Empirical Characterization of Propagation Path Loss and Performance Evaluation for Co-Site Urban Environment

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ABSTRACT

The design of future generation communication systems depends so much on the suitability of path loss methods and their suitability to various regions. However, such models, no matter how accurate, will result in co-channel interference and wastage of power when they are used in environments for which they were not developed. So, the best bet is to perform site-specific measurements. This research work characterizes the propagation path loss in an urban environment for co-site CDMA2000-800MHz (CDMA2000 1x/UMTS800) and GSM900MHz. Received Signal Strength (RSS) measurements were gathered in Enugu from Mobile Telecommunications of Nigeria (MTN) Network (GSM900) and Visafone Network (CDMA2000 1x) in sites where each Network operates alone and where both Networks shared sites (co-site or co-existence). RSS data gathered was used to characterize Enugu Urban Environment and a propagation Path Loss model, suitable for scenario with Base Station antenna height above the average rooftop was subsequently developed. SINR was generated to evaluate the Link performance of co-site operation in comparison to Single Network operation in a site.

KEYWORDS: Received signal strength (RSS), path loss, co-site

1. INTRODUCTION

In Wireless technology, the Propagation Path Loss and Interference level have strong impact on the quality of the Link. The accurate determination of Path Loss and mitigation of interference leads to development of efficient design and operation of quality networks. Equipment vendors specify system parameters for deployed Systems [1], and researches are still ongoing in many Countries, to determine or validate the values of Propagation Path Loss in their own environment. Propagation models have been developed as tools in estimating radio wave propagations as accurately as possible. Models have therefore been created for different environments to predict the Path Loss between the transmitter and receiver. With the growth of wireless Communications, two different Systems or Generations might be deployed in adjacent frequency bands in the same area (CDMA2000 1x/GSM900 or IS-95 CDMA/WCDMA). As more new Operators emerge and more new Mobile Communication Systems are put into use, multiple different Systems are more frequently located at the same site. This phenomenon is called co-site, shared or co-existence network. Radio propagation is heavily site specific and can vary significantly depending on terrain frequency of operation, velocity of mobile terminal, antenna heights etc. accurate characterization of radio channel through key parameters and a mathematical model is important for predicting signal coverage, achievable data rates, specific performance attributes of alternative signaling and reception schemes [2]. Path loss is the reduction in power of an electromagnetic wave as it propagates through space. It is a major component in analysis and design of link budget of a communication system [3]. It depends on frequency, antenna height, receive terminal location relative to obstacles and reflectors, and link distance, among many other factors. Propagation path loss models prediction plays an important role in the design of cellular systems to specify key system parameters such as transmission power, frequency, antenna heights etc. Propagation prediction usually provides two types of parameters corresponding to the large-scale path loss and small-scale fading statistics. The path loss information is vital for the determination of coverage of a base-station (BS) placement and in optimizing it. Without propagation predictions, these parameter estimations can only be obtained by field measurements which are time consuming and expensive [4].

2. RELATED WORKS

Vinko Erceg et al [5] presented a statistical path loss model, derived from 1.9GHz experimental data collected across the United States of America in 95 existing macro cells. They analyzed an extensive body of experimental data, collected by AT&T Wireless Services in several suburban environments across the United States of America, such as New Jersey, Seattle, Chicago, Atlanta and Dallas; providing a good range of terrain categories. With base station antenna heights ranging from 12m to 79m, the base station antenna transmitted continuous wave (CW) signals with an Omni-directional azimuth pattern and gain of 8.14 dBi. The mobile antenna was of 2m height with gain of 2.5 dBi. The data were collected, using Grayson receiver, set for 1-s averaging as the van moved throughout the environment. The result showed that the reference Path Loss was close to the calculated Free Space Path Loss.

$$L_p = A + 10n\text{Log}_{10}\left(\frac{di}{do}\right) + s; \quad d \geq d_o \quad (1)$$

