ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 7, July 2013

Antenna Isolation Technique for Interference Reduction in a Co-Site System

OKOROGU Victor N[1], Onoh G.N[2], Nwalozie G.C[3], Onyishi D.U[4]

Department of Electronic & Computer Engineering, Nnamdi Azikiwe University Awka, Nigeria[1, 3]

Department of Electrical & Electronic Engineering Enugu State University of Science & Technology, Enugu, Nigeria[2]

Department of Electrical & Electronic Eng., Federal University of Petroleum Resources Effurun Delta State, Nigeria[4]

Abstract: Analysis on intermodulation interference and the effect of noise on Receiver sensitivity of the CDMA System due to interference from GSM System in co-site cells showed that the Signal –to –Interference–plus–Noise Ratio (SINR) of Networks when operating separately in different sites is better than in co-site arrangement. This work adopted the Antenna Isolation technique as a viable option to minimize the interference level, in order to ensure harmony and co-existence of shared Networks based on a physical optimization of antenna systems that could be understood as a physical symmetry rotation in space, to vary the antenna tilt and azimuth. The approach independently reduces the interference effects on the distance between the base station antennas. This research analyzes the interference between co-site CDMA2000-800MHz (CDMA2000 1x/UMTS800) and GSM900MHz Base Station Systems due to spurious emission, intermodulation effects and blocking. 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), 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. Antenna Isolation measurements were practically demonstrated in Huawei Laboratory so as not to disrupt traffic on Operators Networks, using token antennas and calibrated cables.

Keywords: Interference, Antenna isolation, co-site and Received signal strength

I INTRODUCTION

Today's society demands fast and reliable wireless radio communication, and as such, radio spectrum grows more and more crowded as a consequence of this. So more spectrally efficient transmission schemes are therefore needed to be able to transmit more bits per Hz bandwidth to relieve the pressure on the bandwidth resources. 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 and due to the close distance between the Systems antennas such as CDMA2000 1x (UMTS800) in the RF environment of GSM900, results in increased Interference, which leads to capacity degradation of both Systems due to lack of RF isolation [1].

The major problem of co-site Systems as in this work is interference, mainly caused by the GSM900 transmitters that radiate spurious and intermodulation (IM) signals that affect the CDMA2000 1x (UMTS800) receiver.

CDMA2000 1x, uses CDMA as the multiple access technique, which is known to be resilient to narrow band interference and multipath fading. However, the degradation suffered as a result of co-existence can sometimes be notable. The primary applications of 3G Systems are interoperability, high throughput rates (up to 2Mbps), permanent connection support, transition to packet connection, providing multimedia services such as audio/video streaming applications and the internet [2].

The main applications of GSM900 Systems are speech and short data messages (SMS) and the connection type is circuit connection. 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. An average number is three BTS and the maximum is twelve. The signal from each transmitter (each transmitter operates in a single frequency with eight timeslots), is mixed in multiple adders and then fed into a Band Pass Filter (BPF) and finally into the antenna. Some of these adders are active so as to provide amplification to the input signals. Active devices tend to be extremely nonlinear [3]. Generation of IM Products is a direct result of nonlinearities which are multiples of the fundamental

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 7, July 2013

frequencies. Odd harmonics such as 3rd order, 5th order and 7th order harmonics show up in the receive bands of the interfered with System, causing IM Interference [1]. This output signal is in general not desirable, whether for the transmitters or for the receivers.

When two or more signals are added in the input of the nonlinear device, with a characteristic (transfer) function of Equation 1, the output then contains several algebraic sums and differences of the input frequencies. Highest odd harmonics considered in this Work is 3rd order.

$$h(t) = a_o + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + \ldots\ldots\ldots\ldots (1)$$

It is obvious that for intermodulation (IM) products to be generated, two or more frequencies and adders (mixers) must be present (emphasis on BS). Some of these adders may be active so as to provide amplifications in the case of transmitters, while for the receivers; the adders (combiners) are entirely passive.

Finally, the signal reaches the UMTS800 receiver (MS or BTS) after travelling through the RF interface and suffering from propagation losses (L_p). This intermodulation (IM) interference generated at the transmitter end is called Active Interference, P_{active} which is the summation of all losses in the transmitter. [5, 6]

$$P_{active} = \sum_{f_i} L_{IM} L_T L_p P_{GSM} \qquad (2)$$

where

f_i is the frequency of the IM product, L_{IM} is the loss arising from IM interference, L_T is the antenna mismatch loss, L_P is the propagation loss in the path from

GSM900 transmitter to UMTS800 receiver while P_{GSM} is the GSM900 Base Station's transmitting Power.

