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Cellular Mobile Signal Propagation; Effects of EIRP and Antenna Gain

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ABSTRACT

This paper compares the cellular mobile network signals and transmission properties of two mobile service networks. The background theories for the propagation of cellular mobile signals were reviewed. A mobile signal analyzer capable of measuring power density was used to measure the received signal power density at varied distances from a base station transmitter. The received signal power density was measured in two scenarios: highly obstructed and less obstructed areas. Based on the results, it was concluded that the network that uses higher EIRP value of 64.5dBm with lower antenna gain of 17.5dB covered more distance up to 3000m from the BS transmitter before fading below -100dB compared to the network that uses lower EIRP of 64.00dBm and higher gain of 18dB, which faded faster below -100dBm from distance of 2250m. Hence, higher EIRP value was concluded to support the transmitted signal to cover more distance with higher strength than higher antenna gain.

Keywords: *Antenna gain, Antenna Height, BS transmitter, Distance, EIRP, Mobile network, Path loss, Received signal power, Telecommunication*

1. INTRODUCTION

There have been empirical and theoretical investigations carried out on cellular mobile radio signals for different technologies and environments [1; 2; 3]. However, little or no practical measurements or observations have been carried out to study the signals transmitted from the base station transmitters of local cellular mobile service providers in the thick forest regions and densely populated areas with very high signal obstructions such as buildings located without spaces between them for instance in most cities in Nigeria. In the present day society cellular mobile network services have gained higher dominance in the telecommunication sector due to its portability and ease of operation. Cellular mobile network services have gone beyond voice services to data, video and control signal for remotely operated systems. The receiving antennas of electronic devices are wirelessly connected to the mobile network Base Station (BS) transmitters as the devices are moved about. Wireless signals transmitted from the BS transmitters are significantly affected by the nature or geography of the environment [2], the characteristic features of the transmitter antenna [3] such as antenna height, gain etc. The propagation of radio waves is influenced by many physical mechanisms, including free space loss, terrain blocking and reflection, foliage absorption, ionospheric reflection and absorption, rain loss and reflection, clear air absorption, Doppler shift, and multipath fading [4].

Since the cellular mobile phone service providers are not using the same technology and signal transmission parameters and people in most urban and rural areas experience continuous call drop, poor signal reception etc. It became an issue we identified imperative to study and to understand the properties of the propagation of the respective signals transmitted from the base station transmitters of some cellular mobile service providers from different locations and the possible effects on the signal transmitted and received at the receiving end of the network. The properties of the cellular mobile radio channel can be categorized into two namely: narrowband and wideband properties while the narrowband comprises mainly of the received power of the propagated signal and the path loss, the wideband concerns delay spread, angles of arrival and impulse response. Since the wideband generation of the cellular mobile radio otherwise known as GSM is described by the narrowband properties and this system is what is widely deployed in the most of the developing countries such as Nigeria, the focus of study in this work is on narrowband properties.

Propagation parameters of the cellular mobile signal transmission which includes antenna height, tilt, antenna gain, EIRP, transmitting frequency etc. are very vital to be considered as practical and theoretical guide to effective mobile network planning. Radio propagation is profoundly site specific and varies considerably based on speed of mobile terminal, frequency of operation and the parameters like Antenna height, Antenna gain, Transmitted power, Path loss, other losses and Receiver sensitivity [5]. The received signal strength depends on the path loss and the parameters of the transmitter and receiver. Quality of call establishment is based on received signal strength. Sharma et al [6] opined that before going for the establishment of expensive system such as wireless systems, mathematical model analysis is necessary to estimate channel environment, frequency band and the desired radio coverage range. Mathematical modeling plays an important role in cell coverage prediction, received signal strength estimation and link budget analysis of mobile radio systems.

