Home

SIGNAL STRENGTH PREDICTION IN THE VHF BAND IN THE EASTERN REGION OF SAUDI ARABIA

Maitham Al-Safwani
Saudi ARAMCO
Dhahran Saudi Arabia
safwanmm@aramco.com.sa

Asrar U. H. Sheikh
Department of Electrical Engineering KFUPM Box 5038, Dhahran 31261
Saudi Arabia
asrarhaq@kfupm.edu.sa

Abstract
Most of radio signal strength prediction models are based on the measurements in temperate climates. A measurement campaign was undertaken in the Eastern Region of Saudi Arabia. This area consists of desert and the climate is hot and humid due to the presence of sea. The measurements were taken in the area around three base stations - Ras Tanura, Abqaiq and Dhahran. The results are used to model path loss in desert environments. The currently available models are modified. The modified models are useful in predicting signal strength in hot and humid climates.

I. Introduction

It is well known that the propagation loss of radio waves is related to frequency, distance, antennae heights, the Earth's curvature, intervening terrain features and atmospheric conditions including humidity, water vapour pressure and temperature. For radio system planning and spatial reuse of frequencies, prediction of propagation loss with reasonable accuracy is important. When frequencies are spatially reused, co-channel becomes important [1-2].
Okumura et al conducted measurements in Japan that lasted more than a decade and produced a series of graphs on radio propagation using frequencies in the range of 150 to 2000 MHz, distances between 1 to 100 Km, and base station antenna heights between 30 to 300m [3-5]. He measured signal strength in areas classified as urban, suburban and open [5].
These curves, very large in number, were tedious to use in designing systems. To alleviate this difficulty, Hata converted Okumura's basic path loss measurements into empirical relations. The basic formula is for use in urban area built on quasi-smooth earth. For suburban and rural areas additional relations are given in the form of correction factors [7]. The Hata's empirical results were later modified to include so-called Epstein-Peterson multiple obstacle diffraction loss model [8]. Hata's empirical relations predicted approximately 6dB increase in the signal level for every doubling of the base station antenna height. However, Lee showed that the 6dB/octave rule of base station antenna height applies only to the flat terrain and is not valid over irregular terrain [9].
In Japan, where Okumura et al conducted measurements, the terrain is radically different from that existing in the Eastern Province of Saudi Arabia. Chicon, for example, showed that in Germany a different model, Urban-Macro model, gives more accurate estimation of signal strength in 1 km^2 area compared with that obtained from Okumura-Hata or Cost-Walfish-Ikegami model [3]. Thus, it is believed that the Okumura-Hata model as such cannot be applied to the terrain of the Eastern Province of the Kingdom of Saudi Arabia is in question and a new model is needed. A series of measurements were taken in the province for model development.
The areas around three VHF radio base stations located in Ras Tanura, Abqaiq and Dhahran were selected for the signal strength measurement campaign.

II. Measurements and Results

The test equipment consists of VHF radio installed at three selected locations, a mobile equipped with a VHF radio, communication test equipment HP-8920 and a Global Positioning System (GPS) receiver. All the components of the test equipment were calibrated. The transmitter and receiver were aligned according to normal industry standards and procedures. The position accuracy for Global Positioning System (GPS) receiver was between 1 and 5 meters. The signal strength measurements were taken over several months and at different times. They were recorded using Communication Test Equipment (HP-8920), installed in a mobile with 1.5m antenna height. In addition, a commercial Global Positioning System (GPS) receiver was used to obtain the Cartesian coordinates at each test point and to find its elevation above sea. The test equipment setup is shown in Figure 1.
A mobile radio transmitter, installed in the test vehicle, was used to activate the base station repeater transmitter. During the repeater transmitter's hold time, signal strength measurements were taken. At each location, the received signal level, the elevation its location coordinates were recorded.
The time, date and weather conditions (i.e., temperature, pressure, vapor pressure, and relative humidity) were recorded for each test point. In addition, the signal strength level was measured at every test point over different two days. These measurements were taken to determine the effect of changes in the atmospheric conditions. The line-of-sight distance to the transmitter, azimuth and the elevation above sea level were obtained for each test point using the EDX SignalPro program.