L_{IM} is a loss factor that indicates the difference in the level between the GSM signal and the intermodulation products.

$$P_{passive} = \sum_{f_i} L'_{IM} L_p P_{GSM} \qquad (3)$$

Hence, the sum of IM interference in the receiver end will be:

$$I_{IM} = P_{active} + P_{passive} \qquad (3)$$

The key benefits of having co-site Systems however, are as follows:

- Encouraging equitable reasonable competition;
- Reducing the number of steel towers, for coordinated operations;
- Reducing infrastructural and network building expense;
- Reducing visual impact.

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 [7]. 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 [8].

II RELATED WORKS

Vinko Erceg et al [9] 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.

$$L_p = A + 10n\text{Log}_{10}\left(\frac{di}{do}\right) + s; \quad d \geq d_o \qquad (4)$$

Fixing A in Equation (4) 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 (5) for Path Loss exponent as:

$$n = (a - bh_1 + c/h_b) + x\sigma_{n,}; \quad 10m \geq h_b \geq 80m \quad (5)$$

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 [10] 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

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 7, July 2013

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.

Sun Jingfei [11] investigated the effects interference and floor noise levels have on deployed systems and receiver sensitivity. When the receiving intermediate frequency (i.f) band of the BTS is B_W (Hz) and its receiving noise coefficient is N_f (dB), the equivalent noise level of the BTS receiver is:

$$N_o = -174 + 10 \text{ Log } B_W + N_f \text{ (dBm)} \quad (6)$$

If the unit of the bandwidth B_w is in MHz, then the equivalent noise level is:

$$N_o = -114 + 10 \text{ Log } (B_W) + N_f \text{ (dBm)} \quad (7)$$

In theory, the receiver sensitivity of the BTS is:

$$S_o = N_o + SIR \text{ (dBm)} \quad (8)$$

where SIR in (dB), is the minimum demodulation Signal-to-Interference Ratio of the receiving system of the BTS. The noise floor level directly affects the Receiver Sensitivity that is, if the noise level increases by 1 dB, the receiver sensitivity of the BTS decreases by 1 dB accordingly [11]. He subsequently compared the typical values of the parameters in the current GSM900 and CDMA 2000 1x system (including IS 95, CDMA2000 and WCDMA).

In actual system implementation, the receiver bandwidth of the system and noise coefficient of the entire receiver usually fails to meet the theoretical value or optimal value as listed in [11] due to increased level of interference in shared-site System, so the theoretical receiver sensitivity are not always realized. It is therefore better to decrease the minimum demodulation Signal-to-Interference Ratio (SIR) by adopting the antenna isolation technique and other interference mitigation techniques in order to improve on system performance. If the intra-frequency spurious interference of the external receiving band is of white noise (AWGN), it is ultimately superimposed on the equivalent noise of the original system which raises the receiver noise level (dB) of the system.

In this Work, the several scenarios where GSM900 signal cause IM interference that can hamper the performance of a CDMA2000 1x receiver (BS or MU) is examined. The inverse case is not of substantial interest because CDMA2000 1x systems are expected to have very few transmitting frequencies (absence of FDMA), though UMTS800 as well, degrade GSM900 System as a result of higher BS transmit Power as its down-link frequency overlap the up-link frequency of GSM BS by 4MHz

III ANTENNA ISOLATION

In practice, single band antennas (vertical polarized antenna: co-polar and cross polar antenna, especially cross polar) are frequently used in mobile network deployments [8] to improve on antenna Isolation. Careful consideration of antenna Isolation is necessary for co-site base stations to avoid excessive interference, thereby reducing losses and improving on Link Quality. The amount of isolation that can be achieved between antennas depends on several factors, such as the physical horizontal separation distance, d_h between the antennas, polarization, radiation pattern of the antennas and whether the antennas are within the main beam of each other, and the conducting properties of the antenna tower. In practice, antenna isolation in excess of 80dB is very difficult to achieve due to secondary phenomena like reflections and scattering from the surrounding environment, mechanical or electrical antenna down-tilt, misalignments, etc [12]. Antenna Isolation can most accurately be determined through on-site measurements though such measurement exercises are usually too costly, time-consuming and are bound to disrupt traffic in an active Network. Hence Network Operators disapprove of on-site Antenna Isolation measurements. As an alternative to on-site Antenna Isolation measurements, different methods of calculating same analytically is proposed as in [13].

The Antenna Isolation values $I_{isolation}$ obtained before and after optimization is then translated into Traffic Parameters (Key Performance Indicators).