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2. LITERATURE REVIEW

2.1 Previous Works

Lorne [7] presented a work on path loss measurements and model analysis of a 2.4 GHz network in an outdoor environment, which outlines the achieved prediction accuracy of a direct-ray, single path loss exponent, adapted Seidel-Rappaport propagation model [8] as determined through measurements and analysis of the established 2.4 GHz, 802.11g outdoor WiFi network deployed on the campus of the Georgia Institute of Technology. In his work [7]; he discussed the viability of using the obtained model parameters as a means for planning future network deployment. Also his analysis of measured data shows that accurate predictive planning for network coverage is possible without the need for overly complicated modeling techniques such as ray tracing. Sharma et al [6] compared the different path loss propagation models which depend on various parameters like frequency and height of antenna at the transmitter side.

Edward et al [3] developed a method to understand the effects of high antenna heights, high gain antenna and down-tilting in light of the present understanding of radio propagation and existing prediction models. According to them, application of the models requires knowledge of the powers. Among the numerous approaches to calculate the path loss, the most suitable was that based on the peak power of the impulse response profile [9]. Vanderau et al [4] examined the relationships between propagation loss and antenna gain at higher frequencies. In their work they presented and showed how dense intelligent infrastructure affects cell size and system capacity, and described the improving high frequency capabilities of Radio Frequency (RF) electronics technology. Soon-soo and Young-Hwan [10] described an EIRP measurement technique for a base-station antenna.

2.2 Background Theories

2.2.1 Equivalent Isotropically Radiated Power (EIRP)

As described by Mike [11], the transmitter parameters are often further simplified using the concept of EIRP. According to him this is useful as it allows treatment of systems with very different antenna characteristics similarly. In radio systems, EIRP is the amount of power that would have to be radiated by an isotropic antenna to produce the equivalent power density observed from the actual antenna in a specified direction. The EIRP is still a function of direction; not assuming power is radiated isotropically. The EIRP allows comparisons between different emitters regardless of type, size or form. From the EIRP, and with knowledge of a real antenna's gain, it is possible to calculate real power and field strength values [12]. The equations (i), (ii) and (iii), describe the models of the propagation of transmitted signal to the point of reception.

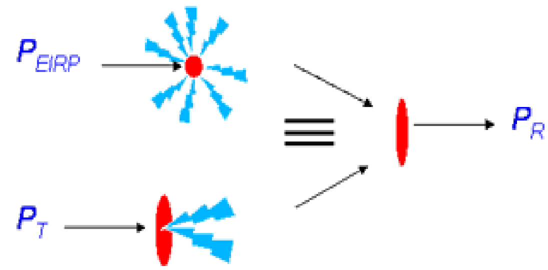

Fig 1: Illustration of the power transmitted from the transmitter to reception at the receiver

$$P_{EIRP} = P_T + G_T - L_T \, dB \qquad \text{(i)}$$

Where

P_T is the transmitter power
G_T is the antenna gain
L_T is the losses in the feeders etc

Received power P_R = EIRP - Path Loss + Receiver antenna gain (ii)

The equations show that the received signal power is determined by the EIRP, receiver antenna gain and the path loss.

2.2.2 Free Space Path Loss

Majority of the cellular mobile radio prediction models [3; 13; 14; 15] were based on path loss equations. Path loss is when the transmitted signal suffers a loss proportional to $1/d^n$, where d is the distance between transmits and receiver antennas and n is a positive number from 2 to 6. For free space transmitter, n=2 and the free space path loss is given in dB [16]. The received power level, P_R at the receiving antenna can be calculated analytically as follows: For the isotropic antenna radiating uniformly in all direction (spherical pattern) the power density, P_R is given by equation (iii).

$$P_R = \frac{P_T}{4\pi d^2} \qquad \text{(iii)}$$

When a directional transmitting antenna with a power given factor G_T is used, the power density at the receiving site is G_T multiply equation (iv):

$$P_R = \frac{P_R G_T}{4\pi d^2} \qquad \text{(iv)}$$

$$\lambda = \frac{c}{f} \qquad \text{(v)}$$

f = the transmission frequency in Hz, C=3x10^{-8} m/s is the free space speed of propagation for electromagnetic waves, and λ is the wavelength in m.

