38-GHz POINT-TO-POINT WIRELESS RADIO LINK PREDICTION BASED ON PROPAGATION AND TERRAIN PATH PROFILE IN RIYADH

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This paper presents a 38GHz point-to-point wireless link prediction study using terrain profile information to be used for a foreseen planning and design in a newly constructed area. Point-to-point link simulations were made using Longley-Rice model in the metropolitan area of Riyadh, Saudi Arabia, which can be considered as an arid region. Several technical parameters and metrics are investigated to study the link status and its availability.

The results showed that the optimum transmitter antenna height for the link is 44 m, and the average link availability for the positive fade margin is approximately 99.997%.

Keywords: propagation prediction, antenna height, fade margin, path inclination, link availability

1. Introduction

Radio communication links, including terrestrial and satellite types, operating at millimeter frequency bands, such as 38GHz, provide large bandwidth and then high capacity for contemporary applications. These applications may be supported via the next communication generation (5G) using telecommunication technologies including mobile, fixed, and satellite that are intended to be integrated [1], [2]. Since running actual field measurements is expensive and time consuming, simulation is necessary to study wireless point-to-point link (in fixed mode) as a broadband terrestrial solution, where it is a common tool to evaluate different applications and systems in the communication environment. Radio planning and prediction help in designing reliable wireless broadband point-to-point solutions to meet expected performance. Although, there are several propagation models used for outdoor propagation in different frequency spectrum band [3] [4], there are three widespread radio propagation standards used for creating radio environment maps; the Longley-Rice Irregular Terrain Model (ITM) point-to-point, Okumura-Hata with diffraction and International Telecommunications Union-Radiocommunications (ITU-R) P.1546 propagation models [5], [6]. In spite of the accuracy of the models can be about 2 to 3 dB and

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standard deviation 5 to 6 dB, if we exclude multipath effect, the ITM model is the best choice in case of terrain data profile is available [7]. It is worth to mention that ITM model is much like ITU-R P.452 model but ITU-R 452 includes some local clutter losses computations based on land cover classification data, otherwise, both models can be supposed to be quite analogous [8].

The presented paper predicts a point-to-point wireless link behavior based on irregular terrain path profile in Riyadh city using Radio Link Longley-Rice simulation model. This prediction study tries to support the foreseen measurements in the modern King Abdullah Financial District (KAFD) area, which is currently under construction, to be connected with surrounding facilities and vital entities. Longley-Rice model has been adopted as a standard by the Federal Communications Commission (FCC), and it is an empirical model used to predict atmospheric attenuation which realistically is extremely difficult to mathematically expressed [9]. It covers wide spectrum frequency bands in the range 20MHz-40GHz and for path lengths about 1-2000 km [10] and it can be utilized in wide variety of terrain profiles. This model takes into account the path geometry of terrain and the refractivity of troposphere to calculate transmission path loss and uses geometrical sight in conjunction with the two-ray model in order `to evaluate of power signal strength. Therefore, Longley-rice model consists of most of the relevant propagation models which include diffraction over multiple knife, rounded edge and over irregular terrain; atmospheric attenuation and atmospheric stratification; precipitation models; tropospheric propagation models; polarization effects; specific terrain data, various climatic areas, etc. [9], [11].

In a recent study [12], it is found that ITM can differentiate between areas where terrain interacts with the first Fresnel zone and where it does not. Also, this study [12] stated that quality of the terrain database effects on the attenuation prediction and elevation angle. In another research work [13], the authors used the Longley-Rice model (ITM) with worldwide Shuttle Radar Terrain Mapping (SRTM) 3-arc-second data which belongs to the National Aeronautics and Space Administration (NASA). They incorporated single knife-edge and double knife-edge models and produced acceptable results compared to experiments findings in most circumstances. However, this study [13] found that at very long paths from the transmitter the Longley-Rice model is overestimating diffraction attenuation, especially in the VHF TV frequency band. In [14] and [15], Deygout, Epstein-Peterson and Giovaneli methods are approximating multiple knife-edge diffraction using geometrical constructions. All the three methods are classic well-established models and provide acceptable consequences [14] [15]. It is found that the relative accuracy of these three methods is comparable with studies of [13] and showed that the three methods are more precise than the ITM model over large distances including diffracting obstacles in the VHF-TV frequency band.