Fixing A in Equation (1) as the Free Space Path Loss at the reference distance, d_o, they calculated the Path Loss Exponent n, as a Gaussian random variable over the population of macro cells within each terrain category. They also deduced that the power law exponent is strongly dependent on the base station antenna height and the terrain category, so they proposed Equation (2) for Path Loss exponent as:

$$n = (a - bh_1 + c/h_b) + x\sigma_{n,} \quad 10m \geq h_b \geq 80m \quad (2)$$

where h_b is the base station antenna height in meters and the terms in parenthesis is the mean of n (with a, b and c in consistent unit); σ_n is the standard deviation of n; x is a zero mean Gaussian variable of n unit standard deviation, N [0, 1]; and a, b, c and σ_n are all data derived constants, for each terrain category.

Purnima and Sigh [6] compared some of the existing empirical path loss propagation models: Stanford University Interim (SUI), Okumura, Hata, COST-231, Log-distance and ECC-33 models; with their measured field data. Measurements were taken in the three regions, depicting the high, medium and low density of urban, suburban and rural setting of India at 900MHz and 1800MHz frequencies, using a Spectrum Analyzer. They deployed a transmitter with power rating of 5KW, taking measurements at regular intervals of 1km to 5km with a reference distance of 1km. Using Matrix Laboratory (MATLAB) graphical representation; they deduced that ECC-33, SUI and Okumura models showed better results in urban areas, while Hata and Log-distance models gave better results in rural environments.

A path loss model, based on field measurements carried out by Vishal Gupta [7] for the suburban city of Mehuwala, Dehra Dun was compared with the Hata model, which is a widely used model in path loss prediction in CDMA based systems. A comparison of Gupta's developed model with Hata model gave significant difference; hence they recommended that for accurate path loss prediction, field measurements must be performed. The measured data was then used to correct the existing model for the fringe environment of Dehra, Uttarakhand, India.
All measurements were taken from a mobile terminal, using 3GHz Micronix Spectrum Analyzer MSA 338, Noise Figure < 4dB, and antenna gain factor of 16.5dB. Transmitted power was 5KW. Measurements were taken in all three zones/sectors of the antennas. For macro cellular systems, the reference distance, as a rule is taken as d_o = 1km. Starting from 1km, measurements were taken in intervals of 500 meters (0.5km) in the three zones.

3. PATH LOSS MODEL

In general, Path Loss (Lp) is expressed as:

$$Lp = \frac{\text{Transmitted Power}}{\text{Received Power}} \quad (3)$$

Which in decibel (dB) is:

$$Lp\ [dB] = 10\text{Log}\left[\frac{Pt}{Pr}\right] dB \quad (4)$$

Most Radio Propagation Path Loss models are derived using a combination of Analytical (theoretical) and Empirical methods. The Empirical approach is based on fitting curves or analytical expressions that create a set of measured data, which has the advantage of implicitly taking into account, all propagation factors through actual field measurements. However, the validity of an Empirical model at transmission frequencies or environments, other than those used to derive the model, can only be established by additional measured data in the new environment, using either of the two practical path loss estimation techniques [8] presented below

3.1 Log-distance Path Loss Model.

This model does not consider the fact that surrounding environment clutter may be vastly different at two different locations, having the same T-R distance separation for outdoor radio channels. In Literature, the average large-scale Path Loss for an arbitrary Transmitter to Receiver (T-R) separation is expressed as a function of distance, using path loss exponent, n as expressed in the equation below

$$Lp\ (di) = Lp\ (do) + 10n\ \text{Log}\left(\frac{d_i}{d_o}\right) \quad (5)$$

Where n is the path loss exponent, which indicates the rate at which the path loss increases with distance, computed from the formula:

$$n = \frac{L_p(d_i) - L_p(d_o)}{10\text{Log}\left(\frac{d_i}{d_o}\right)} \quad (6)$$

A plot of Eq. (5) on a log-log scale shows the modeled path loss as a straight line with a slope equal to 10 dB per decade, while the intercept Lp (do) is the Free Space Path Loss at the reference distance, do.

