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COMPARATIVE ANALYSIS OF OPTIMAL TRANSMISSION RANGE OF Ka-BAND COMMUNICATION LINK BASED ON DIFFERENT DEGREES OF URBANIZATION IN CCIR PATH LOSS MODEL

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Abstract— In this paper, comparative analysis of an optimal transmission range of Ka-band communication link based on different degrees of urbanization as defined in the Comit´e International des Radio-Communication, (CCIR) path loss model is presented. Secant iteration method was used to compute the optimal transmission range based on analytical expressions derived from the link the budget equation and the CCIR pathloss model. The computations were conducted in Mtalab for two different rain rates in the International Telecommunication Union (ITU) rain zone N. The first was at $R_{0.01} = 95\,mm/hr$ which is rain rate (mm/h) exceeded for 0.01% of the average year and the second was at $R_{0.03} = 65\,mm/hr$ which is rain rate (mm/h) exceeded for 0.03% of the average year. The results showed that, for the case where rain rate, $R_{0.01}$ = 95 mm/hr at 0.01 % exceedence with percentage of covered are (PB%) in the range 4% PB ≤ 50%, the optimal transmission range is 1.838817 km at PB(%) =4 % which is for rural area; the optimal transmission range is 1.402416 km at PB(%)= 12 % which is for suburban area and the optimal transmission range is 1.214386 km at PB(%)= 20 % which is for urban area. Also, The results showed that, for the case where rain rate, $R_{0.03}$ = 65 mm/hr at 0.03 % exceedence with PB% in the range 4% PB ≤ 50%, the optimal transmission range is 2.346376 km at PB(%) = 4 % which is for rural area; the optimal transmission range is 1.748445 km at PB(%)= 12 % which is for suburban area and the optimal transmission range is 1.494411 km at PB(%)= 20 % which is for urban area. The models were derived by relating the optimal transmission range to PB% and to the degree of urbanization. In all, the results showed that the higher rain rate gave rise to higher rain fade depth which ultimately reduces the transmission range of the network. Also, higher degrees of urbanization gave rise to higher pathloss which reduces the transmission range of the network.

Keywords— ***Transmission Range, Degree of Urbanization, Path Loss Model, Optimal Transmission Range, CCIR Path Loss Model, Secant Iteration Method***

1. Introduction

As the adoption of wireless network technologies increases, there is increasing demand on researchers to develop more efficient solutions that are cost effective. As such, in recent times, for internet access, the Ka-band has become increasingly adopted as a more efficient option to the Ku-band. In view of this, several researches are being conducted to evaluate the performance of the Ka-band under different condition and climates. In practice, there are numerous things that can affect the quality of received signal strength and the quality of service in the wireless network communication system. Among them are pathloss [1-8], diffraction loss due to obstructions [9-11], multipath fading [12,13] which can be affected by the refractivity gradient of the atmosphere [14-18] and terrain roughness index [19,20]. In this paper, the focus is on the evaluation of the optimal transmission range of the Ka-band microwave network for different degrees of urbanization as defined in the CCIR path loss model [1,21-23].

Also, the study in this paper examined the transmission range of the Ka-band under two different rain rates within the same ITU rain zone. Specifically, the study was conducted at rain rate of $R_{0.01}$ which is rain rate (mm/h) exceeded for 0.01% of the average year and the study was repeated at $R_{0.03}$ which is rain rate (mm/h) exceeded for 0.03% of the average year. The study was meant to evaluate the combined effect of rain rate and degree of urbanization on the optimal transmission range of the Ka-band network. Relevant mathematical equations and data were presented for the study. Eventually, analytical models relating the optimal transmission range to the degree of urbanization were derived for the two different rain rate scenarios.