The authors in [16] showed that the ITM does not work quite well in the line-of-sight (LOS) scenario and in the early diffraction range. Moreover, the ITM does not use more detailed terrain information as other more sophisticated models do. Further, previous evaluations of P.1546 and the ITM [17] have shown that ITU P.1546 and ITM models are valid for path loss predictions above and below 1 km. On the other hand, a study of Full-3D ray-tracing simulations in open areas over irregular terrain [18] found that it should consider three reflections and two diffractions as the optimum setup while performing ray-tracing simulations in open areas over irregular terrain. Additionally, in [19], the deterministic ITM as well as the empirical ITUR-P1546-5 Models have been studied for coverage calculations, and many advantageous and disadvantageous aspects have been reported.

Therefore, Longley-Rice or ITM model is considered the common broadly known overall purpose path loss model. It utilizes supplementary information from public geographic datasets and considers the excess loss from free space by taking into account knife-edge diffractions at terrain obstacles, losses due to the earth curvature, obstruction losses, urban losses and scatter of tropospheric [20]. However, Longley-Rice model doesn't take into account the buildings effects and multipath phenomena. The area of Saudi Arabia can be considered as an arid climate region in which the precipitation rate is lower than the evaporation rate. In this area, for longer distances, clear air fading phenomenon, as well as multipath, may play a leading part in link reliability [21]. Therefore, much longer distance may be achievable in the arid region, giving rise to higher reliability and lower cost. In our simulation, we assumed that the required reliability is 70%.

The rest of this paper is organized as follows. In section 2, the simulation scenario including simulation environment, path and link parameters are described in detail. Simulation procedures, results, and discussions are presented in section 3. Finally, we conclude the paper in section 4.

2. Simulation scenario

2.1 The simulation environment

The point to point link simulation has been performed in this paper using the Radio Coverage tool [22] which is based on the Longley-Rice model. It includes an approximately 1 Tbyte digitized worldwide terrain database. This database is based on the NASA Shuttle Radar Terrain Mapping (SRTM) data along with other sources. The accuracy of the data is about 100 meters in Saudi Arabia. Additionally, other databases provide land cover information and population information. The land cover data shows whether a spot is covered by trees or urban area, for example, so as to increase the accuracy of the propagation model. Whereas, the population data is obtained from publically available United Nations information, and allows estimating the population within the desired areas, however, the population data has not been considered in our work. For setup parameters, we select the transmitter location first, and this can be done by inserting the geographic coordinates of the site (latitude and longitude). In order to get coverage of the transmitter, we set the value of the transmitter power, select the antenna type, the utilized center frequency, elevation of the antenna above ground, and the maximum transmitter range. Also, for point to point link prediction, more information is inserted into the program. It includes transmitter and receiver antenna heights and gains, transmitter power and line loss, receiver line loss and sensitivity, and the required reliability. The main outcome of this program is the path loss and received power.

2.2 Path parameters

The proposed path link (point-to-point wireless radio) scenario is assumed to be in Riyadh metropolitan area. The first point is situated at latitude and longitude of 24.764135°N and 46.641083°E, respectively, which is location of the KAFD to be as a transmitter base station (BS), whereas Al-Imam Mohammad Ibn Saud Islamic University (IMSIU) Tower is adjusted as a receiver point at 24.805970°N and 46.699609°E, as can be seen in Figure 1. The path length hop between KAFD and IMSIU Tower is 7.52 km.