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$$P_R = \left[\frac{\lambda}{4\pi d}\right]^2 P_T G_T G_R \quad \text{(vi)}$$

The path propagation loss, Lp which denotes the loss associated with propagation of electromagnetic waves from the transmitter to the receiver, is given by:

$$L_P = \left[\frac{4\pi d}{\lambda}\right]^2 \quad \text{(vii)}$$

This loss depends on the carrier frequency and the Transmitter-Receiver separation distances. The product $P_T G_T$ is termed the Equivalent Isotropic Radiated Power (EIRP).

$$P_R = 20\log\left[\frac{\lambda}{4\pi d}\right] + P_T + G_T + G_R (dBm) \quad \text{(viii)}$$

2.2.3 Multi-Path Propagation and Fading

According to Edward and Abu [3], the channel is a combination of paths each with its own attenuation, phase distortion, and time delay. A radio signal spreads out in different directions or channels as it radiates away from the broadcast antenna. Parts of the spreading wave will encounter reflecting surfaces and the wave will scatter off these objects. Zhao [17] opined that multipath propagation causes dispersions in delay, frequency and spatial domains; these are dominant phenomena in both terrestrial mobile and fixed wideband communications. Multipath propagation occurs as radio waves reflect off hills, building, vehicles and other obstacles; they establish different transmission paths from transmitter to receiver antennas as illustrated in figure 2. A path is likely to include many reflections in an urban environment, where as in rural areas one reflection per path may be more common. The multi-path creates one of the most difficult problems in the mobile radio environment: fading; fading can be categorized as either frequency-selective or flat fading.

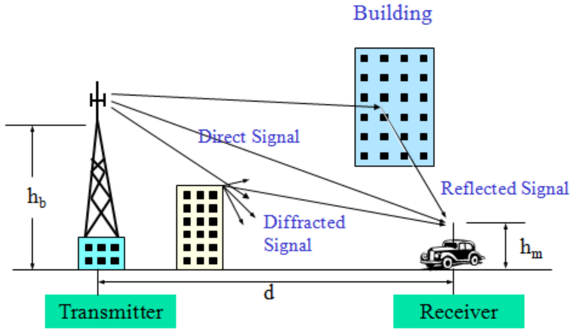

Fig 2: Some radio propagation mechanisms [18]

Frequency-selective fading occurs when the transmitted signal follows different paths each arriving at the receiver antenna at different times. The result is the dispersion of the received signal in time. The signal dispersion in time is typically identified by associating a delay spread with the signal. Different environment produced different delay profiles.

Flat fading is when the transmitted wave scatters off many obstacles, particularly close to the mobile. The result is that the phase and amplitude of each ray arriving at the receive antenna are different. Now, assuming that several rays receive from all directions, the receiver antenna at the same time (i.e. with the same delay) the combined sum of these rays may add up constructively or destructively, to form re-enforcement total concentration or fading.

3. METHODOLOGY

The methodology approach taken in this study comprises of two scenarios. These two scenarios enabled us to categorize the received mobile signal measurements and data collection at the cellular mobile fields of the two mobile service networks. The received signal power density was measured and collected with the use of a cellular mobile network analyzer capable of measuring signal power density in decibel milli watts (dBm). The analysis was carried out by plotting graph of received signal power density and EIRP value against distance and comparing the graphs for the two different mobile service networks in the two scenarios.

First Scenario:

This scenario describes the category in which the base station transmitters are located on high way roads connecting two states or cities where obstructions such as buildings are far located from the transmitter BS. Such transmitters service mostly vehicle user on transit with high speed along such roads. The received signal power measuring equipment was conveyed on a car at varied velocities moving away from the transmitter base station while the readings were recorded. The characteristics of the cellular mobile transmitters were taken as shown in tables 1 and 2.

