Computer Simulation of Hata's Equation for Signal Fading Mitigation.

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ABSTRACT

In today's knowledge-based world, wireless communication plays an important role in economic growth and well-being of people. However, because of the undesirable effects of fading on wireless channel, the information transmission is being impaired. Hence, in order to achieve reliable and effective information transfer, an effective means of reducing the fading effect on wireless channel must be found. Diversity scheme has been observed as an effective means of mitigating the effect of fading. In this paper, space transmission diversity technique was applied to combat fading effect on wireless channel. In carrying out this study, Hata's equation for predicting signal path loss was simulated in C++. The data generated from it was compare with data obtained by another researcher in order to ascertain the accuracy of the program. The result of the study shows that signal fading is directly proportional to both the carrier frequency and the separation between the transmitter and receiver. In addition, the effectiveness of the program was evaluated. The result shows that 75% - 81% of the signal losses due to multi-path fading can be recovered using the scheme. Based on this result, the study was concluded with suggestion of incorporating the scheme in the mobile communication systems so as to enhance information transferring on wireless channel.

(Keywords: multi-path propagation, fading, diversity scheme, radio wave propagation attributes)

INTRODUCTION

In today's society, information is of great value and the demand for the right information at the right time and the right place is growing. This has led to the recent increase in number of wireless communication services and gradual elimination of traditional means of long distance communication via drums, gunshots, smoke signals or blowing horn. In spite of this improvement that wireless communication exhibits over the traditional means of communication, it has been observed that there are some transmission impairments degraded the performance of wireless communication systems (Chinthananda, *et al*., 2001). Some of these observed impairments include fading, co-channel interference and noise. Among these impairments, the fundamental one that makes reliable wireless transmission difficult and ineffective to achieve is fading (Alamouti, 1998). The author reported that fading is the major phenomenon that makes wireless transmission a challenge when compared to fiber, co-axial cable, line-of-sight (LOS) microwave or even satellite transmission.

In order to enhance the performance of wireless communication system, fading mitigation has been one of the most challenging issues in recent years (Bhaskar, 2009, Khalighi and Ros, 2005). Numerous researchers have worked on the study of channel capacity over fading channels. There has been significant theoretical research reported in the area of diversity systems and combining techniques for fading channels (Lombardo, *et al*., 1999, Patenaude, *et al*., 1998, Zhang, 1998, Aalon and Pattaramalai 1996, and Al-Hussaini and Al-Bassiouni, 1985). Various studies have analyzed space diversity techniques in order to combat multi-path fading as well as the shadowing effects in mobile communications.

Similarly, in a data network, different approaches have been used in mitigating the effects of fading. One of those interesting approaches is space–time trellis coding (STC), introduced by Tarokh, *et al.* (1998), where symbols are encoded according to the antennas through which they are simultaneously transmitted and are decoded using a maximum likelihood decoder. According to the authors, this scheme is very effective, as it combines the benefits of forward error correction (FEC) coding and diversity transmission to provide considerable performance gains. The cost of implementing this scheme is its main disadvantage, which increases exponentially as a function of bandwidth efficiency (bits/Hz) and the required diversity order. Therefore, for some applications it may not be practical or cost-effective (Alamouti, 1998).

The STC transmission scheme proposed by Tarokh, *et al* (1998) for flat channels has been extensively analyzed and subsequently be divided into space-time trellis codes (STTC) (Hammons and Gamal, 2000, Tarokh, *et al*., 1998) and space-time block codes (STBC) (Tarokh, *et al*., 1998, Alamouti, 1998). Recently, a new transmission strategy that achieves spatial diversity based on a random signal mapper (RSM) was proposed by Li, *et al*., (2003) for the case of flat-fading channels. In RSM, the bit stream is first encoded with a regular error-correcting code. Then, N copies of the encoder output are generated; where N is the number of transmit antennas. Each of these copies goes through a random signal mapper, whose output is then transmitted through one antenna. This simple scheme achieves full diversity. Furthermore, the RSM receiver has much lower complexity than that of STBCs, which is itself less complex than that of STTCs. In addition, transmit and/or receive antennas can be added to an RSM scheme without significant changes to the system, a flexibility not found in STBCs and STTCs.