3.2 Log-normal shadowing Path Loss Model.

Shadowing is the gradual variation of Received Signal Strength (P_r) around its average value, while fading is the rapid variation in the Received Signal Strength, due to multipath effects. This model describes the random shadowing effect which occurs over a large number of measurement locations, having the same T-R distance separation, but with different levels of clutter on the propagation path. Therefore, including the shadowing factor xσ, into Eq. (5), yields:

$$Lp\ (di) = Lp\ (do) + 10n\ Log_{10}\ (\frac{d_i}{d_o}) + x\varsigma \quad (7)$$

Where xσ is a Zero-Mean Gaussian distributed random variable (in dB) with standard deviation σ (in dB). Using linear regression analysis, the path loss exponent, n, can be determined by minimizing (in a mean square error, sense) the difference between measured and predicted values of equation (6) to yield:

$$n = \frac{\sum_{i=1}^{k}[L_p(d_i) - L_p\ (d_o)]}{\sum_{i=1}^{k} 10\ Log_{10}(\frac{d_i}{d_o})} \quad (8)$$

The standard deviation, σ is equally minimized using the formula:

$$\sigma = \sqrt{\sum \frac{(P_m - P_r)^2}{N}} \quad (9)$$

Where, Pm = Measured Path Loss

Pr = Predicted Path Loss

N = Number of measured data points

Received Power, Pr in (dBm), at any distance D from the Transmitter, with Transmit Power, Pt in (dBm) is given by:

$$Pr\ (dBm) = Pt\ (dBm) – Lp\ (dB) \quad (10)$$

P_r can be evaluated from measured data for any distance (d_i), using the formula:

$$P_r\ (dB) = 10Log\ P_r\ (d_o) \quad (11)$$

or

$$Pr\ (dBm) = 10\ Log\ [\frac{p_r(d_o)}{1mW}] \quad (12)$$

For System Loss therefore:

$$Pr\ (dBm) = Pt\ (dBm) + Gt\ (dB) + Gr\ (dB) – Lt\ (dB) – Lr\ (dB) – Lp\ (dB) \quad (13)$$

where: Gt = Base Station antenna gain factor

Gr = Mobile Unit (GPS) gain factor

Lt = Transmission Line plus Filter Loss between transmitter and transmit Antenna

Lr = Transmission Line plus Filter Loss between receiver and receiver antenna

In most work, Lt and Lr are ignored and when the antenna gain factors are not the same, Equation (13) becomes:

$$Pr\ (dBm) = Pt\ (dBm) + Gt\ (dB) + Gr\ (dB) – Lp\ (dB)$$

The Free Space loss can be simply written as a function of Frequency (F) and Transmitter to Receiver (T – R) distance D,

$$L_{fs} = 32.44 + 20Log\ (f_{MHz}) + 20Log\ (D_{km}) \quad (14)$$

Equation (14) is the Harald T. Friss Free Space Path Loss. Using the Geometrical Theory of Diffraction (GTD) [9, 10], and considering the excess loss due to the diffraction from rooftop down to street level, which takes place at the buildings next to mobile station, and the scatter loss, the path loss is given as:

$L_p = L_{fs} + L_s + L_d$ which if expanded can be expressed as:

$$Lp = -10Log\ [(\frac{\lambda}{4\pi D})^2] - 10Log_{10}\left[\frac{\lambda}{2\pi^2 r}\left(\frac{1}{\theta} - \frac{1}{(2\pi + \theta)}\right)^2\right] - 10Log_{10}\left[(2.35)^2\left(\frac{\Delta h_2}{D}\sqrt{\frac{d}{\lambda}}\right)^{1.8}\right] \quad (15)$$

