku band and the Ka band frequencies [14,15,16,17,18,19]. Such high frequency microwave bands afford higher bandwidth but the signals in such frequency bands are more affected by rain attenuation than the signals in the lower frequency bands [20,21,22,23,24,25,26,27,28,29,30,31].

Accordingly, in this paper, the impact of rain attenuation on the optimal transmission range of Ku band and Ka band satellite links is presented [32,33,34,35,36,37]. The paper utilized the rainfall data of selected cities across Nigerian geopolitical regions to determine how the rain attenuation will affect the optimal transmission range of the terrestrial line-of-sight communication link operating in the Ku band and in the Ka frequency bands. Notably, the optimal transmission range is the transmission range at which the effective fade margin is equal to the estimated rain fade depth that the signal will experience. The International Telecommunication Union (ITU) rain attenuation formula is employed in computing the rain fade depth while the classical link budget equation is employed to determine the effective fade margin and transmission range. The transmission range is adjusted iteratively until the optimal transmission range is obtained at which point the effective fade margin is equal to the rain fade depth. The details of the mathematical expressions and algorithm for obtaining the optimal transmission range for the selected six cities are presented along with numerical examples and discussion of results.

2. METHODOLOGY: COMPUTATION OF THE OPTIMAL PATH LENGTH USING BISECTIONITERATION METHOD

Let fade margin be fm_s, receiver sensitivity be P_S, received signal be P_R, transmitted power be P_T, transmitter antenna gain be G_T, receiver antenna gain be G_R, free space path loss be LFSP, signal frequency in GHz be f, maximum transmission range in km be d, the effective transmission range in km be d_e, maximum fade depth be fd_m and effective fade margin fm_e , then [38];

$$d = 10^{\left(\frac{(P_T + G_T + G_R - fm_S - P_S) - 32.4 - 20\log(f*1000)}{20}\right)} \quad (1)$$

Let k_h, α_h, kv and α_v be the frequency and (horizontal and vertical) polarization dependent coefficients for rain attenuation computation, R_p be the rain rate (A_R), is given as

$$A_R = \text{maximum}\left(\left(K_v(R_p)^{\alpha_v}\right) * \left(K_h(R_p)^{\alpha_h}\right) * d\right) \quad (2)$$

Let fade depth be fd_m , then for high frequency microwave in the Ku and Ka bands

$$fd_m = A_R \quad (3)$$

Let the following parameters also be defined as follows;

$$fm_e = (P_T + G_T + G_R) - (32.4 + 20\log(f * 1000) + 20\log(d_e)) - P_S \quad (4)$$

$$d_{up} = d \quad (5)$$

$$d_{Lw} = \frac{fm_e}{fd_m} \quad (6)$$

$$d_{adj}(i) = \frac{(d_{up} + d_{Lw})}{2} \quad (7)$$

$$Kfm = (P_T + G_T + G_R) - 32.4 - 20\log(f * 1000) - P_S \quad (8)$$

Let percentage error be ϵ_a, then

$$|\epsilon_a| = \left(\frac{(d_{adj}(i) - d_{adj}(i-1))}{d_{adj}(i)}\right) * 100 \quad (9)$$

Specifically, in this study, the iteration stops if $|(d_{adj}(i) - d_{adj}(i-1))| < 0.001$ otherwise the next $d_{adj}(i+1)$ is computed.

$$f(d_{up}) = \left(\text{maximum}\left(\left(K_v(R_p)^{\alpha_v}\right) * \left(K_h(R_p)^{\alpha_h}\right) * d_{up}\right)\right) + 20\log(d_{up}) - Kfm \quad (10)$$

$$f(d_{Lw}) = \left(\text{maximum}\left(\left(K_v(R_p)^{\alpha_v}\right) * \left(K_h(R_p)^{\alpha_h}\right) * d_{Lw}\right)\right) + 20\log(d_{Lw}) - Kfm \quad (11)$$

$$f(d_{adj}(i)) = \left(\text{maximum}\left(\left(K_v(R_p)^{\alpha_v}\right) * \left(K_h(R_p)^{\alpha_h}\right) * d_{adj}\right)\right) + 20\log(d_{adj}) - Kfm \quad (12)$$

a) The root lies between d_{Lw} and $d_{adj}(i)$ if, $f(d_{Lw}) * f(d_{adj}(i) < 0$, then $d_{Lw} = d_{Lw}$ and $d_{up} = d_{adj}(i)$

b) The root lies between if $f(x_\ell) f(x_m) > 0$, $f(d_{up}) * f(d_{adj}) > 0$ then $d_{Lw} = d_{adj}(i)$ and $d_{up} = d_{up}$

c) The root is $d_{adj}(i)$ if $f(d_{up}) * f(d_{adj}(i) = 0$ then stop the iteration.

