Propagation Model Tuning for Terrestrial Microwave Links in Palestine

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Abstract—**In this paper, we have studied the terrestrial microwave links operated by the Palestinian mobile network operator (JAWWAL). Particularly, we have analyzed the path loss power measurements from 90 active terrestrial microwave links at three different frequencies which are 15GHz, 18GHz and 23GHz covering all geographical locations in the West Bank. The length of these microwave links varies from about 0.174Km to 33.864Km. The path loss power measurements were compared with that of the theoretical free-space propagation model as well as with the results obtained from Mentum Ellipse software simulation tool. The root mean square error results show that the free-space model is far away (7.64 dB) from the measured data. Therefore, we have suggested to tune the free-space propagation model based on linear least squares method. The proposed tuned free-space model yields better fit to the measured data with reduced root mean square error of 5.84 dB. In addition, the suggested tuned model yields comparable results to that obtain by Mentum Ellipse simulation.**

Keywords-microwave links; propagation models; free space; path loss; Mentum Ellipse simulation; least squares; Palestine.

I. INTRODUCTION

Microwave links plays a key role in the design of wireless communication systems such as cellular mobile networks, satellite communication systems, radar systems and deep space navigation [1]. In particular, the backhaul of mobile networks mainly consists of line-of-sight (LOS) point-to-point microwave links that connect the base-stations to the core network. Indeed, microwave links connects about 50% of mobile network base-stations worldwide [2]. These microwave links are preferred alternative to cable links as they are easy to install and manage, secure, cheap, and can carry high data rates traffic [3].

The planning of LOS microwave links for wireless communication systems requires accurate and reliable path loss propagation prediction models [4][5]. These propagation models not only consider the free space path loss but also several other impairments such as atmospheric gas absorption, rainfall and snow attenuation, multipath fading, diffraction loss, dust storms loss, etc. [6][7]. Several design factors are taken to account during the planning process including link availability, fade margin, outage probability and average received power [8].

Microwave propagation models have been extensively investigated in the literature. Back to 1970, Morita [9] suggested empirical formulation for the multipath fading of microwave links based on local propagation test results in Japan. The Barnett-Vigants fading model [10][11] was developed by Bell Labs and only takes into account the weather conditions in the United states of America. A worldwide method suggested by International Telecommunication Union (ITU-R P.530) is the most widely used propagation prediction model for the design of terrestrial LOS microwave links [4]. Indeed, the ITU-R P.530 model takes into account several propagation effects relative to free-space which are attenuation due to atmospheric gases and rain, fading due to multipath, and diffraction loss due to obstruction along the path.

In [5], the authors have provided a comparative study between the Barnett-Vigants model and the ITU recommendations. They concluded that the ITU model outperforms the Barnett-Vigants model in-terms of link availability due to multipath as well as for other performance measures. According to [12], the ITU model yields the best performance as compared with existing models applied in many regions around the world. In [13], the ITU recommendations have been upgraded to ITU-R P.530-17 so as to provide prediction methods for the various propagation effects that should be considered in the design of microwave links.

Several authors have investigated the effect of rain attenuation as a major impairment facing the propagation of terrestrial microwave signals with frequencies above 10GHz [14][15][16][17][18]. Indeed, in [14], the authors present results of 3 years measurement of rain attenuation of microwave signal propagation at 18 GHz and 38 GHz for a path length of 3.2 Km in South Korea. The rain attenuation measurements are noticed to be under-estimated by ITU-R P.530-16 model at 18 GHz while over-estimation is noticed at 38 GHz. In [16], the authors studied the effect of rain on the propagation of microwave signals at 26 GHz for 5G link system with path length of 1.3 Km in Malaysia. The results of measurements showed that the rain rate was 120 mm/hr and the rain attenuation was 26.2 dB/km. The authors in [18] introduced an empirical model for the prediction of rain fade slope in the case of point-to-point terrestrial microwave links in Malaysia operating at 15 GHz, 23 GHz, and 38 GHz.

