SPACE-DIVERSITY TECHNIQUE FOR COMBATING SIGNAL FADING IN MOBILE COMMUNICATION SYSTEM IN NIGERIA

BY

POPOOLA, JIDE JULIUS
EEE/92/3609

AUGUST, 2003.

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EEE/92/3609

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NIGERIA.

AUGUST, 2003

CERTIFICATION

This is to certify that this research work was carried out by **Popoola, Jide Julius (EEE/92/3609)** and is accepted as meeting the requirement for the award of Master of Engineering (M.Eng.) degree in Electrical and Electronics Engineering (Communication Option) of the Department of Electrical and Electronics Engineering, The Federal University of Technology, Akure.

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31-8-2003

Date

DEDICATION

This research work is dedicated to **God Almighty** in whom is hidden all the treasures of wisdom and knowledge; **Jesus Christ** my Saviour, the centre of my joy; **Holy Spirit** my inspiration and comforter.

"You are the love of my life
You are the hope I cling to
You mean more than this world to me
I will not trade You for silver or gold
I will not trade You for riches untold
You are; You are my everything".

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ABSTRACT

Fading on wireless channels has been viewed as a problem that must be combated in order to achieve reliable and effective information transfer. In this work, the space-diversity technique was applied to combat fading. The exposition of this technique as well as different theories on path loss propagation and antennas spacing equations were presented.

In carrying out the project, an application program was developed with C++ programming language. The developed program was used to generate the required data, which was later analysed statistically. The performance improvement of the technique was evaluated by comparing the generated data from the program with results from recent related works.

CHAPTER ONE

1.0 INTRODUCTION

Communication is the process of exchanging information. It is what people do to convey their thoughts, ideas, and feelings to one another. People have been communicating with one another from the beginning of mankind. Most humans communicated through the spoken word, as they do today. Yet a considerable amount of communication is still nonverbal. Body movements and facial expressions are still effective communication tools in place today especially at close range. However over long distances, attempts were made as tribesmen signaled one another with drums, gunshots, smoke signals or blowing a horn. But despite these long-distances communication attempts, transmission distances were limited.

Communication took a dramatic turn in the late nineteenth century when electricity was discovered and its many applications explored. This led to the invention of telegraph in 1844 and the telephone in 1876. In 1887 the wireless means of communication through radio was discovered and Marconi demonstrated it in 1897 through its first wireless telegraphy (Frenzel, 1989). From that point on, the exchange of information took a great leap forward with wireless communication systems nearly replacing wire line systems. By this development, communication system had been revolutionalized and had made mobile radio communication system become almost indispensable for all the members of the society as well as the public departments. This is as result of the roles information plays in the society, industry and business organizations.

In spite of this improvement that wireless communication has over the traditional means of communication, Chinthananda, *et al.*, (2001) reported that the performance of wireless communication system is still being degraded by many transmission impairments including fading, cochannel interference and noise. Among these impairments, the fundamental one that makes reliable wireless transmission difficult to achieve is fading (Alamouti, 1998). He reported that fading is the major phenomenon, which makes wireless transmission a challenge when compared to fibre, coaxial cable, line-of- sight (LOS) microwave or even satellite transmissions.

Fading, according to Data Communication Dictionary (1976), is defined as the fluctuation in intensity of any or all components of a received radio signal due to changes in the characteristics of the propagation path. Akbar and Behnaam (1999) reported that fading is the primary causes of the performance degradation in wireless systems and the central among other challenges facing the radio engineers. Therefore, it demands a lot of attention from communication systems designers.

1.1 THE PROJECT MOTIVATION

According to Alberto *et al.*, (2002), the ultimate goal of any communication (e.g. mobile) system is to provide error-free, high-throughput communication. They reported further that, the system must provide to the receiver signal that is strong enough to overcome all forms of interference as well as to ensure that the received signal is free from distortion and fading. Unfortunately, the wireless mobile channel has made it difficult to achieve these goals. This is because unlike the fixed channel, the wireless channel in mobile system usually experiences fading which normally results in fluctuating of signal-to-noise ratios (SNRs) which do lead to poor voice quality, slow link speed, and dropped calls (Alberto *et al.*, 2002). Hence a lot of attention should be given to fading. This is the motivation behind this work because being able to combat it will contribute greatly towards moving the communication industry forward.

