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Comparative Analysis Of Terrain Roughness Parameters For Two Selected Sites In Nigeria With Elevation Profile Sampled At Different Resolutions

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***Abstract*—In this paper, comparative analysis of terrain roughness parameters for two selected sites in Nigeria is presented. The terrain roughness parameters are determined from elevation profile sampled at five different resolutions using online elevation profile software. The first site studied has starting coordinates (latitude and longitude) of 5.26278, 7.26095 and ending coordinates of 5.80372, 6.81257 while site 2 has starting coordinates of 6.47657, 7.48975 and ending coordinates of 5.81597, 7.25327. The five different sampling resolutions are; 10 seconds, 30 seconds, 1 minute (60 seconds), 10 minutes (600 seconds). Specifically, the terrain roughness parameter is the standard deviation of elevation profile for the data set. The complete elevation profile data has a total of 512 data points sampled at 5 seconds interval. However, for the five sampling resolutions used in the study, their total number of sample data points are 257 for the 10 seconds,87 for the 30 seconds, 44 for the 1 minute, 6 for the 10 minutes and 3 for the 30 minutes. The results showed that in all the sampling resolutions site 2 has higher elevation, higher average elevation and most importantly higher standard deviation of elevation (terrain roughness value) than site 1. Based on the results, site 2 with average terrain roughness parameter value of 77.071 m is very rough terrain whereas site 1 with average terrain roughness parameter value of 21.287 m is smooth terrain. Also, the results showed that the sampling resolution significantly affect the terrain roughness parameter. The very high sampling resolutions have smaller number of total sample points and eventually smaller roughness parameter value than the very low sampling resolutions. The study is particularly useful for wireless network designers who uses the terrain roughness parameter to determine the multipath fade depth based on International Telecommunication Union (ITU) detailed multipath fade model.**

Keywords—Terrain Roughness, Elevation Profile,Sampling Resolution, Roughness Parameter,Wireless Communication

I. Introduction

Nowadays, wireless communication systems are the dominant communication technology across the globe [1,2,3,4,5,6]. The advancements in the information and communication technologies have also attracted more users with more demand for wireless network resources at acceptable quality of service. This has place a running challenge on the wireless network services provides to take all necessary measures to handle all foreseeable issues that may affect the performance of the system.

Among other things, wireless signal is subjected to signal loss due to the prevailing atmospheric conditions [7,8,9,10,11,12,13] and obstructions in the signal path [14,15,16]. In addition, studies have shown that the path profile also affect the signal in some ways. As such, one of the ways the effect of the path profile has been studied is the terrain roughness index which is basically the standard deviation of the path elevation profile [17,18,19,20]. The terrain roughness index has been used to calculate multipath fading [21,22,23,24] and in some cases, it has also been used to optimize path loss models [25,26].

Generally, the terrain roughness index is determined from the path elevation profile. The availability of online path elevation profile tools has made it possible to generate the requisite elevation dataset and to compute the terrain roughness index of any given area. In this paper, the terrain roughness index of two selected sites in Nigeria is presented. The study used elevation profile sampled at different resolutions to compute and compare the terrain roughness index of the two locations. The values of the roughness index obtained

II. Methodology for Determination of Terrain Roughness Index from Elevation Profile Data

A. The Tool and Procedure for Collection of Elevation Profile Data

In this study, online elevation profile software is used to generate the elevation dataset which provides 512 elevation data points where each data point consists of distance from the starting point, elevation, latitude and longitude. For the study smaller resolutions are used rather than the 1º used by ITU which is too large and coarse for most studies. The sampling resolutions used in this study are elevation data captured at the following sampling rates: 10 Seconds, 30 Seconds, 1 Minute (60 seconds), 10 minutes (600 seconds) and 30 minutes (180 seconds) . In practice, one degree (1°) resolution is equivalent to a distance of 110 Km, and then, the selected resolution sizes are equivalent to distance of 305.556 m for 10 seconds resolution, 916.67 m for the 30 seconds resolution, 1833.33 m for the 1 minute resolution, 18333.4 m for the 10 minutes resolution and 55000.2 for the 30 minutes resolution.

The two sites studied have the following starting and ending coordinates (latitude and longitude);

Site 1: Starting coordinates (latitude and longitude) 5.26278, 7.26095 and ending coordinates (latitude and longitude) 5.80372, 6.81257.