In wireless reception diversity, several signal combining techniques were used in the literature. The most widely used techniques among them are the maximal ratio combining (MRC), equal gain combining (EGC) and selection diversity (SD) (Ugweje and Grover, 2000). In MRC, the output of the diversity combiner is the weighted sum of the branched signals making the output optimum. The input signals are co-phased and proportionally weighted to the signal level, signal power or signal-to-noise (SNR). In EGC, the weights are normalized to unity. This implies that the individual strength of a branch signal is not taken into consideration. In SD, the combiner selects the input that has the highest or most desirable signal level. This selection process is based on some quality measurement, which can be signal level, power level or the SNR. Ideally, the diversity branch having the largest SNR is usually selected for the information recovery. The advantage of the SD over the others is its simplicity of implementation in practical applications.

As reported by Ugweje and Grover (2000), among all other linear diversity techniques, the MRC provides the maximum possible improvement that a diversity system can attain in fading channels. While MRC is considered optimal, there is need to continuously estimate the gain of each path. This does not always convenient in providing the complicated adaptive weighting capability required for true maximal ratio combining. Hence, significant signal processing is required for its implementation. As the number of the users increase, the level of signal processing needed also increases, which make the approach somehow complex. On the other hand, SD is simple and usually employed for its simplicity in implementation.

Generally, speaking, multiple antennas diversity can be employed either at the transmitter or receiver (Liu, *et al*., 2002, Chinthananda, *et al*., 2001, Fosschini, *et al*., 1999, Fosschini and Gans, 1998 and Winters, 1987). The authors reported that diversity schemes, either transmission or reception, are classical powerful techniques that provide wireless link improvement at relatively low cost. In mobile radio communication system, it is practicable to employ diversity at the base station rather than at the mobile units (Alamouti, 1998). The author reported that a base station has the ability to serve hundreds to thousands of remote or mobile units. It is therefore more economical to add equipment to base stations rather than the remote or mobile units.

Based on this advantage of transmission diversity scheme, this work was centered on a transmit diversity scheme for mitigating signal fading. The objectives of the work were to determine the relationship between signal fading and carrier frequency as well as to investigate the robustness of the diversity scheme in signal fading mitigation. The study was carried out using computer simulation model. Having discussed the background introduction in this section, the rest of the paper is organized as follows: In the second section, how multi-path propagation gives rise to different fading types was briefly reviewed. Also, in the section, a brief reviewed of different diversity types was done. In the third section, the detail of computer simulation developed was presented. In the fourth section, the obtained data from the simulation were discussed. Finally, in the fifth section, which is last section, the concluding remarks were drawn.

MULTI-PATH PROPAGATION AND FADING MITIGATION TECHNIQUE

Multi-path Propagation

In wireless telecommunication, multi-path is the propagation phenomena that results in radio signals reaching the receiving antenna by two or more paths. Causes of multi-path include atmospheric ducting, ionospheric reflection and refraction, and reflection from water bodies and terrestrial objects such as mountains and buildings. Radio wave propagation consists of three main attributes, namely, reflection, diffraction and scattering (see Figure 1).

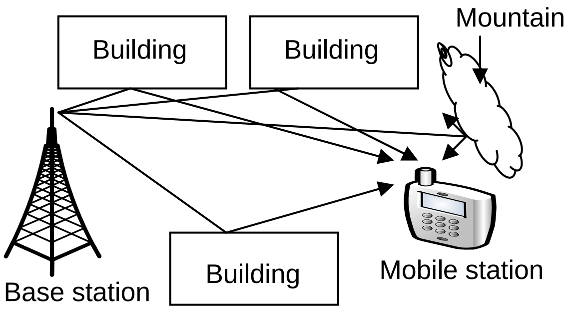


Figure 1: Multi-path Propagation Model.

Multi-path radio signal propagation occurs on all terrestrial radio links. The radio signals not only travel by the direct line of sight (LOS) path, but as the transmitted signal does not leave the transmitting antenna in only the direction of receiver, but over a range of angles even when a directive antenna is used. Consequently, the transmitted signal spread out from transmitter and they will reach other objects: hills, buildings, reflection surfaces such as the ground water, etc. The signals may reflect of a variety of surfaces and reach the receiving antenna via paths other than the direct LOS path. When the radio signals arrive at the receiver via variety of paths, the overall signal received is the sum of all the signals appearing at the antenna. Sometimes, these signals may be in phase with the main signal and will add to it to increase its strength. At other times, they will be out of phase or interfere with the main signal, therefore resulting in overall signal strength reduction.

