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Investigation and Modeling of Power Received at 1800 MHz in a Mountainous Terrain: Case Study of Igarra in Edo State, Ajaokuta and Okene in Kogi State, Nigeria

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Abstract: This study presents an investigation of power received at 1800 MHz in a mountainous terrain. The net monitor software installed in NOKIA handset was used to conduct measurements of the received signal strength from fixed transmitting base station. Received signal strength measurements were conducted in Igarra, Ajaokuta and Okene from August 2007 to July 2008. The data was analysed to determine the propagation path loss exponent. The path loss exponent determined is 3.58, which is evident for the poor GSM signal in the mountainous environment. Empirical model (prediction) was proposed for the received power in the mountainous environment. The result of the Empirical model developed was validated by comparing with the measured values and an existing model. The result of the Empirical model when compared with measured values and an existing model (Egli model) showed a mean percentage error of 5.90 and 7.65%, respectively. The result from the comparison is satisfactory. Therefore, we can infer that the model developed to predict power received in a mountainous environment is very efficient.

Key words: Path loss, propagation path loss exponent, prediction model, power received, signal strength, mobile communication

INTRODUCTION

The mobile radio channel places fundamental limitations on the performance of wireless communication systems. The transmission path between the transmitter and the receiver can vary from simple line-of-sight to one that is severely obstructed by buildings, mountains and foliage (Rappaport, 2003). Unlike wired channels that are stationary and predictable, radio channels are extremely random and do not offer easy analysis. Even the speed of motion impacts how rapidly the signal level fades as a mobile terminal moves in space. Modeling the radio channel has historically been one of the most difficult parts of mobile radio system design and is typically done in a statistical fashion, based on measurement made specifically for an intended communication system or spectrum allocation (Rappaport, 2003).

The mechanisms behind electromagnetic wave propagation are diverse, but can generally be attributed to reflection, diffraction and scattering. Reflection occurs when a propagating electromagnetic wave impinges upon an object, which has very large dimensions when compared to the wavelength of the propagating wave. Reflections occur from the surface of the earth and from buildings and walls. Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities (edges). The secondary waves resulting from the obstructing surface are present throughout the space and even behind the obstacle, giving rise to a bending of waves around the obstacle, even when a line-of-sight path does not exist between transmitter and receiver. At high frequencies, diffraction, like reflection, depends on the geometry of the object, as well as the amplitude, phase and polarization of the incident wave at the point of diffraction. In a mountainous terrain, the mountain may be present between the transmitter and receiver, which cause severe diffraction loss. Scattering occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength and where the number of obstacles per unit volume is large. Scattering waves are produced by rough surfaces, small objects, or by other irregularities in the channel. In practice, foliage, street signs and lamp posts induce scattering in a mobile communications system. The performance and reliability of digital cellular systems may

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be affected adversely by the diffraction loss if not taken into consideration when predicting the power received (Rappaport, 2003).

Previous researchers have demonstrated that radio frequency signal propagates in an obstacle environment with a high attenuation. However, it is not practicable to move such an obstacle in the interest of improved radio service (Schwartz, 2004). Thus, one can investigate what happens to the radio signal when it comes in contact with such obstacle with a view to know the signal characteristics. This research therefore, reveals the performance evaluation of GSM signal in mountainous environment.

MATERIALS AND METHODS

The method used here involves a comprehensive literature review and then a careful study of each mountainous environment and each base station. Received signal strength level (power received) were measured from a distance (d) from the base station for the environments investigated. The data were analysed to determine the propagation path exponent. Each environment were visited 72 times and power received were taken in active mode during the downlink transmission. However, in order for a comprehensive investigation, each environment were visited evenly within the 3 climatic seasons (raining season, dry season and hammattan season) in Nigeria.