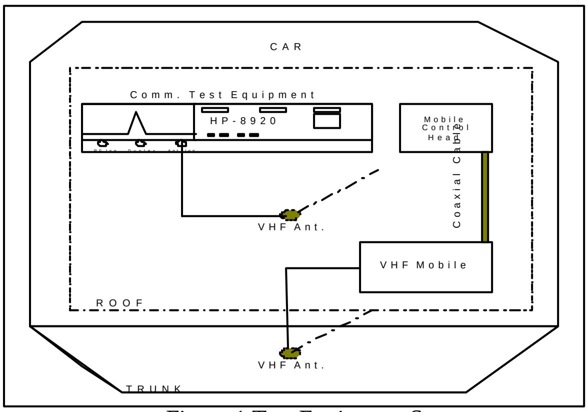

Figure 1 Test Equipment Setup

A. Description of Measurement Campaign Area

Abqaiq is located in the southern part of the Eastern Province, some 50km away from the Arabian Gulf. The average terrain is approximately 100 meters above the sea level. The high elevation of Abqaiq area enhances the signal level particularly when the receiver is on the Abqaiq-Dhahran highway.

Ras Tanura is a city in the Eastern Saudi Arabia and is a seaport on the Arabian Gulf. It has a residential area, vegetations, oil refinery and storage tanks. The average height of buildings in this area is about 4 meters and wood is used in most of building walls. The terrain surrounding Ras Tanura can be classified as quasi-smooth and is composed of sporadic bushes. Figure 2 shows in some detail the topographical details around Ras Tanura. Most of the measurements readings were taken around Ras Tanura because of (a) possibility of anomalous propagation (b) many inland routes provide measurements points and (c) likelihood of interference.

Figure 2 Area Covered During the Field Measurements

The terrain of Dhahran area is irregular and composed of high wedges and hills; it has residential areas, farms and foliages. The average height of Dhahran buildings is more than five meters above the ground. This area is irregular and composed of large number of sand dunes and hills. It exists at a high elevation at this area is 4 meters and most of building walls are made from wood.

B. Roads Selected in the Coverage Campaign

The signal strength were taken in Abqaiq, Ras Tanura and Dhahran area on Abqaiq-Dhahran Highway, Saihat-Ras Tanura Road, Juaymah-Jubail Road, King Fahd International Airport (KFIA) Road, Abu Hadriyah Road and Dhahran-Safwa Road. The elevation of Abqaiq-Dhahran highway decreases going away from Abqaiq then increases when we approach Dhahran area as shown in Figure 3. There are a small number of buildings and trees located on Abqaiq-Dhahran roadsides. The selected roads at Ras Tanura area are shown in Figure 4.

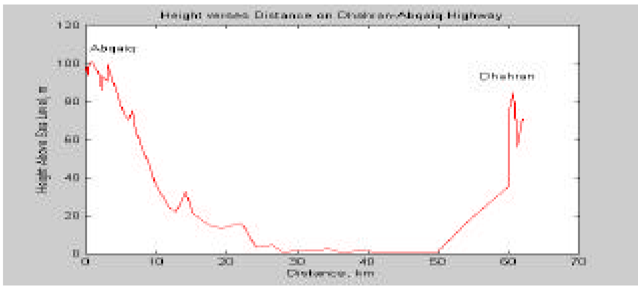

Figure 3 Height Variation on Dhahran-Abqaiq Highway

The Saihat-Ras Tanura Road is a part of Dammam-Jubail highway. On the sides of this road there are farms and some buildup areas. The road height increases near to Saihat to reach 22 meters then decreases to 1 meter above sea level at Ras Tanura. The terrain rises at some locations and along the two sides of this road there are some bushes. Juaymah-Jubail Road is also a part of Dammam-Jubail highway. The height of this road increases slightly until it reaches 15 meters above sea level at about 40 kilometers away from Juaymah, and then it decreases to 8 meters in Jubail. There are small numbers of trees beside the road and several buildup areas and bushes.