Points a,b and c are expressed as follows

If $|(d_{adj}(i) - d_{adj}(i-1))| < 0.001$ or $f(d_{up}) * f(d_{adj}(i) = 0$ then stop otherwise continue the iteration with $d_{adj}(i) = \frac{(d_{up} + d_{Lw})}{2}$ where d_{up} and d_{Lw} are computed based on the expressions in a and b. Notably, the optimal path length (d_{opt}), is the value of $d_{adj}(i)$ at which $f(d_{up}) * f(d_{adj}(i) = 0$.

Then, fm_{opt} which is the fade margin at the optimal point is given as ;

$$fm_{opt} = \text{maximum}\left(\left(K_v(R_p)^{\alpha_v}\right) * \left(K_h(R_p)^{\alpha_h}\right) * d_{opt}\right) \quad (13)$$

Then, $FSPL_{opt}$ which is the free space path loss at the optimal point is given as;

$$FSPL_{op} = 32.4 + 20\log(f*1000) + 20\log(d_{opt}) \quad (14)$$

The rainfall data for some selected twenty Nigerian cities are obtained from [38] as shown in Table 1. The average annual rainfall data (M) was used to estimate $R_{0.01}$, which is the point rainfall rate (mm/hr) at 0.01 % exceeded time using the Chebil's model as follows;

$$R_{0.01} = 12.2903(M)^{0.2973} \quad (15)$$

Table 1 **R**ainfall data of the selected twenty Nigerian cities

S/N	City Name	Longitude	Latitude	Annual Mean Accumulated Rain (mm)
1	Kaduna	7.45	10.60	1266.4
2	Bauchi	9.82	10.28	1051.4
3	Sokoto	5.25	13.02	676.1
4	Maiduguri	13.08	11.85	611.6
5	Katsina	7.68	13.02	533.9
6	Yola	12.47	9.23	992.3
9	Ikeja	3.33	6.58	1465.6
10	Ibadan	3.90	7.43	1397.1
11	Ondo	4.83	7.10	1660.1
12	Port Harcourt	7.02	4.85	2397.2
13	Owerri	7.00	5.48	2383.9
14	Calabar	8.35	4.97	2891.8
15	Markurdi	8.53	7.73	1276.2
16	Oshogbo	4.58	7.78	1321.1
17	Ikorin	4.58	8.48	1249.0
18	Lokoja	6.73	7.78	1310.6

(Source: [38])

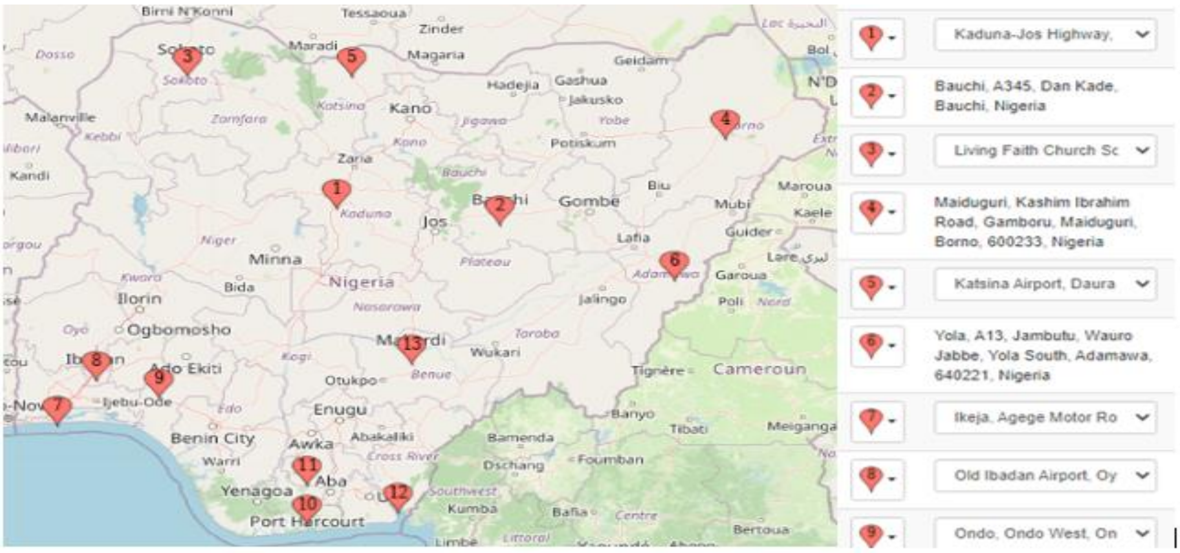

Figure 1 The map plot of the selected twenty Nigerian cities

3. RESULTS AND DISCUSSION

The result of the $R_{0.01}$ computed using the Chebil's model is presented in Table 2. The result showed that Calabar in Cross River State has the highest rainfall rate (mm/hr) at 0.01 % exceeded time ($R_{0.01}$) value of 131.39 mm/hr while Katsina State has the lowest $R_{0.01}$ value of 79.51 mm/hr.