Measurements and analysis of power received

Investigated environment: Three different environments were investigated. They are Igarra in Edo State, Ajaokuta and Okene, both in Kogi State. A total of 10 sites were visited in the 3 environments investigated. The choice of the number of sites in each environment was based on; the availability of the network provider, the desire to take an exhaustive measurement that will cover all possible terrain conditions and convenience. The GLO network was used in this investigation. In Igarra there was one existing base station at the period of the investigation. In Igarra, one site was used, in Ajaokuta, 6 sites were used and in Okene, 3 sites were used for this investigation. The Igarra area lies within latitudes 7°00'N-7°30'N and longitudes 6°00'E-6°30'E at the northern fringe of Edo State (Aigbedion, 2006). Okene is located at 7°33'N, 6°14'E (Wikipedia, 2008a), while Ajaokuta is located approximately 7°33'22''N, 6°39'18''E (Wikipedia, 2008b). Rocks are densely distributed in Okene, relatively less densely distributed in Ajaokuta and relatively sparsely distributed in Igarra. The service providers masts in these environments investigated have sectoral antennas placed at about 30 m above ground level. These transmitting antennas are dual band antennas. They radiate at 900/1800 MHz. The names and locations of the sites are shown in Table 1.

Measurement conditions: Measurements were taken from August 2007 to July 2008. Each site in the investigated environment was visited 6 times in every month. Within the 1st week in every month, the site at Igarra was visited 3 times; this visit was repeated in the 3rd week. Within the 2nd week of every month, the sites at Okene and Ajaokuta were visited 3 times each and repeated in the 4th week. This condition was adhere strictly for every month during the period of the investigation. The measurements were taken in the active mode and within the various possible climatic conditions.

The measurements were carried out on the BCCH control channel and therefore, were not affected by frequency hoping and downlink power control algorithms (Schwartz, 2004).

Measurement procedures: The measurement setup is shown in Fig. 1. A NOKIA handset equipped with a net-monitor software is used to measure the received signal strength level (power received) at a distance (d) from the base station. The software comprises of a scale, which represent the power received in dBm. For every site in the environment investigated, power received at a distance 100 m from the base station was measured. Power received at a distance interval of 100 m from the initial test point up till the distance of 2 km was measured. At any test point 25 samples readings of the power received were recorded. The measurements were taken from August 2007 to July 2008.

Table 1: Names and locations of the sites

Names of site	Site location
Igarra base station	Igarra
Check point base station	Okene
Main market base station	Okene
Ohinohi's palace base station	Okene
Lagos Estate base station	Ajaokuta
Abuja Estate base station	Ajaokuta
Adogo base station	Ajaokuta
Ukpake base station	Ajaokuta
Quarry base station	Ajaokuta
Pacs-mekon base station	Ajaokuta