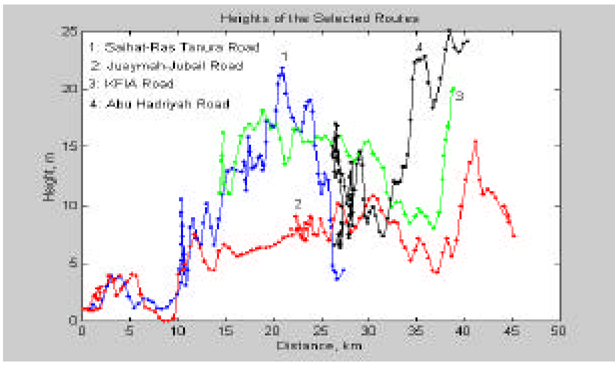

Figure 4 Variation of Height of the Selected Routes

King Fahd International Airport (KFIA) Road runs across an open area with a small number of elevated points. There are no trees or buildings but fences run along both sides of the road at a distance of about 15 meters. Abu Hadriyah Road is located 23 km away from Ras Tanura radio base station. It provides access to the main cities located in the North of the Eastern Province. The density of trees and buildings increases in the South and decreases in the North where the terrain becomes more irregular.

Top

The Dhahran-Safwa Road is a part of the Dhahran-Jubail highway. The radio base station located in Dhahran area provides the radio coverage. Other locations in Safwa and Abu Maan areas were selected to refine the models for Ras Tanura radio base station. The height of the selected path variation with distance is shown in Figure 5.

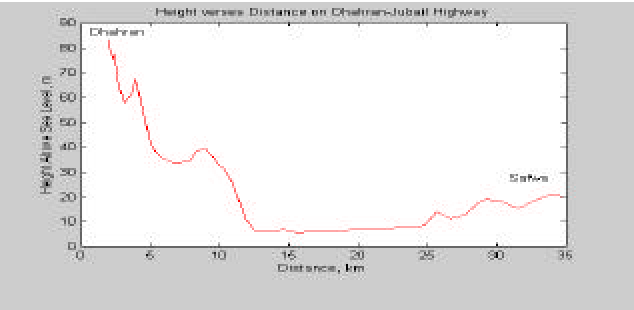

Figure 5 Height Variation on Dhahran Abqaiq Highway

C. Measurement Results

A large number of measurements were taken around Ras Tanura radio base station in January and February of year 2001. The measurements were repeated on a number of selected roads at different times (morning, evenings and night) under different weather conditions. It was observed that the weather does have noticeable effect on the received signal strength. However, this topic being outside the scope of this work is not discussed any further.

III Comparison with the Existing Models

A. Models Selected for the Pre-test.

Three path loss models were used to predict the signal strength around Ras Tanura area so that the predictions could be compared with the field measurements. These models were selected on the basis of operating frequency, antenna height, and terrain type.

A.1 Okumura –Hata Model

The Hata formula is applicable to a flat terrain over distances up to 30km, transmitter antenna heights to 200m and maximum receiver antenna heights of 10m [8].

Path loss for urban area is defined by,

$$L_u = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_b) - ah_m + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) \quad (1)$$

where f is frequency in MHz, h_b base height in meters above average terrain along 3-15 km, ah_m mobile height correction factor, d distance from transmitter to the receiver in kilometers.

The mobile height correction factor for a medium to small city (Open or Suburban areas) is estimated by,

$$ah_m = (1.11\log_{10}(f) - 0.7)h_m - (1.56\log_{10}(f) - 0.8) \quad (2)$$

where h_m mobile antenna height above ground (in meters). In the case of Rural, quasi-open areas, the path loss model is,

$$L_{ro} = L_u - 4.78[\log_{10}(f)]^2 + 18.33\log_{10}(f) - 35.94 \quad (3)$$

A.2 Hata-Extended/Epstein-Peterson Diffraction

The Okumura-Hata model is adjusted for various distances and antenna heights as follow. If $d > 20$ km,

$$L_{H-E} = L_{Hata} + 10.5 + 0.15\log_{10}(400h_b)(d - 20) \quad (4)$$

If $d > 64.36$ km,

$$L_{H-E} = L_{Hata} - 0.28(d - 64.36) \quad (5)$$

If $h_b > 300$ meters,

$$L_{H-E} = L_{Hata} - 4.7\left|\log_{10}\left(\frac{6.2}{d}\right)\right|\left(\frac{h_b - 300}{600}\right) \quad (6)$$

For more accurate estimation, the following correction is considered. If $d > 40.2$

$$L_{H-E} = L_{Hata} - 0.18\log_{10}\left(\frac{1500}{f}\right)(d - 40.2) \quad (7)$$

L_{Hata} is the path loss in dB computed using Okumura-Hata model, L_{H-E} the path loss in dB with the extended Okumura-Hata model, f *is* frequency in MHz, d the distance from transmitter to receiver in km, h_b the effective base height in meters. This model calculates diffraction losses using Epstein-Peterson multiple obstacle diffraction loss method.