1.2 THE OBJECTIVES OF THE RESEARCH

There are two objectives of this study. They are the general objective and the specific objectives.

1.2.1 GENERAL OBJECTIVE OF THE RESEARCH

The general objective of this research is to develop a method of preventing fading in mobile communication in Nigeria.

1.2.2 THE SPECIFIC OBJECTIVES OF THE RESEARCH

The specific objectives of this research are to:

(i) Develop an application program for predicting antenna spacing in combating signal fading in an outdoor environment.

(ii) Evaluate the performance of the program.

1.3 RESEARCH METHODOLOGY

Different theories on path loss propagation and antennas spacing equations in mobile system were compiled and analysed in order to arrive at the best equations applicable to the Nigerian situation. This was followed by the design and development of an application computer program that can predict the optimum distance between two or more antennas in order to combat signal fading in an outdoor mobile system based on minimum specifications of the input values of the carrier frequency, transmitter antenna height, receiver antenna height and the correlation coefficient value.

The program was developed with C++ programming language. During the developmental stages, necessary formalities were added to make the program interactive. The developed program was used to generate the required data.

Finally, the effectiveness of the program was evaluated by comparing the generated data with standard data from formulas. In addition, the generated data were analysed statistically.

1.4 EXPECTED CONTRIBUTION TO KNOWLEDGE

The research work will contribute to knowledge by providing:

(i) An improvement on the traditional repeater method of combating signal fading in mobile communication.

(ii) Computer prediction device in siting of communication systems.

CHAPTER TWO

2.0 LITERATURE REVIEW

By definition, the term "mobile-radio communications" describes any radio communication link between two terminals of which one or both are in motion or halted at unspecified locations and of which one may actually be a fixed terminal known as a base station. This definition applies to both mobile-to-mobile and mobile-to-fixed radio communication links. The mobile-to-mobile link could in fact consist of a mobile-to-fixed-to-mobile radio communication link. The term "mobile" itself on the other hand applies to land vehicles, ships at sea and aircraft.

Nowadays, the term mobile-radio communications is deemed to embrace almost any situation where the transmitter or receiver is capable of being moved – whether it actually moves or not. In mobile environment, the signal transmission over a mobile radio path is reciprocal in the sense that the locations of the transmitter and receiver can be interchanged without changing the received signal characteristics (Parsons, 1992). He reported that discussion could therefore proceed on the basis of transmission in either direction without loss of generality. However, he added this word of caution that ambient noise levels at the two ends of the link may not be the same and so reciprocity with respect to the signal characteristics does not imply reciprocity with respect to the signal-to-noise ratio.

2.1 HISTORICAL REVIEW OF LAND MOBILE COMMUNICATION

Land mobile communication has a very long history that it is almost the same as that of radio communication. The early work of Hertz in the 1880's showed that electromagnetic wave propagation was possible in free space and hence demonstrated the practicality of radio communications. In 1892, Sir William Crookes predicted telegraphic communication over long distances using tuned receiving and transmitting apparatus and Marconi later turned this work into the first practical communication system. In 1897, Marconi was succeeded in communicating from The Needles, Isle of Wight, to a tugboat over a distance of about 18 miles by establishing a radio link over the distance by using two elevated antennas. Although it seems highly unlikely that Marconi thought of this experiment in terms of mobile radio, it was certainly mobile radio and the birth of mobile communication system.

Before the 2nd World War, mobile communication was mainly applied to military and public safety services but after the war it began to be applied to public telephone services. The first public mobile phone services was the Mobile Telephone System (MTS) introduced in the United States in 1946. In this system, operation was simplex and call placement was handled by a full duplex and automatic switching system. The Improved Mobile Telephone System (IMTS) was introduced in 1969 using a 450-megahertz (MHz) band. Although IMTS was widely introduced as a standard mobile phone system, it was not able to cope with the rapidly increasing demand because it was a large-zone system and its assigned bandwidth was not sufficient. Therefore, a more advanced and high-capacity land mobile communication system called Advanced Mobile Phone Service (AMPS); was introduced in 1983. The most important feature of AMPS is that it employs a cellular concept to achieve high system capacity. In 1989 Nippon Telegraph and Telephone (NTT), in Japan, started analog cellular phone service with a narrowband high-capacity system.