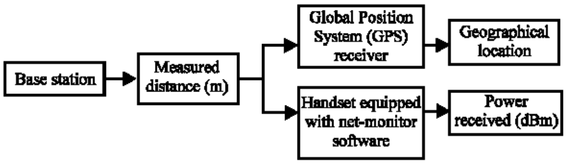

Fig. 1: Schematic diagram showing measurement setup

Table 2: Average power received for the period of the investigation

	Mean P_r (dBm)									
Dist. d (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
100	-53.96	-51.86	-54.50	-52.00	-52.59	-53.66	-52.57	-54.91	-52.85	-53.67
200	-57.37	-59.88	-58.39	-57.93	-59.00	-59.39	-57.98	-59.81	-57.91	-58.99
300	-60.28	-65.25	-61.64	-62.57	-65.20	-64.60	-62.45	-65.55	-62.32	-65.44
400	-62.32	-70.06	-61.73	-68.61	-70.06	-70.29	-66.34	-64.66	-65.98	-64.66
500	-61.57	-68.69	-64.27	-72.23	-74.08	-69.69	-70.00	-69.23	-69.22	-70.07
600	-64.69	-74.94	-68.33	-76.11	-78.86	-75.35	-73.19	-73.32	-73.16	-75.18
700	-65.70	-77.67	-72.45	-75.16	-82.20	-78.00	-78.72	-77.57	-74.81	-79.05
800	-69.27	-81.64	-76.32	-78.66	-80.32	-80.17	-76.07	-80.59	-77.17	-80.56
900	-73.71	-79.13	-75.77	-81.53	-83.78	-83.73	-81.06	-82.76	-81.52	-82.67
1000	-73.60	-84.79	-79.46	-83.54	-86.47	-82.12	-83.34	-84.50	-79.59	-84.38
1100	-77.33	-86.35	-83.41	-84.01	-85.30	-85.49	-84.81	-85.83	-83.31	-87.15
1200	-79.30	-87.55	-85.20	-86.70	-87.81	-89.07	-87.97	-87.46	-85.21	-85.69
1300	-82.88	-89.02	-88.85	-85.37	-88.77	-88.16	-86.58	-89.02	-86.96	-88.63
1400	-83.62	-90.00	-87.10	-88.11	-90.47	-89.56	-86.56	-91.81	-88.84	-89.58
1500	-82.10	-92.21	-90.64	-91.93	-92.04	-90.84	-90.76	-90.46	-90.49	-91.17
1600	-84.23	-91.15	-92.11	-90.40	-93.26	-93.36	-92.52	-93.16	-92.01	-93.83
1700	-87.52	-93.36	-95.36	-92.27	-94.32	-92.08	-93.68	-94.62	-94.41	-92.47
1800	-89.31	-94.38	-94.41	-93.35	-94.99	-94.57	-94.90	-96.90	-93.30	-94.05
1900	-92.68	-95.33	-95.82	-94.62	-96.01	-95.64	-96.36	-96.86	-95.34	-95.13
2000	-94.57	-97.25	-97.01	95.65	-97.20	-96.72	-97.39	-97.03	-96.29	-94.33

Data collection and presentation: Following the measurement procedures above, the average power received and its standard deviation for each site investigated in every month were computed for analysis. The average power received for the period of the investigation is shown Table 2.

Data analysis: The use of Mat lab computer program was employed in the analysis of the data collected. This method finds the values of the constant n (path loss exponent) in the chosen equation using best-fitted curve approach. This is justified by the fact that the estimates obtained are the most precise, unbiased estimates that are linear functions of the observations (Saunders, 2007).

Let L_p, d and n represent path loss, distance from the base station and path loss exponent, respectively. Most generic system studies address networks in which all mobile units have the same area-mean received power expressed as (Saunders, 2007);

$$L_p = d^n \tag{1}$$

Taking the log of Eq. 1, we have

$$n = 10 \log L_p / 10 \log d \tag{2}$$

Let X represents the ratio of 10 log (L_p) to that of log (d), it follows that

$$n = X/10 \tag{3}$$

From Eq. 2, it can be seen that a plot of 10 log (L_p) against log (d) will yield a gradient equivalent to the path loss exponent (n).

Applying Matlab programme to the data in Table 2, a plot of the power received in dBm against the log of the distance (m) for each site is shown in Fig. 2-11.

Determination of path loss exponent: The rate of decay of the received signal (path loss exponent) can be determined from the graphs (Fig. 2-11). The values of the path loss exponent (n) and the intercept (I) for each site are shown on the graphs. The values of the path loss exponent (n) and the intercept (I) for each site is tabulated in Table 3.

In order to determine the path loss exponent of a mountainous environment, we propose that the average path loss exponent of the investigated sites be used as the path loss exponent for a mountainous environment. It is computed as shown;

$$n = (3.3 + 3.6 + 3.8 + 3.6 + 3.6 + 3.5 + 3.7 + 3.6 + 3.6 + 3.5)/10 = 3.58$$

Development of the proposed empirical model for received power: The expression for the power received at a distance (d) from the transmitter is given as Saunders (2007):

$$P_r = P_t W_c \left(\frac{d_0}{d} \right)^n \tag{4}$$

where:

P_r = The power received

P_t = The power transmitted do is the reference distance for antenna far-field

n = The path loss exponent

W_c = The wave constant

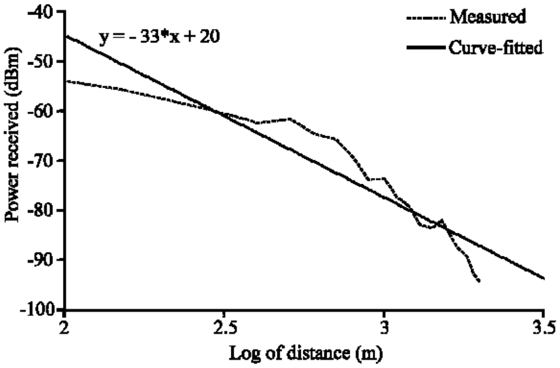

Fig. 2: Plot of power received in dBm against log of distance (m) for site 1

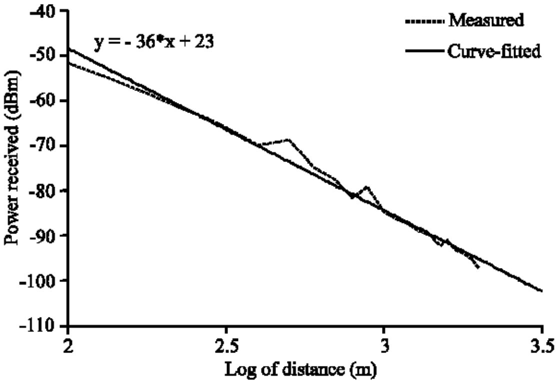

Fig. 3: Plot of power received in dBm against log of distance (m) for site 2

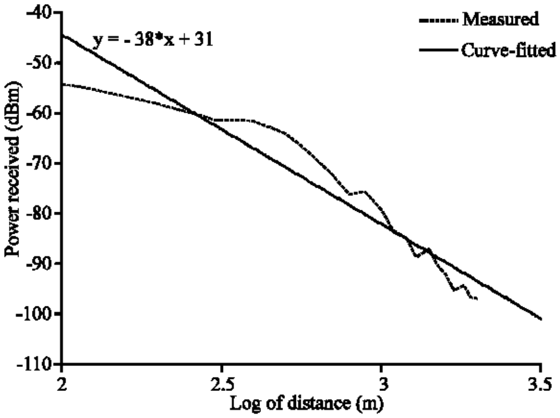

Fig. 4: Plot of power received in dBm against log of distance (m) for site 3

The expression for the wave constant at a reference distance do for antenna far-field is given as Saunders (2007)