At times, there will be changes in the relative path lengths. This could result from either transmitter or receiver moving, or any of the objects that provide a reflective surface moves. This will result in phases of the signal arriving at the receiver changing, and in turn this will result in the signal strength varying. This causes the fading that is present on many radio signals.

When a mobile receiving antenna receive a large number of reflected and scattered signals, because of the signal cancellation effect, the instantaneous received power seen by a moving antenna becomes a random variable, dependent on the location of the antenna. Under this condition, Rayleigh fading is caused by multi-path reception. Similarly, Nakagami fading occurs in multi-path scattering with relatively larger time-delay spreads, with different clusters of reflected signals or waves. Rician fading, also, occurs as a result of multi-path propagation. This fading occurs when the paths of the signal are of varying strength.

Since, modern wireless communication systems are typically used in urban setting, where many high buildings, foliage and street signs are located between the transmitter and receiver, the radio transmission environment in urban areas is characterized by multi-path propagation. At the receiver, due to the presence of the multiple electromagnetic signals, more than one signal will be received. Since the electromagnetic signals travels at the speed of light, and since every path has a geometrical length possibly different from that of the others, there are different air travelling times. The effects of multi-path include constructive and destructive interference, and phase shifting of the signal that causes signal fading. The resulted receiving signal, $y(t)$, at time, t, is expressed mathematically as:

$$y(t) = \sum_{n=0}^{N-1} \rho_n e^{j\phi n} \delta(t - \tau_n) \qquad \textbf{(1)}$$

where N = the number of received signals or electromagnetic path to the receiver;

τ_n = the time delay of the generic n^{th} signals,

$\rho_n e^{j\phi n}$ = the complex amplitude of the generic received signal.

Fading Mitigation Technique

In wireless communication, fading is the attenuation that a carrier modulated telecommunication signal experiences over certain propagation media. It is the fluctuation in intensity of any or all components of a radio signal due to changes in the characteristics of the propagation path, as observed by the receiver. In wireless system, fading may either be due to multi-path propagation, referred to as multi-path induced fading, or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading. Fading causes poor performance in communication system because it results in a loss of signal strength or power without reducing the power of the noise. Its effects can be combated by using diversity scheme.

A diversity scheme is a method of improving the reliability of message signal by using two or more communication channels with different characteristics. The scheme is based on the fact that if two or more independent samples of a random process are taken, these samples will fade in an uncorrelated manner. Therefore, it follows that the probability of all the samples being below a given level simultaneously is very much less than the probability of a single sample being below that level (Popoola and Adeloye, 2007, Suthuraman and Balakrishnan, 1983 and Lee, 1982).

Different classes of diversity schemes are available. The common ones are: time diversity, frequency diversity, space diversity and polarization diversity. In time diversity, multiple versions of the same signal are transmitted at different time. For frequency diversity on the other hand, the same signal is transmitted using several frequency channels or spread the same signal over a wide spectrum that is being affected by frequency-selective fading. Polarization diversity scheme however entails transmission and reception of multiple versions of a signal via antennas with different polarization. In space diversity, used in this study, the signal is transferred over several different propagation paths. In a wired communication network, space diversity is achieved by transmitting the same signal through multiple wires. However, in a wireless communication network, the space diversity is achieved by antenna diversity whereby multiple antennas are used.

Multiple antennas diversity can be employed either at the transmitter, known as transmission diversity or receiver, also know as reception diversity (Liu, *et al*., 2002, Chinthananda, *et al*., 2001, Fosschini, *et al*., 1999, Fosschini and Gans, 1998 and Winters, 1987). Liu, *et al*., 2002 and Chinthananda, *et al*. (2001) reported that diversity schemes either transmission or reception diversity has been observed as a classical powerful technique that provides wireless link improvement at relatively low cost.

MATERIALS AND METHODS

Model Simulation

In carrying out this work, Hata's equation for predicting propagation path loss (L_P) and ITU-R Recommendation Report 327-2 (1974) for predicting optimum antennas spacing were used. The Hata's equation used was modified to make it suitable and applicable to Nigeria area nomenclature. The modification has no adverse effect on the origin equation, as only the area nomenclature used was amended in agreement with convention uses in Nigeria (Basorun, 2003). Likewise, the ITU-R Recommendation Report 327-2 (1974) was modified as explained in Popoola and Adeloye (2007) to obtain equation (5) used for the optimum antennas spacing prediction.