2. Methodology

The optimal transmission range of Ka-band microwave link is computed using the Comit´e International des Radio-Communication, (CCIR) pathloss model and Secant iteration method. The computations are conducted for two different rain rates in the International Telecommunication Union (ITU) rain zone N. The first is at $R_{0.01} = 95\,mm/hr$ which is rain rate (mm/h) exceeded for 0.01% of the average year and the second is at t $R_{0.03} = 65\,mm/hr$ which is rain rate (mm/h) exceeded for 0.03% of the average year.

The CCIR model computes pathloss as follows [1,21-23];

$$LPccir = A + B\log_{10}(d) - E \quad (1)$$

where

$$A = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_b) - a(h_m) \quad (2)$$

$$a(h_m) = [1.1\log_{10}(f) - 0.7]h_m - [1.56\log_{10}(f) - 0.8] \quad (3)$$

$$B = 44.9 - 6.55\log_{10}(h_b) \quad (4)$$

Where f is frequency in MHz; d is distance in km; 150 MHz≤ f≤ 1000 MHz; 30m ≤h_b ≤ 200m; 1m≤ h_m≤ 10 m and 1 km ≤ d ≤ 20 km. Also, E is the degree of urbanization and PB is the percentage of covered area (the area can be covered with building or other items). Hence, when the area is covered by about 16 % buildings, then E = 0. Typically, PB ≥ 16 % for urban area; PB < 16 % (assume that PB = 8 %) for sub-urban area and PB < 16 % (say, PB =3 %) for rural area.

The link budget equation for computing the received signal strength and transmission range based on CCIR model is given as follows;

$$\mathrm{P_R} = \mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R} - LP_{CCIR} = fm_s + P_S \tag{5}$$

Where $\mathrm{P_R}$ is the received signal power (dBm), $\mathrm{P_T}$ is the transmitter power output (dBm), $\mathrm{G_T}$ is the transmitter antenna gain (dBi), $\mathrm{G_R}$ is the receiver antenna gain (dBi), LP_{CCIR} is the CCIR-based pathloss, fm_s is the specified fade margin in dB and P_s is the receiver sensitivity in dB

Therefore, with respect to CCIR model, the effective transmission range (d_{eCCIR}) is given as:

$$LP_{CCIR} = A + B\,log_{10}(d) - E = \mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R} - fm_s - P_S \tag{6}$$

$$d_{eCCIR} = 10^{\left(\frac{(\mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R} - fm_S - P_S) - \mathrm{A} + \mathrm{E}}{B}\right)} \tag{7}$$

Hence, the effective Hata CCIR based pathloss, $\left(LP_{CCIR_{\mathrm{e}}}\right)$ is given as:

$$LP_{HATA_{\mathrm{e}}} = A + B\log_{10}(d_{eCCIR}) - E \tag{8}$$

Effective Received Power (P_{ReCCIR}) is:

$$P_{ReCCIR} = \mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R} - LP_{HATA_{\mathrm{e}}} \tag{9}$$

Effective Fade Margin (fm_{eCCIR}) is:

$$fm_{eCCIR} = (\mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R}) - (A + B\log_{10}(d_{eHATA}) - K) - P_S \tag{10}$$

The effective rain fading (fd_{meCCIR}) at d_{eCCIR}) is;

$$fd_{meCCIR} = \max\left(\left(\mathrm{K_v}(\mathrm{R_{po}})^{\alpha_\mathrm{v}}\right)d_{eCCIR}, \left(\mathrm{K_h}(\mathrm{R_{po}})^{\alpha_\mathrm{h}}\right)d_{eCCIR}\right) \tag{11}$$

The optimal transmission range, $doptCCIR$ occurs at the value of $deCCIR$ where $fmeCCIR = fdmeCCIR$. In this paper, the $deCCIR$ is iteratively adjusted using a secant numerical iteration mechanism until the optimal value is attained.

