Analysis of Ambient Noise Level and its Impact on the Capacity and Coverage of CDMA System

Ohaneme C.O., Idigo V.E., Oguejiofor O.S. and Nnebe S.U.

Abstract--Communication services have been the most intriguing things to network users in recent times. Hence there is the need to provide adequate communication facilities such as robust technologies in order to sustain the number of subscribers that are connected to wireless network daily. Therefore this paper provides the best platform to study the effect of ambient noise on wireless cellular network and how it affects the capacity and coverage of the cellular system. Special consideration is given to the Visafone CDMA network cellular environment of South-East Nigeria for the study from where the received signal levels from base stations are taken at various locations. The system is simulated using Matlab to give the vivid account of the effects of ambient noise within the cellular network and how it can be reduced. The simulation results show that at lower ambient noise, an advantage of a network capacity is achieved.

Keywords: Ambient noises, wireless network, electromagnetic waves, thermal noise, reuse efficiency and ionosphere.

I INTRODUCTION

The capacity of cellular network system is regarded as the most important feature of wireless system when the scarce resource is considered. Since the radio spectrum being allocated for communication purposes cannot be increased, the need to make the maximum use of the available scarce resource to its fullest capacity become inevitably important.

The importance of the usage lies in the number of users the network can support which translates into the system capacity. Since CDMA multiple access system is interference limited, there is the need to take into consideration the environmental factors which may contribute to the non-performance of the system in the form of noise. Ambient noise in cellular system tends to undermine the effort of using an efficient and better access technology in providing adequate system capacity for the users at the most affordable rate.

Therefore, this work considers the effect of ambient noise level in CDMA wireless system and then how it can affect the capacity and coverage areas in wireless networks.

The environments through which communication services are transmitted tend to be distorted as a result of ambient noise. Ambient noise can be defined as the electrical noise that emanates as a result of system being disturbed by natural phenomena such as cosmic rays, atmospheric properties and other artificial or man-made properties that are present in a particular period of time under consideration. The noise can be signals from other nearby network users that are able to penetrate the system in use. The aggregate of the noise constitute various types of problems that degrade the quality of service in any given network. The study of ambient temperature can be related to (i) the thermal noise experienced by system circuit components as a result of the changes in the surrounding temperature, and (ii) the thermal noise being experienced in the atmospheric layer of an atmosphere surrounding the area in focus. This layer tries to portray the manner by which electromagnetic waves are either reflected, refracted or both, with respect to thermal noise. The reflection and refraction bring about path losses within the communication medium thereby degrading the quality of service in mobile cellular system. In the former case, the circuit components must be subjected to proper temperature screening so that the required level of temperature is maintained for the circuit components as the electronic structure of the components may be disturbed by the change in ambient temperature. Fig. 1 shows the propagation of electromagnetic waves through wireless propagation (unbounded) medium (i.e., free space) [1].

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Dr. C.O. Ohaneme, Department of Electronic and Computer Engineering Nnamdi Azikiwe University, Awka, Nigeria
Dr. V.E. Idigo, Department of Electronic and Computer Engineering, Nnamdi Azikiwe University, Awka, Nigeria
S.O. Oguejiofor, Department of Electronic and Computer Engineering, Nnamdi Azikiwe University, Awka, Nigeria.
S.U. Nnebe, Department of Electronic and Computer Engineering, Nnamdi Azikiwe University, Awka, Nigeria.