$$W_c = \frac{\lambda^2}{(4\pi d_0)^2} \qquad (5)$$

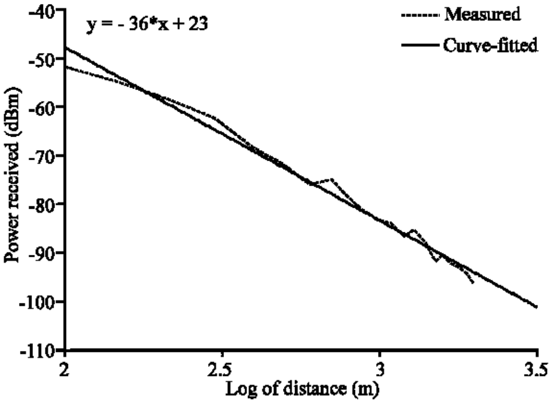

Fig. 5: Plot of power received in dBm against log of distance (m) for site 4

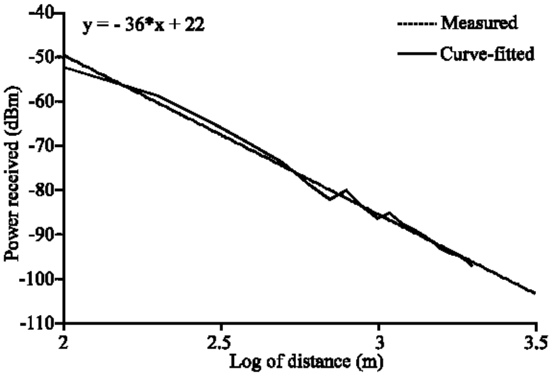

Fig. 6: Plot of power received in dBm against log of distance (m) for site 5

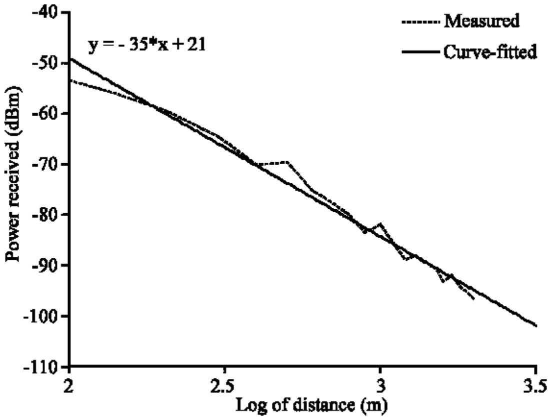

Fig. 7: Plot of power received in dBm against log of distance (m) for site 6

Equation 5 can also be expressed

$$W_c = \left(\frac{\lambda}{4\pi d_0}\right)^2 \qquad (6)$$

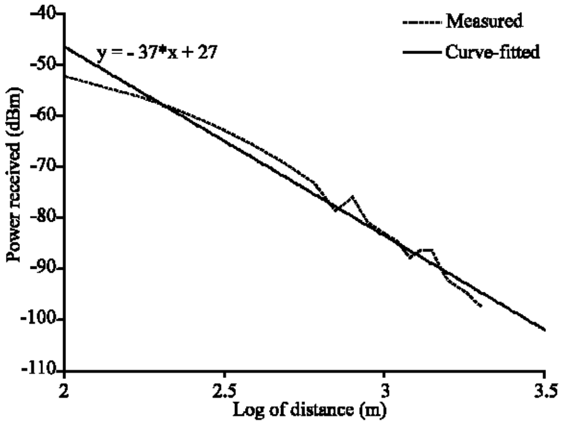

Fig. 8: Plot of power received indBm against log of distance (m) for site 7

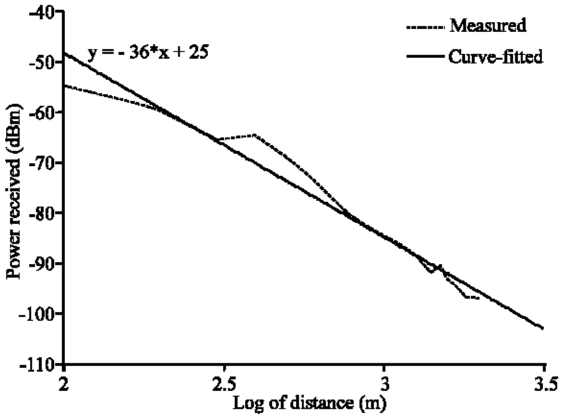

Fig. 9: Plot of power received in dBm against log of distance (m) for site 8

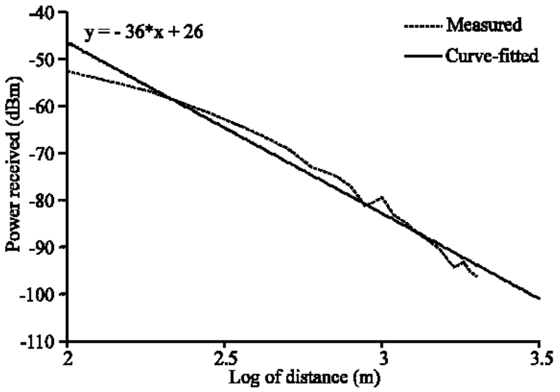

Fig. 10: Plot of power received in dBm against log of distance (m) for site 9

where:

λ = The wavelength

π = A constant, equal to 3.143

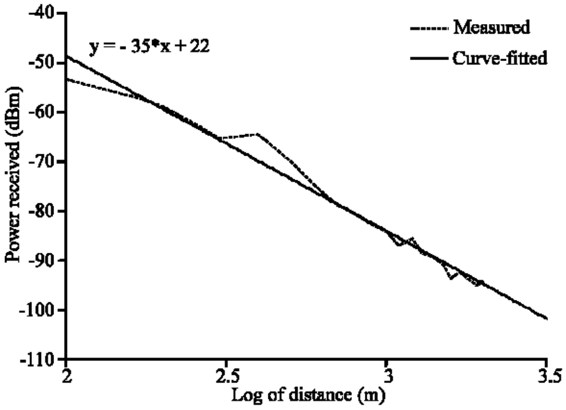

Fig. 11: Plot of power received in dBm against log of distance (m) for site 10

But

$$\lambda = \frac{c}{f}$$

where:

c = The speed of light

f = The frequency of the signal under consideration

Taking the log of Eq. 4, we have

$$P_r\left(\text{dBm}\right) = P_t\left(\text{dBm}\right) + W_c\left(\text{dB}\right) - 10n\log\left(\frac{d}{d_0}\right) \tag{8}$$

Also, taking the log of equation, we have

$$W_c\left(\text{dB}\right) = 20\log\left(\frac{\lambda}{4\pi d_0}\right) \tag{9}$$

At 1800 MHz,

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{1.8\times10^9} = 0.1667$$

For outdoor propagation, do is recommended to be chosen between (10-100) m (Saunders, 2007). Substituting, the values of λ and do = 10 m into Eq. 9, we have

$$W_c = 20\log\left(\frac{0.1667}{4\times3.143\times10}\right)$$
$$= -57.55\text{dB}$$

Substituting the value of W_c into Eq. 8, we have;

$$P_r\ (\text{dBm}) = P_t\ (\text{dBm})\ \text{-}57.55\text{-}10n\log\left(\frac{d}{do}\right) \tag{10}$$

Table 3:The values of the path loss exponent (n) and intercept (i) for the mountainous environments investigated

Mountainous environments	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Values of n	3.3	3.6	3.8	3.6	3.6	3.5	3.7	3.6	3.6	3.5
Values of I	20.0	23.0	31.0	23.0	22.0	21.0	27.0	25.0	26.0	22.0

Table 4: Data for the comparison of measurement for site 1-10, empirical and Egli model for distance between 100 m and 2 km

	Mean P_r (dBm)											
Dist. d (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Empirical	Egli
100	-53.96	-51.86	-54.50	-52.00	-52.59	-53.66	-52.57	-54.91	-52.85	-53.67	53.35	-41.94
200	-57.37	-59.88	-58.39	-57.93	-59.00	-59.39	-57.98	-59.81	-57.91	-58.99	64.13	-53.98
300	-60.28	-65.25	-61.64	-62.57	-65.20	-64.60	-62.45	-65.55	-62.32	-65.44	70.43	-61.02
400	-62.32	-70.06	-61.73	-68.61	-70.06	-70.29	-66.34	-64.66	-65.98	-64.66	74.90	-66.02
500	-61.57	-68.69	-64.27	-72.23	-74.08	-69.69	-70.00	-69.23	-69.22	-70.07	78.37	-69.90
600	-64.69	-74.94	-68.33	-76.11	-78.86	-75.35	-73.19	-73.32	-73.16	-75.18	81.21	-73.06
700	-65.70	-77.67	-72.45	-75.16	-82.20	-78.00	-78.72	-77.57	-74.81	-79.05	83.60	-75.74
800	-69.27	-81.64	-76.32	-78.66	-80.32	-80.17	-76.07	-80.59	-77.17	-80.56	85.68	-78.06
900	-73.71	-79.13	-75.77	-81.53	-83.78	-83.73	-81.06	-82.76	-81.52	-82.67	87.51	-80.11
1000	-73.60	-84.79	-79.46	-83.54	-86.47	-82.12	-83.34	-84.50	-79.59	-84.38	89.15	-81.94
1100	-77.33	-86.35	-83.41	-84.01	-85.30	-85.49	-84.81	-85.83	-83.31	-87.15	90.63	-83.59
1200	-79.30	-87.55	-85.20	-86.70	-87.81	-89.07	-87.97	-87.46	-85.21	-85.69	91.98	-85.10
1300	-82.88	-89.02	-88.85	-85.37	-88.77	-88.16	-86.58	-89.02	-86.96	-88.63	93.23	-86.49
1400	-83.62	-90.00	-87.10	-88.11	-90.47	-89.56	-86.56	-91.81	-88.84	-89.58	94.38	-87.78
1500	-82.10	-92.21	-90.64	-91.93	-92.04	-90.84	-90.76	-90.46	-90.49	-91.17	95.45	-88.98
1600	-84.23	-91.15	-92.11	-90.40	-93.26	-93.36	-92.52	-93.16	-92.01	-93.83	96.46	-90.10
1700	-87.52	-93.36	-95.36	-92.27	-94.32	-92.08	-93.68	-94.62	-94.41	-92.47	97.40	-91.15
1800	-89.31	-94.38	-94.41	-93.35	-94.99	-94.57	-94.90	-96.90	-93.30	-94.05	98.29	-92.15
1900	-92.68	-95.33	-95.82	-94.62	-96.01	-95.64	-96.36	-96.86	-95.34	-95.13	99.13	-93.09
2000	-94.57	-97.25	-97.01	95.65	-97.20	-96.72	-97.39	-97.03	-96.29	-94.33	99.93	-93.98