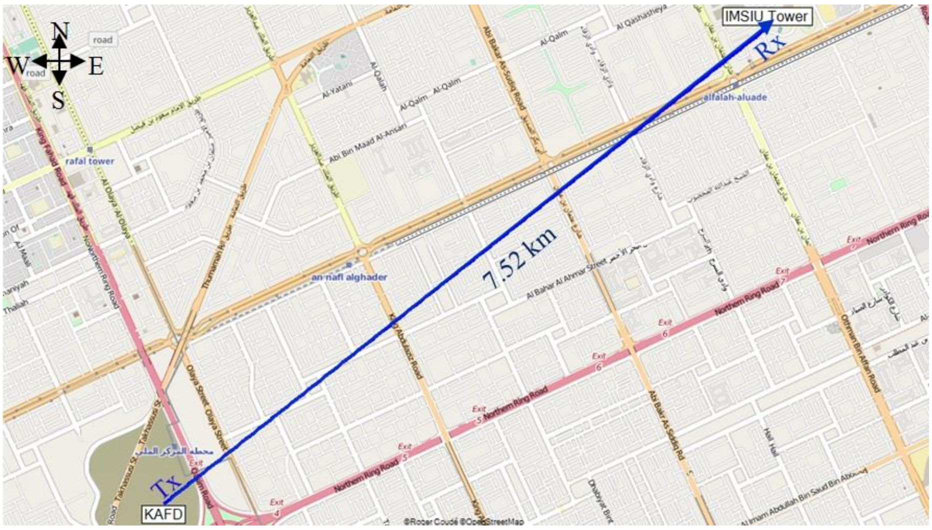

Fig. 1. The geographical area of the proposed point-to-point radio link between KAFD and IMSIU in Riyadh city.

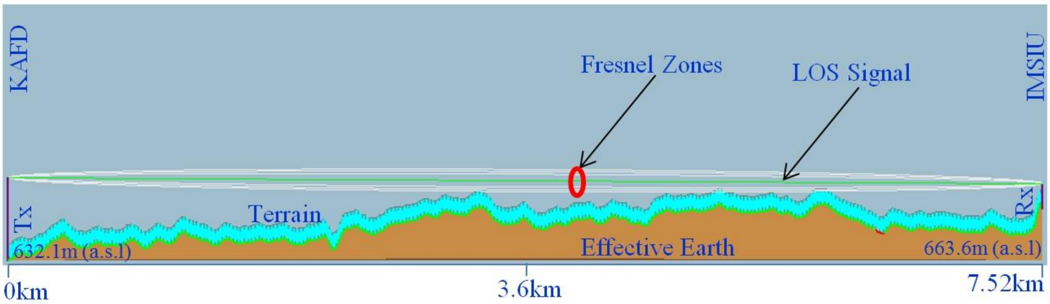

Fig. 2. Terrain path profile (elevation data) of microwave LOS radio link of KAFD and IMSIU Tower.

Path profile along the link is illustrated in Figure 2 using Radio Link tool [22]. The terrain profile for the path determines the ground elevation by 632.1 m and 663.6 m above sea level (a.s.l) for KAFD and IMSIU, correspondingly. For the path clearances, the Fresnel zone radius, r, is obtained to be 3.86 m, and 80% of Fresnel zone radius is 3.09 m. For a good link, clear Line of Sight (LOS) is required to maintain enough strength of the signal. Normally, a percentage of blockage of 20% Fresnel zone can cause slight loss to the link. But, further than 40% blockage, signal loss will be substantial. The formula used for determining the radius of the widest point of the Fresnel zone (m) is [23]:

$$r = 17.32\sqrt{\frac{d}{4f}} \tag{1}$$

where *d* is the distance, km, between the transmitter and receiver antennas and *f* is the carrier frequency, GHz.

2.3 Link parameters

The link budget by this ITM model takes into consideration all significant losses except multipath and building losses. The total losses in addition to free space loss include urban loss, obstruction loss and statistical losses. Table 1 lists the main parameters of the 38GHz KAFD-IMSIU link which are inputs to ITM model. In this table, it is indicated that the KAFD transmitter uses a directional antenna with a gain of 17 dB and radiates a power of 20 watt (43.01 dBm), while the receiver sector antenna at IMSIU has a gain of 2 dB. The power radiated by the transmitter antenna is 20 watt, and the receiver has a threshold of -113.02 dBm (0.5 μV). The path length link (7.52 km) is with a required link reliability of 70%. In addition, the azimuth angles for the Tx and Rx antennas are adjusted at 70° and 225° for KAFD and IMSIU antennas, respectively.