4. Results and Discussion

The link parameters used for the computation in Matrix Laboratory (MATLAB) are given in Table 1. MATLAB software was used to determine the optimal transmission range for the case where rain rate, $\mathrm{R_{0.01}}$= 95 mm/hr at 0.01 % exceedence with PB = 4 % and E = 14.94850022. The Secant iteration computation of the optimal transmission range and other optimal link parameters are shown in Table 2. The results in Table 2 is for the rural area based on the value of PB=4%. The results for the suburban area (PB = 12 %) are shown in Table 3 while that of the urban area (PB = 20 %) is shown in Table 4. The Secant iteration computation of the optimal transmission range for the case where rain rate, $\mathrm{R_{0.01}}$= 95 mm/hr at 0.01 % exceedence with PB % in the range 4 % PB ≤ 50% are shown in Table 5 and Figure 1. The results showed that, for the case where rain rate, $\mathrm{R_{0.01}}$= 95 mm/hr at 0.01 % exceedence with PB % in the range 4% PB ≤ 50 %, the optimal transmission range is 1.838817 km at PB(%) = 4 %, which is for rural area; the optimal transmission range is 1.402416 km at PB(%) = 12 % which is for suburban area and the optimal transmission range is 1.214386 km at PB(%) = 20 % which is for urban area. Based on the graph in Figure 1, the optimal transmission range is related to the percentage of covered area, PB% as follows;

$$dopt(km) = -0.3683316683\,Ln(PB\%) + 2.329342272 \tag{12}$$

The model of Eq 12 has coefficient of regression value, $R^2 = 0.9982099018$.

Similarly, the graph of the optimal transmission range versus degree of urbanization, E for the case where rain rate, $\mathrm{R_{0.01}}$ = 95 mm/hr at 0.01 % exceedence with PB% in the range 4 % PB ≤ 50 % is given in Figure 2. Based on the graph in Figure 2, the optimal transmission range is related to the degree of urbanization, E as follows;

$$dopt(km) = 0.033(E) + 1.311 \tag{13}$$

The model of Eq 13 has coefficient of regression value, $R^2 = 0.998$.

Table 1: The values of the link parameters used for the computation in MATLAB

Frequency, *f* in MHz	**Transmitter Power, P_T (dB)**	**Transmitter Antenna Gain, G_T (dB)**	**Receiver Antenna Gain, G_R (dB)**	**Specified Fade Margin, fm_s (dB)**	**Receiver Sensitivity, P_s (dB)**
30000	25	20	20	20	-87
Percentage outage, *Po* at 0.01 % exceedence	**Percentage availability, Pa (%) at 0.01 % exceedence**	**Rain rate, $\mathrm{R_{0.01}}$ (mm/hr) at 0.01 % exceedence**	**Percentage outage, Po at 0.03 % exceedence**	**Percentage availability, Pa (%) at 0.03 % exceedence**	**Rain rate, $\mathrm{R_{0.03}}$ (mm/hr) at 0.03 % exceedence**
0.01	99.99	95	0.03	99.97	65

kh	ah	kv	av	Rain Zone	
0.2403	0.9485	0.2291	0.9129	N	

Table 2: Secant iteration computation of the optimal transmission range for the case where rain rate, $R_{0.01}$ = 95 mm/hr at 0.01 % exceedence with PB = 4% and E=14.94850022

Cycle	Transmission range (km)	CCIR PATH Loss (dB)	Received Power (dBm)	Effective Fade Margin (dB)	Effective Rain Fade Depth (dB)	Effective Fade Margin - Effective Fade Depth (dB)
0	1	109.6962	-44.69624	42.30	18.06	2.42E+01
1	1.880784	119.1353	-54.13528	32.86	33.96	-1.09E+00
2	1.838883	118.7986	-53.79862	33.20	33.20	-1.72E-03
3	1.838817	118.7981	-53.79808	33.20	33.20	-4.30E-09
4	1.838817	118.7981	-53.79808	33.20	33.20	0.00E+00

Table 3: Secant iteration computation of the optimal transmission range for the case where rain rate, $R_{0.01}$=95 mm/hr at 0.01 % exceedence with PB = 12% and E=3.020468849