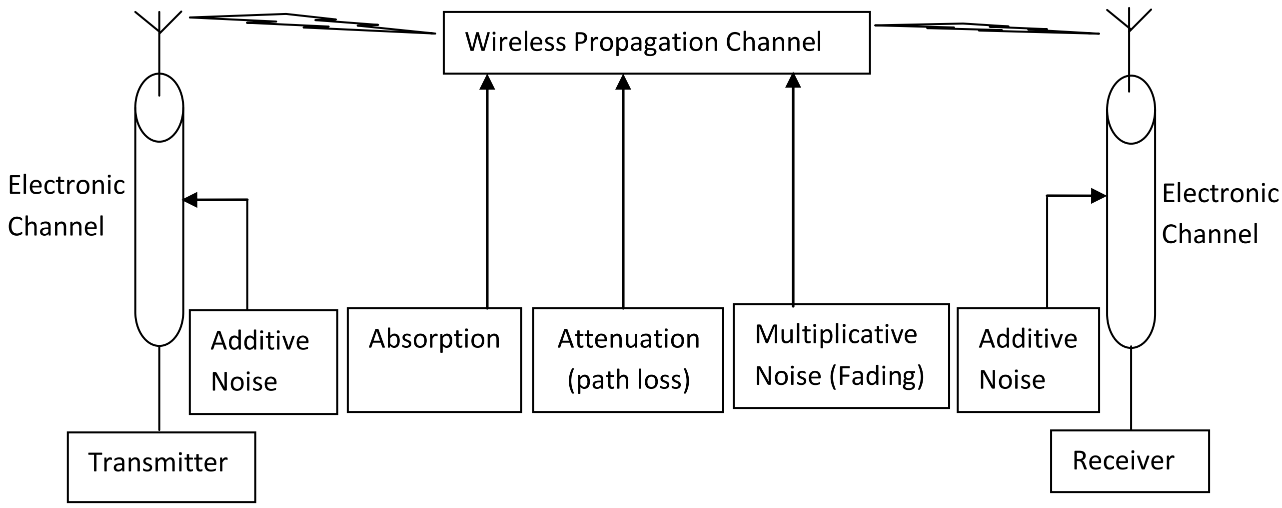

Fig. 1: Propagation of electromagnetic waves through unbounded medium

(A) Propagation Path loss over Wireless Communication Environments

As EM signals propagate from one points (transmitters) to the other points (receivers), the level of the transmitted signals tend to vary with distance. In effect, levels of the received signals at various distances away from the transmitter deteriorate in a way that at a point no signal will be received irrespective of the fact that transmitter continues to transmit signals. Whether in the guided or unguided medium, signal strength reduces in level with distance. The rates at which the signals deteriorate depend largely on the type of medium through which they are propagated. Hence, the rate at which it propagates through guided medium is quite different from the rate at which it propagates through unguided medium. The losses that are experienced in guided media are less than those experienced in unguided media. In the unguided medium, the path loss is inversely proportional to the power of the distance with reference to the reference distance from the transmitting station (Base station). The power is determined by the environment through which the signals propagate and is termed path loss exponent. This path loss exponent describes the level of attenuation of the signals in a particular environment as the receiver moves away from the transmitter. Different environments which may range from free space (pure line of sight or unobstructed) environments to heavily populated urban (non-line-of-sight or heavily obstructed) environments associated with high rise buildings and vegetations. With the presence of these obstructions in urban and sub-urban environments, the LoS between the transmitting antenna and the receiving antenna is hampered. Thus a lot of impairments as a result of these obstructions tend to degrade the received signals by mobile users. So, in order to determine the level of signal propagations in these environments, the path loss exponents of different environments are normally used. The path loss exponent is the degree at which transmitted signal deteriorates with respect to the distance of the mobile user in a wireless system. Table 1 shows the path loss exponents for various environments [2].

Table 1: Path loss Exponents for Different Environments

Environment	Path loss Exponents
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building LoS	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Ambient noise as a result of wireless channel impairments contributes to the losses in signal being propagated in space. This is due to troposcopic and ionospheric conditions of the wireless channels through which the signals propagate. The noise associated with these media give the receiver the attenuated version of the transmitted signal, which is always in its entirety short of the expected results from the transmitted signals. Therefore mobile users roaming within these atmospheric conditions receive degraded version of the transmitted signals as a result of the effect they have on the transmitted signals.

When studying microwave signal penetration through the ionosphere, it must be known that some quite exotic radio signal propagation through the ionosphere can take diverse forms. These forms at which they penetrate the medium actually give the nature of the propagated signals through them. Hence, the ionospheric medium is characterized by the reflections, refractions and absorption which tend to attenuate the signal being propagated through it.

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These reflections and refractions depend on the frequency of the signal and the ionization density of the medium especially in the D and E-layer. The theory of propagation with ground reflections and the knowledge of the attenuation involved at each ionospheric refraction is satisfactory to explain the short- and medium-range communications (maximum of 10,000 km).