Site 2: Starting coordinates (latitude and longitude) 6.47657, 7.48975 and ending coordinates (latitude and longitude) 5.81597 , 7.25327.

For each of the case study sites the online elevation profile software was used to capture the elevation profile data at a resolution of 5 seconds which is about a distance of 152.778 m between the adjacent data points. The required dataset resolutions are multiples of the 5 seconds sampling rate used in the data capture, as such appropriate multiples of the data capture sampling rate are used to obtained the required dataset resolutions for the study.

B. The Terrain Roughness Index Based On Elevation Data

The 512 different path profile data points capture are numbered from 0 to 511. Accordingly, in the path profile, there are a total of say N profile points (where N =5120 . Let n denote the n^{th} elevation profile point where n= 0,1,2,3,…N and let d_n denote the distance in Km and E_n denote the elevation in meters of the n^{th} elevation profile point from the first $(n = 0)$ elevation profile point. Hence, for a transmitter at elevation profile point n= 0 and a receiver at elevation profile point n = N, the path length d is given as;

$$d = d_N - d_0 \quad (1)$$

Where $d_0 = 0$. Let $\overline{\mathrm{E}}$ denote the mean elevation in meters of all the elevation profile points E_n where n = 1,2,3,…, N, hence;

$$\overline{\mathrm{E}} = \frac{\sum_{n=1}^{n=N}(E_n)}{N} \quad (2)$$

Let $S_{a(m)}$ be the terrain roughness index in meters which is the standard deviation (σ) of the path profile. Then [24,27];

$$S_{a(m)} = \sigma = \sqrt[2]{\left(\frac{\sum_{n=1}^{n=N}(E_n-\overline{\mathrm{E}})^2}{N-1}\right)} \quad (3)$$

III. Results and Discussions

The computations are conducted using the same set of sampling resolutions for each of the two case study sites. The elevation profile for the 10 seconds sampling resolution at the two sites is shown in Figure 1. According to the results, for the 10 seconds sampling resolution the total number of sample data point is for both sites 257. However, the average elevation for site 1 is 92.49520463 m while for site 2 is 230.680829 m. Also, the standard deviation of elevation profile for site 1 is 20.72572396 m while for site 2 is 78.00899535.

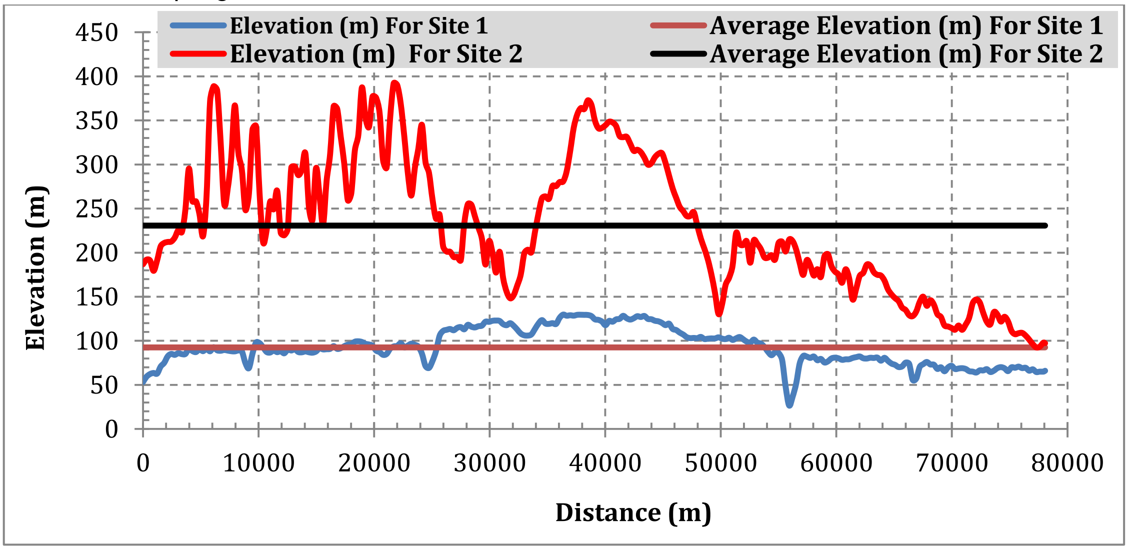

Figure 1: Elevation Profile for the 10 Seconds Sampling Resolution at the two sites

The elevation profile for the 30 seconds sampling resolution at the two sites is shown in Figure 2. According to the results, for the 30 seconds sampling resolution the total number of sample data point is 87 at the two sites. The average elevation for site 1 is 91.79364851 m and 228.6596009 m for site 2 while the standard deviation of elevation profile is 21.19887248 m for site 1 and 80.64182255 m for site 2.