Cycle	Transmission range (km)	CCIR PATH Loss (dB)	Received Power (dBm)	Effective Fade Margin (dB)	Effective Rain Fade Depth (dB)	Effective Fade Margin - Effective Fade Depth (dB)
0	1	121.6243	-56.62427	30.38	18.06	1.23E+01
1	1.418354	126.8466	-61.84664	25.15	25.61	-4.57E-01
2	1.402436	126.678	-61.67800	25.32	25.32	-5.65E-04
3	1.402416	126.6778	-61.67779	25.32	25.32	-8.68E-10
4	1.402416	126.6778	-61.67779	25.32	25.32	0.00E+00

Table 4: Secant iteration computation of the optimal transmission range for the case where rain rate, $R_{0.01}$=95 mm/hr at 0.01 % exceedence with PB=20% and E=-2.52574989

Cycle	Transmission range (km)	CCIR PATH Loss (dB)	Received Power (dBm)	Effective Fade Margin (dB)	Effective Rain Fade Depth (dB)	Effective Fade Margin - Effective Fade Depth (dB)
0	1	127.1705	-62.17049	24.83	18.06	6.77E+00
1	1.22031	130.1456	-65.14562	21.85	22.03	-1.80E-01
2	1.214389	130.0729	-65.07295	21.93	21.93	-1.21E-04
3	1.214386	130.0729	-65.07290	21.93	21.93	-5.46E-11
4	1.214386	130.0729	-65.07290	21.93	21.93	0.00E+00

Table 5: The Secant iteration computation of the optimal transmission range for the case where rain rate, $R_{0.01}$=95 mm/hr at 0.01 % exceedence with PB% in the range 4% PB≤50%

Percentage of Covered Area, PB (%)	Optimal Transmission range (km)	Degree of Urbanization	Optimal Transmission range (km)

		(E)	
4	1.838817	14.94850	1.838817
8	1.558759	7.42275	1.558759
12	1.402416	3.02047	1.402416
16	1.295229	-0.10300	1.295229
20	1.214386	-2.52575	1.214386
30	1.073006	-6.92803	1.073006
40	0.977318	-10.05150	0.977318
50	0.905920	-12.47425	0.905920