Although each analog cellular system has high capacity, it was not sufficient to satisfy the rapidly increasing demand for cellular services. Therefore Europe, the United States, and Japan have independently developed digital cellular systems as the second-generation cellular systems. In Europe, Group Special Mobile (GSM) was organized under the Conference of European Posts and Telecommunications (CEPT); that standardized the GSM system in 1988. Today, GSM stands for Global System for Mobile communications – which has becomes almost indispensable item to everybody in this country.

2.2 MOBILE COMMUNICATION CONCEPTS

A typical mobile communication system as shown in Fig. 2.1, consists of mobile terminals, base stations, mobile switching centers, and telecommunication channels. Those telecommunication channels are either of a fixed nature (cables or dedicated radio links), to provide connections between base stations and mobile switching center or mobile radio channels between mobile terminals and base stations servicing those terminals. Unlike fixed telecommunications, the mobile radio channels are nonstationary and exhibit a high level of unpredictability with regard to channel characteristics. In addition, due to the nature of radio communication and low directivity of antennas used, there is always a possibility of strong interference from other users of the radio spectrum.

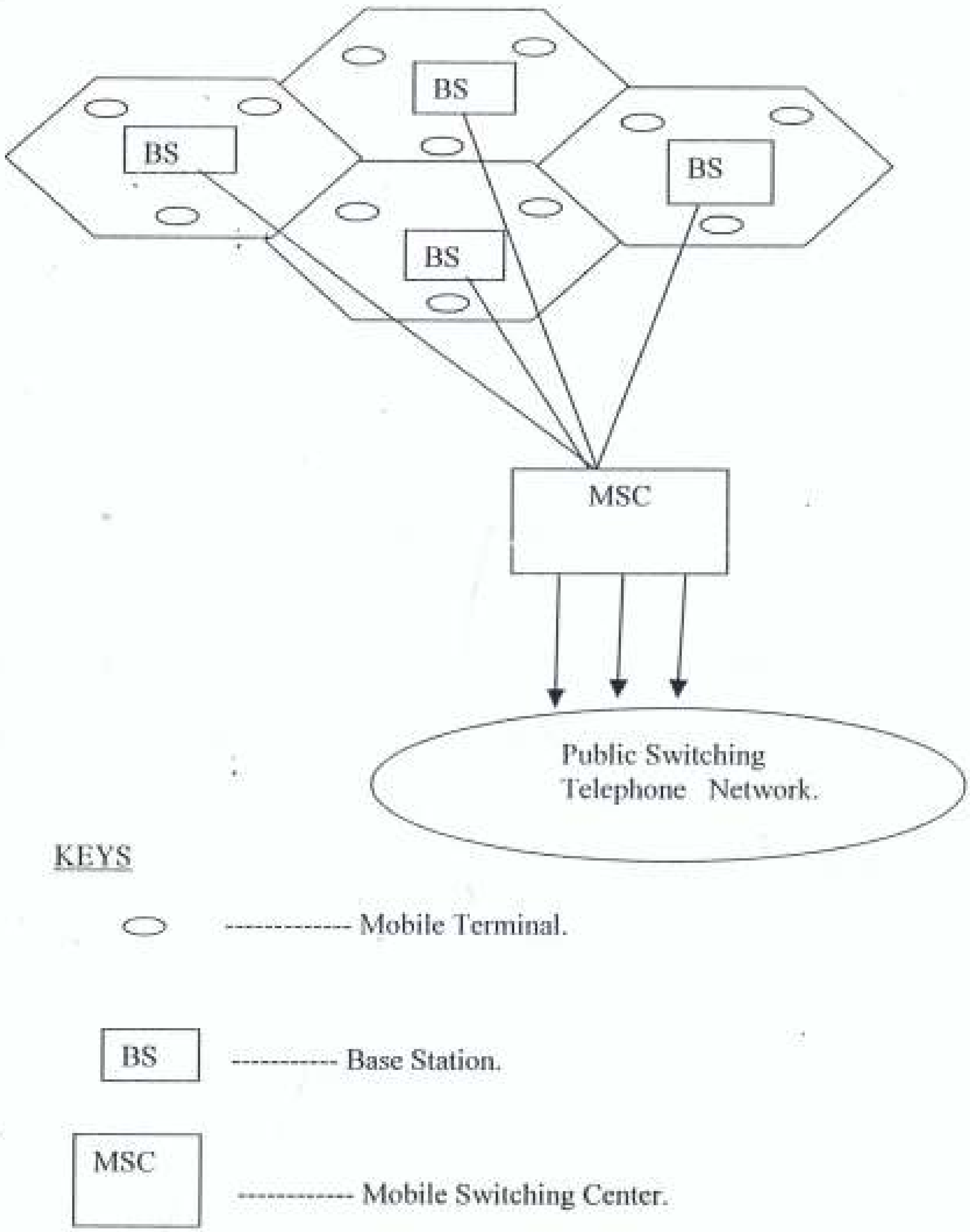

Fig. 2.1 Configuration of a Mobile Communication System

In addition to the telecommunication channel in mobile system, there is another channel called the control channels. The function of the control channels are to transmit and receive data necessary to set up a call and moving it to an unused voice channel. Also it helps in managing the handovers between base stations. They are also used for constant monitoring of the system and for synchronization purposes.

The base station serves as a bridge between all mobile users in its coverage areas and the mobile switching center (MSC). The MSC acts as a central switching point, closing the traffic among the connected base stations, and serves as a gateway to the Public Switching Telephone Network (PSTN). It also coordinates all activities of the base stations and accommodates all billing and maintenance functions.

2.3 CLASSIFICATION OF MOBILE COMMUNICATION SYSTEMS.