A. *Horizontal space isolation calculation*

The antenna isolation between spatially separated antennas is usually modeled based on measurements. An antenna isolation measurement configuration is illustrated in Figure 1, where two spatially separated antennas (antenna 1 and antenna 2) are connected to a network analyzer. A signal at GSM900 operating centre frequency is generated by the network analyzer and sent to the input of antenna 1; the output of the signal at antenna 2 is measured and recorded by the network analyzer. With calibrated connection cables, by taking into account the cable loss, the difference of signal power level at the output of antenna 2 and that at the antenna 1 input is taken as antenna isolation. High values (over 70dB) for horizontal separation, measured for different horizontal distances between the two antennas, at different angles of down tilt, and different bore-sight angle directions is an indication of good isolation, confirming reduced interference effects. The polarization of Antennas deployed by MTN and Visafone are cross-polar Antennas. The horizontal Space antenna isolation for a scenario as in Figure 1 can be computed analytically, using the following equation

$$I_H \text{ [dB]} = 22 + 20\log (d_h/\lambda) - (G_{Tx} + G_{Rx}) - (SL_{Tx} + SL_{Rx}) \quad (9)$$

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 7, July 2013

where Equation (9) for horizontal space distance, d_h between two antennas satisfies the following approximate far-field condition: $d_h \geq 2D^2/\lambda$ [14].

However, the accuracy of this approximation decreases with decreasing antenna gain, but where polarizations differ, antenna isolation will increase.

The parameters involved are defined as follows:

D[m]: the maximum dimension of the largest of the transmitter or receiver Antenna

I_H[dB]: isolation between horizontally separated transmitter and receiver antennas

d_h [m]: the horizontal distance from the centre of interferer antenna to that of the interfered with receiver antenna

λ[m]: the wavelength of the interfered with system frequency band

G_{Tx}[dBi]: maximum gain of the transmitter antenna with respect to an isotropic antenna (dBi)

G_{Rx}[dBi]: maximum gain of the receiver antenna with respect to an isotropic antenna (dBi)

SL_{Tx}[dB]: gain of the side-lobe with respect to the main-lobe of the transmitting antenna (negative value),

SL_{Rx}[dB]: gain of the side-lobe with respect to the main-lobe of the receiver antenna (negative value).

Equation (10) can be deduced from the Friis formula, which gives the following relation (in the linear domain) between the received Power (P_r) and transmitted Power (P_t) for line-of-sight conditions:

$$\frac{P_r}{P_t} = (G_{Tx} * SL_{Tx})(G_{Rx} * SL_{Rx})(\lambda/4\pi\, d_h)^2 \qquad (10)$$

By introducing the isolation $I_F = \frac{P_r}{P_t}$ and converting the Friis formula to dB scale, Equation (9) above is deduced. The Friis formula, and thus Equation (10) above, does not only apply to horizontal separation between antennas, but to any arbitrary separation. Antenna isolation is primarily a function of the wavelength, antenna types (Omni vs directional), antenna characteristics (down-tilt, gain, radiation patterns, etc.) and relative spatial configurations [14].

Figure 1: Antenna configuration for horizontal separation distance

B. *Vertical space isolation calculation*

Vertical separation can be employed to isolate two antennas in a co-site situation. However, this basic configuration is relevant to co-location arrangement and is depicted in Figure 2, while a combination of horizontal and vertical separation is the option more relevant for co-site arrangement as depicted in Figure 3. Vertical separation is fixed at 1m while the horizontal separation was varied for the measurement process. Cross polar operation is assumed to be employed.

Vertical isolation can be computed by the following equation [9]:

I_V [dB] = 28 + 40*log (d_V/λ) – ($G_{Tx} + G_{Rx}$) (11).

Usually, gains of BTS antennas take approximations, $G_{Tx} = G_{Rx}$ = 0dBi. Hence Equation (11) becomes:

$$I_V \text{ [dB]} = 28 + 40*\log (d_v/\lambda) \qquad (12)$$

where

I_V[dB]: isolation between vertically separated transmitter and receiver antennas.

d_V[m]: the vertical distance from the interferer antenna to the interfered with receiver antenna, measured from radiation centre-to-radiation centre

λ[m]: the wavelength of the interfered with system frequency band.

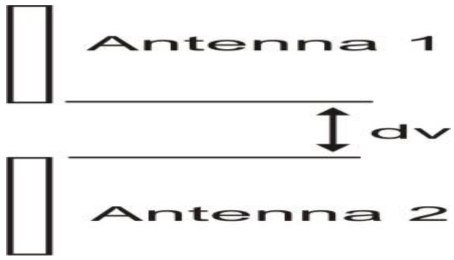

Figure 2:Antenna configuration for vertical separation (co-location)

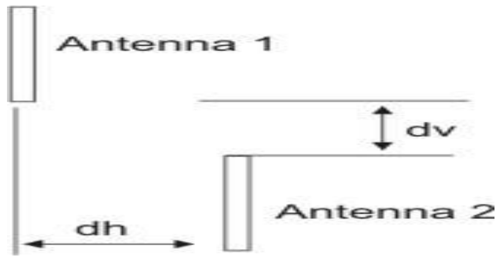

Figure 3 :Antenna configuration for vertical separation (co-site)