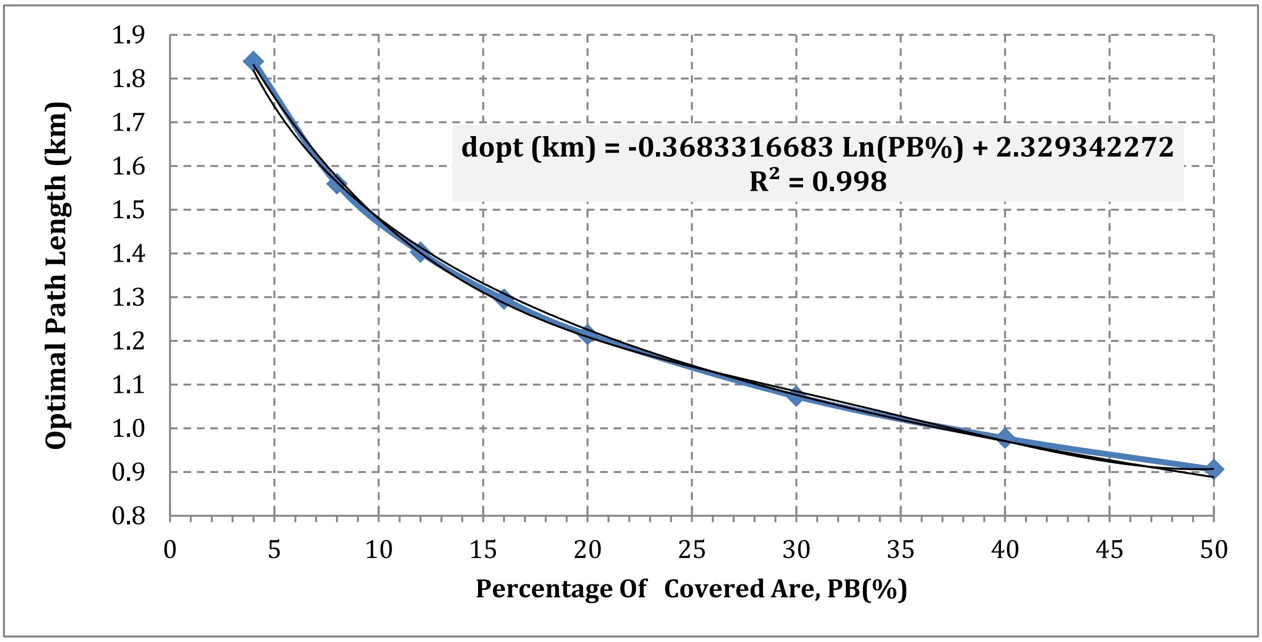

Figure 1: Optimal transmission range versus PB% for the case where rain rate, $R_{0.01}$= 95 mm/hr at 0.01 % exceedence with PB% in the range 4% PB ≤ 50%

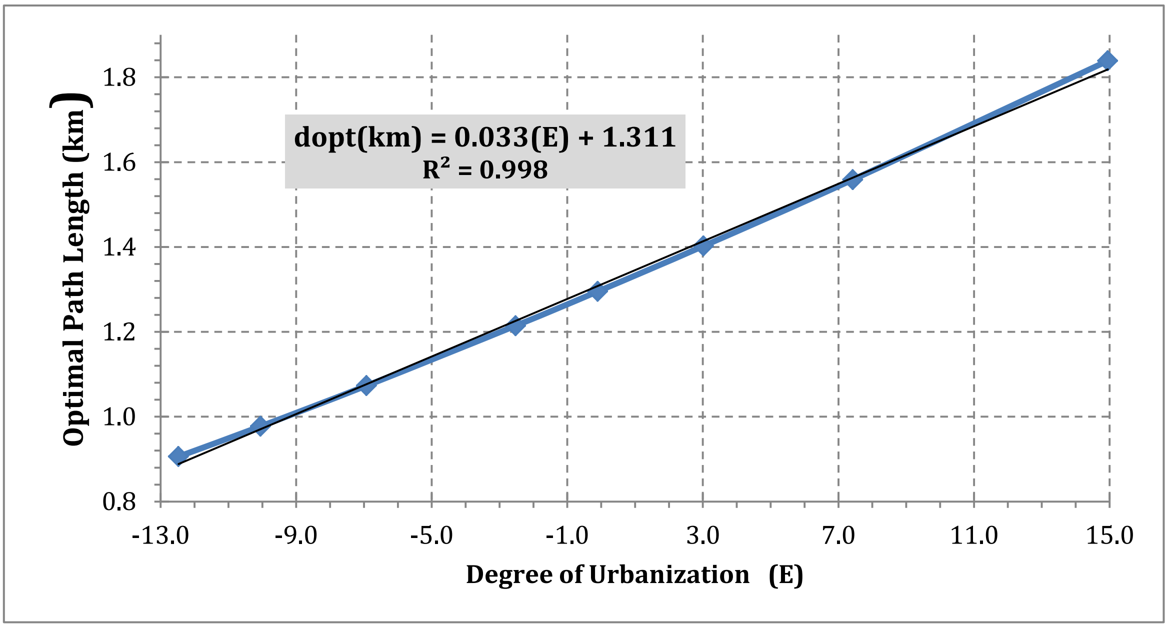

Figure 2: Optimal transmission range versus degree of urbanization, E for the case where rain rate, $R_{0.01}$=95 mm/hr at 0.01 % exceedence with PB% in the range 4% PB ≤ 50%

Furthermore, MATLAB software was used to determine the optimal transmission range for the case where rain rate, $R_{0.01}$ = 95 mm/hr at 0.01 % exceedence with PB = 4% and E = 14.94850022. The Secant iteration computation of the optimal transmission range and other optimal link parameters are shown in Table 6 for the case where rain rate, $R_{0.01}$= 95 mm/hr at 0.01 % exceedence with PB = 4% and E = 14.94850022.

