Original Article

Enhancing the Performance of Wideband Code Division Multiple Access (WCDMA) Network Using Antenna Diversity Technique

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ABSTRACT

This paper focuses on the use of antenna diversity technique in enhancing the performance of Wideband Code Division Multiple Access network. Several field measurements of received signal strength were obtained from a WCDMA network with the help of spectrum analyzer and global positioning system. In this paper also, the characterization of the propagation environment was done using the pathloss exponent and empirical pathloss model. Results show that the pathloss exponent of the field environment where the network is situated resulted in 3.63.The use of antenna diversity on the same network gave a pathloss exponent of 2.51.

Keywords: WCDMA, Network, Antenna diversity technique, Pathloss.

INTRODUCTION

Wireless communication services have been growing at a very rapid rate in recent times. Today, the requirement of wireless communication by subscribers to provide high voice quality, data rate services, multimedia features, and lightweight communication devices is also increasing at a rapid rate. But, the wireless operators cannot meet with such demand from these subscribers since the communication channel suffers a lot of impairments that reduce signal reception on the wireless network[1]. These impairments include attenuation, distortion, multipath fading, reflection, and refraction[2]. One of the third Generation (3G) wireless networks that are prone to this phenomenon is Wideband Code Division Multiple Access (WCDMA). Several attempts have been made by these wireless network operators to provide the satisfactory voice and data rate services by deploying more base stations to the existing ones. But, these methods are not cost effective and economical option since the wireless operators are interested in maximizing their profit. Therefore, the need for new technique that will be efficient and cost effective way of improving the signal reception on the wireless network without the relocation or addition of more base stations to the existing ones has emerged. This technique is called antenna diversity. Diversity is an effective means of reducing multipath fading that reduces signal reception in wireless network and it improves the performance over a fading radio channel[3]. The various types of diversity include; frequency, time and space diversity. Space diversity also known as antenna diversity is one of the several wireless diversity schemes that uses two or more antennas to improve the quality and reliability of a wireless link[4]. Space diversity is effective in mitigating multipath situations since multiple antennas offer the receiver several observations of the same signal and each antenna experiences a different interference environment. The basic idea of using antenna diversity is that if one antenna is experiencing a deep fade, it is likely that another one has a sufficient signal and collectively the entire system can provide a robust link which decrease the number of drop-outs and lost connections.

FADING

The received signal exhibits fluctuations in signal level called fading. As these variations represent the change of the strength of the electrical field as a function of the distance from the transmitter, a mobile user will experience variation in time. The signal level of the continuous time received signal α(t) is composed of two multiplication component, α_s, and α_r, as follows[6]:

$$\alpha(t) = \alpha_s(t)\,\alpha_r(t) \qquad (1)$$

Where, α_s (t) is called slow fading and represents the long time variations of the received signal, whereas α_r (t) represents the short-term (or multipath) fading.

(I) Slow fading

This fading is caused by long-term shadowing effects of building or natural features in the terrain. It can be described as the local mean of fast fading signal. The statistical distribution of the local mean has been studied experimentally and was shown to be influenced by the antenna height, the operating frequency and the type of environment[7].

(II) Fast fading

The fast fading also called short-time fading results from rapid fluctuations of the received signal in space. It is caused by scattering of the signal off objects near the moving mobile. Fast fading is also called Rayleigh fading because it is modeled by Rayleigh statistical distribution. Multipath propagation creates the most threat to signal degradation in wireless communication system. Signals that are reflected off other surface may combine with the desired signal but be out of phase. The multipath channel impulse response is given by:

$$h(\tau,t) = \sum \beta_i(t)\,\delta(\tau - \tau_i(t)) \qquad (2)$$

Where N is the number of paths, β_i is the complex gain and the subscript, $_{i,}$ is the delay of the ith arriving path[8].