***C** Slant space isolation calculation*

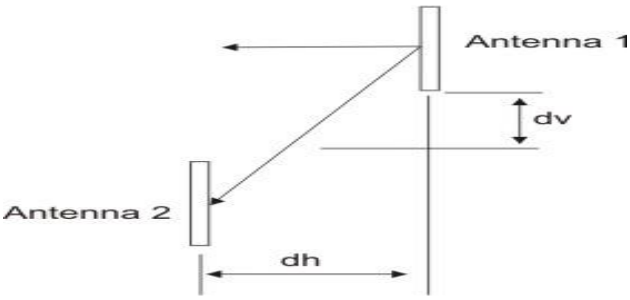

Figure 4 :Antenna configuration of slant separation

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 7, July 2013

When one of the antennas of Figure 3 above is down-tilted, Antenna configuration of slant separation, Figure 4 is unwittingly configured [15]. Slant isolation can be computed by the following equation:

$$I_S[dB] = (I_V - I_H) * (\alpha/90°) + I_H \qquad (13)$$

α[°]: the vertical angle between the transmitter antenna and receiver antenna.

IV PATH LOSS MODEL

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

$$Lp = \frac{\text{Transmitted Power}}{\text{Received Power}} \qquad (14)$$

Which in decibel (dB) is:

$$Lp\ [dB] = 10\text{Log}\left[\frac{Pt}{Pr}\right] dB \qquad (15)$$

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

A. *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

$$Lp\ (di) = Lp\ (do) + 10n\ \text{Log}\left(\frac{d_i}{d_o}\right) \qquad (16)$$

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

$$n = \frac{L_p(d_i) - L_p(d_o)}{10\text{Log}\left(\frac{d_i}{d_o}\right)} \qquad (17)$$

A plot of Eq. (16) 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.

B. *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. (16), yields:

$$Lp\ (di) = Lp\ (do) + 10n\ \text{Log}_{10}\left(\frac{d_i}{d_o}\right) + x\sigma \qquad (18)$$

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 (17) to yield:

$$n = \frac{\sum_{i=1}^{k}[L_p(d_i) - L_p(d_o)]}{\sum_{i=1}^{k} 10\ \text{Log}_{10}\left(\frac{d_i}{d_o}\right)} \qquad (19)$$

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

$$\sigma = \sqrt{\sum \frac{(P_m - P_r)^2}{N}} \qquad (20)$$

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:

$$Pr\ (dBm) = Pt\ (dBm) - Lp\ (dB) \qquad (21)$$

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

$$P_r\ (dB) = 10\text{Log}\ P_r(d_o) \qquad (22)$$

or

$$Pr\ (dBm) = 10\ \text{Log}\left[\frac{p_r(d_o)}{1mW}\right] \qquad (23)$$

For System Loss therefore:

$$Pr\ (dBm) = Pt\ (dBm) + Gt\ (dB) + Gr\ (dB) - Lt\ (dB) - Lr\ (dB) - Lp\ (dB) \qquad (24)$$

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 (24) 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,

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 7, July 2013

$L_{fs} = 32.44 + 20Log\,(f_{MHz}) + 20Log\,(D_{km})$ (25)

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:

$$Lp = -10Log\left[\left(\frac{\lambda}{4\pi D}\right)^2\right] - 10Log_{10}\left[\frac{\lambda}{2\pi^2 r}\left(\frac{1}{\theta} - \frac{1}{(2\pi+\theta)}\right)^2\right] - 10Log_{10}\left[(2.35)^2\left(\frac{\Delta h_2}{D}\sqrt{\frac{d}{\lambda}}\right)^{1.8}\right] \quad (26)$$

V 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. 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 5 shows the graphical location of sites were measurements were taken. The instrument used in gathering data, was the Transverse Electromagnetic Wave (TEMS) Investigation Application software programmed in a Laptop shown in figure 6 below. The RSS values gathered were used to determine the Propagation Path Loss and Path Loss Exponent for Enugu Urban Environment and Signal to Interference plus Noise Ratio (SINR).