The Secant iteration computation of the optimal transmission range for the case where rain rate, $R_{0.03}$ = 65 mm/hr at 0.03 % exceedence with PB% in the range 4% PB ≤ 50% are shown in Table 7 and Figure 2. The results showed that, for the case where rain rate, $R_{0.03}$ = 65 mm/hr at 0.03 % exceedence with PB % in the range 4% PB ≤ 50% , the optimal transmission range is 2.346376 km at PB(%) = 4 % which is for rural area; the optimal transmission range is 1.748445 km at PB(%)= 12 % which is for suburban area and the optimal transmission range is 1.494411 km at PB(%)= 20 % which is for urban area. Based on the graph in Figure 3, the optimal transmission range is related to the percentage of covered area, PB % as follows:

$$dopt\ (km) = -0.49Ln(PB\%) + 3.004 \tag{14}$$

The model of Eq 14 has coefficient of regression value, $R^2 = 0.997$.

Similarly, the graph of the optimal transmission range versus degree of urbanization, E for the case where rain rate,$R_{0.03}$ = 65 mm/hr at 0.03 % exceedence with PB% in the range 4% PB ≤ 50% is given in Figure 4. Based on the graph in Figure 4, the optimal transmission range is related to the degree of urbanization, E as follows;

$$dopt(km) = 0.045(E) + 1.628 \tag{15}$$

The model of Eq 15 has coefficient of regression value, $R^2 = 0.997$. The graph used to visualize the difference between the optimal transmission range obtained for the two rain rates and for the various percentage of covered areas is shown in Figure 5. In all, the higher rain rate gave rise to higher rain fade depth which ultimately reduces the transmission range of the network. Also, higher degrees of urbanization gave rise to higher pathloss which reduces the transmission range of the network.

Table 6: Secant iteration computation of the optimal transmission range for the case where rain rate, $R_{0.03}$=65 mm/hr at 0.03 % exceedence with PB=4% and E=14.94850022

Cycle	Transmission range (km)	CCIR Pathloss (dB)	Received Power (dBm)	Effective Fade Margin (dB)	Effective Rain Fade Depth (dB)	Effective Fade Margin - Effective Fade Depth (dB)
0	1	109.6962	-44.69624	42.30	**12.60**	2.97E+01
1	2.465192	123.1785	-58.17845	28.82	**31.06**	-2.23E+00
2	2.346868	122.4435	-57.44346	29.56	**29.57**	-9.33E-03
3	2.346376	122.4403	-57.44032	29.56	**29.56**	-1.66E-07
4	2.346376	122.4403	-57.44032	29.56	**29.56**	0.00E+00

Table 7: The Secant iteration computation of the optimal transmission range for the case where rain rate, $R_{0.03}$=65 mm/hr at 0.03% exceedence with PB% in the range 4% PB≤50%

PB (%)	Path Length (km)	Degree of Urbanization (E)	Path Length (km)
4	2.346376	14.94850022	2.346376
8	1.961503	7.422750325	1.961503
12	1.748445	3.020468849	1.748445
16	1.603301	-0.10299957	1.603301
20	1.494411	-2.52574989	1.494411
30	1.305377	-6.928031	1.305377
40	1.178611	-10.0515	1.178611
50	1.08474	-12.47425	1.08474