A.3 Lee's Model

The path loss model derived by Lee is generally used to predict the path loss over a flat terrain. This model is based on two factors, the 1-mile (1.6 km) power intercept and γ, the path loss slope [10]. The received power at d km from the transmitter is expressed as,

$$P_r = 10\log_{10}\left[P_{ro}\left(\frac{d}{d_o}\right)^{-g}\left(\frac{f}{f_o}\right)^{-n} a_o\right] \quad (8)$$

where P_r is the received signal strength at a distance r from the transmitter, P_{r0} the received power at 1 mile from the transmitter, d the distance between the transmitter and the receiver, d_0 =1 mile (1.6 km), γ Path loss slope (experimentally determined), f actual carrier frequency, f_0 nominal carrier frequency, 900 MHz, n propagation exponent, n=2 for $f < 450$ MHz in suburban or open area, a_0 a correction factor account for antenna heights, transmit power and antenna gain that differ from the nominal conditions. Lee's model used base station antenna height of 30.48 m (100 ft), base transmitter power of 10 W and antenna gain = 6 dB reference to a dipole gain, mobile station antenna height of 3m, and gain of 0dB above a dipole gain.

A.4 Lee's Correction Factor (a_0) A correction factor is applied to Lee's Model for a frequencies above 30 MHz [10]. The correction factor is:

$$\alpha_0 = \alpha_1\alpha_2\alpha_3\alpha_4\alpha_5$$

$$\alpha_1 = \left(\frac{h_{nb}(m)}{30.48m}\right)^2 \qquad \alpha_2 = \left(\frac{h_{nm}(m)}{3m}\right)^v$$

$$\alpha_3 = \left(\frac{P_{nt}(W)}{10W}\right) \qquad \alpha 4 = \left(\frac{G_{nm}}{4}\right) \quad (9)$$

$$\alpha_5 = \text{different antenna-gain correction factor at mobile unit}$$

Top

where h_{nb} is the new BS antenna height, h_{nm} the new MS antenna height, P_{nt} new transmit power, G_{nm} the new MS Antenna Gain. The value of v is specified to be 2 for mobile antenna height of greater than 10m and 1 for antenna heights of less than 3m.

$$L_p = P_t - P_r$$

$$L_p = P_t - P_{ro} + 10 g \log_{10}\left(\frac{d}{1.6}\right) + 10 n \log_{10}\left(\frac{f}{900}\right) - 10\log_{10}(\alpha_0) \qquad (10)$$

B. Path Link Simulation Tools

EDX SignalPro and Matlab programs were used to model the path loss and signal strength in the Eastern Province. The EDX SignalPro uses area topographic data and advanced propagation models that account for terrain and ground features [8]. It was applied to simulate the signal strength for Ras Tanura radio base station.

Matlab is applied in the simulation of the path loss for Ras Tanura radio base station. It compares the calculated and the measured path losses. In addition, it provides tools to modify the available path loss models based on field measurements.

C. Prediction at Ras Tanura Area

Using EDX SignalPro and Matlab programs, the signal strength was estimated for Ras Tanura radio base station. Matlab program was used to calculate the signal strength around Ras Tanura radio base station using more than one path loss models. The signal strength around Ras Tanura is given by,

$$SGN = 10\log_{10}(P_t) + G_r + G_t - L_m - L_{tca} - L_{tco} - L_{rcc} - L_{ro} \qquad (11)$$

where SGN is the signal strength, P_t the transmit power, G_r the receiver antenna gain, G_t the transmitter antenna gain, L_m is the miscellaneous losses, L_{tca} the coaxial cable loss, L_{tco} the connector loss, L_{rcc} the receiver cable and connector loss, and L_{ro} the path loss.