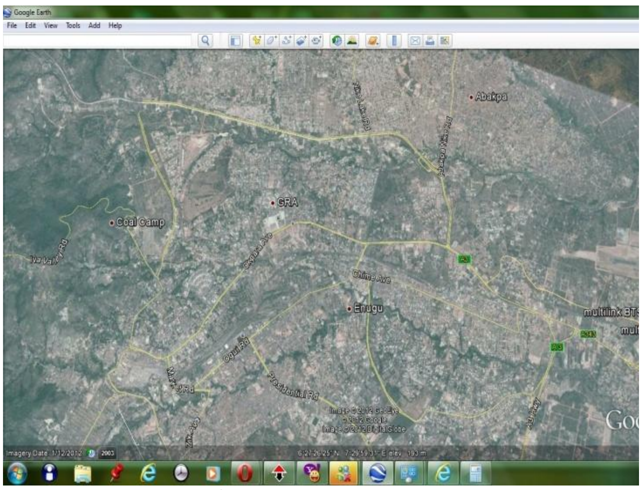

Figure 5: Map of Test Bed – Enugu Urban Environment

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 6: TEMS Measurement Tool used for Field gathering of RSS Data

Note that the position of the UMTS800 (CDMA2000 1x) Mobile Station can be anywhere within the footprint of a GSM900 BTS, while the UMTS800 Base Station can be exactly on one GSM Base Station (when the Provider is the same, that is, coordinated operation), or in a random position (when Systems belong to different Service Providers that is, un-coordinated operation, as in this Research. This scenario is shown in Figure 7 and figure 8, where a UMTS800 Base Station and a UMTS800 Mobile Station suffer from IM effects caused by the adjacent GSM900 transmitters. The design was same as that for gathering RSS measurements. For Antenna Isolation measurements conducted in the Laboratory, the design is depicted in Figure 9.

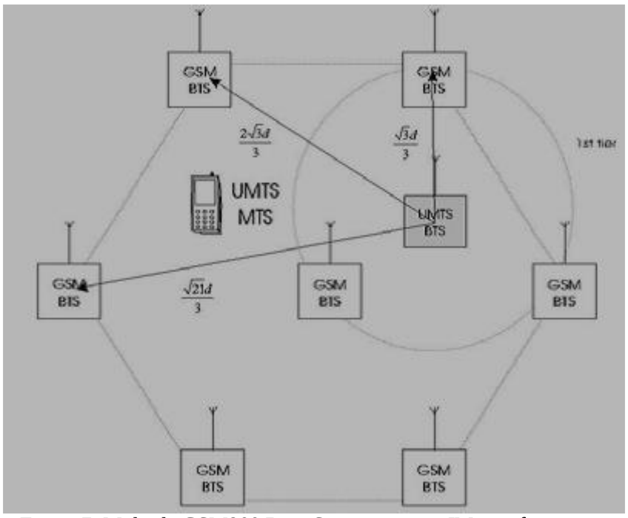

Figure 7: Multiple GSM900 Base Stations causes IM interference to UMTS800 Base Stations or Mobile Stations (uncoordinated Operations)

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 7, July 2013

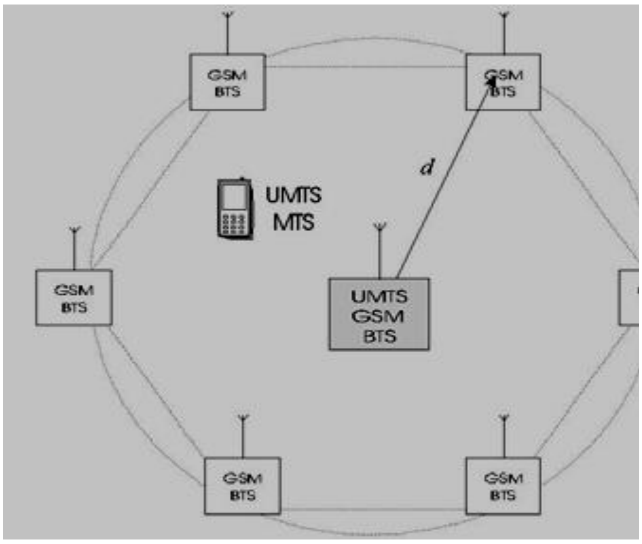

Figure 8: Multiple GSM900 Base Stations causes IM interference to UMTS800 Base Stations or Mobile Stations (coordinated Operation)