Now recall that the path loss exponent (n) of the investigated mountainous environment is 3.58. Assume that the power transmitted, P_t = 40 dBm as in case of GSM systems, Eq. 10 becomes:

$$\begin{aligned} P_r &= -17.55\text{-}35.8\log\left(\frac{d}{do}\right) \\ P_r &= -17.55 + 35.8\log 10\text{-}35.8\log d \\ P_r &= \ 18.25\text{-}35.8\log d \end{aligned} \tag{11}$$

Equation 3.11 is the Empirical model developed to predict power received.

Egli model (Wikipedia, 2007): As with many other propagation models, Egli is based on measurement and then a model developed for received signal power is shown in Eq. 12:

$$P_r = \left(\frac{40\text{MHz}}{f}\right)^2 \frac{(h_t h_m)^2}{d^4} P_t G_t G_m \tag{12}$$

where:

P_r = Power received (Unit: dBm)
P_t = Power transmitted (Unit: dBm)
F = frequency of transmission (Unit: MHz)
h_t = Height of the base station antenna (Unit: m)
h_m = Height of the mobile station antenna (Unit: m)
d = Distance from base station antenna. Unit: m
G_t = Gain of the base station antenna (Unit: dimensionless)
G_m = Gain of the mobile station antenna (Unit: dimensionless)

Comparison of the empirical model, egli model and measured values for the 10 sites: The empirical and egli models were used to compute the values of power received when d is (100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000) m.

The results were compared with data from measured values of power received for the 10 sites and the result is shown in Table 4.

The relative error of the predicted (Empirical) compared to the measurement for the ten sites investigated is determined. The mean error of predicted (Empirical) for the 10 sites is computed to be 5.90%. Similarly, the relative errors of the existing model (Egli model) compared to the measurement for the 10 sites investigated and the empirical model are also determined. The mean errors are computed to be 4.56 and 7.65%, respectively.

CONCLUSION

The study embarked upon to investigate the power received at 1800 MHz in a mountainous terrain. The quality of the signal is poor in the mountainous terrain experiencing shadowing effects created by the presence of obstacles including hills and rocks between the BTS and the MS. The obstacles create a shadowing effect, which decreases the received signal strength. This is evident in the path loss exponent determined for the mountainous environment.

The key issue in mobile planning is the prediction of received signal strength in the investigated areas. It is therefore, pertinent to develop a model to predict signal strength of the environment investigated.

The power received from a GSM signal in a mountainous environment was determined using Igarra, Ajaokuta and Okene as case study. From the measured received power in these environment, an Empirical model was developed for power received which, when compared with both the measurement and existing model was found to be satisfactory. However, measurements taken from Ajaokuta (Site 5-10) conform better with the Empirical model, closely followed by Okene (Site 2-4) before Igarra (Site 1). The mean percentage error of the predicted (Empirical) compared to the measurement for the ten sites investigated is computed to be 5.90%, also when compared with existing model, the mean percentage error is computed to be 7.65%. Hence, we can also conclude that the model developed to predict the power received in a mountainous environment is very efficient.

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