4.RESEARCH METHODOLOGY

The Research was conducted, in Enugu urban environment and Received Signal Strength (RSS) measurements was gathered from both GSM900 and UMTS800 Base Trans-receive Stations of both MTN and Visafone that deploys a transmitting Centre frequency of 947.5MHz and 876.87MHz respectively, and transmitter power in the range of 20W and 30W, mounted on steel towers spatially separated by a horizontal distance in co-site cells, with average tower height of 30meters. Field experimental data (RSS) were gathered to be able to optimize the model derived, whose validity must be tested, since the model is bound to be useless and should not be deployed, if its validity cannot be tested. RSS measurements up to a distance of 1250meters, were gathered in four (4) sites in Enugu Urban, were both GSM and CDMA Systems co-exist in shared sites, and two (2) other sites, were they operate alone, one (1) each for CDMA and GSM Systems. Figure 1 shows the graphical location of sites were measurements were taken. The instrument used in gathering data, that is, the Received Signal Strength (RSS) was the Transverse Electromagnetic Wave (TEMS) Investigation Application software programmed in a Laptop shown in figure 2 below. The measurement tool was sourced from Huawei Technologies (Installers of GSM and CDMA equipment for both MTN and Visafone).

The Radio Propagation Simulator (TEMS) which serves as the Mobile Unit, in this instance, records the base station and each test point coordinates (latitudes and longitudes), together with the Received Signal Strength (RSS).

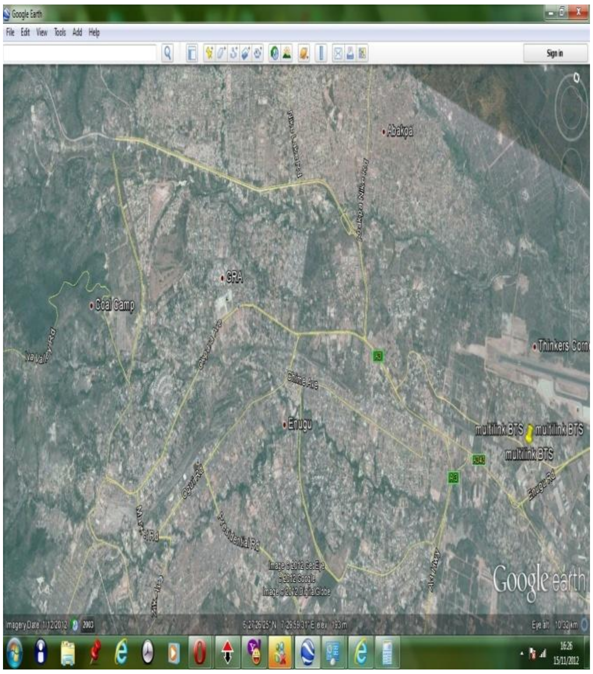

Figure 1: Map of Test Bed – Enugu Urban Environment

Figure 2: TEMS Measurement Tool used for Field gathering of RSS Data

5. RESULTS AND DISCUSSION

Ten (10) different Received Power measurements were conducted in each of the three sectors of the six (6) target BTS during the three (3) periods as in the timing schedule, and since variances were observed in the measurements, at the same distance in the different sectors for all the BTSs, signifying different levels of clutter on the Propagation path (distance between the Transmitter and Receiver), the Mean or Average value of the measured data (Received Signal Strength) was noted as in Table 1.

Recall equation 12, when the Received Power is in dBm unit (decibel relative to milliwatt), the Received Power, P_r is expressed as:

$$\text{Pr (dBm)} = 10 \text{ Log } [\frac{p_r(d_o)}{1mW}],$$

where Pr (do) or Rxav is in unit of Watts, converted to decibel (dB) and do is the close-in reference distance. Pr can hence be evaluated from the RSS measured data, for any distance (di), using Equation (11):

Pr (dBm) = 10 log Pr (do);

where d_o is the close-in distance of 100meters.