Mobile communication systems are classified into generations in accordance with evolution of systems in time. The indicators for generation classifications involve: transmission techniques, supported services, and status of unification. With these indicators, mobile communication system was successfully classified into two major generations; namely the First-generation systems and the Second- generation systems. The standards for the Third-generation systems are currently being developed as reported by Webster (1999) to provide mobile multimedia telecommunications and universal coverage.

2.3.1 FIRST GENERATION MOBILE RADIO SYSTEMS

The First-generation systems were introduced in the early 1980s and used analog techniques basically for speech services. Although these systems are essentially concerned with the transmission of speech signals, they are able to transmit data but at relatively low bit rates (Steele, 1992). They are usually referred to as 'analogue' systems as the speech signals are not digitally encoded prior to transmission on a radio frequency (RF) carrier. However, all the command and control of the network is digital. The user accesses the systems by means of frequency division multiple accesses (FDMA). When a cell is connected, the mobile user is assigned a frequency band exclusively for his or her use until the call is completed. There are numerous analogue mobile radio networks. These include the Nordic Mobile Telephone (NMT) system, the American Advance Mobile Phone Service (AMPS), the British Total Access Communications System (TACS), etc. The radio links in the first generation systems are simple compared to those found in the second-generation system. The link is essentially in the transmission of either speech or data. The transmission of speech is through frequency modulation (FM) while data is by frequency shift keying (FSK).

2.3.2 SECOND- GENERATION SYSTEMS

The Second- generation systems evolved in the late 1980s. They utilize digital techniques for speech services. Apart from speech, they equally support some low-rate data services. Second-generation systems may be further classified into cellular, cordless, and professional radio systems. The standards for the Third-generation systems are currently being developed as reported by Webster (1999) to provide mobile multimedia telecommunications and universal coverage.