(III) Rayleigh fading

The probability density function of the signal, $f_R(r)$ can be described using a Rayleigh distribution given by[9]:

$$f_R(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}} \qquad for \quad r \geq 0 \qquad (3)$$

Where σ^2 the variance, r is the signal, and $f_R(r)$ is the probability density function. The value σ is a function of the average power of the envelope received by the antenna. Often the cumulative distribution function of the received signal can be the integral of equation (3) or the probability that the envelope is less than a certain value, r. In a Rayleigh channel, the cumulative distribution function is given by $F_R(r)$ and mathematically expressed as[10]:

$$F_R(r) = \int_{-\infty}^{r} f_R(r)dr = 1 - e^{-\frac{r^2}{2\sigma^2}} \qquad for \quad r \geq 0 \qquad (4)$$

(IV) Flat fading

Flat fading occurs when the latest copy of the signal arrives at base station after a time duration that is smaller than symbol bit period[11]. When the time difference becomes an appreciable percentage of the symbol bit period, Inter Symbol Interference (ISI) can occur. Flat fading is typical in large cells under FDMA and TDMA schemes and may require additional 20 or 30dB transmitter powers to maintain efficient transmission during deep fade.

Determining pathloss exponent of propagation channel

Pathloss occurs when the received signal becomes weaker and weaker due to increasing distance between the mobile station and base station. The extent to which signal degradation occurs in a communication channel can be known by determining the pathloss exponent of the environment. Therefore, pathloss exponent, n, of an environment shows the variation of signal loss in an environment. The pathloss exponent, n, and the received signal strength obtained from field measurement can be used to completely characterize a propagation environment under consideration. The mean path loss, $P_L(d_i)$ [dB] at a transmitter receiver separation, d_i, is given as[16]:

$$P_L(d_i)\,[\text{dB}] = P_L(d_0)\,[\text{dB}] + 10n\log_{10}\left(\frac{d_i}{d_0}\right) \qquad (5)$$

Where n = pathloss exponent,

$P_L(d_0)$ = pathloss at known reference distance d_0.

For free space model n is regarded as 2. The free-space model however is an over idealization, and the propagation of a signal is affected by reflection, diffraction and scattering. Of course, these effects are environment (indoors, outdoors, rain, buildings, etc) dependent. However, it is accepted on the basis of empirical evidence that it is reasonable to model the pathloss, $P_L(d_i)$ at any value of d at a particular location as a random and log-normally distributed random variable with a distance-dependent mean value[17]. That is:

$$P_L(d_i)\,[\text{dB}] = P_L(d_0)\,[\text{dB}] + 10n\log_{10}\left(\frac{d_i}{d_0}\right) + S \qquad (6)$$

Where S, the shadowing factor is a Gaussian random variable with values in dB. The path loss exponent, n, is an empirical constant which depends on propagation environment.

In order to determine the pathloss coefficient, n, of the test bed environment, equation (5) can be used to manually compute it as:

$$n = \frac{\{P_L(d_i) - P_L(d_0)\}}{10\log_{10}\left(\frac{d_i}{d_0}\right)} \qquad (7)$$

But, using linear regression, the value of n can be determined from the measured data by minimizing total error R^2 as follows:

$$R^2 = \sum_{i=1}^{M}\left[P_L(d_i) - P_L(d_0) - 10n\log_{10}\left(\frac{d_i}{d_0}\right)\right]^2 \qquad (8)$$

Differentiating equation (8) with respect to n,

$$\frac{\partial R^2(n)}{\partial n} = -20\log_{10}(d)\sum_{i=1}^{M}\left[P_L(d_i) - P_L(d_0) - 10n\log_{10}\left(\frac{d_i}{d_0}\right)\right] \qquad (9)$$

Equating $\frac{\partial R^2(n)}{\partial n}$ to zero,

$$0 = -20\log_{10}(d)\sum_{i=1}^{M}\left[P_L(d_i) - P_L(d_0) - 10n\log_{10}\left(\frac{d_i}{d_0}\right)\right] \qquad (10)$$

$$\sum_{i=1}^{M}\left[P_L(d_i) - P_L(d_0)\right] - 10n\log_{10}\left(\frac{d_i}{d_0}\right) = 0 \qquad (11)$$

$$\sum_{i=1}^{M}[P_L(d_i) - P_L(d_0)] \_ \sum_{i=1}^{M}\left[10nlog_{10}\left(\frac{d_i}{d_0}\right)\right] = 0 \qquad (12)$$

$$\sum_{i=1}^{M}[P_L(d_i) - P_L(d_0)] = \sum_{i=1}^{M}\left[10nlog_{10}\left(\frac{d_i}{d_0}\right)\right] \qquad (13)$$