For urban areas (i.e. Medium or Mega cities) L_P (in dB) is expressed as follows:

$$L_P = 69.55 + 26.16\log_{10} f_c - 13.82\log_{10} h_t - a(h_r) + (44.9 - 6.55\log_{10} h_t)\log_{10} d \tag{2}$$

where

$150 \le f_c \le 1500 (f_c \ in\ MHz),$

$f_c = the\ carrier\ \ frequency;$

$30 \le h_t \le 200 (h_t\ in\ m),$

$h_t = transmitting\ antnna\ height;$

$1 \leq d \leq 20 (d \ in \ km),$

$d = distance \ between \ transmitter \ and \ receiver.$

$a(h_r)$ = the correction factor for the receiving antenna and is computed as follows:

For a Medium –size city:

$$a(h_r) = (1.1 \log_{10} f_c - 0.7)h_r - (1.56 \log_{10} f_c - 0.8) \tag{2a}$$

where:

$1 \leq h_r \leq 10 \ (h_r \ in \ m)$

For a Mage –size city:

$$a(h_r) = 8.29(\log_{10} 1.54h_r)^2 - 1.1 : f_c \leq 200MHz, \quad or \ 3.2(\log_{10} 11.75h_r)^2 - 4.97 : f_c \geq 400MHz \tag{2b}$$

For Suburban areas i.e. Towns

$$L_{PS} = L_P(urban) - 2\left[\log_{10}\left(f_c/28\right)\right]^2 - 5.4 \tag{3}$$

where:

L_P is given by equation (2) and $a(h_r)$ for equation (2) is given by equation (2a).

For Rural or Open areas i.e. Villages

$$L_{PO} = L_P(urban) - 4.78(\log_{10} f_c)^2 + 18.33 \log_{10} f_c - 40.94 \ (dB) \tag{4}$$

where:

L_P is given by equation (2) and $a(h_r)$ for equation (2) is given by equation (2a). $L_{PS} \ and \ L_{PO}$ are the path loss for suburban (town) and rural (village) areas respectively.

Antenna Spacing Prediction

$$d_s = \frac{21.45V}{f_c}\sqrt{(-\log_{10} \rho)} \quad (m) \tag{5}$$

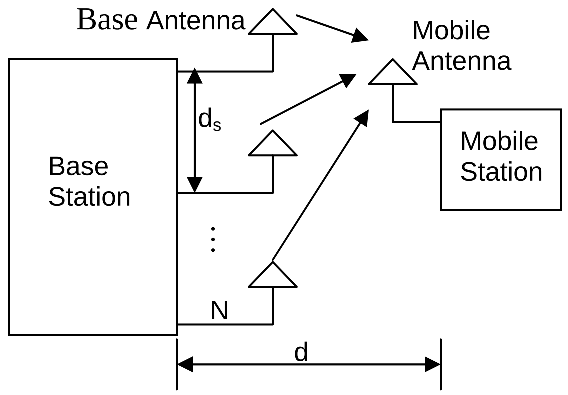
where:

d_s = the spacing between the antennas array at the transmitter in metre (m),

V = the velocity $(3.0 \times 10^8 \ m/s)$.

$\rho =$ the correlation coefficient.

The space-transmit diversity model (Figure 2) was transformed into computer application programming written in C++ programming language based on Equations (2), (2a), (2b), (3), (4), and (5). The data generated from the simulated model were discussed in the following section.



ds = optimum separation between the transmitting or base antennas.
d = distance between base and mobile antenna.
N = number of array antennas used.

Figure 2: Modeled Space Transmit-Diversity.

RESULTS AND DISCUSSION

Table 1: Validation of the Present work by Comparing its Data with Past Work.

Parameter	Sigma Wireless (2001): Practical	Present Work: Simulation
Carrier frequency, f_c.	850 MHz	850 MHz
Correlation coefficient, ρ.	0.7	0.7
Transmitter's Antenna height, h_t.	33 m	33 m
Antenna spacing, d_s.	3.0 m	2.98 m
$\eta = \frac{h_t}{d_s}$	11.0	11.07

The accuracy of the developed model was first validated by comparing the data generated from the study with a practical data quoted by Sigma Wireless Technologies (2001) under the same condition (Table 1). The result shows that there is a deviation of 0.02 m (2 cm) between the antenna spacing value obtained in this study and the value obtained by Sigma Wireless Technologies (2001). The value obtained in this study is 0.02 m smaller than the obtained value in the reference work; which is significantly minimal. This variation brings about the differences in η i.e. the ratio of the transmitting antenna height (h_r) to the separation distance (d_s) between transmitter and receiver as shown in Table 1.