(B) Effect of Temperature on Electromagnetic Waves

Electromagnetic waves travel through space. The space traverses through different environmental scenarios that cut across different temperature levels. Temperature plays prominent roles on quality of the modulated signals that translates into electromagnetic waves that are transmitted through a medium. The quality of signals produced depends largely on both the channel characteristics and ambient noise due to circuit elements that make up the entire communication system. The ambient noise which can be man-made and natural is considered to have contributed to the noise figure of the system which gives the channel the undue interferences that limit the system capacity and coverage.

However, propagation of signals through the atmosphere is hampered by the presence of particles that degrade the signal performance. In the atmosphere, the signals are faced with absorptions, reflections, refraction, and scattering.

Absorptions by the atmosphere depend on the frequency of the transmitting signal. Hence, at frequencies above 50 GHz, the atmosphere acts as a shield to a wireless link reducing cross talk with other links. Between frequencies 50 and 60 GHz the attenuation of electromagnetic waves by the atmosphere increases from 0.5 dB km^{-1} to almost 20 dB km^{-1}. This attenuation provides a natural shield for electromagnetic waves that is useful in many wireless applications. The atmospheric attenuation can also be due to absorption by water vapour (H_2O) and molecular oxygen (O_2) in the atmosphere [3]-[6]. Rain drops can also cause scattering which further attenuates the waves.

In transmitting through an absorbing atmosphere (or other medium) the signal is attenuated and a temperature observed which is a function of the atmospheric (ambient) temperature and the absorption. The observed temperature as given by [3] is

$$T = T_a(1 - e^{-\tau}) \qquad (1)$$

Where T_a = atmospheric temperature, K

$\tau = x\alpha$ = absorption coefficient, dimensionless

x = distance through absorbing medium, m

α = absorption coefficient, N_p m^{-1}.

It can therefore be inferred that the atmospheric temperature and the constituents of the environment (i.e., absorbing medium) contribute immensely to the degraded version of transmitted signals in wireless system.

(C) Thermal Noise Characteristics and its Effect on Mobile Radio Signal

In wireless system, certain minimum Signal-to-Noise Ratio (SNR) at the receiver is required to provide a certain minimum acceptable quality of transmitted signals in a network. For example, in the case where a single base station (BS), and a single mobile station (MS) receives within the cellular environment, the performance of the system can only be hampered by the surrounding noise sources because interference is neglected. However, interference comes into effect when multiple BSs and MSs are deployed in a noise-limited environment. Then the performance of the system is determined only by the strength of the useful signal and the noise. Thence, any reduction in noise in a system translates into improved quality of service in a network, as the signal strength of the signal is maintained to a reasonable extent and through a reasonable range (distance). Hence, as MS moves further away from the BS, the received signal level decreases, and at a certain distance, the SNR does not achieve the required signal threshold for reliable communications. Therefore, the range of the system is noise-limited; equivalently it can be called *signal-power limited*, because too much noise or too little signal power leads to bad link quality of the system [4]-[7]. The received signal decrease as the distance of MS from the BS increases. The inverse square law gives the level of the received signal strength in an outdoor, environment. It is given by level of the received power, P_R as

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 \qquad (2)$$

where G_R and G_T are the gains of the receive and transmit antennas respectively, $\boldsymbol{\lambda}$ is the wavelength, d is the distance and P_T is the transmit power. Besides, frequency of the transmitted signal also play vital role in determining the level of the received signal at a particular location.

However, the noise that disturbs the signal can consist of several components, such as:

(i) *Thermal Noise*: in this phenomenon, the environmental temperature T_e the antenna sees give the spectral density of the thermal noise present. The temperature of the earth is approximately 300K while the temperature of the (cold) sky is approximately $T_e \approx 4K$. Also, the noise power spectral density at the isotropically radiated environmental temperature of 300K is

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$N_o = K_b T_e$ (3) where K_b is the Boltzmann's constant which equals $1.38 \times 10^{-23} J/K$, and the noise power P_n, is given as

$P_n = N_o B$ (4) where B is the bandwidth of the receiver. If 1Hz of the bandwidth is considered, the noise power in logarithmic value (dB) is given as $N_o = -174 dB_m$. Therefore, the noise power contained in B bandwidth is given as

$$N_o = (-174 + 10\log_{10} B) dB_m \quad (5)$$

Thermal noise is otherwise known as the natural noise that is generated within the system [4].