2.4 CELL CLUSTER ARRANGEMENT IN MOBILE SYSTEM

Communications between a moving mobile station (MS) and another MS, or between a MS and a fixed station, generally involves the use of cellular techniques. The basic concept in FDMA (and TDMA) cellular mobile radio is to divide the spectrum, say W, assigned by the regulatory body into equal parts Bc, and to allocate Bc to each base station (BS) in a cluster of N-BSs until all the bandwidth W (= NBc) is used. Conceptually each BS may be viewed as being located at the center of hexagonal cell, which as reported, by Steele (1992) is not physically realized and the hexagons are tessellated to provide a continuous mosaic over a geographical area as illustrated in Fig. 2.2. The radiated power from a BS is sufficient to provide adequate radio coverage for all the MSs traveling in its domain, or cell.

As the assigned frequency band W is totally used by the cluster of N-BSs, it must be repeatedly reused if contiguous radio coverage is to be nationally provided. This means that N-cell clusters must be tessellated as shown Fig. 2.3 where seven cell clusters are shown. The consequence of tessellating clusters is that a MS traveling in, say, cell-4 of a particular cluster will experience interference from BSs located in cell 4 of other clusters that are transmitting to MSs in their cells using the same frequency.

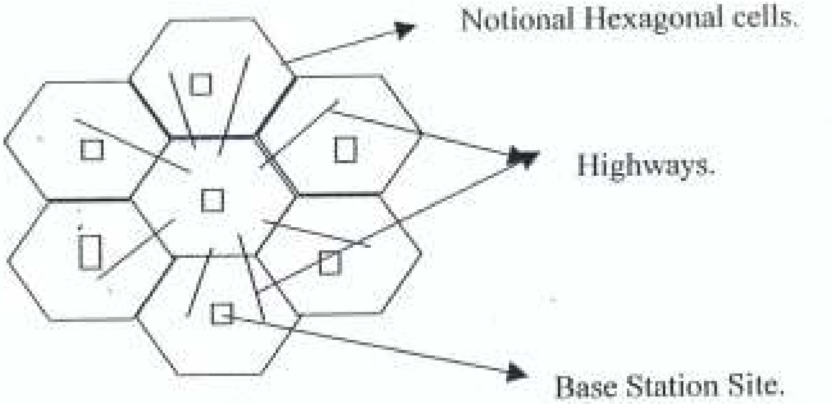

Fig. 2.2 A cluster of hexagonal cells overlapping geographical areas.