Therefore, $n = \frac{\sum_{i=1}^{M}[P_L(d_i) - P_L(d_0)]}{\sum_{i=1}^{M}\left[10log_{10}\left(\frac{d_i}{d_0}\right)\right]}$ (14)

Equation (14) can be used in determining the pathloss exponent, n, of the test bed environment which is essential in characterizing the propagation environment.

Mathematical analysis of two-branch maximal ratio combining

Figure 1 shows the baseband representation of a typical two-branch maximal ratio combining. The mathematical analysis of the two branch maximal ratio combining is as follows:

Let the channel between the transmit antenna and receive antenna x be denoted by h_x and the channel between the same transmit antenna and receive antenna y be denoted by h_y. These channels at time t can be modeled by a complex multiplicative distortion $h_x(t)$ for receiver antenna x and $h_y(t)$ for receiver antenna y. Thus, the channels $h_x(t)$ and $h_y(t)$ are given by the expressions[23]:

$$h_x(t) = h_{x=}\alpha_x e^{j\theta_x} \qquad (20)$$

$$h_y(t) = h_{y=}\alpha_y e^{j\theta_y} \qquad (21)$$

It is observed that as the signals $s_x, and\ s_y$ transverse these channels, noise and interference are added to the signals reaching the two receivers x and y. Therefore, the resulting received baseband signals on the x and y antennas are expressed as:

$$r_{x=} h_x\, s_x + n_x \qquad (22)$$

$$r_{y=} h_y\, s_y + n_y \qquad (23)$$

Where, s_x, and s_y are the signal reaching the antenna x and antenna y respectively. Also, n_x and n_y represent receiver noise and interference on the x and y channels respectively. Assuming n_x and n_y are Gaussian distributed, the maximum likelihood decision rule at the receiver for the received signals is to choose signal if and only if:

$$d^2(r_x, h_x\ s_i) + d^2(r_y, h_y\ s_i) \le d^2(r_x, h_x\ s_k) + d^2(r_y, h_y\ s_k) \qquad (24)$$

But, the expression d^2(x, y) is the squared Euclidean distance between signals x and y and is expressed as follows:

$$d^2(x, y) = (x-y)(x^* - y^*) \qquad (25)$$

Therefore, the receiver combining scheme, $\hat{S}_o$, for two branch MRC is determine as follows:

$$\hat{S}_o = h_x^* r_x + h_y^* r_y \qquad (26)$$

Substituting the values of r_x and r_y into equation (2.26).

$$\hat{S}_o = h_x^*(h_x\, s_x + n_x) + h_y^*(h_y\, s_y + n_y) \qquad (27)$$

$$\hat{S}_o = (\alpha_x^2 + \alpha_y^2) S_x + h_x^*\, n_x + h_y^*\, n_y \qquad (28)$$

Expanding equation (24) and using equation (25) and (28), we choose the highest signal, S_i, if and only if :

$$(\alpha_x^2 + \alpha_y^2)|S_i|^2 - \hat{S}_o S_x^* - S_x^* S_i \le (\alpha_x^2 + \alpha_y^2)|S_k|^2 - \hat{S}_o S_k^* - S_x^* S_k, \text{ for } i \ne k \qquad (29)$$

For Phase Shift Key (PSK) signals (equal energy constellations).

$$|S_i|^2 = |S_k|^2 = E_s$$

Where E_s is the energy of the signal. Therefore, for PSK signals, the decision rule in equation may be simplified to choose S_i if and only if:

$$d^2(\hat{S}_o, S_i) \leq d^2(\hat{S}_o, S_k), \text{ for } i \neq k \qquad (30)$$

Data collection and experimentation

In this section the measurement environment as well as the location of the base station from where the field data was collected is described. Also the equipment used during the experimentation and their specifications were equally described. These measurements are necessary in order to ascertain the efficiency of the network under consideration before the introduction of the propose antenna diversity.