Table 1 Average Received Signal Strength (RSS) or R_{XAV}

Distance (m)	RSS (dBm)
100	-44
150	-45
200	-47
250	-49
300	-51
350	-53
400	-55
450	-57
500	-60
550	-62
600	-63
650	-65
700	-67
750	-69
800	-71
850	-73
900	-75
950	-77
1000	-79
1050	-80
1100	-83
1150	-84
1200	-85
1250	-87

Recall that the gradual reduction of the Signal Strength (Power), as the Transmitter and Receiver (T-R) distance increases is called Path Loss as expressed in Equation (4); that is:

$$\text{Path Loss} = \text{Lp (di) dB} = 10 \text{ Log } [\frac{P_t}{P_r}] \text{ (dB)},$$

which is then evaluated using measured data (Average Received Power) from Table 1. From Equation (11), at a close-in distance, do of 100m, the Median Received Power is:

Power (Rxav) = Pr (dBm) = - 44 dBm.

That is, -44 = 10 Log Pr or Log Pr = -4.4

Hence $Pr = 10^{-4.4} = 3.981 * 10^{-5}$ dB and Pt = 30W =14.77 dB.

Working with decibel (dB) unit, the measured Path Loss value becomes:

$$Lp\ (di) = 10Log\ [\frac{P_t}{P_r}] = 10\ Log\ \frac{14.77}{3.981 * 10^{-5}} = 55.69\ dB.$$

Subsequent values of Path Losses for specified distances, 0.1km≤ di ≤1.25km; are evaluated, using same procedure and presented in Table 2, and a plot average measured path loss against distance is shown in figure 3

Table 2: Average Measured Path Loss for Enugu Urban

Distance (km)	Median R_{XAV} (dBm)	Measured Path Loss L_p (d_i) [dBm]
0.10	-44	56
0.15	-45	57
0.20	-47	59
0.25	-49	61
0.30	-51	63
0.35	-53	65
0.40	-55	67
0.45	-57	69
0.50	-60	72
0.55	-62	74
0.60	-63	75
0.65	-65	77
0.70	-67	79
0.75	-69	81
0.80	-71	83
0.85	-73	85
0.90	-75	87
0.95	-77	89
1.00	-79	91
1.05	-80	92
1.10	-83	95
1.15	-84	96
1.20	-85	97
1.25	`-87	99

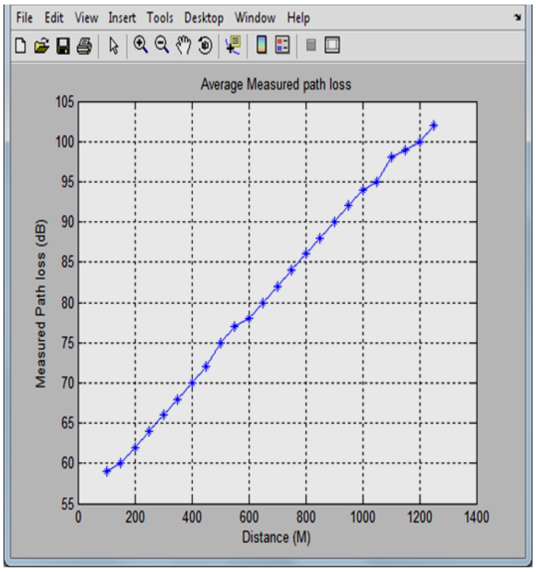

Figure 3: Simulation of Average Measured Path Loss for Enugu Urban

Path Loss Exponent indicates the rate at which Path Loss increases with distance. Path Loss can therefore, be Estimated or Predicted, using data obtained from field measurements, which are substituted into Equation 5

$$Lp\ (di) = Lp\ (do) + 10n\ Log\ (\frac{d_i}{d_o})$$

From field measurement, at close-in distance, (do) of 0.1 km, Lp (do) = 56 dB.