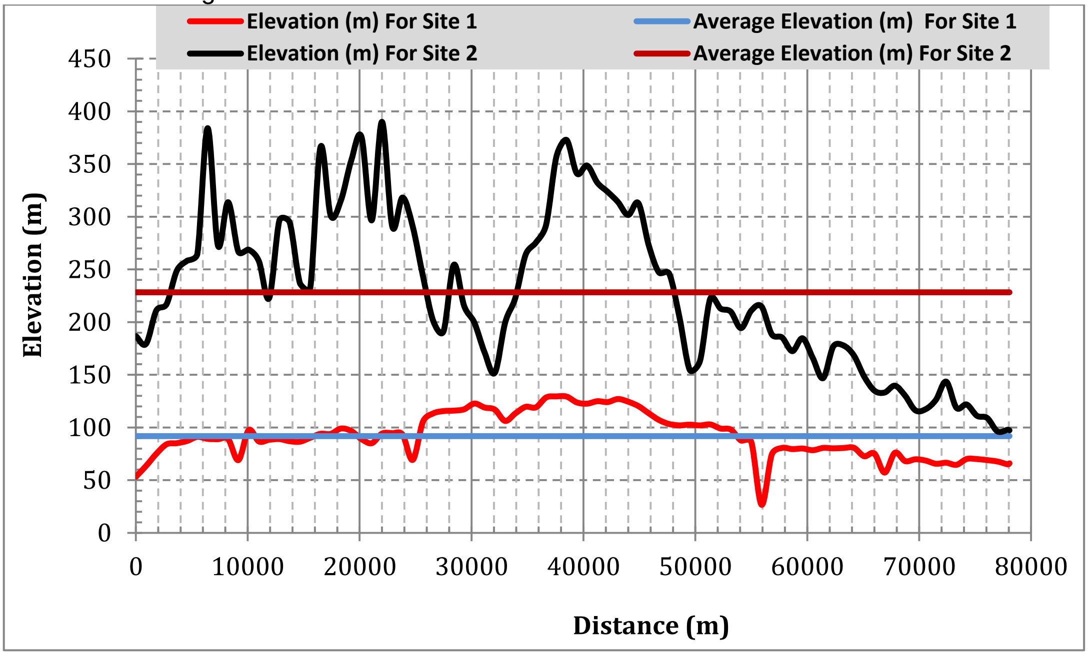

Figure 2: Elevation Profile for the 30 Seconds Sampling Resolution at the two sites

The elevation profile for the 1 minute sampling resolution at the two sites is shown in Figure 3. According to the results, for the 1 minute sampling resolution the total number of sample data point is 44 at the two sites. The average elevation for site 1 is 92.28782409 m and 228.2583462 m for site 2 while the standard deviation of elevation profile is 20.09251777 m for site 1 and 78.18758522 m for site 2.