(A) Description of measurement environment

The map of Awka town and its environs is shown in Figure 3. Awka town is located in the south - east part of Nigeria and it is the capital of Anambra State of Nigeria. The test bed environment is located in Awka along Enugu-Onitsha Express way at a location with longitude of 7.0678° E and latitude of 6.2069° N. (See figure 2.)

(B) Test bed environment

The Test bed environment where the base station is located is shown in Figure 4. The base station is located at a location between the Judiciary road and secretariat road. The Longitude and latitude of the base station location is 7.0799^{o}N and 6.2352^{o}E respectively. (See figure 3.)

(C) Measurement Route

The measurement route where the field data was collected is shown in Figure 5. It comprises of the location of the base station, small houses and vegetations. The length of the measurement route is up to 1000meters and the base station is near the secretariat building. (See figure 4.)

(D) Equipment used and specification

(I) Base station specification

Frequency of operation: 881.79MHz
Height: 37m
Transmitting Power: 44.4dBm
BER: 0.987
Antenna Type: conventional antenna system (sectorized)
Antenna gain=16dBi

(II) Spectrum analyzer specification

Type: bench top
Model: AT5011
Frequency of operation: 0.15-1050 MHz
Manufacturer: Shenzhen Atten Electronics Co., Ltd.

EXPERIMENTAL SETUP

The block diagram of the experimental test bed setup used for the research work is shown in Figure 5. It comprises of the base station transceiver which emanates the transmitted signal and it belongs to Visafone network. The transmitted signal is been measured from the transmitting base station using the spectrum analyzer, made by Shenzhen Atten, of model AT5011. These received signal strength were measured and analyzed with the help of software installed and embedded in the spectrum analyzer. The Global Positioning System measures the angular coordinate, deviation and distance of the mobile unit from the transmitting base station therefore, with the help of the processed described the received signal strength over several distances of up to 700 meters are recorded and they are shown in Table 1&2

Data analysis

Figure 6 shows the rate at which Pathloss increases as the distance from the base station increases. The pathloss exponent, n, of the test bed area is 3.63 as obtained from the measured data. The developed model from field data can be used in predicting RSS.

Good agreement between the field RSS and predicted RSS is observed in Figure 7. Line of best fit exist between the two graphs.

Figure 8 shows the response of the diversity antenna system in enhancing the performance of the WCDMA network by minimizing multipath fading and multiple access interference. There is a greater improvement on the performance of the WCDMA network .The pathloss exponent of 2.51 obtained using antenna system unlike that of 3.63 obtained from the characterized test bed environment.

The rate at which signal lost is minimal when antenna diversity is used on the network as compared to the large signal loss experienced when no diversity is used on the network.

CONCLUSION

In communication network, the major problem is how to convey the information efficiently as possible within limited bandwidth, although most of the information bits are lost through fading. In order to minimize the bit error rate on the network, the loss of information and signal fading should be minimized. In this paper we considered using antenna diversity to reduce the error performance of the signal and compared the technique with conventional antenna system.

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Table 1. Average result for received signal strength carried out on Visafone network on all the weeks with the average