The effects of dust and sand storms on the propagation of terrestrial microwave signals are recently studied by several authors [19][20][21]. Indeed in [19], the authors investigated the effect of dust storms and signal diffraction on terrestrial microwave links in Saudi Arabia for different 5G operating frequencies. It was noticed that increasing the operating frequency will increase both dust storm loss and diffraction loss. In [20], the authors monitored the weather conditions and signal propagation loss due to dust storms on 21 GHz terrestrial microwave link in Sudan for a period of one year. The results show that dust storms increase humidity and hence increases dramatically signal propagation loss. The authors in [21] have suggested a machine learning based model that utilize meteorological information to predict propagation loss due to dust storms for 22GHz terrestrial microwave link in Sudan.

In this paper, we have analyzed the propagation loss power measurements from 90 active terrestrial microwave links operated at carrier frequencies 15GHz, 18GHz and 23GHz covering all geographical locations in the West Bank-Palestine. A tuned free-space path loss model is suggested that can take into account the various sources of signal attenuation impairments. The results of the proposed model are compared with that obtained by the Mentum Ellipse software simulation tool.

The rest of the paper is organized as follows. In section II, tuning of the free space propagation model is introduced based on least squares. Section III presents the path loss power measurements form 90 microwave links as well as the simulation results from Mentum Ellipse simulations and the results of the tuned model. Conclusions remarks are drawn in section IV.

II. FREE SPACE PROPAGATION MODEL TUNING

The free space propagation model is widely used to model the propagation path loss over LOS terrestrial as well as satellite microwave communication links. The free space loss is the ratio of the transmitted signal power P_t to the received signal power P_r, and can be expressed as [22]:

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2 L}{G_t G_r \lambda^2} \tag{1}$$

where d is the distance between the transmitter and the receiver, $\lambda = c/f$ is the wavelength, $c = 3 \times 10^8 m/s$ is the light speed, f is the carrier frequency. G_t and G_r are the gains of the transmitting and the receiving antennas, respectively. $L \geq 1$ is a loss factor not related to propagation. Usually, for the case of perfect free space propagation the loss factor is set to $L = 1$.

The Free Space Loss (L_{FS}) in dB can therefore be written as:

$$L_{FS} = 92.45 + 20\log(d) + 20\log(f) - G_{tdB} - G_{rdB} \tag{2}$$

where the transmitter and receiver antenna gain in units of dB is given by:

$$G_{dB} = 20\log(f) + 20\log(D) + 17.8 \tag{3}$$

with D is the microwave antenna diameter.

In this paper, we suggest that the loss factor L in (1) can take into account other kinds of losses such as losses due to gases, rain, snow, diffraction, fading, etc.

Therefore, we propose to tune the free space model in (2) as follows:

$$L_{FS(Tuned)} = L_{FS} + \Delta L_1 \tag{4}$$

where the difference between the tuned model and the free space model ΔL_1 is suggested to have the form:

$$\Delta L_1 = c_1 + c_2 \log(d) \tag{5}$$

with c_1 and c_2 are the coefficients of the tuned model that should be evaluated based on the path loss measurements. For this purpose, let us define the difference between the measured path loss $L_{measured}$ and the free space path loss L_{FS} as follows:

$$\Delta L_2 = L_{measured} - L_{FS} \tag{6}$$

Taking into account that we have N path loss power measurements corresponding to N microwave links, let us define the following sum of squared errors function:

$$\begin{aligned} \mathrm{E}(c_1, c_2) &= \sum_{n=1}^{N} (\Delta L_{1n} - \Delta L_{2n})^2 \\ &= \sum_{n=1}^{N} ((c_1 + c_2 \log(d_n)) - \Delta L_{2n})^2 \end{aligned} \tag{7}$$