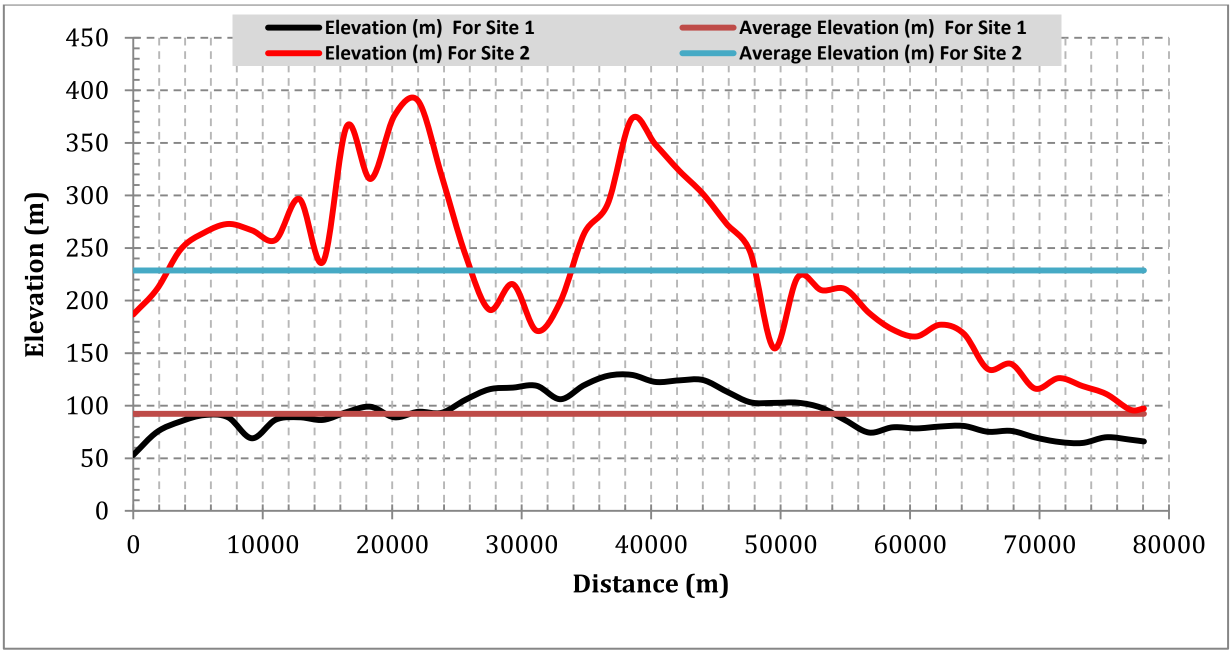

Figure 3: Elevation Profile for the 1 Minute Sampling Resolution at the two sites

The elevation profile for the 10 minutes sampling resolution at the two sites is shown in Table 1 and Figure 4. According to the results for the 10 minutes sampling resolution the total number of sample data point is 6 at the two sites. The average elevation for site 1 is 82.904725 m and 203.6280017 m for site 2 while the standard deviation of elevation profile is 27.75130019 m for site 1 and 88.6550656 m for site 2.

Table 1: Distance (m), elevation (m), total number of sample data points , average elevation (m) and standard deviation of elevation (m) for site 1 and 2 at 10 minutes sampling resolution

Data point Sample Number	Distance (m)	Elevation (m) For Site 1	Elevation (m) For Site 2
1	0.000	53.167	186.789
2	18332.490	99.000	315.662
3	36664.970	128.456	292.412
4	54997.460	86.221	210.955
5	73329.950	64.585	118.660
6	78065.840	66.000	97.291
Total Number of Sample Data points		6	6
Average Elevation (m) for site 1 and 2		82.905	203.628
Standard Deviation of Elevation (m) for site 1 and 2		27.751	88.655

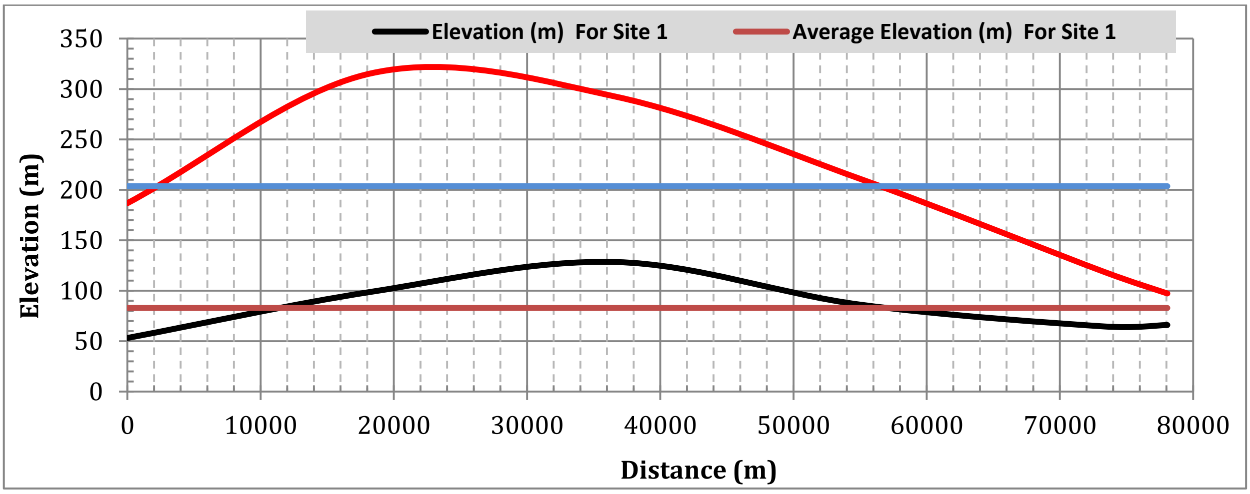

Figure 4: Elevation Profile for the 10 Minutes Sampling Resolution at the two sites