D(m)	RSS (dBm)	RSS (dBm)	RSS (dBm)	RSS (dBm)	RSS (dBm)	RSS (dBm)	RSS (dBm)	RSS (dBm)	RSS (dBm)	RSS (dBm)	AVERAGE RSS (dBm)
100	-68.21	-68.10	-67.94	-67.50	-68.10	-68.00	-67.84	-67.89	-68.30	-67.52	-67.94
200	-74.50	-73.75	-74.50	-73.75	-75.05	-73.80	-73.75	-73.70	-75.05	-73.75	-74.16
300	-87.25	-87.24	-87.00	-88.00	-84.05	-87.000	-87.36	-87.00	-86.50	-87.00	-86.84
400	-87.50	-88.00	-85.50	-87.25	-87.00	-87.25	-88.00	-84.90	-87.40	-87.10	-87.04
500	-90.53	-92.25	-91.50	-93.00	-90.53	-91.50	-93.00	-90.53	-92.00	-91.56	-91.64
600	-100.00	-99.24	-99.45	-99.07	-99.10	-99.25	-99.50	-99.27	-99.17	-99.05	-99.33
700	-104.00	-103.25	-103.24	-103.25	-104.00	-103.00	-102.66	-102.65	-102.60	-102.65	-103.13

Table 2. Pathloss obtained using conventional antenna and antenna diversity on WCDMA network

Distance from Tx [m]	Field data pathloss: ($Lp(d_i)=94.74+36.Log(d_i)$)	Antenna diversity pathloss - ($Lp(d_i)=94.74+25.1Log(d_i)$)
100	94.78	94.78
200	105.71	102.34
300	112.10	106.76
400	116.63	109.89
500	120.15	112.32
600	123.03	114.31
700	125.46	115.99