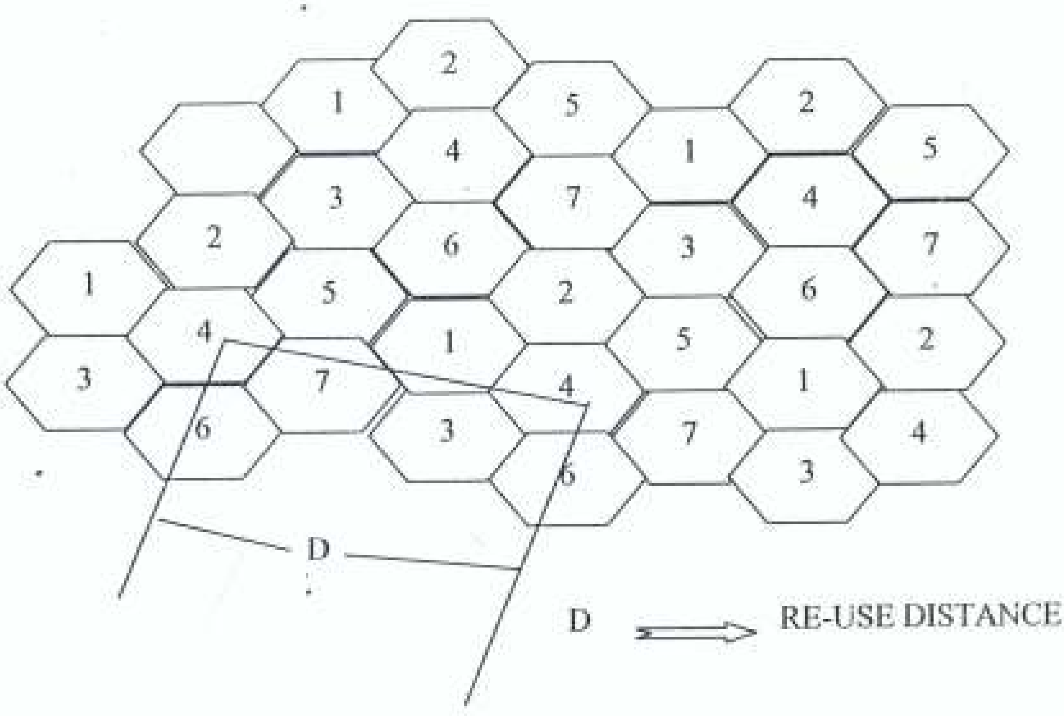

Fig. 2.3 Tessellated clusters of cells; Seven cells per cluster.

For the seven-cell cluster there are six significant interfering BSs, although only four are shown in Fig. 2.3. This interference is known as cochannel interference. The BSs that use the same radio frequencies must be sufficiently separated for the cochannel interference to be acceptably small. As a result, mobile radio communications are often referred to as being interference limited in that the BSs are moved close together to increase the density of users, but not so close that the cochannel interference results in unacceptable speech quality to the mobile user (Steele, 1992).

2.4.1 FREQUENCY REUSE STRATEGIES

In a wireless communication system that covers a wide area with many users, not all users can be accommodated if the available bandwidth is used only once in the entire coverage area. Two or more distinct channels can exist in the same frequency band if some mechanism is used to minimize interference between the channels. Typically spatial separation, either in distance, angle, or polarization is exploited for frequency reuse. In such a system capacity per unit area must be sufficient for the density of users and their usage patterns. Capacity per unit coverage area can be measured in bits/second/km^2.

2.4.2 CELLULAR FREQUENCY REUSE

Cellular frequency reuse is the basis of cellular and personal communication systems (PCS). In these systems frequencies are reused in geographically separated areas, or cells. A reuse pattern using clusters of N cells is established, and each of these N cells uses a different subset of the available frequencies. Each cluster of cells uses the same frequencies in this manner. Cells that use the same frequency are far enough apart that the interfering signals received in any cell from co-channel cells are much weaker than the signals that originate within that cell. This frequency reuse approach introduces co-channel interference, and capacity is limited by interference as well as by noise. Cellular frequency reuse allows modern systems to offer much higher capacity than older radiotelephone systems that used the available channels only once to cover a large metropolitan area.

For planning purposes the cells are considered to be hexagonal or circular, although in practice their shapes determined by radio coverage and are irregular as shown in Fig. 2.3. The hexagonal shape is, nonetheless, a useful approximation. For N-cell frequency reuse, the reused distance, D, between co-channel cells with radius, R according to Lee (1989) and Steele (1992) is given;

$$D = \sqrt{3N}\ R \qquad \text{--} \quad (2.1)$$

$$\Rightarrow \quad D = \begin{cases} 3.46R, & N = 4 \\ 4.6R, & N = 7 \\ 6R, & N = 12 \\ 7.55R, & N = 19 \end{cases}$$

To each cell, the same bandwidth Bc is assigned but not the same frequency band. If each user is allocated a bandwidth Bu, then the maximum number of channels per cell is Bc/Bu. For a cell covering an area A, the density of channels is Bc/(A-Bu). By making A small, the channels' density increases. Consequently, in city centers where the density of MSs is high the cell radius may be only 1 km, while in remote or rural areas the radius may be some 35 km and yet still be sufficient to accommodate users' demand (Steele, 1992).

According to Lee (1989), if all the cell sites transmit the same power, then as N is increasing the frequency-reused distance D also increases. This increased D reduces the channel that cochannel interference may occur. He reported that, theoretically, a large N is desired. However, the total number of allocated channels is fixed. Hence when N is too large, the number of channels assigned to each of N cells becomes small. Therefore, this can result in trunking inefficiency, as the blocking probability will definitely large.