(ii) *Man-made (artificial) noise*: this is the type of noise generated by human beings either intentionally or unintentionally in the course of discharging their duties on earth. The man-made noise can be due to (a) *spurious emissions* from electrical appliances as well as radio transmitters designed for other frequency bands which spill over into a large bandwidth that includes the range of frequencies in which wireless communication systems operate. For urban outdoor environments, car ignitions and other impulse sources are an especially significant source of noise. For communication operating in licensed band, such spurious emissions are the only source of man-made noise. It lies in the nature of the license (for which the license holder usually has paid) that no other intentional emitters are allowed to operate in this band. In contrast to thermal noise, man-made noise is not necessarily Gaussian, i.e., the noise that are due to the movement of particles in electronic components that make up a complete communication system [4]-[8]; (b) *other man-made emission sources* that are worthy to mention in wireless communication system are its operation in unlicensed band (i.e., ISM band). In this band, everybody is allowed to generate (emit electromagnetic radiation) as long as certain restrictions with respect to transmit power, e.t.c., are fulfilled. The most important of these bands is the 2.45 GHz ISM band.

(iii) *Receiver noise*: this is another source of noise of interest in wireless communication engineering. Since receiver circuits consist of amplifiers and mixers, it is pertinent to note that as the received power is being amplified for better processing, so also are the accompanied noise. This effect is described by the noise figure F, which is defined as the SNR at the receiver output (typically after down-conversion to baseband) divided by the SNR at the receiver input. However, as the amplifier have gain, noise added in the later stages does not have as much of an impact as noise added in the first stage of the receiver. These prevailing circumstances in noise-limited environments can be extended to wireless cellular system where capacity of the network and its area of coverage are often affected by the presence of noise. The presence of the ambient noise disturbs the propagation of electromagnetic waves within the environment under consideration. It reduces the signal quality, thereby limiting the number of mobile users that access the network. This work has therefore provided the necessary models that will help in evaluating the effect of these ambient noise sources on the network coverage and system capacity.

II SYSTEM MODEL

In this paper a CDMA network considered is Visafone, one of the mobile network providers in Awka, South-East Nigeria, as the test-bed. Here, some signal strength measurements were carried out for us to have the information on the attenuation levels of signals at suburban city of Awka, Nigeria. The data collected after the measurements are as shown in Table 2. The table shows the received signal level, the transmitted power TRX, from the base station, the distance in meters of the mobile station from the transmitting base station and the transmitting frequency of the network in MHz.

Table 2: Measured data from Visafone Netwoork

Distance (m)	Received Signal Level (dBm)	TRX Power (dBm)	TRX Frequency (MHz)
100	-56	41.4	878.87
200	-66	41.4	878.87
300	-63	41.4	878.87
400	-73	41.4	878.87
500	-87	41.4	878.87
600	-75	41.4	878.87
700	-82	41.4	878.87
800	-83	41.4	878.87
900	-82	41.4	878.87
1000	-90	41.4	878.87
1100	-85	41.4	878.87
1200	-83	41.4	878.87
1300	-84	41.4	878.87
1400	-83	41.4	878.87
1500	-85	41.4	878.87
1600	-88	41.4	878.87
1700	-89	41.4	878.87
1800	-92	41.4	878.87

The level of signal attenuation from the table gives the first hand information on the effect of distance and other environmental factors including interference on the propagating signals at the suburban city of Awka. So, using this as the test bed, several models are developed that will showcase the effect of noise in a wireless network.

A CDMA cellular system may consist of many CDMA cell sites. In this work we concentrate on one particular cell called the serving cell, which is surrounded by the other cells in the system. The receiver power at the serving cell (P_b) is given as

$$P_b = \rho_n N_o B + P_s + \sum_i P_i \quad (6)$$

where ρ_n is the total noise figure that includes ambient noise and receiver noise that exceeds the thermal noise level. ρ_n is dependent on RF carrier frequency. N_o is the thermal noise density, B is the receiver bandwidth. The P_i summation is the total serving cell receiving CDMA power from all other cells in the system. P_s is the total received CDMA power from all users within the serving cell that can be expressed by [5] as

$$P_s = M v P_r \quad (7)$$

where M is the number of users within the serving cell, v is the channel (voice) activity factor, and P_r is the single mobile received signal level at the base station receiver. Assuming the CDMA system uses $k = 1$ cell reuse pattern, the frequency reuse efficiency q_f is given by