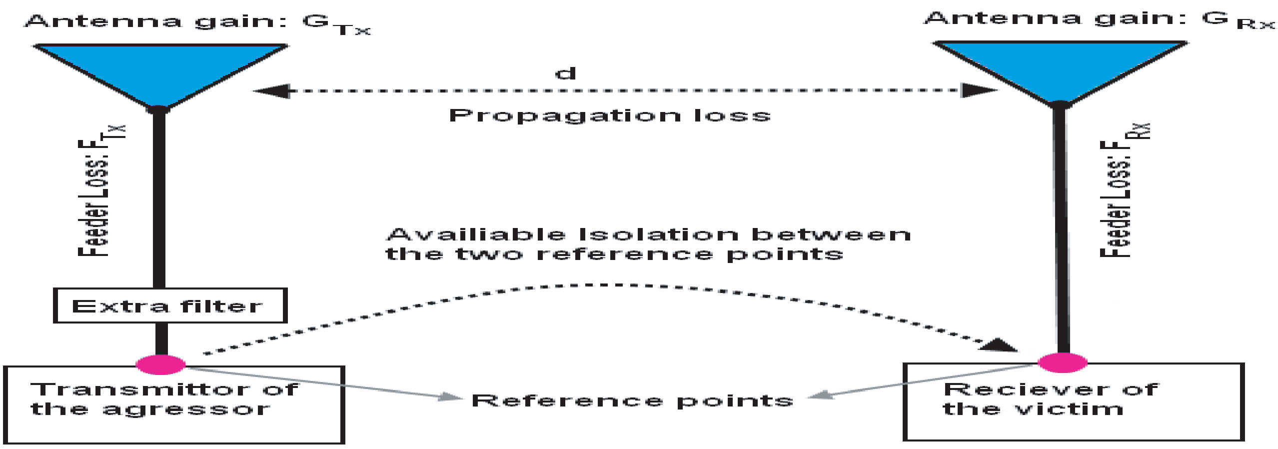

Figure 9: Design for Antenna Isolation Measurements

VI 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 23, when the Received Power is in dBm unit (decibel relative to mill watt), the Received Power, P_r is expressed as:

Pr (dBm) = 10 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 (22):

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

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

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 7, July 2013

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 (15); that is:

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

which is then evaluated using measured data (Average Received Power) from Table 1. From Equation (22), 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 a plot average measured path loss against distance is shown in figure 10

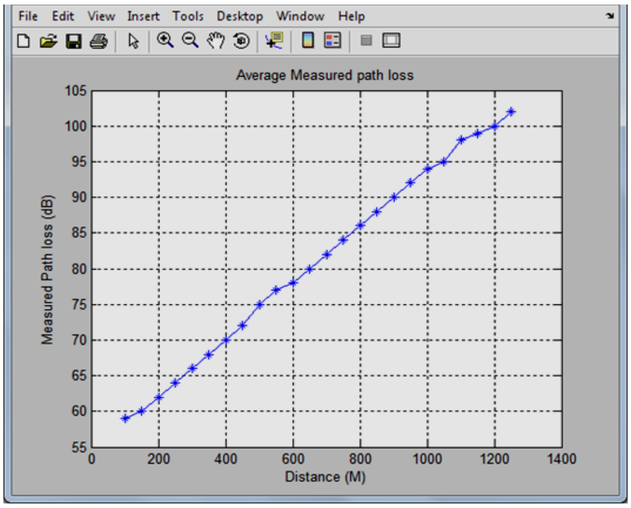

Figure 10: Simulation of Average Measured Path Loss for Enugu Urban

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 16

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 (17), 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 (19)

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

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:

$$e(n) = \sum_{i=1}^{k}[L_p(d_i) - L_p(d_o)]^2 \quad (27)$$

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 7, July 2013

The value of n, which minimizes the Mean Square Error (MSE), is obtained by equating the derivative of Equation (27) to zero, and solving for n:

$$\frac{\partial e(n)}{\partial n} = 0 \qquad (28)$$

From the result of the evaluation we have that equation (27) becomes;

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

Applying Equation (28): $\frac{\partial e\,(n)}{\partial n} = 0$, 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 (20) is used to determine the Standard Deviation, σ (dB) about the mean values. The standard deviation, σ of the log-normal shadowing about its mean value is 6dB

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

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

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

$$Lp\,(d) = 62 + 31.1 \log\,(D) \qquad (29)$$

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 and simulated in figure 11 The RSS (Pr) is therefore, calculated under the same set of transmission conditions using same simulation parameters [11, 12 ,13].

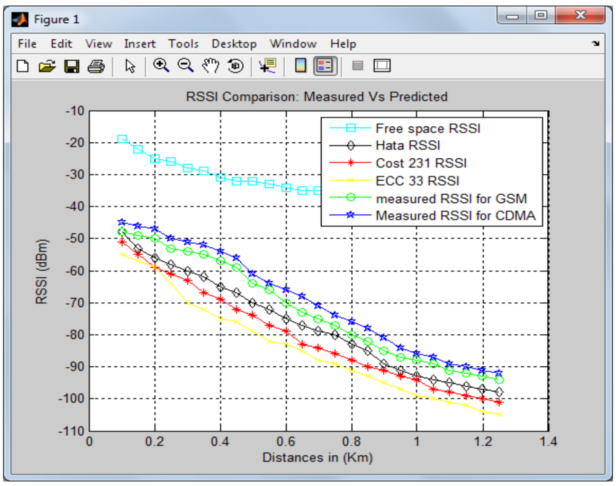

Figure 11: RSS Comparison – Measured Vs Predicted (Traditional Models)

Recall that the quality of the Link or performance of Systems in a shared site is dependent on the Noise floor level and interference the Systems are subjected to. An increase in Noise floor level and Interference causes the Link Attenuation, A_p or Total losses (dB) to be so high, such that the Isolation value would be low (dB) and the Received Signal Strength (RSS) or P_r may be below the threshold of Receiver Sensitivity of the BTS Low Noise Amplifier (LNA).