2.5 NETWORK CONTROL IN MOBILE SYSTEM

As mentioned above when describing cellular clusters, it was stated that cochannel interference from other cells and adjacent channel interference from users of adjacent channels affect the quality of system. Hence, a network that will establish and terminate calls with mobiles, track the mobiles as they travel, enable their calls to be switched between BSs to maintain call quality and channel interference free is a necessity. To achieve all these qualities, the network control system was introduced in mobile communication system. The technology behind the British Total Access Communications System (TACS) network as a typical example was reviewed below.

2.5.1 NETWORK FOR BRITISH TACS

In TACS network arrangement as reported by Steele (1992), the BSs are connected by permanent links to mobile switching centers (MSCs) which are computer controlled telephone exchanges specifically designed for handling cellular services. The MSCs in turn are connected to the public switched telephone network (PSTN) and to other MSCs. The arrangement is shown in Fig. 2.5. It enables MSs to communicate with other MSs and non-mobile users. It also allows cells to be connected to MSs who are not in their home area.

In the system, the cellular network must keep track of all the MSs that are subscribers to the network. It does this by forming traffic areas, which consist of groups of cells. The MSCs log the current locations of all MSs through a process known as registration. When the MS is switched on, but is not making a call, it constantly listens to one of the common signaling channels transmitted by the BSs to determine the traffic area in which it is currently residing. In case the quality of the current signaling channel deteriorates as the MS travels it scans the signaling channels until it finds one with an acceptable quality. If the traffic area has changed the MS automatically, and unknown to the user, calls the new BS, gives its identification number, and is thereby registered in the new traffic area. The old or former BS de-registers the MS.