$$q_f = \frac{P_s}{P_s + \sum P_i} \quad (8)$$

Substituting equations 7 and 8 into equation 6 yields

$$P_b = \rho_n N_o B + \frac{M v P_r}{q_f} \quad (9)$$

The receiver power rises over the thermal noise floor by a factor Z given by [5]

$$Z = \frac{P_r}{N_o B} = \rho_n + \frac{M v P_r}{q_f N_o B} \quad (10)$$

Through Z, a relationship between the theory and measurement results are established. We should recall that CDMA system energy per bit-to-interference power per Hz ratio ${E_b}/{I_o}$,

$$\therefore \quad E_b = \frac{P_r}{R_b} \quad (11)$$

$$I_o = \rho_n N_o + \frac{v P_r}{B}\left(\frac{M}{q_f} - 1\right) \quad (12)$$

where R_b is the signal bit rate. Combining equations 10, 11 and 12 result in

$$\frac{\left(\frac{E_b}{I_o}\right)v}{B/R_b} = \frac{\frac{(Z-\rho_n)q_f}{M}}{Z - \frac{(Z-\rho_n)q_f}{M}} \quad (13)$$

Expressing the pole capacity m_p of CDMA carrier in another way as

$$m_p = \frac{\left[1 + \frac{\frac{B}{R_b}}{\left(\frac{E_b}{I_0}\right)v}\right]}{k} \quad (14)$$

For simplicity, let $k = 1$ in equation 14, then the number of users within the servicing cell $M(= m_p)$ becomes

$$M = m_p q_f \left(1 - \frac{\rho_n}{Z}\right) \quad (15)$$

Defining CDMA cell loading X as

$$X = \frac{M}{m_p q_f} \quad (16)$$

we have that

$$Z = \frac{\rho_n}{1 - X} \quad (17)$$

Equation 15 is therefore the CDMA capacity formula while equation 17 relates to the CDMA system coverage.

III SYSTEM SIMULATION AND RESULTS

System simulation in this work utilized the software implementation of the developed models to arrive at the effect of noise in CDMA wireless network capacity and coverage. Table 3 shows some of the assumed parameters during the course of simulation. The simulation was carried out using Matlab. This simulation software helps us to arrive at the graphical representation of the capacity and coverage of wireless system in relation to the noise level in the surrounding area.

Table 3: Simulation parameters used

Parameters	Values
Cellular band noise	9 dB
Total PCS-band noise	5 dB
Channel bandwidth B	1.24MHz
E_b/I_o	7 dB
Bit-rate R_b	9.6 kbps
Noise N_o	-174 dBm
Frequency reuse factor q_f	0.7
Channel (voice) activity factor v	0.45

Having looked at the models carried out to showcase the effect of various qualities of service parameters on the capacity of wireless network, it is important that some graphical method be used to show the effect of noise on wireless system capacity and coverage. A critical look at Fig. 2 shows the variation of capacity of cellular network with the energy-bit per interference ratio as a result of ambient temperature in CDMA system. It shows an increase in system capacity when the energy-bit per interference decreases.

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Fig. 3 summarizes the reaction of system capacity to data bit-rate. In this case, the increase in bit-rate translates into decrease in the capacity of the network. However, at the bit-rate of 5.4 bit/sec, the capacity of the network goes to the minimum value of 20. Hence, 20 mobile users can be supported at this bit-rate. Again, the effect of the thermal noise factor in wireless system is evaluated graphically in Fig. 4. In this figure, the number of mobile users that can be supported by the network is determined by the noise level within the noise-limited environment. Hence, environmental factors such as noise play prominent roles in the estimation of system capacity by specifying the number of mobile users that the network can support.

Fig. 5 shows the effect of noise on the number of mobile users. It depicts the relationship between the energy-bit per noise density on the radio propagation, and how they limit the number of mobile users that access the network due to interference and noise.