Estimates or Predicted values of Path Loss at specified distances are calculated as follows:

At di = 0.1km = do,

$$Lp\ (di) = 56 + 10n\ log\ \frac{1}{1} = 56$$

At d_o = 0.1km and di = 0.15km,

$$Lp\ (di) = 56 + 10n\ log\ \frac{0.1.5}{0.1} = 56 + 1.8n$$

Subsequent evaluations were carried out in the same manner. The path loss exponent, n, can be manually calculated using Equation (6), or derived statistically through the application of linear regression analysis technique by minimizing in a mean square sense, the difference between the Measured Path Loss and the Predicted (Estimated) Path Loss as given by equation (8)

$$n = \frac{\sum_{i=1}^{k}[L_p(d_i) - L_p(d_o)]}{\sum_{i=1}^{k} 10 \ Log_{10}(\frac{d_i}{d_o})}$$

where the term Lp (di) represents Measured Path Loss or (Pm), and Lp (do) represents Predicted Path Loss or Pr and k is the number of measured data or sample points. The expression, Lp (di) – Lp (do), that is, (Pm – Pr) is an error term with respect to n, and the sum of the mean squared error, e(n), is expressed as:

$$e(n) = \sum_{i=1}^{k}[L_p(d_i) - L_p(d_o)]^2 \qquad (16)$$

The value of n, which minimizes the Mean Square Error (MSE), is obtained by equating the derivative of Equation (16) to zero, and solving for n:

$$\frac{\partial e(n)}{\partial n} = 0 \qquad (17)$$

From the result of the evaluation we have that equation (16) becomes;

$$\sum_{i=1}^{K}(Pm - Pr)^2 = 1554.03n^2 - 9669.26n + 15783$$

Applying Equation (33): $\frac{\partial e(n)}{\partial n} = 0$, that is, 2[1554.03n] – 9669.26 = 0

Hence, 3108.06n – 9669.26 = 0;

This shows that,

3108.06n = 9669.26

Therefore, $n = \frac{9669.26}{3108.06} = 3.11$

It follows that Path Loss exponent n, for Enugu Urban Environment is 3.11

Equation (9) is used to determine the Standard Deviation, σ (dB) about the mean values:

$$\sigma = \sqrt{\sum \frac{(P_m - P_r)^2}{N}} = [\frac{1554.03n^2 - 9669.26n + 15783}{N}]^{\frac{1}{2}}$$

That is, $\sigma = [\frac{1554.03 * 3.11^2 - 9669.26 * 3.11 + 15783}{24}]^{\frac{1}{2}}$

$= [\frac{752.26}{24}]^{\frac{1}{2}} = 5.598$ dB ≅ 6 dB.

The standard deviation, σ of the log-normal shadowing about its mean value is 6dB

Hence, Lp (di) = 56 + 3. 11 log ($\frac{d_i}{d_o}$) + 6 dB

Therefore, the resultant Path Loss Model for shadowed Enugu Urban Environment is:

Lp (di) = 62 + 31.1 log ($\frac{d_i}{d_o}$), that is;

Lp (d) = 62 + 31.1 log (D) (18)

To lend credence to our derived Proposed Path Loss model, this work compared the statistically predicted result of Received Signal Strength and that of other existing (traditional) models, with the measured results (Table 3). The RSS (Pr) is therefore, calculated under the same set of transmission conditions using same simulation parameters [11, 12, 13]. Figure 4 shows the simulation result of table 3.

Table 3: RSS Comparison - Measured versus Predicted

Distance/Models	Measured CDMA2000 1x	Measured GSM900	Free Space	Hata	COST-231	ECC-33
0.10	-45	-48	-19	-48	-54	-55
0.15	-46	-49	-22	-53	-55	-57
0.20	-47	-50	-25	-56	-59	-59
0.25	-50	-53	-26	-58	-61	-64
0.30	-51	-54	-28	-60	-63	-70
0.35	-52	-55	-29	-62	-67	-72
0.40	-54	-57	-31	-65	-69	-75
0.45	-56	-59	-32	-67	-72	-76
0.50	-61	-64	-32	-70	-74	-79
0.55	-64	-66	-33	-72	-77	-82
0.60	-66	-70	-34	-75	-79	-83
0.65	-68	-73	-35	-77	-83	-85
0.70	-71	-75	-35	-79	-84	-88
0.75	-74	-77	-36	-80	-86	-89
0.80	-76	-80	-36	-83	-88	-91
0.85	-78	-82	-37	-85	-90	-93
0.90	-81	-85	-38	-89	-91	-95
0.95	-84	-87	-38	-91	-93	-97