Then, the least squares estimation of the coefficients c_1 and c_2 can be obtained by minimizing the error function in (7) as follows [23]:

$$\frac{\partial \mathrm{E}(c_1, c_2)}{\partial c_1} = 0 \tag{8}$$

$$\frac{\partial \mathrm{E}(c_1, c_2)}{\partial c_2} = 0 \tag{9}$$

It follows that:

$$c_1 = \frac{\sum_{n=1}^{N} (\log(d_n))^2 \times \sum_{n=1}^{N} \Delta L_{2n} - \sum_{n=1}^{N} \log(d_n) \times \sum_{n=1}^{N} \log(d_n) \Delta L_{2n}}{N \sum_{n=1}^{N} (\log(d_n))^2 - \left(\sum_{n=1}^{N} \log(d_n)\right)^2} \tag{10}$$

$$c_2 = \frac{N \sum_{n=1}^{N} \log(d_n) \Delta L_{2n} - \sum_{n=1}^{N} \log(d_n) \times \sum_{n=1}^{N} \Delta L_{2n}}{N \sum_{n=1}^{N} (\log(d_n))^2 - \left(\sum_{n=1}^{N} \log(d_n)\right)^2} \tag{11}$$

Therefore, the tuned free space propagation model can be expressed as:

$$\begin{aligned} L_{FS(Tuned)} = {} & 92.45 + 20\log(d) + 20\log(f) - G_{tdB} \\ & - G_{rdB} + c_1 + c_2 \log(d) \end{aligned} \tag{12}$$

The tuned free space path loss model $L_{FS(Tuned)}$ in (12) can then be compared with the free space model L_{FS} in (2) as well as with the measured path loss $L_{measured}$ by computing the root mean square error (RMSE) as follows:

$$RMSE = \sqrt{\frac{1}{N} \sum_{n=1}^{N} \left(L_{measured} - L_{FS(Tuned)}\right)^2} \tag{13}$$

where N is the number of path loss power measurements corresponding to N microwave links.

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III. MEASUREMENTS, SIMULATIONS AND RESULTS

In this section, the path loss power measurements for 90 microwave links covering all areas of the West-Bank/Palestine are presented at carrier frequencies 15GHz, 18GHz and 23GHz. In addition, Mentum Ellipse software simulation package is used to simulate these 90 microwave links. Indeed, Mentum Ellipse is a powerful software tool for planning, dimensioning, and optimization of microwave links and wireless backhaul networks. Mentum Ellipse design is mainly based on the ITU recommendation [24]. It has libraries of geographical information of the whole world. Creation of a microwave link is possible between any two microwave towers that are LOS with each other's at specific latitude and longitude. Mentum Ellipse shows the clearance between two towers and gives a total path loss. Some of these losses can be eliminated by changing in the sites proprieties like antenna height, azimuth angle and elevation angle. Fig. I shows the properties of a microwave link between site-3 and site-10.

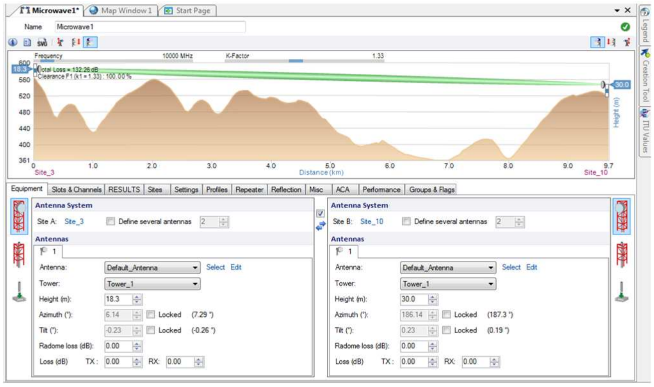
Table I, Table II and Table III present the path loss of the free space model, measured path loss, Mentum Ellipse path loss and tuned model path loss of 30 microwave links for frequencies 15GHz, 18GHz and 23GHz, respectively. Fig. II, Fig. III and Fig. IV show the path loss for the various models at frequencies 15GHz, 18GHz and 23GHz, respectively.