Table 1: Type A network transmitter antenna Base Station (less obstructed area)

Height (H_t)	**32m**
Transmitting at frequencies (fc)	900/1800Mz
Radiated power (P_T)	46dBm
Transmitting antenna gain (G_T)	18dB gain
Effective Isotropic Radiated Powers (EIRP)	64dBm

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Table 2: Type B network transmitter antenna Base Station (less obstructed area)

Height (H_t)	**33m**
Transmitting at frequencies (fc)	900/1800Mz
Radiated power (P_T)	47dBm
Transmitting antenna gain (G_T)	17.5dB gain
Effective Isotropic Radiated Powers (EIRP)	64.5dBm

Second Scenario:

This scenario describes the setup in which the transmitters are located in highly obstructed area where tall buildings are closely located around the transmitter. Received signal power readings here were taken in the premises of the nearby buildings moving away from the transmitters. The characteristics of the transmitters located in such area are shown in tables 3 and 4.

Table 3: Type A network transmitter antenna Base Station (highly obstructed area)

Height (H_t)	**32m**
Transmitting at frequencies (fc)	900/1800Mz
Radiated power (P_T)	46dBm
Transmitting antenna gain (G_T)	18dB gain
Effective Isotropic Radiated Powers (EIRP)	64dBm

Table 4: Type B network transmitter antenna Base Station (highly obstructed area)

Height (H_t)	28m
Transmitting at frequencies (fc)	900/1800Mz
Radiated power (P_T)	47dBm
Transmitting antenna gain (G_T)	17.5dB gain
Effective Isotropic Radiated Powers (EIRP)	64.5dBm

4. RESULTS

The received power measured from type B network for the corresponding distances and frequencies is higher than on the type A network received power only by 0.5dBm, the value by which the EIRP of the type B network BS transmitter exceeds that of the type A transmitter. Type A network transmitters use lower BS transmitter power and higher BS antenna gain while type B network uses the opposite of these values with higher EIRP.

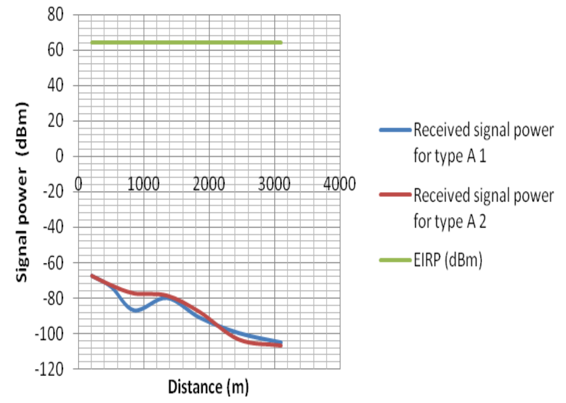

Fig 3: Graphs of received signal power and EIRP against distance for type A network for the two scenarios

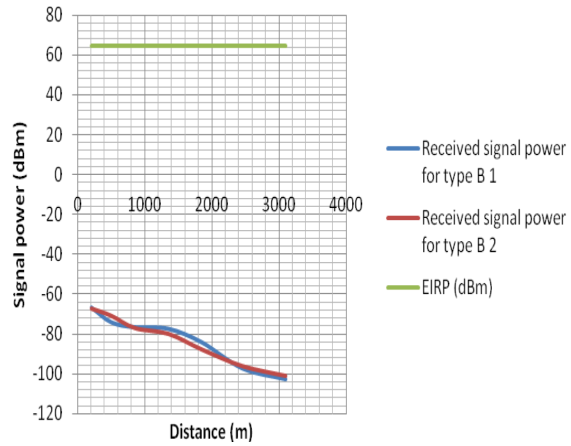

Fig 4: Graphs of received signal power and EIRP against distance for type B network for the two scenarios.