The result of the optimal transmission range of the Ka-band frequency of 40 GHz for the selected cities is shown in Table 3. The results showed that Calabar in Cross River State has the lowest optimal transmission range (Dopt) of 753.9 m while Katsina State has the highest optimal transmission range of 1028.5 m. Based on the results for the Ka-band frequency of 40 GHz presented in Table 3, an empirical analytical model that relates the optimal transmission range, Dopt in meters to the rainfall rate, $R_{0.01}$ in mm/hr is given as;

$$Dopt = 15408(R0.01)^{-0.618} \quad (16)$$

The result of the optimal transmission range of fixed point terrestrial Ku-band frequency of 18GHz for the selected cities is shown in Table 4. The results showed that Calabar in Cross River State has the lowest optimal transmission range (Dopt) of 1662.3 m while Katsina State has the highest optimal transmission range of 2445.6 m. Based on the results for the Ka-band frequency of 18 GHz presented in Table 4, an empirical analytical model that relates the optimal transmission range, Dopt in meters to the rainfall rate, $R_{0.01}$ in mm/hr is given as;

$$Dopt = 70722\,(\mathbf{R0.01})^{-0.769} \quad (17)$$

In all, the results in Figure 2, Figure 3 and Figure 4 showed that the optimal transmission range of the Ka band is smaller in all the cities than their corresponding values for the Ku-band frequency. Also, the results showed that the higher the rain fall rate, the higher the rain attenuation and also rain attenuation increases with increase in frequency.

Table 2 **R**ainfall data of the selected twenty Nigerian cities

S/N	**City Name**	**R0.01** (mm/hr)
1	Katsina	79.51
2	Maiduguri	82.79
3	Sokoto	85.30
4	Yola	95.60
5	Bauchi	97.26
6	Ikorin	102.37
7	Kaduna	102.79
8	Markurdi	103.03
9	Lokoja	103.85
10	Oshogbo	104.09
11	Ibadan	105.84
12	Ikeja	107.35
13	Ondo	111.41
14	Owerri	124.06
15	Port Harcourt	124.26
16	Calabar	131.39

Table 3 The result of the optimal transmission range of the Ka-band frequency of 40 GHz for the selected cities.

S/N	**City Name**	**R0.01** (mm/hr)	**Dopt (m)**
1	Katsina	79.51	**1028.5**
2	Maiduguri	82.79	**1003.5**
3	Sokoto	85.3	**985.4**
4	Yola	95.6	**918.9**
5	Bauchi	97.26	**909.2**
6	Ikorin	102.37	**880.9**
7	Kaduna	102.79	**878.7**
8	Markurdi	103.03	**877.4**
9	Lokoja	103.85	**873.1**
10	Oshogbo	104.09	**871.9**
11	Ibadan	105.84	**862.9**
12	Ikeja	107.35	**855.4**
13	Ondo	111.41	**835.8**
14	Owerri	124.06	**781.5**
15	Port Harcourt	124.26	**780.7**
16	Calabar	131.39	**753.9**