TABLE I. PATH LOSS FOR 30 MICROWAVE LINKS AT 15GHZ.

Link Length (Km)	Free space loss L_{FS} (dB)	Measured path loss $L_{measured}$ (dB)	Mentum Ellipse loss (dB)	Tuned $L_{FS(Tuned)}$ (dB)
0.731	38.25	50	47.28	44.06
1.257	42.959	44.8	44.7	48.77
1.542	44.734	51.2	50.77	50.55
2.239	47.973	61.3	59.08	53.79
2.479	48.857	59.5	50.08	54.67
3.239	51.18	61.3	57.08	56.99
3.313	51.376	57	56.23	57.19
3.623	52.153	72.4	71.05	57.97
3.626	52.16	54.3	49	57.97
3.667	52.258	58.7	58.89	58.07
4.484	54.005	51.7	49.88	59.82
4.814	64.822	66.3	65.75	70.64
5.121	55.159	61.4	57.2	60.97
6.183	56.796	66.3	57.44	62.61
6.573	57.327	60.6	59.27	63.14
6.933	57.79	62.5	58.93	63.6
7.144	58.051	72.4	71.05	63.86
7.2	58.118	59.4	58.49	63.93
7.524	58.501	75.1	70.46	64.31
7.82	58.836	59.1	60.02	64.65
7.922	58.949	64.2	62.3	64.76
8.309	59.363	54	52.47	65.18
9.38	60.416	61.2	57.07	66.23
9.522	60.546	65.8	65.73	66.36
9.564	60.585	66.7	61.85	66.4
11.144	61.913	71.5	67.79	67.73
12.925	63.2	66.2	61.41	69.01
13.249	63.415	65.8	64.8	69.23
17.849	66.004	68.2	67.26	71.82
33.864	60.367	68.6	67.3	66.18

TABLE II. PATH LOSS FOR 30 MICROWAVE LINKS AT 18GHZ.

Link Length (Km)	Free space loss L_{FS} (dB)	Measured path loss $L_{measured}$ (dB)	Mentum Ellipse loss (dB)	Tuned $L_{FS(Tuned)}$ (dB)
0.313	38.066	40.5	38.57	42.96
0.402	40.24	34.5	40.68	45.13
0.426	30.744	56.3	53.11	35.64
0.444	41.103	41.1	28.08	46
0.472	41.634	45.8	42	46.53
0.605	33.791	41.1	28.08	38.68
0.775	35.941	45.8	42	40.83
0.834	36.579	44.3	37.04	41.47
0.95	37.71	52.6	38.23	42.6
1.433	51.28	51.1	52.3	56.17
2.091	44.563	46.1	45.1	49.46
2.199	45	50.9	49.73	49.89
2.481	46.048	57.2	58.06	50.94
2.536	56.238	53.3	52.1	61.13
2.645	46.604	55.3	54.36	51.5
2.736	46.898	76.1	62.74	51.79
3.076	47.915	56	49.11	52.81
3.257	48.412	51	49.68	53.31
3.582	49.238	61.7	61.49	54.13
3.665	49.437	53.5	51.5	54.33
4.078	60.364	62.3	62.63	65.26
4.11	50.432	53.6	51.69	55.33
4.138	50.491	62.7	62.74	55.39
4.54	51.297	54	53.14	56.19
5.779	53.393	58.2	55.5	58.29
6.036	53.77	62.7	55.52	58.66
6.378	54.249	57.4	55.68	59.14
6.614	54.565	74.3	56.49	59.46
6.777	54.776	60.2	64.14	59.67
7.397	55.537	61.7	57.03	60.43



Name: Microwave1

Frequency: 10000 MHz

K-Factor: 1.33

Total Loss = 132.26 dB

Clearance F1 (k1 = 1.33) : 100.00 %

Site A: Site_3

☐ Define several antennas 2

Antenna: Default_Antenna

Tower: Tower_1

Height (m): 18.3

Azimuth (°): 6.14 ☐ Locked (7.29 °)