Table 1

The key KAFD-IMSIU link parameters

Description	Unit	Value
Radio frequency	GHz	38
Power transmitted	dBm	43.01
Transmitter latitude	º	24.764135
Transmitter longitude	º	46.641083
Transmitter ground elevation (a.s.l)	m	632.1
Transmitter antenna gain	dBi	17
Transmitter antenna height	m	15-70
Transmitter antenna type	-----	directional antenna
Transmitter antenna azimuth angle	º	70
Transmitter line loss	dB	3.0
Receiver latitude	º	24.805970
Receiver longitude	º	46.699609
Receiver ground elevation (a.s.l)	m	663.6
Receiver antenna height	m	15
Receiver antenna type	------	sector antenna
Receiver antenna azimuth angle	º	225
Receiver antenna gain	dBi	2
Receiver sensitivity	dBm	-113.02 dBm
Receiver line loss	dB	0.5
Distance between Tx and Rx	km	7.52
Required reliability	%	70

3. Simulation procedures, results and discussions

The coverage prediction offers benefit for recognizing suitable locations for the transmitter nodes and relays in the intended area. It is also possible to use the coverage area for predicting the power level in the area and is more usually used in link/network planning. The coverage area resulted by the directional antenna has been plotted in Figure 3 (a and b), and the azimuth angle of the transmitter antenna has been adjusted using the trial and error method until getting a good signal strength at the receiver antenna. Where, the antenna azimuth offered the highest gain of the transmitter antenna at IMSIU receiver at an angle of 70°. In Figure 3, the straight line represents the path between the Tx and Rx antennas. The green color indicates to the strong signal strength (its shape looks like the radiation pattern of Yagi-Uda directional antenna), while the yellow color for the coverage area represents the weak signal. In this figure, the strong signal field is 63.8 dBμV/m and the weak signal field is 53.8 dBμV/m, with a strong signal margin of 10 dB. From the statistics, the weak signal covers an area of 193 km^2, whereas the strong signal covers 106 km2. In Figure 3, it can be noted that the power level of the geographical area located in the peak points of the main lobe of the radiation pattern for the transmitted antenna (Uncovered area) has a very weak

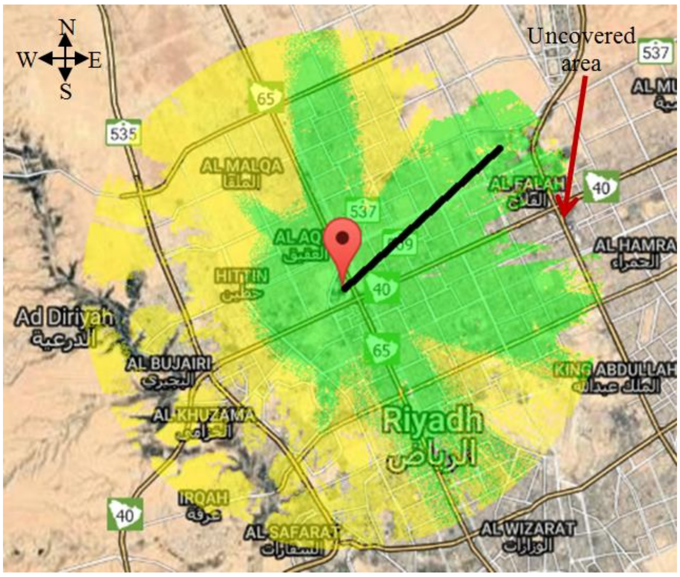

Fig. 3. Directional antenna coverage prediction with resolution of 30.0 m/Pixel and antenna azimuth angle of 70º.

power level or it is under outage, and this is due to the fact that the area is obstructed by high-level terrain area as well as this area has a ground elevation (a.s.l) less than the transmitted point by 30m. In addition to this, beyond the horizon distance, both of the direct and reflected signals are obstructed by the curvature of the Earth.