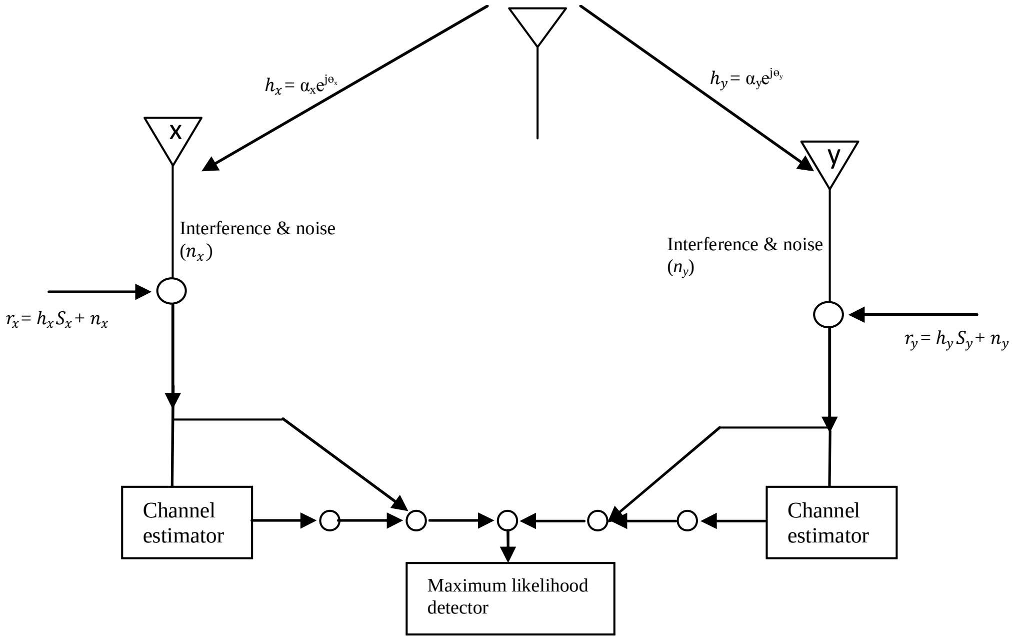

Figure 1. Baseband representation of the classical two-branch MRC

Figure 2. Map of Awka town and surrounding environs

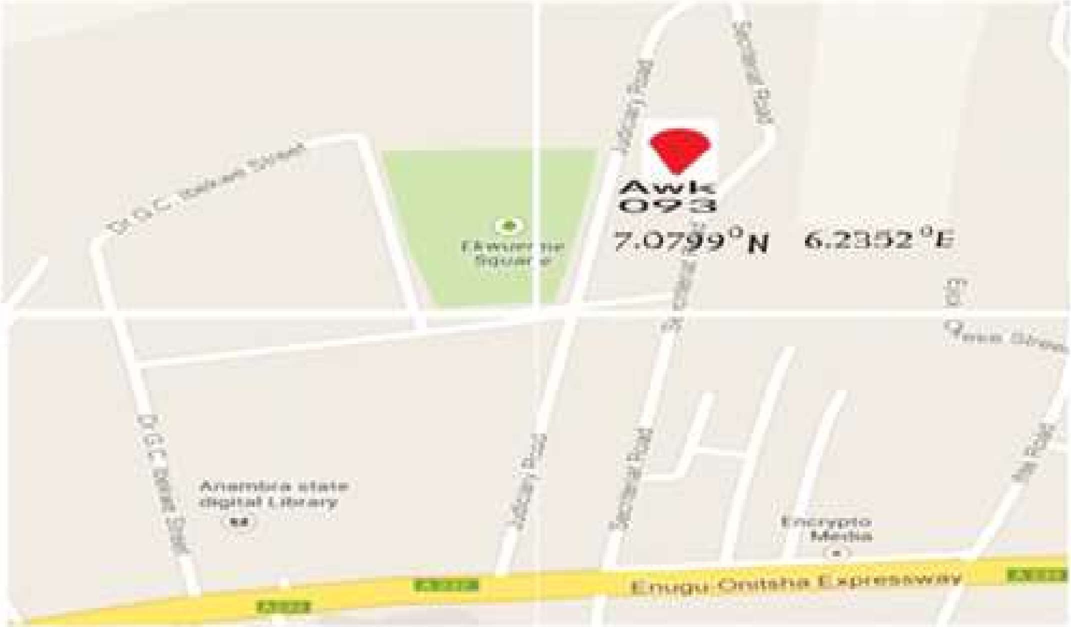

Figure 3. Map of Test bed environment [google map]