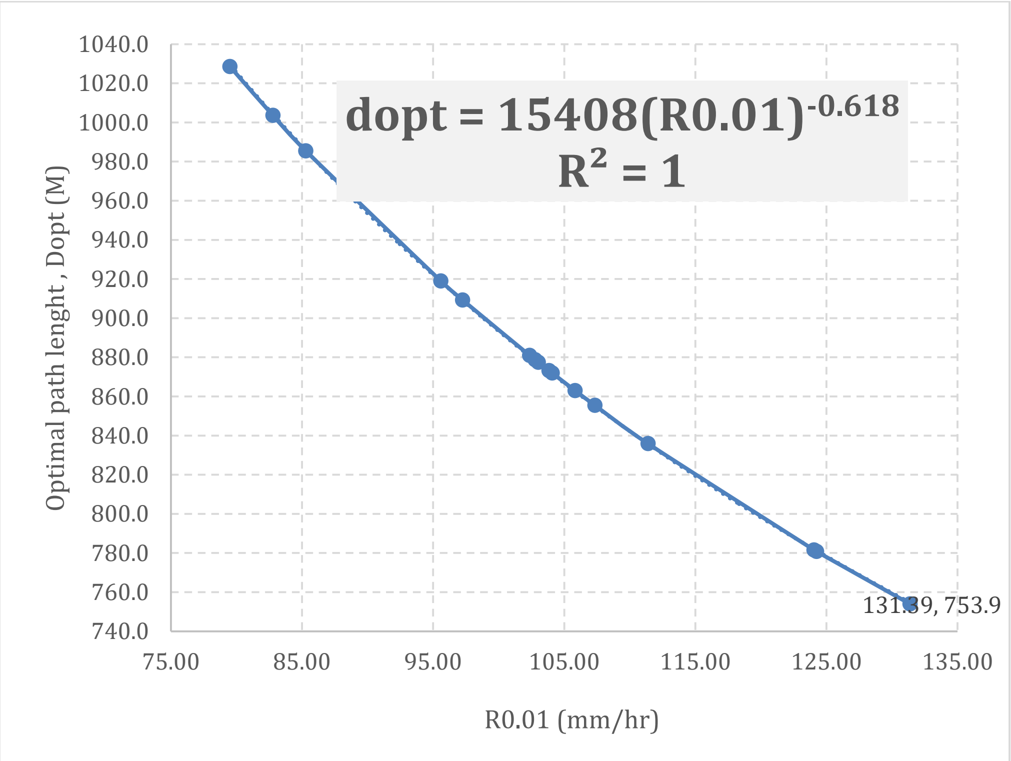

Figure 2 The result of the optimal transmission range of the Ka-band frequency of 40 GHz for the selected cities based on their rainfall rates

Table 4 The result of the optimal transmission range of the Ku-band frequency of 18 GHz for the selected cities.

S/N	City Name	R0.01	Dopt (M)
1	Katsina	79.51	**2445.6**
2	Maiduguri	82.79	**2372.4**
3	Sokoto	85.3	**2319.5**
4	Yola	95.6	**2127.0**
5	Bauchi	97.26	**2099.2**
6	Ikorin	102.37	**2018.3**
7	Kaduna	102.79	**2011.9**
8	Markurdi	103.03	**2008.3**
9	Lokoja	103.85	**1996.1**
10	Oshogbo	104.09	**1992.6**
11	Ibadan	105.84	**1967.1**
12	Ikeja	107.35	**1945.7**
13	Ondo	111.41	**1890.7**
14	Owerri	124.06	**1738.8**
15	Port Harcourt	124.26	**1736.6**
16	Calabar	131.39	**1662.3**