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

$$SINR = \frac{S}{1+N_o}, \qquad (30)$$

Where S is the resulting RSS (P_r) values gathered from field measurements (Table 1) and N_o is a constant (-109dBm)[12]. Figure 12 shows the link performance of co-site in comparison with that of a single site.

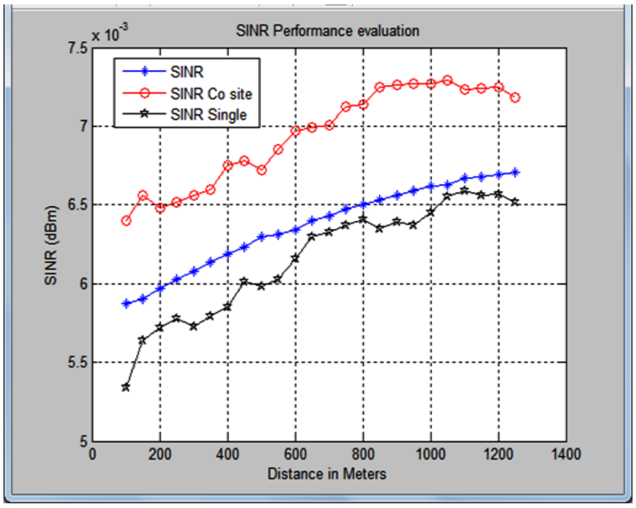

Figure 12: Simulation of SINR performance evaluation

Table 3: Result of Laboratory demonstration of Measured Isolation Values

Antenna configuration	Measured Isolation
Horizontal separation 3 m/8 m	56 dB/61 dB
Horizontal separation 3 m with 0°/+15°boresight angle rotation	56 dB/60 dB
Horizontal separation 3 m with 0°/4°electrical down-tilt	56 dB/75 dB
Vertical separation 0 m	70 dB
Vertical separation 1 m with different antenna pole (horizontal separation 1m)	75 dB
Vertical separation 0.5 m with 0°/4°electrical down-tilt	75 dB/83 dB

Careful analysis of Table 3 shows mitigation or reduction of interferences and IM effects as the separation distances (both horizontal and vertical) increases. Same goes for the electrical down tilt, as the azimuth (angle) of one of the

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 7, July 2013

Antennas changes from 0^o to 4^o. SIR for the interfered with System (UMTS800) is evaluated using Equation (31)

$$SIR = \frac{G_p * S_i}{N_o + I_{GSM} + I_{IM}} \quad (31)$$

$G_p = \frac{W}{R}$ = Processing gain = 3174.5

S_i = Power of one UMTS800 channel = 1mW ≅ -0.09dBm.

N_o = -109dBm

I_{GSM} = 10dB [4]

I_{IM} = 60dB [4]

Converting dB values to dBm and evaluating Equation (31) yields:

$$SIR = \frac{3174.5*(-0.09)}{-109+40+90} = \frac{-285.71}{21} = -13.60$$

Literature value for SIR (UMTS800) is -12 to – 16

From literature, Capacity in a CDMA system is extracted, as

$$\text{Cell capacity } k = 1 + \frac{G_p}{v*p*(1+I_{UL})} \quad (32)$$

if we solve for k (Eq. 16)

$$k = 1 + \frac{G_p}{v*p*(1+I_{UL})} = 1 + \frac{3174.5}{0.5*4.9*1.55} = 837$$

Hence, 837 Mobile Users can be supported in the Network, if System is not interfered with by GSM900 System. When UMTS800 System is interfered with, Capacity degradation can be evaluated by noting the minimum allowed received power at the UMTS800 BS before and after being interfered with, by Signal GSM900 Base Station.

$$P_{min} \text{ before} = \frac{N_o*SIR}{G_p - \alpha*SIR*(k-1)*(1+I_{UL})} \quad (33)$$

$$= \frac{(-109)(-13.6)}{3174.5-0.5\,(-13.6)(836)(1.55)}$$

$$= \frac{1482.4}{11985.94} = 0.1237 \text{ W}$$

Calculating the minimum allowed received power at UMTS800 BS after the presence of the GSM900 signal by judging I_{GSM900}, is as shown in Equation (34).