After the validation of the data generated from the study, the two set objectives were considered. The first objective is to study the fading impact at different frequency bands in urban, suburban and rural areas of Nigeria. The results obtained on this objective were presented in Figures 3 – 6. The figures are the pictorial representation of the signal losses in rural (villages), suburban (towns) and urban (medium and mega cities) areas. The results show that the signal losses increases with increase in carrier frequency as the distance between the transmitter and receiver are increasing. Also, from Figures 3 –6, it is observed that the signal losses in the mega urban areas are the highest follow by the signal losses in the suburban areas while those in the rural areas are the lowest for the same carrier frequency and the same distance between the transmitter and receiver. The work therefore buttress the findings of both Sampei (1997) and Lee (1982) that signal fading increases with increase in distance between the transmitter and receiver. This is because high building for instance that responsible for multi-path propagation and indeed signal fading are common in the mega city compare to medium city, town and villages.

The second objective is on the study of the robustness of the diversity scheme in mitigating fading. The results obtained from this objective were shown in Figures 7 – 10. The figures show the differences in the level of the signal losses experiences when the diversity scheme was applied and when it was not applied. With the same carrier frequency, it was observed that the degree of signal fluctuation or fading varies, with the highest signal fading in the mega city and the lowest in the village. Table 2 was used to finally summarize the effective of the scheme in mitigating signal fading in those areas. The Table shows that over 70% of the signal losses when no diversity scheme was applied were regained with the application of the diversity scheme. Also, the Table revealed that highest percentage (78.6% - 81.1%) of the signal was recovered in the rural area while only 75.5% - 78.4% were recovered in the mega city.

CONCLUSION

From this study, it is established that all radio systems suffer from signal fading, which are influenced by either the distance between transmitter and receiver, motion, and/or by terrain effects. Also, it is obvious that fading has different impact on different frequency bands in different ways due to how the signal travels in each band (wavelengths).

Fading effects in mobile reception are difficult to avoid since it occur as a result of the environment whereby the radio signal is being propagated. However, the work as shown that with application of diversity scheme, the effect of fading can be minimized. The study has shown the application of the scheme in Nigeria environment as well as how effective it works. It is therefore, suggested that if the scheme can be incorporated into the mobile communication system worldwide, the negative effect of signal fading will be reduced if not completely eliminated. Also from the result of this study, it is obvious that the implementation of scheme in mobile communication system will indeed enhance information transfer on wireless communication systems.

Table 2: The Scheme effectiveness at various carrier frequencies and areas

Area	**Carrier Frequency, f_c, (MHz)**				
	600	**800**	**1000**	**1200**	**1400**
Rural (Village)	81.1%	79.5%	79.1%	78.8%	78.6%
Suburban (Town)	80.1%	78.7%	78.2%	77.4%	77.3%
Urban (Medium city)	81.2%	80.0%	79.4%	78.8%	78.4%
Urban (Mega city)	78.4%	78.6%	77.6%	76.4%	75.5%

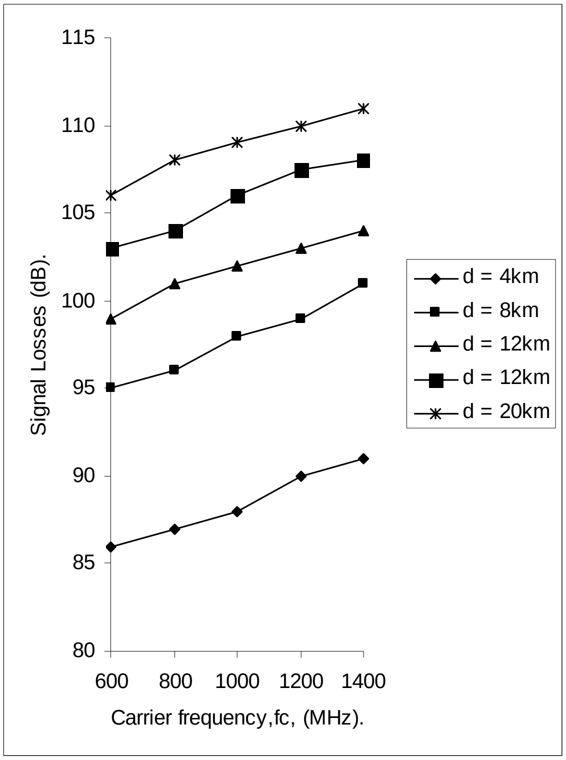


Figure 3: Signal Losses as a Function of Carrier Frequency in Village.