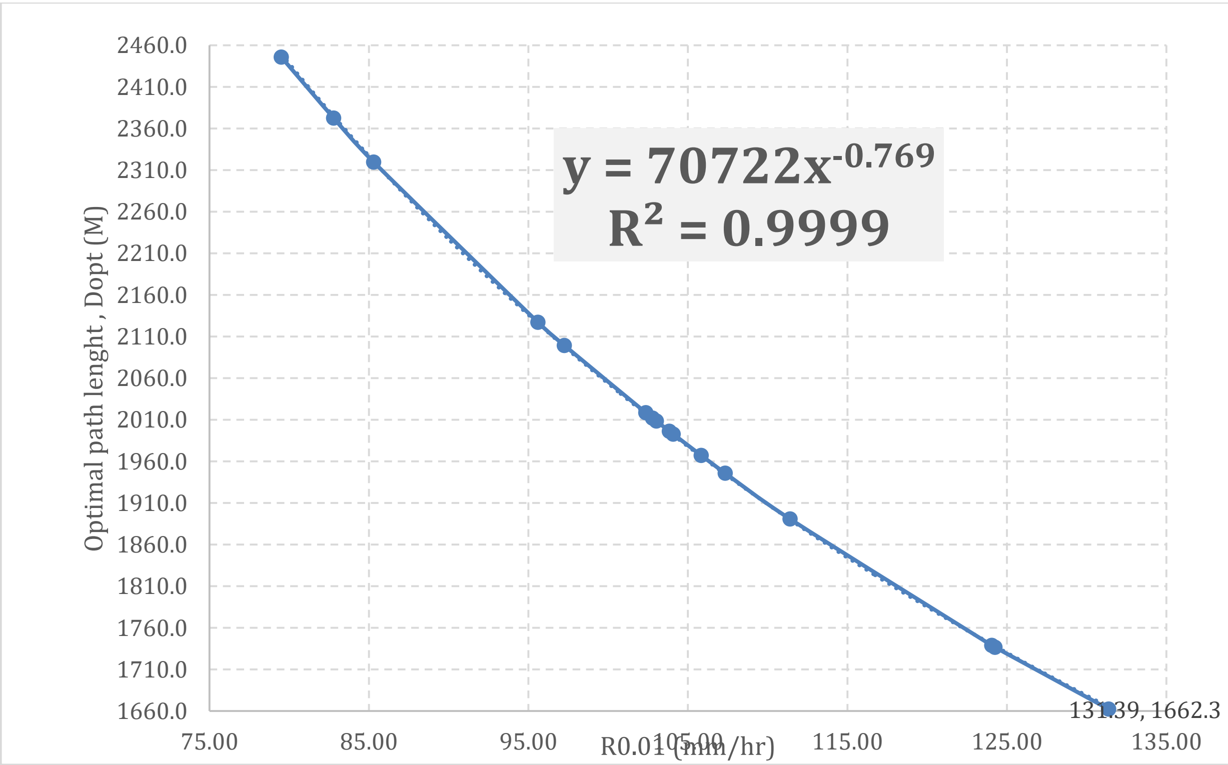

Figure 3 The result of the optimal transmission range of the Ku-band frequency of 18 GHz for the selected cities based on their rainfall rates

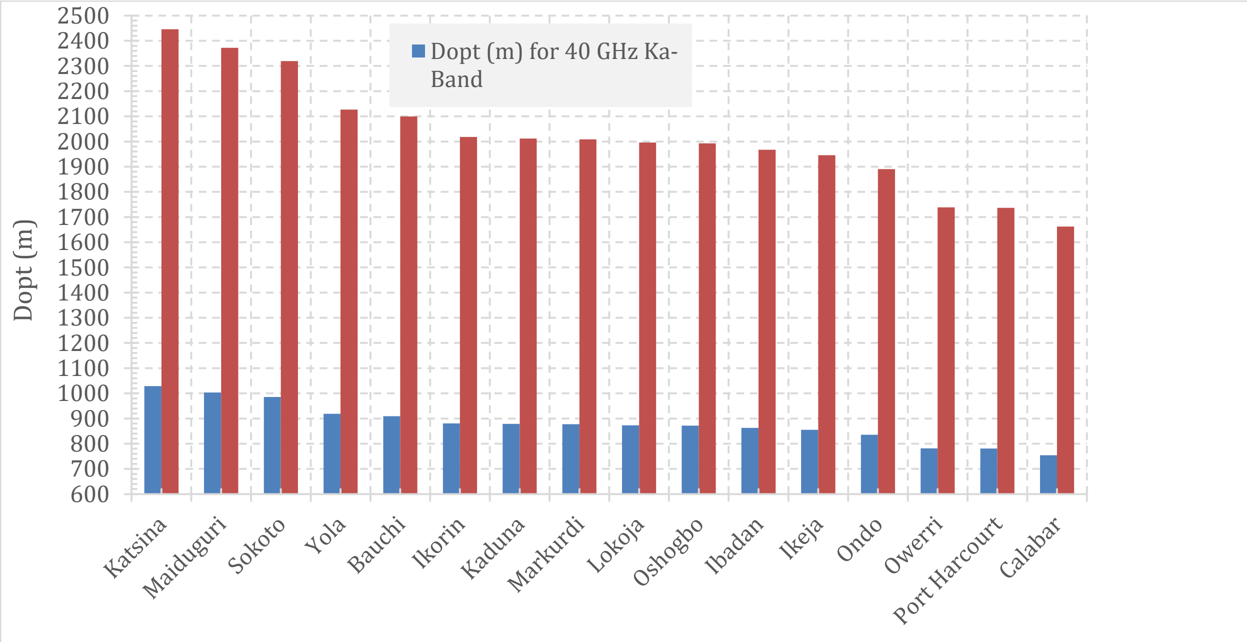

Figure 4 The bar chart showing the optimal transmission range of the Ku-band and Ka-band frequencies for the selected cities

4. CONCLUSION

The optimal transmission range for line-of-sight terrestrial microwave link in the Ka and Ku frequency bands are presented for selected cities in Nigeria with different rainfall rate. The computation of the optimal transmission range is meant to demonstrate how rain can affect the transmission range of microwave links operating in different frequencies. The results showed that the optimal transmission range is significantly affected by the rainfall rate. Also, the higher frequency Ka band had higher rain attenuation and consequently smaller transmission range when compared with the Ku band frequency.

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