When the 38GHz KAFD-IMSIU link has been initiated by setting a fixed value for the IMSIU antenna height at 15 m and varying the KAFD antenna height from 15-70 m by 1 m step, the power signal strength, dBm, has been obtained. The received signal power strength (RSPS) is plotted in Figure 4.

In Figure 4, it can be noted that signal power strength fluctuates with transmitter antenna height and the link outage will occur when the antenna height is less than 21 m. The apparent very small fluctuation in signal power strength is due to the fact that the radius of Fresnel zones is small because of the receiver antenna is still not high enough. At this point, there is no clear LOS between KAFD-IMSIU antennas and the received signal strength becomes less than the receiver sensitivity, and then the receiver cannot capture the signal from the transmitter. After 21 m transmitter height, the ratio of Fresnel zone earth clearance to Fresnel zone radius starts to increase till it becomes more than 60%, where the radio path is said to be “Clear LOS” and no diffraction loss experiences. In Figure 4, it can be also seen that the stronger received signal power (RSPS) is about 88.08 dBm at an antenna height of 44 m.

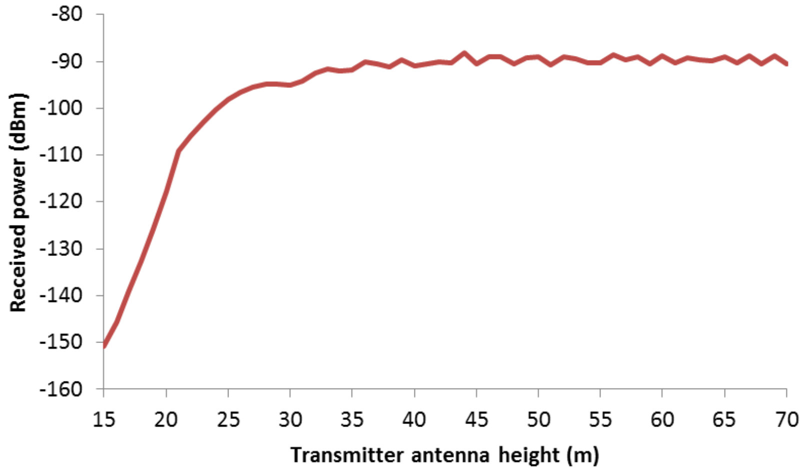

Fig. 4. The received signal power strength versus transmitter antenna height

The cumulative distribution function (CDF) of the received signal is shown in Figure 5. It can be noted that nearly 16% of the received signal power strength (RSPS) achieves a fade margin of 10 dB (-103 dBm). For an illustration, in Figure 5 the X value (X: -103) represents the received power in dBm, while the Y value (Y: 0.1607) indicates to the percentage values (16.07%) which are less than the received power -103 dBm. Whereas 60% of the RSPS (approximately -90 dBm) has about more than 23dB fade margin. In addition, 12.5 % of the results do not satisfy the receiver threshold, so this percentile of RSPS is less than the receiver sensitivity -113.02 dBm.

In the irregular terrain such as our link under study, the path inclination is considered a significant factor affecting the received signal. If h_t denotes to the total height (m) of the transmitter antenna, including the elevation above sea level (a.s.l) and the earth terrain level at the transmitter site. Also, if h_r is the total height (m) of the receiver antenna, including the elevation above sea level (a.s.l) and the earth terrain level at the receiver site, then the path inclination can be expressed as in (2) [24] [25]:

$$\varepsilon_p = \frac{h_t - h_r}{d} \tag{2}$$

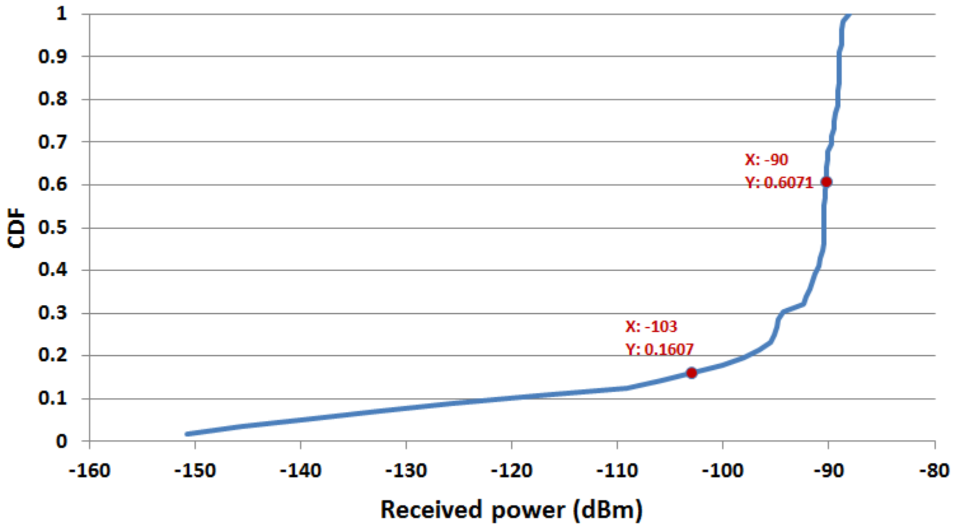

Fig. 5. The cumulative distribution function (CDF) of the RSPS.

where d is the distance in km. From (2), it can be concluded that the path inclination can be zero when the path link is horizontal, i.e.,

$$h_t = h_r \tag{3}$$

This occurs when h_t =15.5 m in our case. On the other hand, the maximum inclination is at maximum antenna height difference of 55 m (h_t=70m) which is 7.3 mrad, as shown in Figure 6. At the recommended antenna height by this study, the path inclination equals to 3.86 mrad. As it can be extracted from (2), as the difference between the antennas height increases as the path inclination also increases. But, the inclination is inversely proportional with the distance between the antennas.

On the other hand, downtilting angle is an important factor in point-to-point link, it can concentrate (increase or decrease) the coverage area as per other system parameters. The formula for calculating the antenna tilting angle is expressed by (4) [26]:

$$\theta = \tan^{-1}\left(\frac{h_t - h_r}{5280\,d}\right) \tag{4}$$

where d is the distance between Tx and Rx, and h_t and h_r are the height of transmitter and receiver antennas, respectively. The angle is negative when h_t is smaller than h_r, and positive when h_r is smaller than h_t. In Figure 6, it is found out that the difference between each increment in antenna height by one meter corresponds to increment by tilt angle by 0.07-0.08°, and the difference value depends on the distance between the two antennas, i.e., the increment in tilt angle becomes small if the distance between the two antennas is large and vice versa. For example, in our KAFD-IMSIU link, the parameters d, h_t and h_r are 7.52 km, 40 m and 15 m, respectively, the tilting angle is 0.191° (as shown in Figure 6, X: 40m for the transmitter antenna height and Y: 0.191° for the downtilting angle). However, if, for instance, d was 500 m, the angle would be 2.862° (out of Figure 6 range). Additionally, it can be noticed that the downtilting angle line/curve is not perfectly straight with the variable transmit antenna heights, and there is a fluctuation of 0.01-0.02° between each two consecutive transmitter antenna heights. From Figure 6, it can be noted that downtilt angles are small due to the fact that separated distance is an average and the path inclination is small.