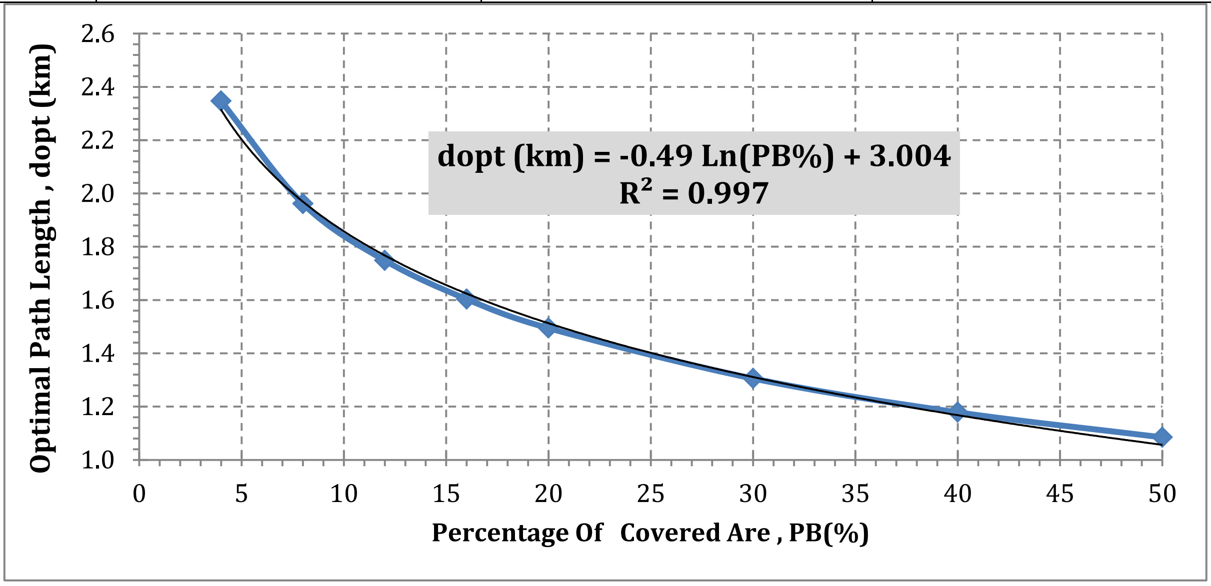

Figure 3: The graph of the optimal transmission range versus PB% for the case where rain rate, $R_{0.03}$= 65 mm/hr at 0.03% exceedence with PB% in the range 4% PB≤50%

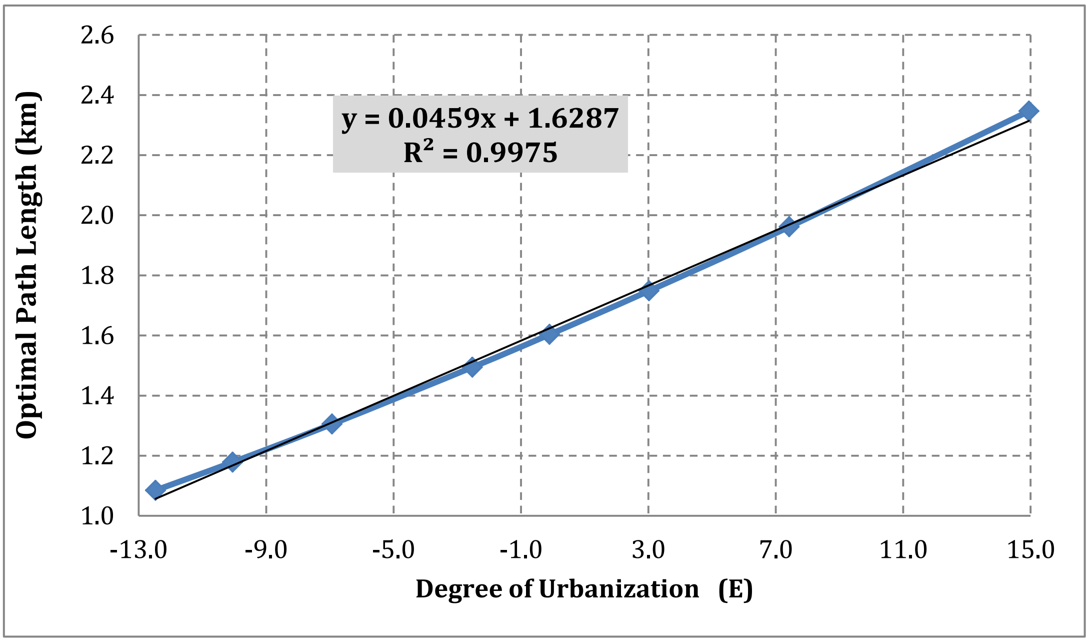

Figure 4: The graph of the optimal transmission range versus degree of urbanization, E for the case where rain rate, $R_{0.03}$=65 mm/hr at 0.03 % exceedence with PB% in the range 4% PB ≤ 50%