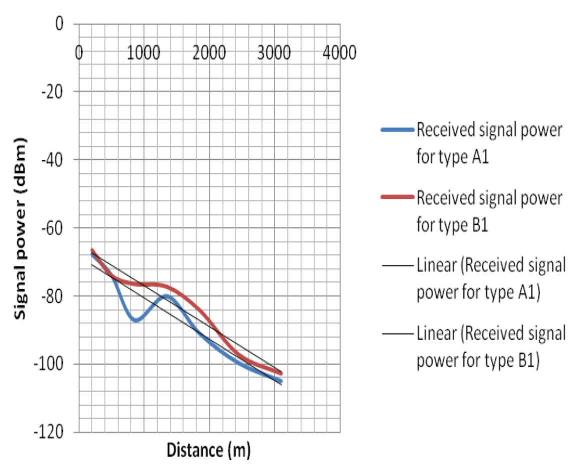

Fig 5: Graphs of received signal power against distance for type A and B networks in scenario 1

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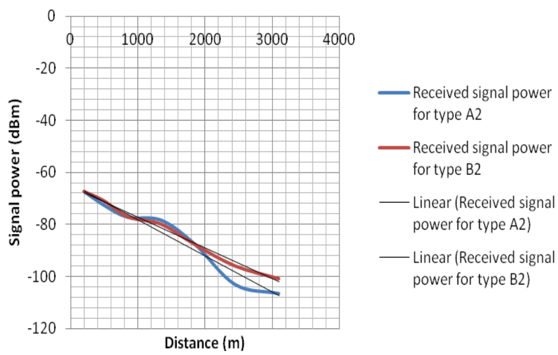

Fig 6: Graphs of received signal power against distance for type A and B networks in scenario 2

4.1 Discussions

Type B network uses higher EIRP value of 64.50dBm than the type A network which uses 64.00dBm and type A network uses higher gain value 18dB compared to type B network which uses 17.5dB. In the two scenarios studied, the type A network uses the same antenna height of 32m while the type B network uses varied antenna heights of 28m for highly obstructed area and 33m for the highway area.

Comparing the type A network received signal behaviors (figure 3) in the two scenarios, the received signal power faded faster below -100dBm in highly obstructed area than in the less obstructed area. Also, comparing the type B network received signal power (figure 4) behavior in the two scenarios; the received signal power for the both areas appeared to have approximately the same features.

Type B network received signal power has more coverage and strength compared to that of type A network within 3000m distance from the BS transmitters of the two network providers in a less obstructed area as illustrated in figure 5. The linear received signal power graph against distance (figure 5) for the type B network maintained higher and parallel measurements of 0.50dBm compared to the type A network linear received signal power linear graph. This difference in received signal strength is as a result of the 0.50dBm difference in their respective EIRP values with the type B network using the higher value.

In a highly obstructed area, the two networks had approximately the same received signal strength covering up to 2000m distance from the BS transmitters as illustrated in figure 6. However, beyond 2000m distance from the BS transmitters, the type A network signal strength faded faster below -100dBm at about 2250m distance while the type B network received signal strength covered up to 3000m distance before fading below -100dBm.

5. CONCLUSIONS

The type A network was confirmed to use lower EIRP value of 64.00dBm with a higher antenna gain 18dB while the type B network uses higher EIRP value of 64.50dBm with lower antenna gain of 17.5dB gain and based on the result, it was concluded that the higher antenna gain of 18dB and height of 32m have less influence or effect to achieve higher received signal strength and coverage especially in a highly obstructed environment.

It was also concluded that the type B network which uses higher EIRP value of 64.5dBm with lower antenna gain of 17.5dB covered more distance up to 3000m from the BS transmitter before fading below -100dBm compared to type A network that uses lower EIRP of 64.00dBm and higher gain of 18dB gain which faded faster below -100dBm at distance of 2250m. Hence, the higher EIRP value of 64.5dBm used by type B network supported the transmitted signals to achieve higher received signal strength and coverage in both scenarios.

Therefore, it was concluded that the higher EPRP value has greater effect on the received signal strength, supporting the transmitted signal for more distance coverage with higher strength compared to higher antenna gain.

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