Besides, the network coverage in the noise-limited environment can be likened to the extent the transmitted signal can propagate through the transmission channels until the signal finally dies down due to attenuations. These channels through which signals are propagated, in this case, the atmosphere, cannot be isolated completely from noise. Hence, complete path loss for a transmitted signal can be said to be the composite of the noise and interferences from other mobile stations and base stations within the cellular environment. In the light of this, Fig. 6 shows the variations of signal levels measured along some distances in the area of propagation. This spells out the effect of propagation environment, which constitute noise and interference, on the transmitted signals. Moreso, this can in a way be compared to the attenuation of transmitted signal (path loss) through the communication channel. Therefore using the measured data as shown in Table 1, Fig. 6 was arrived at. This helps to ascertain the level of signal attenuation as a result of the propagation through noise-limited channel. It can be seen that the level of attenuation of the signal follows the path loss pattern of signal in a network.

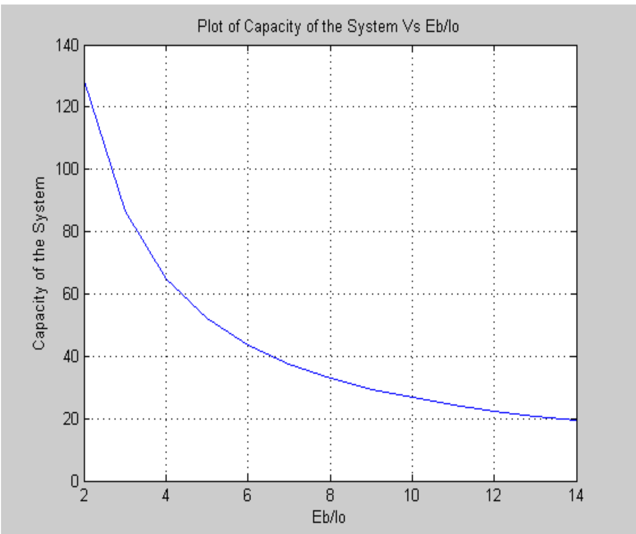

Fig. 2: Graph showing Network Capacity Vs E_b/I_o

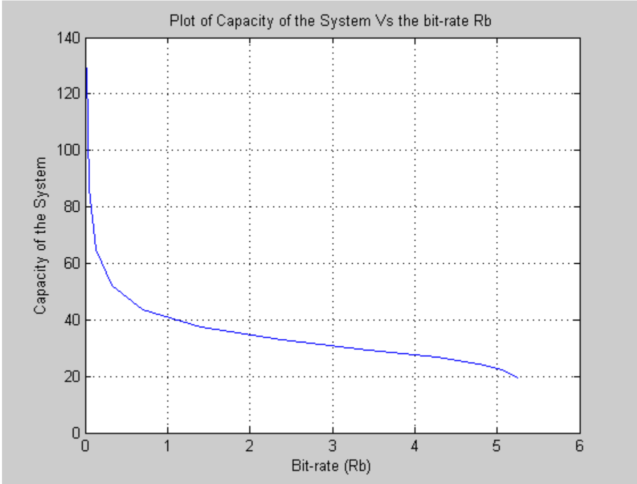

Fig. 3: Graph showing system capacity Vs Bit-rate (R_b)