$$P_{min} \text{ after} = \frac{(N_o + I_{GSM\ 900})*SIR}{G_p - \alpha*SIR*(k-1)*(1+I_{UL})} \quad (34)$$

$$= \frac{(-109)(-13.6)}{3174.5-0.5\,(-13.6)(836)(1.55)}$$

$$= \frac{938.4}{11985.94} = 0.0783 \text{ W}$$

UMTS800 Capacity when interfered with, by GSM900 MS could be adduced, using Equation below.

$$K_{int} = 1 + \left[\frac{G_P P_{min} \text{ before}}{v*\rho*I_{UL}}\right] \quad (35)$$

$$= 1 + \left[\frac{3174.4*0.1237}{0.5*4.9*1.55}\right] = 1 + \frac{392.68}{3.7975} =$$

1 + 103 = 104

Percentage of capacity loss can be calculated as

$$\% \text{ capacity loss} = \left[1 - \frac{k_{int}}{k}\right] * 100\% \quad (36)$$

$$= \left[1 - \frac{104}{837}\right] *100\% = 87.6\%$$

% Capacity loss above indicates that the UMTS800 System is seriously impaired by the Intermodulation effects, arising from the Signal of GSM900 System.

This would result to serious Call dropping (over 80%), blocking and unavailability of service as only 104 Users can be supported bt the System that would have hither to, supported 837 Users.

Antenna isolation is therefore necessary in co-site Base Stations in order to avoid excessive interference, thereby reducing losses and improving on Link quality.

Before optimization, Antenna Isolation was 65.66 dB.

After optimization, Antenna Isolation was 71.26dB.

$$\% \text{ improvement} = \left[\frac{71.21-65.66}{65.66}\right] * 100\% = 8.5\%$$

VII CONCLUSION

This research contains IM interference analysis and techniques to mitigate the effects of IM in shared-site Systems, using Antenna Isolation Method. 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. Antenna Isolation technique was adopted as the most feasible and most cost effective solution to mitigate cross-modulation and intermodulation products, produced by strong un-attenuating GSM900 Signals that mix with the Local oscillator of the LNA of the UMTS800 BS Receivers

REFERENCES

[1] 1. Wu Jiang, S. Liang, Niu Kai, and Wu Weiling, "Capacity Loss Due to Co- Existence of WCDMA and CDMA2000 Systems", Journal, School of Information Engineering, Beijing university of Posts and Telecommunications, 2003.

[2] C. Smith and D. Collins, "3G Wireless Networks", McGraw-Hill Companies Inc, 2nd Ed; New York, 2007.

[3] Greg Agami, Yi-Chiun Chen and C. C. Lee, "Using RF Filtering to Reduce Competitor Induced Interference", in IEEE Transactions on Vehicular Technology, Vol. 51, No. 2, March 2002.

[4] SONY Mobile Communication Data book – Technical specifications.

[5] Report ITU-R M.2244, "Isolation between antennas of IMT Base Station in The Land Mobile Service", November, 2011.

[6] Asia Pacific Telecommunity, "APT report on studies on the existence between IMT-2000 technologies and other wireless access technology in adjacent and near adjacent frequency band", APT/AWF/REP-4, August 2007.

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

[8] Magdy F. Iskander and zhengging Yun, "propagation prediction Models for Wireless communication systems," IEEE Trans.

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 7, July 2013

On Microwave theory and techniques, vol. 50 No.3 march 2002

[9] 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.

[10] 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

[11]S. Jingfei, "Mitigating Interference between LTE and2G/3G networks", Huawei Communications Publication; Vol. 3, Issue 53, pp44-46, Dec. 2009.

[12]. J. Gavan, "Main Effect of Mutual Interference in Radio Communication Systems Using Broad-Band Transmitters," IEEE Trans. Electromagn. Compat., vol. EMC-28, no. 4, pp. 211-219, June 1986.

[13] C. C. SU, "A rigorous derivation of the relation between the effective area and the directive gain and its extension to lossy antennas", IEEE Trans Antennas Propagation, 2001, 49(3): 413-418.

[14] L. C. Sanchez, "Simulation and Performance Evaluation of Co-existing GSM And UMTS Systems" Dissertation for the degree of Master of Engineering in Electronics/Telecommunications, Department of Technology and Buill Environment, University of Gavle, Sweden, January 2010

[15]. R. Price, "Fundamentals of Wireless Networking", McGraw-Hill Publishers, Pp 133, 478- 483, 2007

[16] K. T. Awad, K. T. Wang and Z. Li, "AnIntegrative overview of the open Literatures Empirical Data on the Indoor Radio Channel's Temporal Properties", IEEE Transactions on Antennas and Propagation, Vol. 56, No. 5 pp1451-1468, 2008

[17] 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.