1.00	-86	-88	-39	-93	-94	-99
1.05	-87	-89	-39	-94	-97	-100
1.10	-89	-91	-39	-95	-98	100
1 .15	-90	-92	-40	-96	-99	-102
1.20	-91	-93	-40	-97	-100	-104
1.25	-92	-94	-40	-98	-101	-105

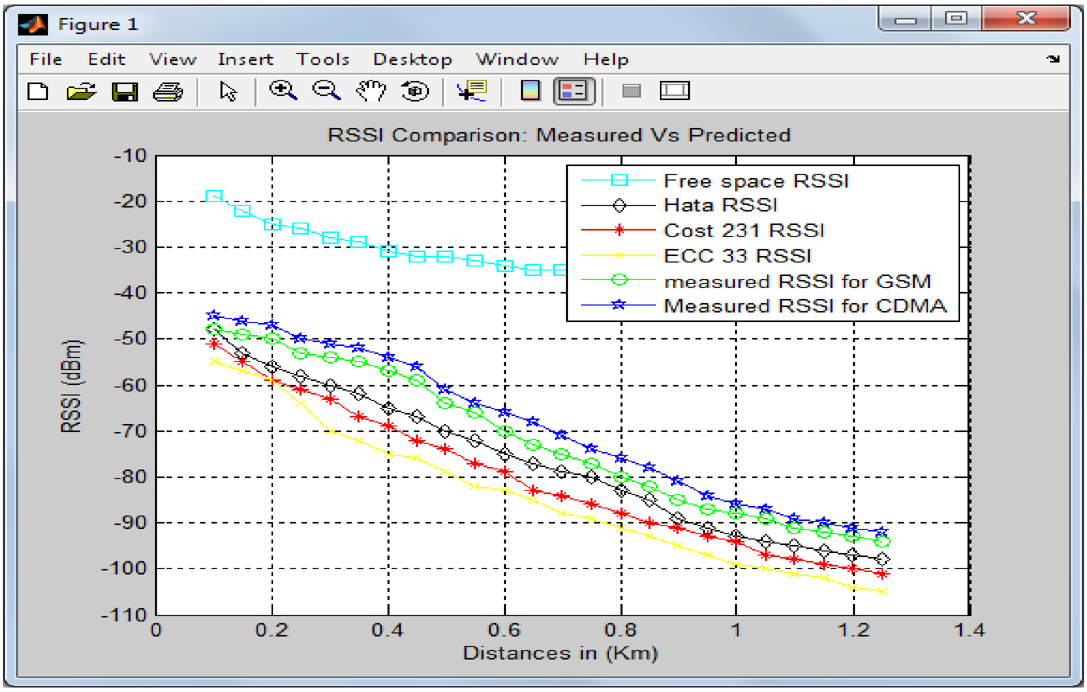

Figure 4: RSS Comparison – Measured Vs Predicted (Traditional Models)

In this work, SINR was generated to evaluate the Link performance of co-site operation in comparison to Single Network operation in a site using Equation below;

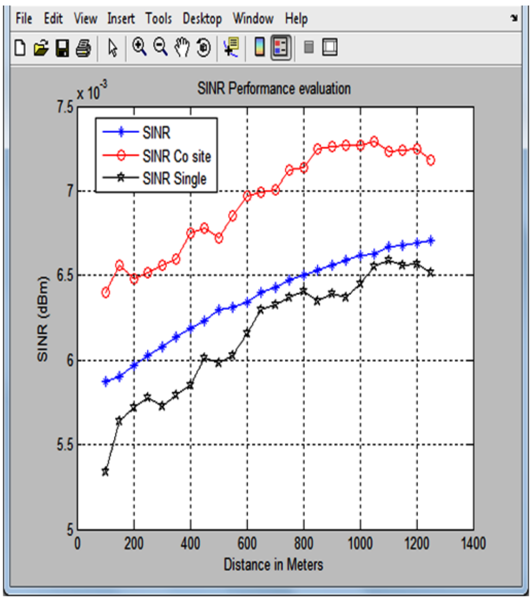

Figure 5: Simulation of SINR performance evaluation

$$SINR = \frac{S}{1+N_o} \quad (19)$$

Where S is the resulting RSS (P_r) values gathered from field measurements (Table 1) and N_o is a constant (-109dBm) [7].