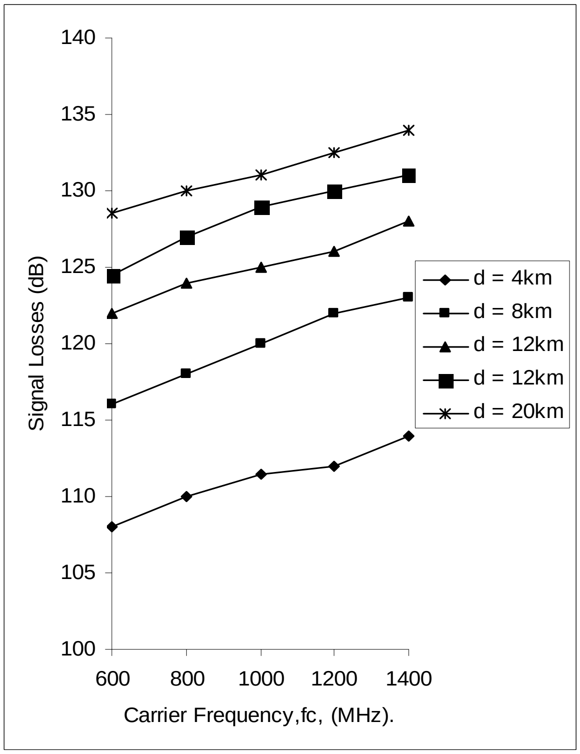


Figure 5: Signal Losses as a Function of Carrier Frequency in Medium City.

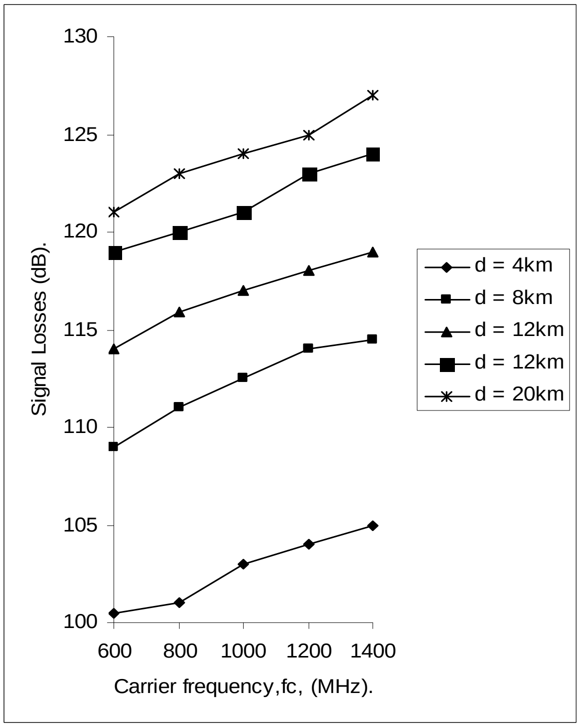


Figure 4: Signal Losses as a Function of Carrier Frequency in Town.

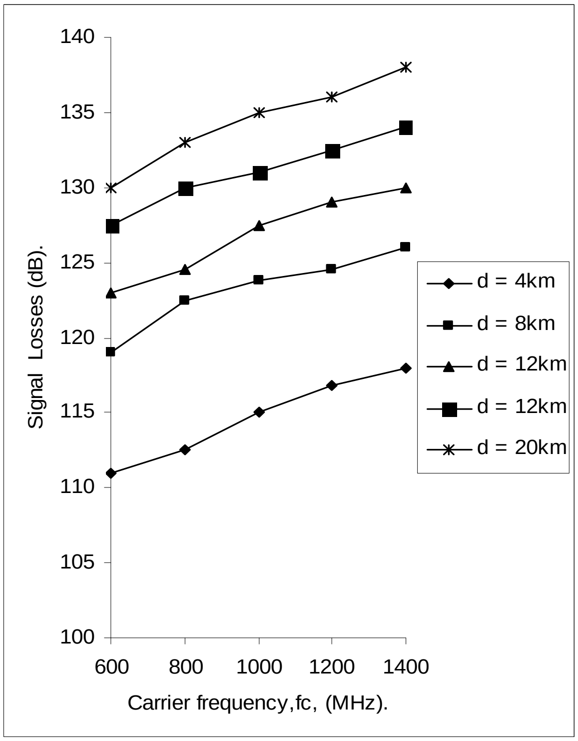


Figure 6: Signal Losses as a Function of Carrier Frequency in Mega City.