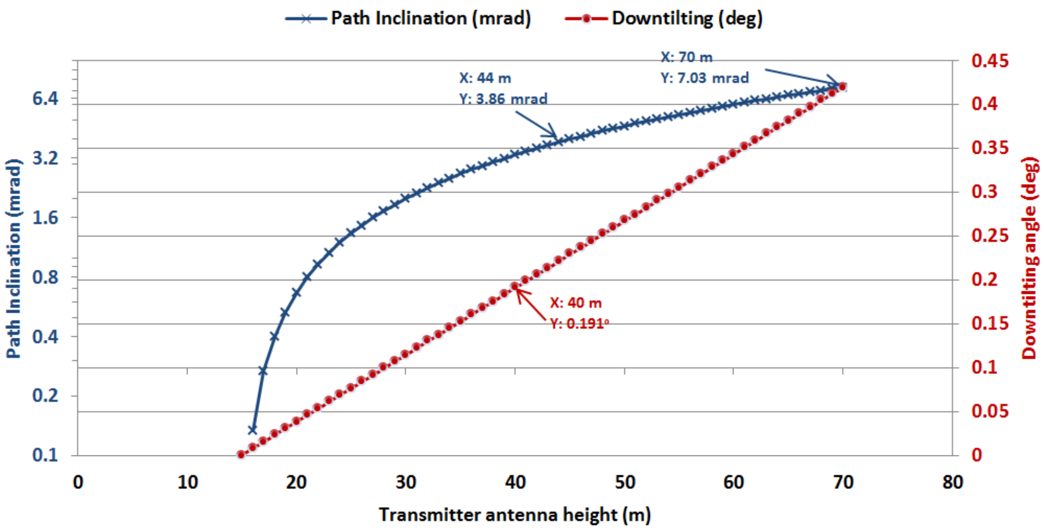

Fig. 6. The path inclination and downtilting angle versus transmitter antenna height for the KAFD-IMSIU Link

For the fade margin, it is derived from the link budget calculation, and this parameter can be then used to find the link availability in the terrestrial microwave radio link. In this context, the link availability is the main design parameter for many fixed terrestrial microwave radio links. When the fade margin is negative, this means that the signal is received under the targeted bit error rate (BER), or outage may take place. The fade margin, FM, can be calculated as [27]:

$$FM = RSP - R_S \tag{5}$$

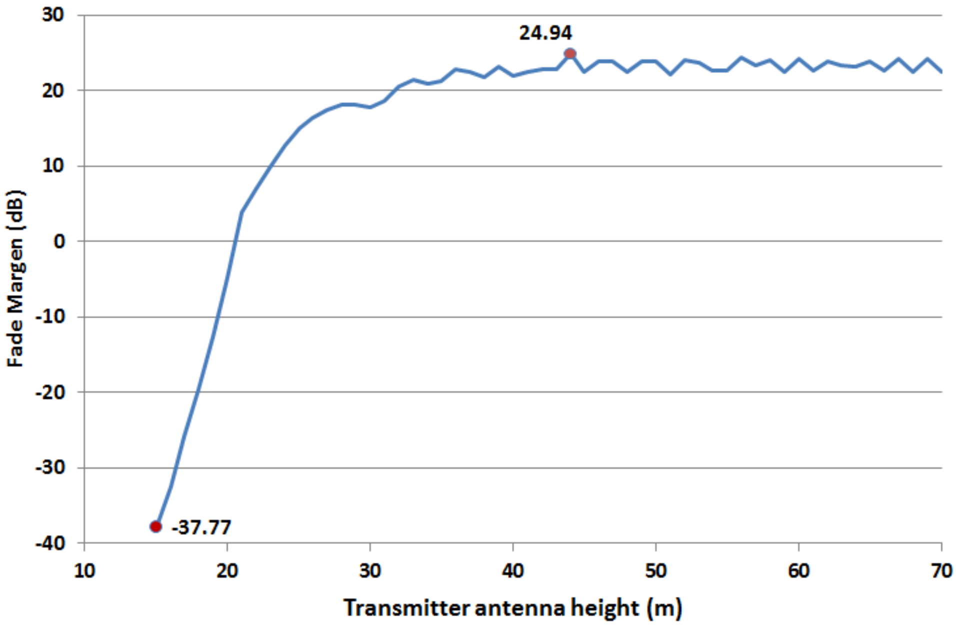

Fig. 7. The fade margin versus transmitter antenna height for the KAFD-IMSIU link.

where RSP is the received signal strength and R_s is the sensitivity of the receiver. Greater fade margins mean less repeated occurrences of minimum performance levels (low BER and less outage times). To realize highly reliable link, a minimum fade margin should be 20-30 dB, however, in case of fade margin of less than 10 dB, there are possible schemes/options to improve upon this figure which can include using antenna with higher gain, increasing the elevation angle, or adding a repeater to the path. In Figure 7, the fade margin corresponding to the transmitted antenna height is illustrated. It can be seen that the maximum fade margin is approximately 25 dB which is at a transmitter antenna height of 44 m. Whereas, the minimum margin, about -38 dB, is at the height of 15 m, where there is no possible connection.