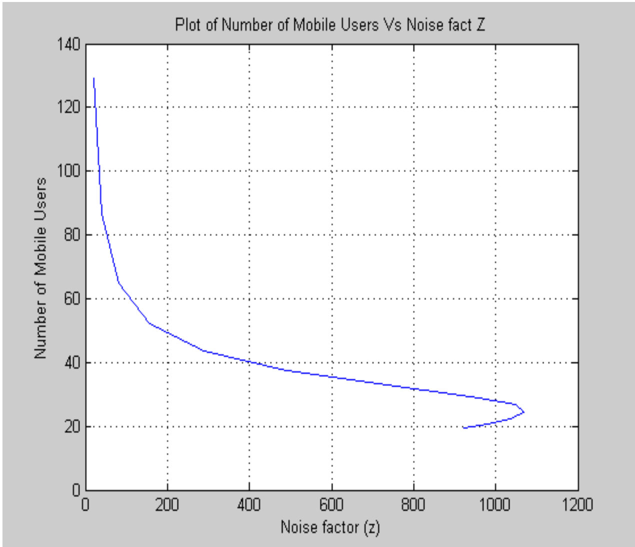

Fig. 4: Graph showing number of mobile users Vs Noise factor

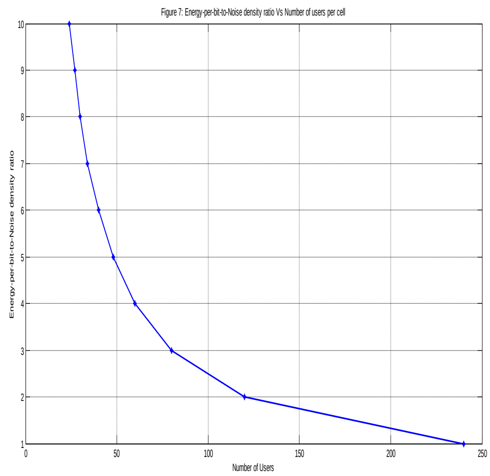

Fig. 5: Energy- per- bit- Noise density ratio Vs Number of Users

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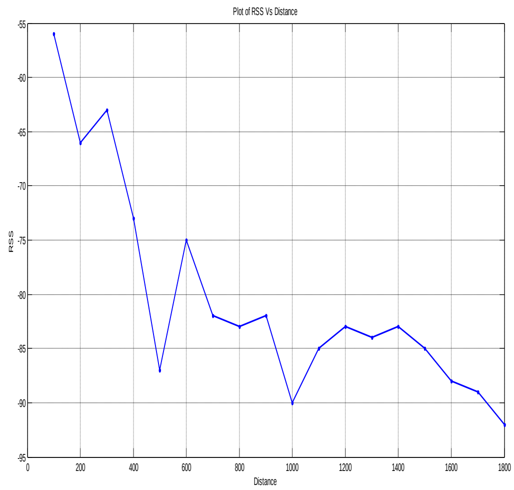

Fig. 6: graph showing the variation of received signal strength (RSS) with Distance

IV CONCLUSION

The impact of noise in communication system has been a worrisome phenomenon when cellular coverage and system capacity are considered as the key performance indices in communication industry. Having gone through the intricacies of modeling the noise-limited environment in the quest of finding how ambient noise affect the capacity and coverage, this paper has succeeded in portraying the efficacy of the developed models in the analysis of the effect of noisy environment on signal propagation in wireless system. Therefore, it also arrived at a conclusion that any reduction in a cellular environmental favtors translated into the reduction in signal attenuation thereby improving the system capacity. The extent of signal coverage was equally investigated, and it was found that once the atmosphere is free of noise particles and obstructions, signals can be propagated to farther distances thereby increasing the area of coverage. Ambient noise and temperature being natural phenomena that has effect on environment, has been found to contribute a great percentage in signal degradation and network coverage.

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AUTHORS PROFILE

Ohaneme Cletus Ogbonna obtained Ph.D in Communication Engineering from Enugu State University of Science and Technology (ESUT), Enugu, Nigeria with research interest in wireless network and spectrum management. He is currently a lecturer in the Department of Electronic and Computer Engineering, Nnamdi Azikiwe University, Awka, Nigeria. He is a member of IAENG. E-mail: engrohaneme@yahoo.com

Idigo Victor Eze is currently Head of Department Electronic and Computer Engineering, Nnamdi Azikiwe University, Awka, Nigeria. He is an Associate Professor with research interest in wireless communication. He is a member of the following professional bodies: IEEE, IAENG and IACSIT. E-mail: viceze2006@yahoo.com

Oguejiofor Samuel Obinna is currently a lecturer in the Department of Electronic and Computer Engineering, Nnamdi Azikiwe University, Awka, Nigeria. He holds B.Eng. in Electronic and Computer Engineering from Nnamdi Azikiwe University Awka, Nigeria. He is also pursuing his M.Eng. in Communication Engineering from the same Department and Institution. E-mail: obynola@yahoo.com

Nnebe Scholastica Ukamaka is currently a lecturer in the Department of Electronic and Computer Engineering, Nnamdi Azikiwe University, Awka, Nigeria. She holds B.Eng., and M.Eng. in Communications Engineering from the departments of Electrical/Electronic and Computer Engineering and Electronic and Computer Engineering of Nnamdi Azikiwe University Awka, Nigeria. She is also pursuing her Ph.D in Communication Engineering in the same institution, with research interest in Wireless Sensor Network and Systems. E-mail: scholar.nnebe@gmail.com

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