Figure 4. Measurement route

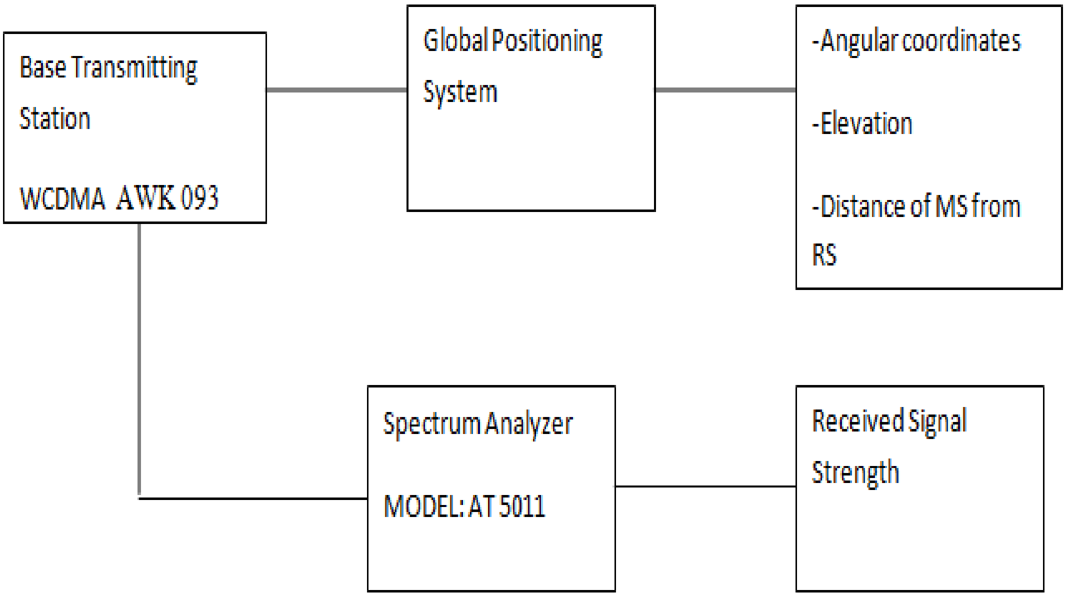

Figure 5. Block diagram of experimental test bed set up

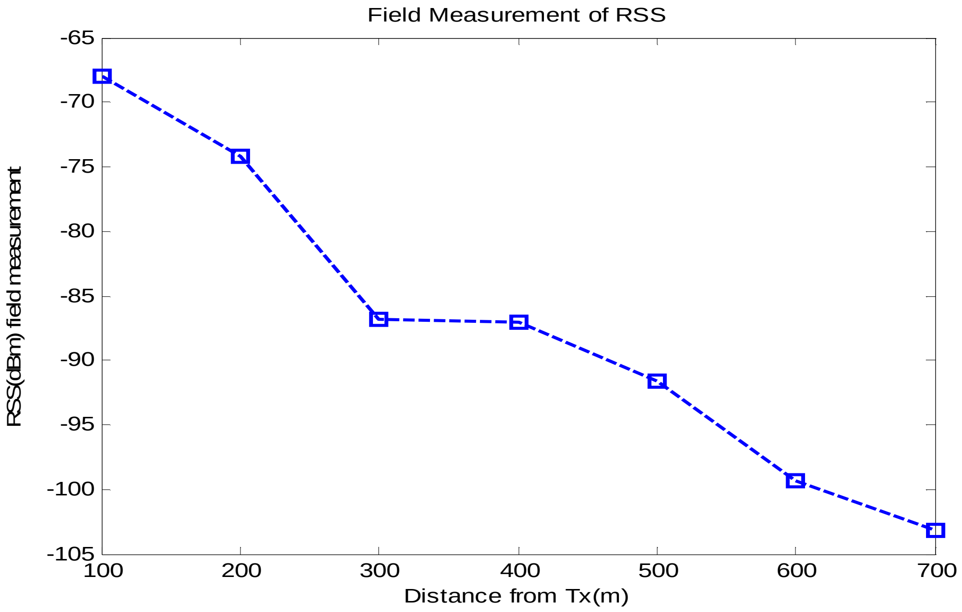

Figure 6. RSS vs. distance for the characterized environment

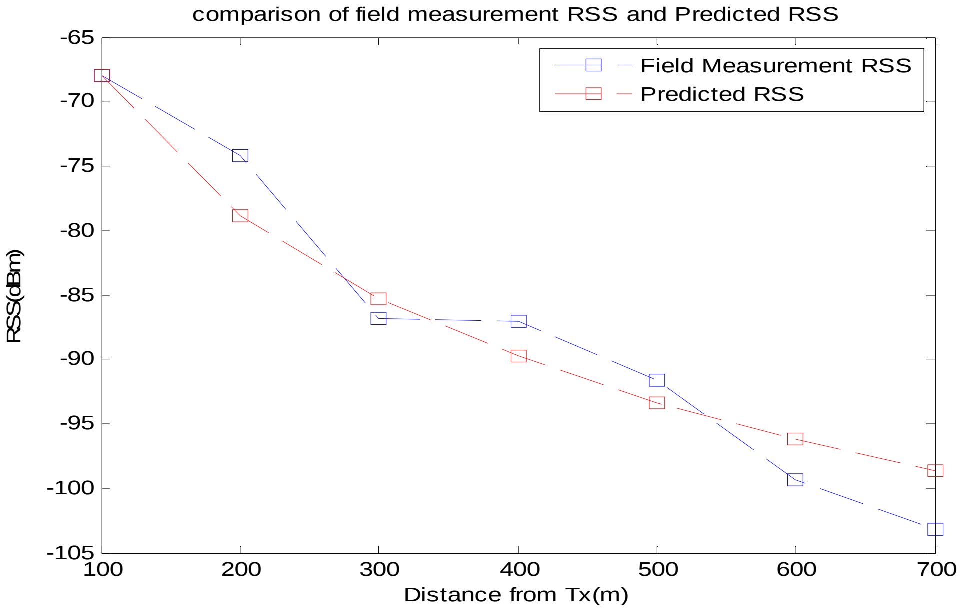