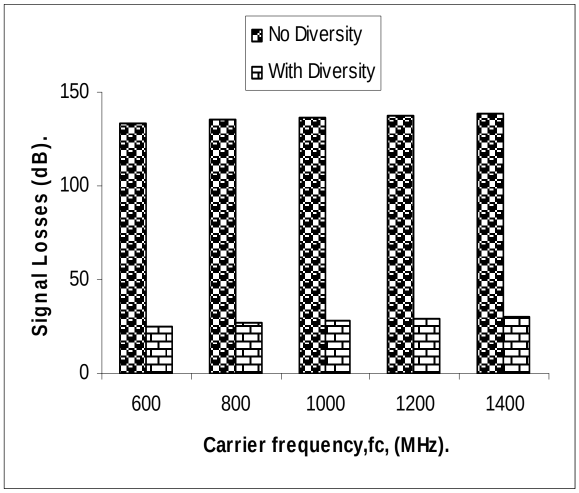


Figure 7: Signal Losses With and Without Application of Diversity Scheme in Village.

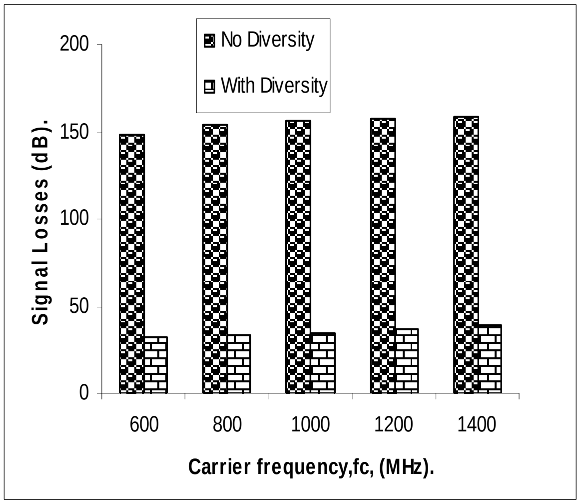


Figure 8: Signal Losses With and Without Application of Diversity Scheme in Town.

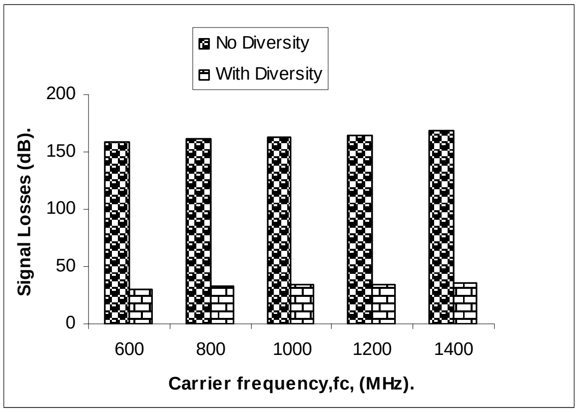


Figure 9: Signal Losses With and Without Application of Diversity Scheme in Medium City.

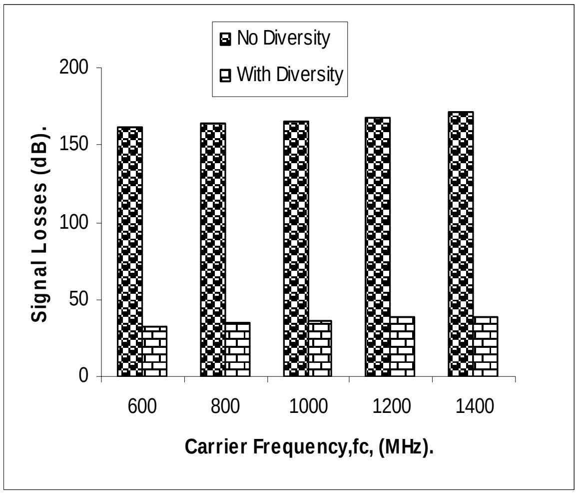


Figure 10: Signal Losses With and Without Application of Diversity Scheme in Mega City.

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