The elevation profile for the 30 minutes sampling resolution at the two sites is shown in Figure 4. According to the results for the 30 minutes sampling resolution the total number of sample data point is 3 at the two sites. The average elevation for site 1 is 68.46251333 m and 165.0116033 m for site 2 while the standard deviation of elevation profile is 16.66408387 m for site 1 and 59.87958926 m for site 2.

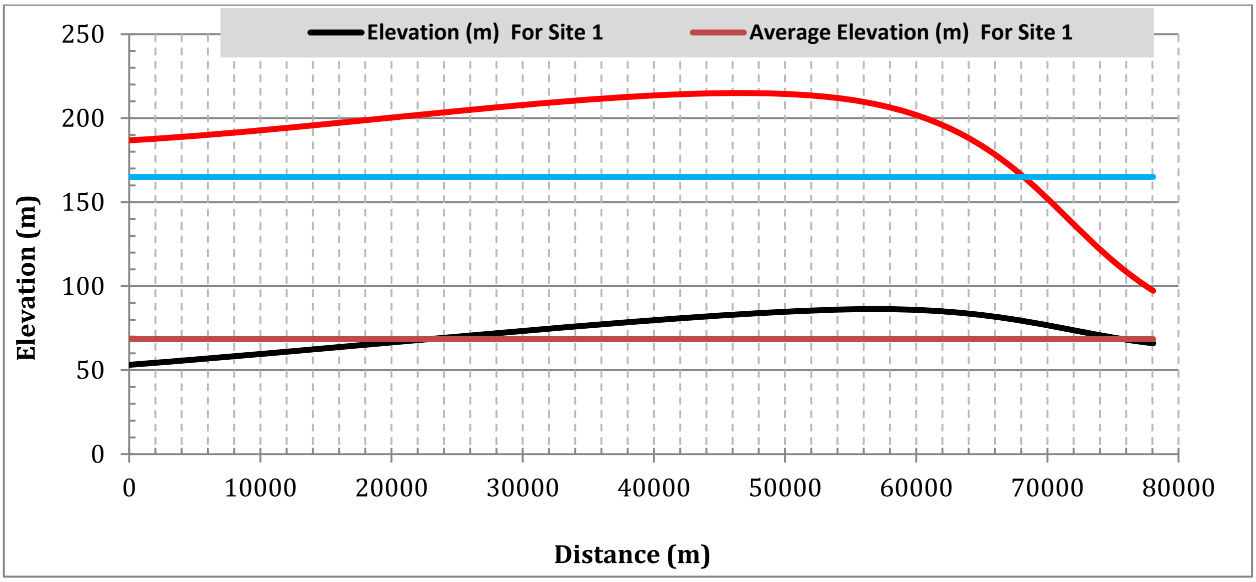

Figure 5: Elevation Profile for the 30 Minute Sampling Resolution at the two sites

The summary of the standard deviation of elevation , average elevation (m) and total number of sample data points for all the sampling resolutions at the two sites are given in Table 2 while the plot of the standard deviation of elevation for the five sampling resolutions for the two sites are given in Figure 6. In all, site two has higher elevation , higher average elevation and most importantly higher standard deviation of elevation than the site 1. The graph plot of elevation in all the sampling resolutions all show that site two has higher elevation that also varied so much from the average elevation value and this is why site two has higher standard deviation of elevation than site 1. Based on the results, site 2 with average terrain roughness parameter value of 77.071 m is very rough terrain whereas site 1 with average terrain roughness parameter value of 21.287 m is smooth terrain.

Furthermore, the results show that the sampling resolution affect the value of the terrain roughness parameter. Specifically, at very high resolutions, the number of sample points reduces significantly and hence the deviation from the mean elevation reduces as well which give rise to smaller roughness parameter.