C.1 *Hata-Okumura Model:* Ras Tanura area is regarded as a quasi-open area so equations (1), (2), (3) and (11) are used in the simulations. The height of the transmitting antenna is the height above the average ground averaged over a distance of 3 to 15 km from the transmitter. Over a path length of 15 km path, 50 height measurements were obtained and average height was calculated. This procedure gave 72.5m the effective height of the transmitting antenna. Figure 6 shows the predicted signal strength. It was observed that the predicted signal strength did not match the field measurements. Several reasons could be cited.

The foliage could have caused greater signal attenuation. The Root Mean Squared Difference (RMSD) is used to calculate the difference between the actual and the predicted signal strengths. This quantity is also used to compare different path loss models for all areas measured.

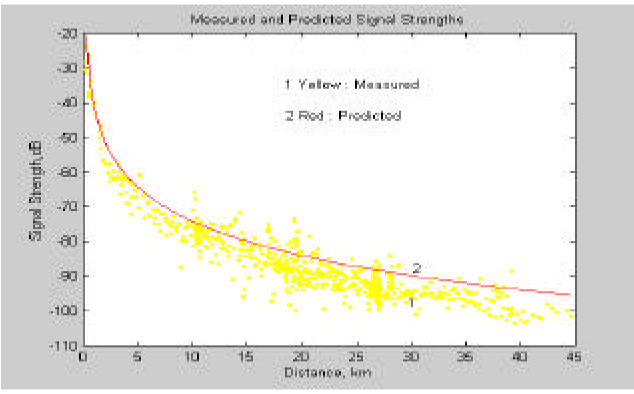

Figure 6 Actual and Predicted Signal Strengths Using Hata

The RMSD for Hata-Okumura model is defined and calculated for Ras Tanura as,

$$RMSD = \sqrt{\frac{\sum_{n=1}^{656}(Actual(n) - Predicted(n))^2}{656}} = 5.6 \qquad (12)$$

The result is acceptable but may be modified to get a better fit.

C.2 Hata/ Epstein Model

EDX SignalPro Program was used to simulate the signal strength around Ras Tanura radio base station. In the simulations, 4/3 effective earth's factor and 6 dB fade margin were used. The model selected for this simulation is Hata-Epstein Model. This model results in a satisfactory outcome and RMSD of 6.7.

IV A Modified Model

The actual and predicted signal strengths were compared to find the net differences between them; the median of the differences was added to the prediction model to minimize the discrepancies from the actual signal strengths. The added quantity was increased and decreased through iteration process so that more accurate prediction is made.

A. A New Path Loss Model (NPLM)

The dependency of the loss on distance is defined as path loss slope. Two mathematical formulae are obtained to represent the actual path loss. We used the following procedures:

1.The actual path loss was compared to $10\alpha\log10(ed)$, e and α are constants and d is a matrix contains distances of the test points from the radio base station.

2.The comparison between the actual and predicted path losses was based on the median of differences between them. Iterative method was used to find the constants, e and α. The values $e = 231.3$ and $\alpha = 3.44$, resulted in the best fit to the measured data. The parameters of h_b, h_m and f were taken from the free space model. The new path loss model is expressed as:

$$L_m = 10\log_{10}(ed)^a - 20\log_{10}(h_b h_m) + 20\log_{10}(f) + C$$

C=0, for TR (13)

The predicted signal strength is shown in Figure 7, the

Top

RMSD is 3.48. A new amount added to the above formula to compensate for terrain effect, it is $g\ log_{10}(hma/10)$, $g_1 = 7.3/6$. The new RMSD is 3.34.

$$L_{TM} = L_M + g_2 \log_{10}(hma / hav)$$

For Ras Tanure area $g_2 = 7.3/6$. (14)

The simulation result is shown in Figure (7)