Tilt (°): -0.23 ☐ Locked (-0.26 °)

Radome loss (dB): 0.00

Loss (dB) TX: 0.00 RX: 0.00

Site B: Site_10

☐ Define several antennas 2

Antenna: Default_Antenna

Tower: Tower_1

Height (m): 30.0

Azimuth (°): 186.14 ☐ Locked (187.3 °)

Tilt (°): 0.23 ☐ Locked (0.19 °)

Radome loss (dB): 0.00

Loss (dB) TX: 0.00 RX: 0.00

Figure 1. Mentum Ellipse microwave link simulation parameters.

According to the results presented in Table I, Table II, and Table II and that shown in Fig. II, Fig. III and Fig, IV, the path loss increases by increasing the microwave link length as well as by increasing the frequency. It can be noticed that the average path loss of the free space model is far away from that of the measured path loss and simulated path loss. In addition, the tuned free space model provides better fit to the measured path loss and has comparable results to that of the Mentum Ellipse simulation.

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TABLE III. PATH LOSS FOR 30 MICROWAVE LINKS AT 23GHZ.

Link Length (Km)	Free space loss L_{FS} (dB)	Measured path loss $L_{measured}$ (dB)	Mentum Ellipse loss (dB)	Tuned $L_{FS(Tuned)}$ (dB)
0.174	32.8955	34.3	33.15	33.923
0.236	45.0428	49.8	47.2	46.07
0.238	35.6161	40.7	35.24	36.643
0.287	37.2422	37.8	34.2	38.269
0.353	48.5401	45.5	41.49	49.567
0.398	49.5822	46.7	44.9	50.609
0.433	29.2143	34.9	29.06	30.241
0.475	51.1184	55.6	53.2	52.145
0.512	42.27	42.3	41.78	43.297
0.519	42.3879	40.8	41.34	43.415
0.555	52.4704	53.2	51.86	53.497
0.568	43.1715	47.4	45	44.198
0.752	45.6089	49	44.56	46.636
0.782	45.9487	46	44.96	46.976
0.825	55.9136	55.6	54.38	56.94
0.839	46.5598	50.5	46.11	47.587
0.844	46.6114	47.3	46.47	47.638
0.903	47.1983	51.4	46.53	48.225
1.186	49.5663	51	49.16	50.593
1.203	49.6899	55.5	51.23	50.716
1.284	59.7559	54.1	56.62	60.782
1.38	50.8821	53.1	52.81	51.909
1.607	52.2049	48.5	45.38	53.231
1.804	53.2093	62.8	52.89	54.236
2.163	54.7857	55	54.07	55.812
2.198	54.9251	51.6	54.26	55.951
2.475	55.9561	48.5	55.78	56.982
2.554	44.629	55.5	51.32	45.655
4.873	61.8405	58.1	59.1	62.866
7.59	54.0894	56.5	55.21	55.115

The optimized coefficients of the tuned free space model that minimized the least square error cost function in (7) are summarized in Table IV. It can be noticed that the value of the first coefficient c_1 plays the key role in the tuning of the model while the effect of the second coefficient c_2 is negligible. In addition, increasing the frequency will generally decrease the value of the two coefficients.

Table V summaries the RMSE calculated as in (13) for the free space model, Mintum Ellipse simulation, and the tuned free space model. It can be noticed that the RMSE of the free space model has the largest value while that of the Mentum Ellipse has the lowest value for all the frequencies considered. This implies that the Mentum Ellipse simulation results are the closest to the measurements. The tuned free space model has comparable results to that of the Mentum Ellipse simulation. Indeed, the average RMSE of the tuned free space model for the three frequencies considered is about 5.84 dB while that of the Memtum Ellipse simulation is about 4.62 dB. The free space model has the worst average RMSE of 7.64 dB. The reason why the Mentum Ellipe simulation results outperform that of the suggested tuned free space model is that the former adopts much more complicated models based on ITU recommendations.