6. CONCLUSION

The rapid growth of Cellular Radio in the 800MHz band (3G) and its deployment in the RF environment of existing 2G Networks (GSM900) results in increased Interference level for co-site or shared-site Systems, since Signals generated is an interference source to all other Systems in the crowded RF environment. A typical design policy for GSM infrastructure is to maintain multiple transmission stations (BTS) in one transmitting Antenna in order to increase the Cell capacity.

Real time Received Signal Strength measurements were gathered from ten (10) sites where MTN GSM Systems co-exists with VISAFONE CDMA20001x (UMTS800) Systems. The RSS measurements enabled this work to determine the Path Loss and characterize Enugu Urban environment. The result obtained for the Path Loss Exponent is in tandem with reviewed works for shadowed urban environment.

The Link quality assessment showed better Quality Service when Systems are operating alone than in Co-Site arrangement due to increased level of Interference in relation to SINR parameter.

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8. REFERENCES

[1] Ayyappan, K, et al, "propagation Model for Highway in mobile communication system", 2008, indio

[2] Jorgen A. B et al, "propagation measurements and Models for wireless communication channels", January 1996, IEEE communication Magazine, vol.33, No 1, PP 42.

[3] Minuddin A.A. et al, "Aaurte path loss prediction in wireless Environment", July 2007, the institute of Engineers (India), Vol. 88, PP 9.

[4] Magdy F. Iskander and zhengging Yun, "propagation prediction Models for Wireless communication systems," IEEE Trans. On Microwave theory and techniques, vol. 50 No.3 march 2002

[5] V. Erceg, et al, "An Empirically based path loss model for Wireless Channels in Suburban Environment" IEEE Journal on selected areas in Communications, vol. 17, No. 7, 1999.

[6] M.G. brown, et al, "comparison of empirical propagation path loss models for fixed wireless access systems", Vehilcicular Technology conference, 2005,IEEE Date: 30 may-1 June 2005 vol:1 PP 73-77

[7] V. Gupta, S. C. Sharma and M. C. Bansal, "Fringe Area Path loss Correction factor for Wireless Communications", Information Journal of Recent Trends in Engineering, vol.1, No.2, 2009.

[8] Alam Nima et al, "Dynamic path Loss Exponent Estimation, in a vehicular Network, using Doppler Effect and Received Signal Strength, 2007.

[9] D. C. Green, "Radio Systems III", Pitman Publishing Ltd; 39 Parker Street, London WC2B 5PB, 1st Ed; pp157-186, 1979.

[10] M. Dolukhanov, "Propagation of Radio Waves", Mir Publishers, Moscow, p.26, 1971.

[11] A. O. Ogbomudia (Lt. Col), "The Signaller, a Quarterly Journal of the Nigerian Army Signals", Telecommunications problem in the Armies of 3rd World Countries, Vol. 3, Sept. 1989

[12] W. C. Y. Lee, "Mobile Communications Engineering", McGraw-Hill Inc., 1982.

[13] V. Gupta, S. C. Sharma and M. C. Bansal,"Fringe Area Path loss Correction factor for Wireless Communications", International Journal of Recent Trends in Engineering, vol.1, No.2, 2009.

[14] Z. Nadir, member, IAENG, et al, "path loss Determination using Okumure Hata Model And splice interpolation for Missing Data for Oman", Proceedings of the world congress on Engineering 2008 Vol 1, WCE 2008 July 2-4, 2008, London, U.K.