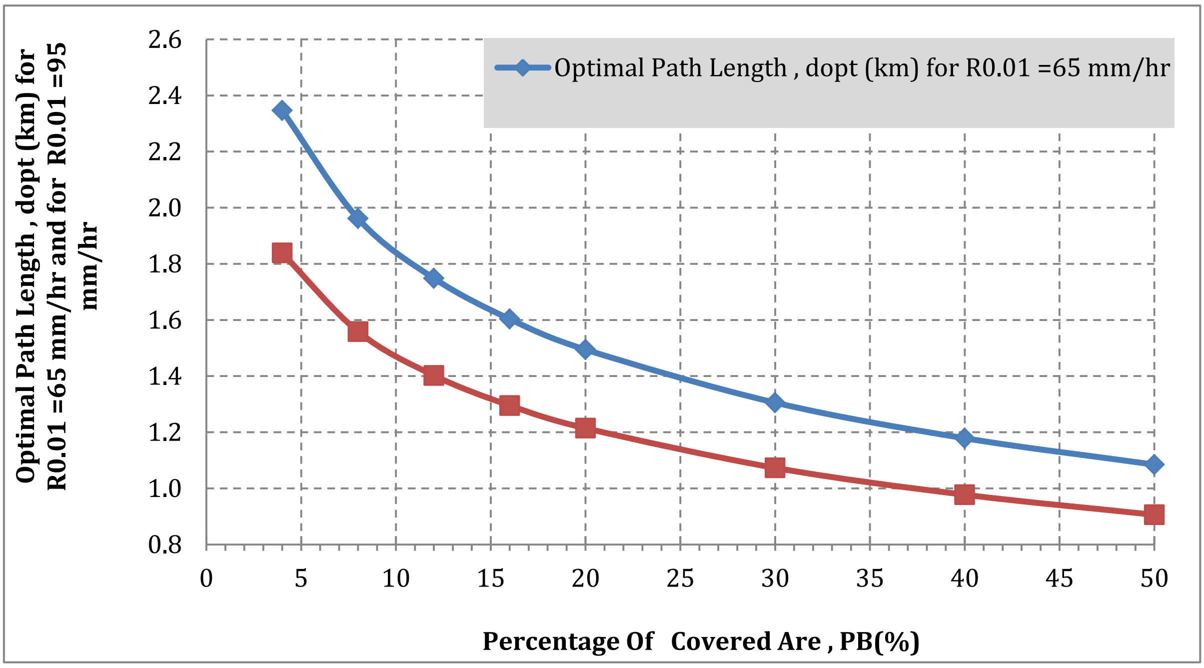

Figure 5: The graph used to visualize the difference between the optimal transmission range obtained for the two rain rates and for the various percentage of covered areas

4. Conclusion

The optimal transmission range of wireless network is studied under different rain rates and varying degrees of urbanization. The degree of urbanization used in the study was the one defined in the Comit´e International des Radio-Communication pathloss model. Secant iteration method was used to compute the optimal transmission range based on analytical expressions derived from the link budget equation and the CCIR pathloss model. The results showed that the higher rain rate gave rise to higher rain fade depth which ultimately reduces the transmission range of the network. Also, higher degrees of urbanization gave rise to higher pathloss which reduces the transmission range of the network. Hence, based on the results, networks in the suburban area and rural area will have a higher transmission range than the networks in the urban areas.

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