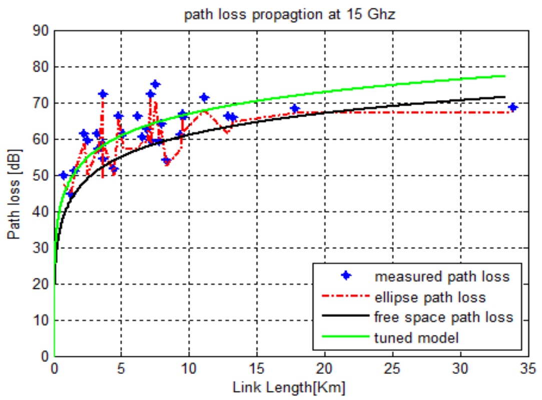

Figure 2. Path Loss versus link length for the various models at 15GHz.

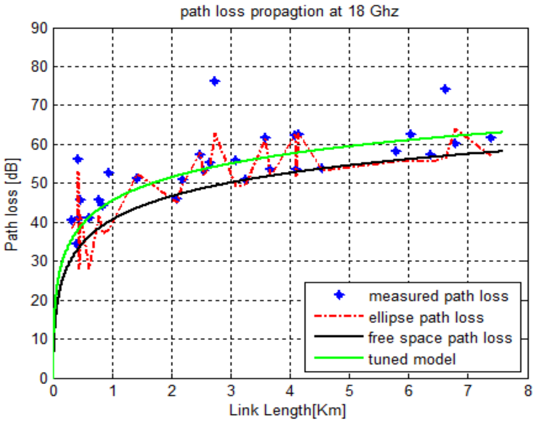

Figure 3. Path Loss versus link length for the various models at 18GHz.

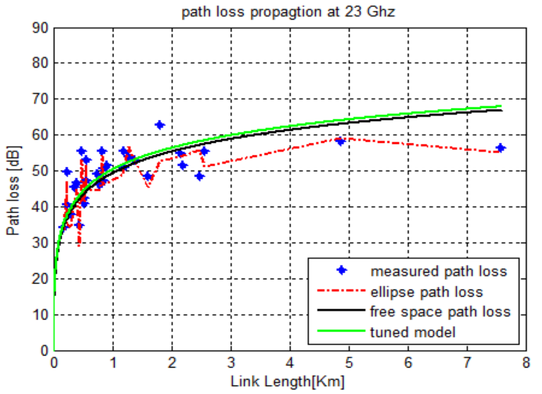

Figure 4. Path Loss versus link length for the various models at 18GHz.

TABLE IV. OPTIMIZED COEFFIECEINTS OF THE TUNED MODEL.

Frequency	**Optimized Coefficients of the Tuned Free Space Model**	
	c_1	c_2
15 GHz	5.81	-0.0011
18 GHz	4.98	0.00065
23 GHz	1.0267	-0.00104

TABLE V. RMSE OF THE VARIOUS METHODS.

Frequency	**Root Mean Square Error (RMSE) in dB**		
	Free Space Model	***Mentum Ellipse Simulation***	***Tuned Free space Model***
15 GHz	8.202	3.539	5.545
18 GHz	10.366	6.679	7.827
23 GHz	4.359	3.657	4.160

IV. CONCLUTIONS

This paper presents propagation path loss measurements for 90 microwave links operating in West-Bank/Palestine at three carrier frequencies 15 GHz, 18 GHz and 23 GHz. A tuned free space propagation model is suggested to fit the measurements in the least squares error sense. The proposed tuned model is simpler than the ITU-R P.530 model and can take into account the various sources of attenuation impairments. The RMSE results of the suggested tuned model are compared with that of the standard free space model as well as with the Mentum Ellipse simulation results. It was observed that the suggested tuned free space model succeeded to reduce the average RMSE from 7.64 dB to 5.84 dB. In addition, the suggested tuned free space model yields comparable results to that obtain by Mentum Ellipse simulation.

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