Figure 7. Measured and Predicted RSS Vs. distance

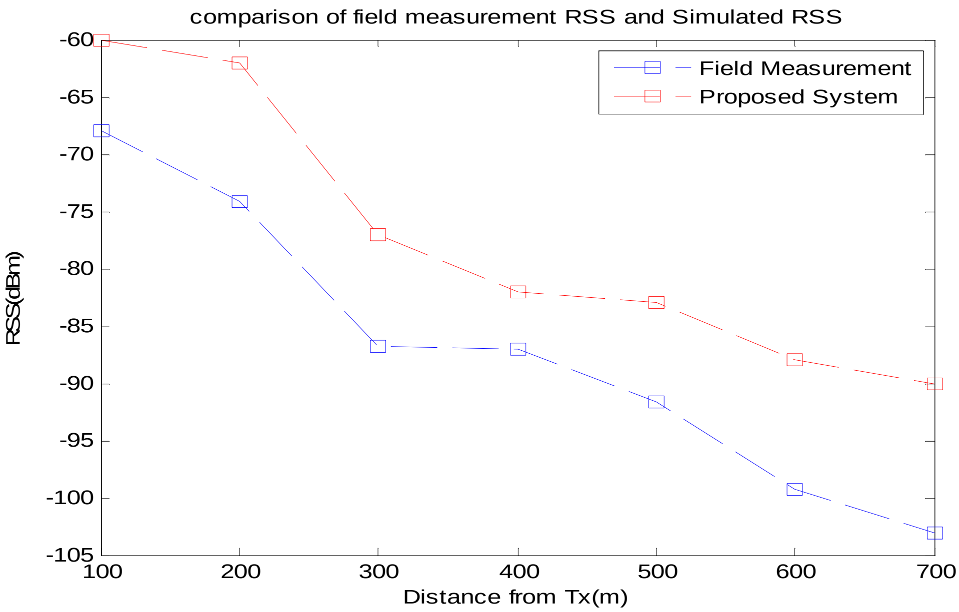

Figure 8. RSS (field)+Rss (diversity)Vs Distance

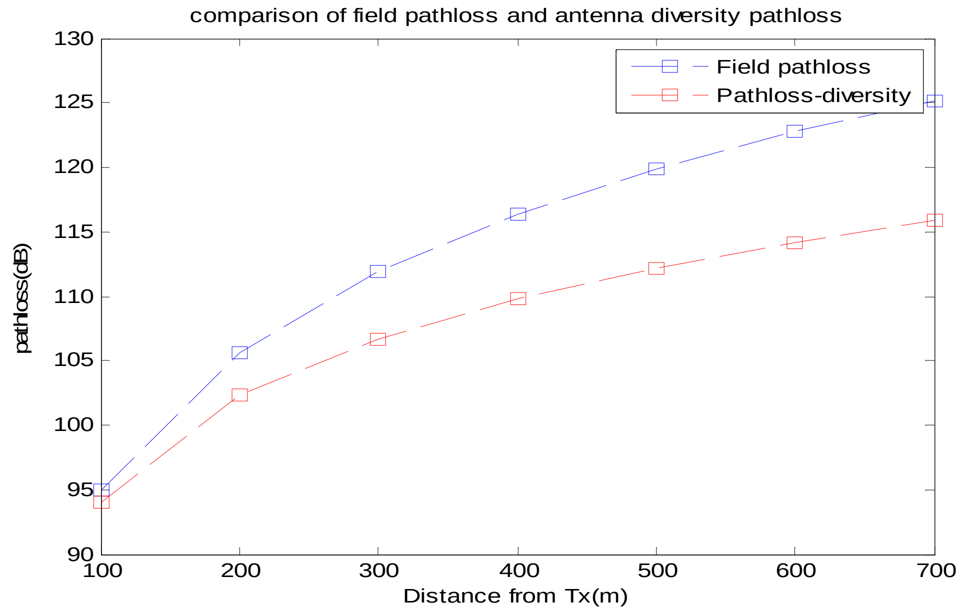

Figure 9. Pathloss Vs distance (Response of antenna diversity on the WCDMA network