Table 2 Summary of the standard deviation of elevation , average elevation (m) and total number of sample data points for all the sampling resolutions at the two sites

Parameter Name	10 Seconds	30 Seconds	1 Minute	10 minutes	30 minutes	Average Value For All Resolutions
Standard Deviation of Elevation (m) for site 1	20.72572	21.19887	20.09252	27.7513	16.66408	21.287
Standard Deviation of Elevation (m) for site 2	78.009	78.18759	80.64182	88.65507	59.87959	77.071
	10 Seconds	**30 Seconds**	**1 Minute**	**10 minutes**	**30 minutes**	
Average Elevation (m) for site 1	92.4952	91.79365	92.28782	82.90473	68.46251	85.589
Average Elevation (m) for site 2	230.6808	228.2583	228.6596	203.628	165.0116	211.248
	10 Seconds	**30 Seconds**	**1 Minute**	**10 minutes**	**30 minutes**	
Total Number of Sample Data points for site 1	257	87	44	6	3	79.400
Total Number of Sample Data points for site 2	257	87	44	6	3	79.400

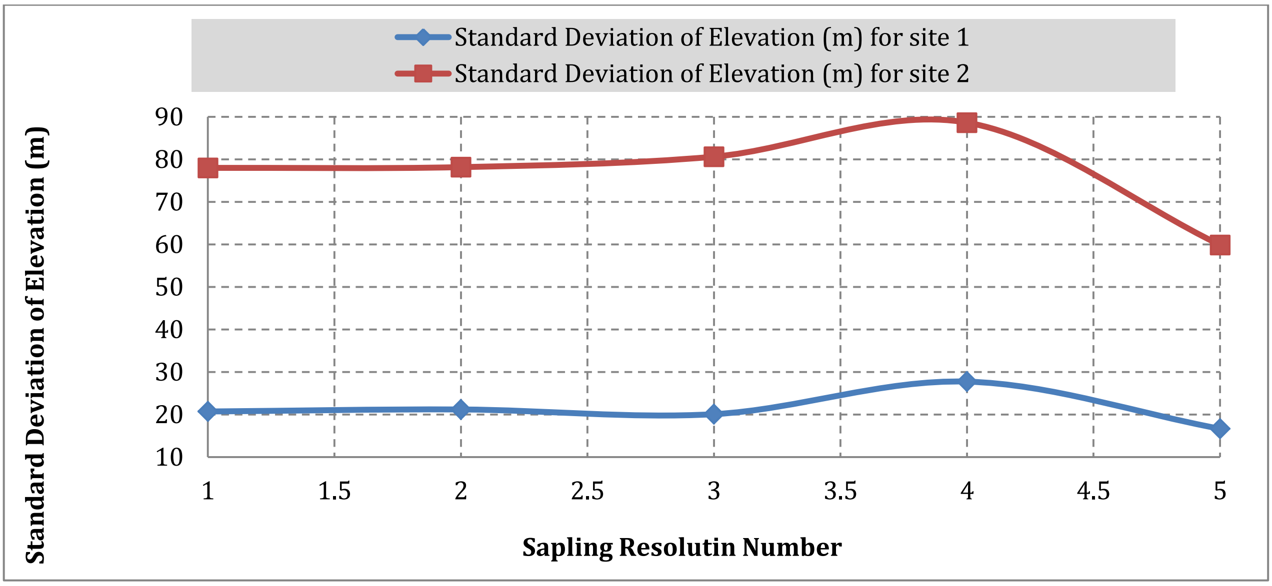

Figure 6 The standard deviation of elevation for the five sampling resolutions for the two sites

IV. Conclusion

Determination of the roughness parameter for two case study sites in Nigeria is presented. An online elevation profile software tool is used to obtain the elevation profile data ate the two case study sites considered in the study. Five different sampling resolutions were used on the elevation profile data at the two sites and the average elevation and standard deviation of elevation were determined for each of the sampling resolutions. The five different sampling resolutions are; 10 Seconds, 30 Seconds, 1 Minute (60 seconds), 10 minutes (600 seconds) and 30 minutes (180 seconds). The results showed that the sampling resolution significantly affect the terrain roughness parameter. The very high sampling resolutions have smaller number of total sample points and eventually smaller roughness parameter value than the very low sampling resolutions. The study is particularly useful for wireless network designers who uses the terrain roughness parameter to determine the multipath fade depth based on ITU detailed multipath fade model.

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