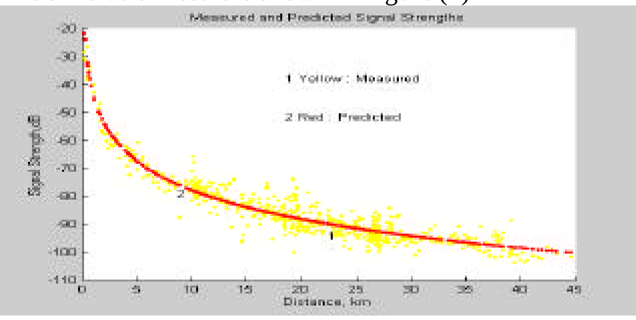

Figure 7 Signal Strengths for RT Using NPLM

V. Signal Strengths Prediction For Ras Tanura Area

A. Modified Hata Model (MHM)

Ras Tanura area has many high structures e.g. as plant, power plant, workshops, oil tanks, trees etc. The propagation data measured in this area is affected by the industrial structures. The area around Ras Tanura can be divided into two regions; the first consists of buildings, trees and fences within the distance of less than 5 km. In the second region lies beyond 5 km, where the number of buildings is sparse but the region is dotted by some high structures like oil and gas tanks. The presence of trees, sporadic bushes and fences also degrade the signal level. Ras Tanura area is considered as quasi-open area. The correction factor for quasi-open area obtained by Hata was modified to reflect the environment at Ras Tanura. The modified Okumura-Hata model was obtained by using the following procedure.

Path loss measurements around Ras Tanura radio base station were compared with the Okumura-Hata. A close fit was obtained by modifying path loss formula for urban area, mobile height factor, and the quasi-open area correction factor.

The discrepancies between the measured and the predicted signal strength values were attributed to the environment in Ras Tanura area, generally higher loss was by buildings, trees and terrain bushes.

The new correction factors for the terrain was obtained by adding the median of the differences between the measured and the calculated to the quasi-open area correction factor. An iterative process was used to minimise the RMSD between the actual and predicted path losses. The best fit to the measured data was obtained when area correction factor was 4.5. The RMSD is 3.45.

Conclusions

Two issues impair radio communication: poor coverage and interference. These issues should be assessed during radio system design when path loss calculations are done.

Most existing radio signal propagation models are based on measurements conducted outside Saudi Arabia, which may not be particularly applicable to desert conditions.

The available path loss models were used to predict and modified to fit the actual propagation data of Abqaiq, Ras Tanura and Dhahran radio base stations. A new model, was developed based on real field propagation data to match the actual path loss. More field propagation data at different frequencies and antenna heights are needed to develop frequency dependent models.

References

[1] E. N. Singer, Land Mobile Radio System. New Jersey: Prentice Hall, Inc., 1994.

[2] O. Andrisano, M. Chiani, and V. Tralli, etc..”Impact of Co-channel Interference on Vehicle-to-Vehicle Communications at Millimeter Waves.” IEEE, Singapore ICCS/ISITA 92.

[3] D.J. Cichon, Th. Kürner, W. Wiesbeck, "A new wave propagation model for urban and suburban macro cellular coverage prediction", Proc. IEEE International Antennas and Propagation Symposium AP'93, pp. 1073-1076, 1993.

[4] K. Siwaik, Radio Propagation and Antennas for Personal Communications. London: Artech House, 1995.

[5] Y. Okumura, E. Ohmori, T. Kawano, K. Fukuda, “Field Strength and its Variability in VHF and UHF Land-Mobile Radio Services,” Elec. Commun. Lab., vol. 16, pp. 825-873, Sept.-Oct. 1968.

[6] G. Hess, Handbook of Land-Mobile Radio System Coverage. London, Artech House, 1998.

[7] M. Hata, “Empirical Formula for Propagation Loss in Land Mobile Radio Services,” IEEE Trans. Veh. Technol., vol. VT-29, no. 3, pp. 317-325, August 1980.

[8] EDX Signal Pro Manual.

[9] W. Y. Lee, “ Studies of Base Station Antenna Height Effect on Mobile Radio,” IEEE Trans. Veh. Technol., vol. VT-29, pp.252-260, May. 1980.

[10] W.C.Y. Lee, Mobile Communications Design Fundamentals, Sams, Indianapolis, 1986.

[11] ITU-R P.453-6, The Radio Refractive Index: Its Formula And Refractivity Data, 1997.

[12] ITU-R P.370-7, VHF And UHF Propagation Curves For The Frequency Range From 30 MHz To 1000 MHz, 1995.

Top