The link availability has been also predicted in terms of the percentage of time, P_w, that fade depth is exceeded in the average worst case/month using Barnett-Vigants model which is expressed as follows [28].

$$P_W = \left(\left(6\times10^{-7}Cfd^3\right)10^{-FM/10}\right). \quad (6)$$

Where C is the geoclimatic factor and it equals to 0.25 for good propagation conditions in dry climates such as in Riyadh city, f is the carrier frequency, GHz, d is the link distance, km, and FM is the fade margin, dB. The link unavailability versus transmitter antenna height is plotted in Figure 8.

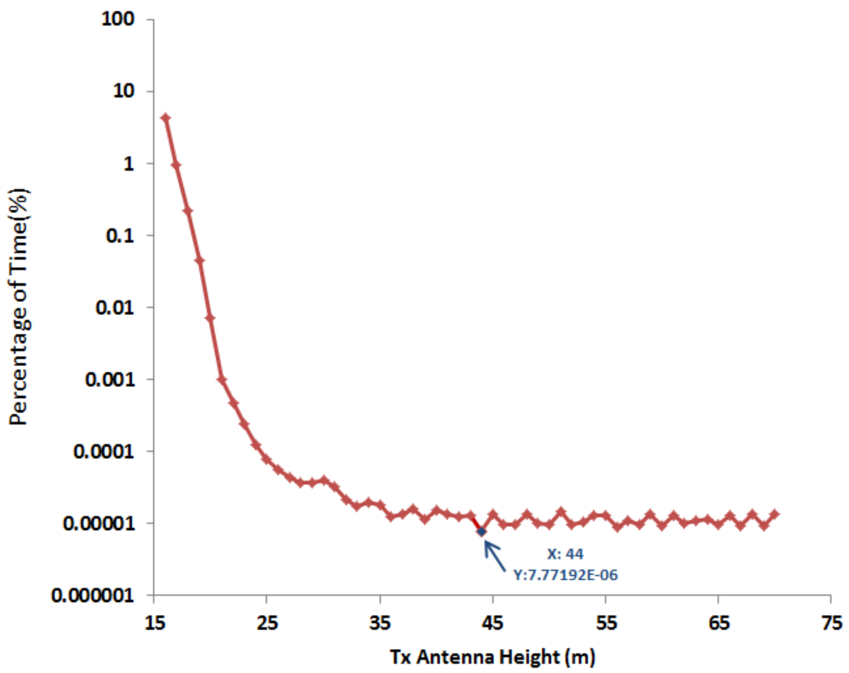

Fig. 8. The link unavailability versus transmitter antenna height for the KAFD-IMSIU link.

It can be noted that the link availability is 99.999% (this value can be calculated by subtracting the percentage of time (unavailability of 7.77192 x 10^{-6}) in Figure 8 (Y value) from the unity) at 44 m antenna height of the transmitter which can be considered an optimum height and it can be said that the link is reliable at this point. On the other hand, the link availability is negative and unreliable at all with using lower antenna heights. From the results, it has been found that the average link availability for the positive fade margin is approximately 99.997%.

4. Conclusions

This paper presented a prediction study to support the future planning of the expected measurements in the modern KAFD area under construction to be connected with surrounded vital places. A 38GHz KAFD-IMSIU link has been initiated using Longley-Rice model with irregular terrain profile. Coverage prediction and technical parameters including received power strength at the IMSIU receiver have been obtained and analyzed. It has been shown that the antenna height has a significant effect on the received signal and the entire system performance. The recommended transmitted antenna height for the KAFD-IMSIU link is 44 m and the maximum fade margin is approximately 25 dB. The overall results indicated to that as transmitter antenna height (path inclination) increases tilting angles increase, while obstruction loss and urban loss decrease.

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