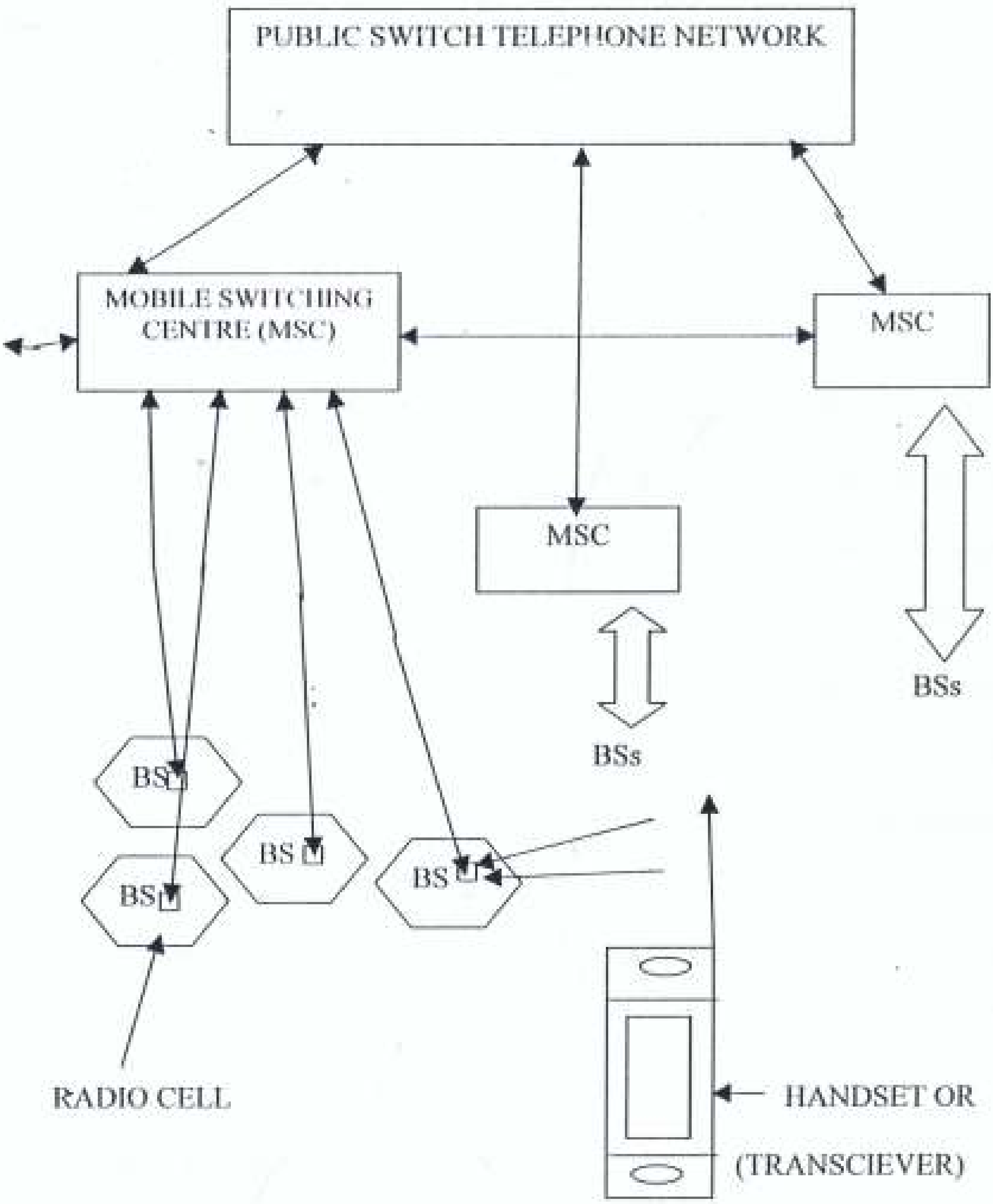

Fig. 2.4 Network arrangement for TACS

2.5.2 HANDOVER OR HAND-OFF PROCESS IN MOBILE SYSTEM.

When a call has been established and a conversation is in progress the MS may travel near the edge of its cell. In case the communications quality becomes unsatisfactory, the network is required to ensure that the MS changes its BS to one that can provide a better quality channel. This process of switching from one BS to another BS is called handover or hand-off. The handover process is required to be automatic, with no interruption of the call.

To facilitate the handover procedure the BS constantly monitors the received signal levels from all mobiles with speech transmissions in progress. When a received signal level drops below a threshold, it informs the MSC that a hand-off may be required. The MSC commands all the surrounding base stations to measure the signal strength of the mobile, and then chooses the BS with the strongest received signal to handle the call. Once the new base station has been informed of the handover request, and the radio channel allocation has been made, the original base station is commanded to send a control message to the mobile to have it re-tune to the newly assigned channel. This happens automatically within a few seconds, and the mobile user is aware of only a very brief break in transmission of about 400ms as reported by Steele (1992) when the actual handover takes place.

2.5.3 CONTROL CHANNELS

The TACS control channels are used for the co-ordination of mobiles and for all call set-up procedures. Functionally, there are three types of control channel: dedicated control channels, paging channels and access channels. All mobiles are permanently programmed with the channel numbers of the dedicated control channels and they scan these channels at switch-on. The dedicated control channels carry basic information about the network and inform the mobiles about the channel numbers of the paging channels.

The paging channels are used both to transmit messages to specific mobiles, for example, to alert them of incoming calls, and for general network information, such as traffic area identity, channel numbers of the access channels and access methods to be used by mobiles. The access channels are used by mobiles for accessing the network to initiate out-going calls, to register their location and to respond to paging calls.

2.5.4 SIGNALLING CHANNELS

There are generally four different types of channels that are used for communication between the base station and mobiles. They are namely:

(i) Forward Voice Channels (FVC): these are the types of channels used for voice transmission from base station to mobiles.

(ii) Reverse Voice Channels (RVC): these are channels used for voice transmission from mobiles to the base station.

(iii) Forward Control Channels (FCC): these are channels used for transmission of signaling data from the base station to mobiles.

(iv) Reverse Control Channels (RCC): these are channels used for transmission of signaling data from mobiles to the base station.

They are referred to as the signaling channels. The four signaling channels are as shown in Fig. 2.6. The FCC and the RCC are used for setting-up calls, as well as maintaining constant between BS and MS when no calls are in progress. The FVC and RVC must be compatible with a standard with a standard voice channel. Data messages on the FVC and RVC are kept short because they are inserted periodically into the users voice channel.

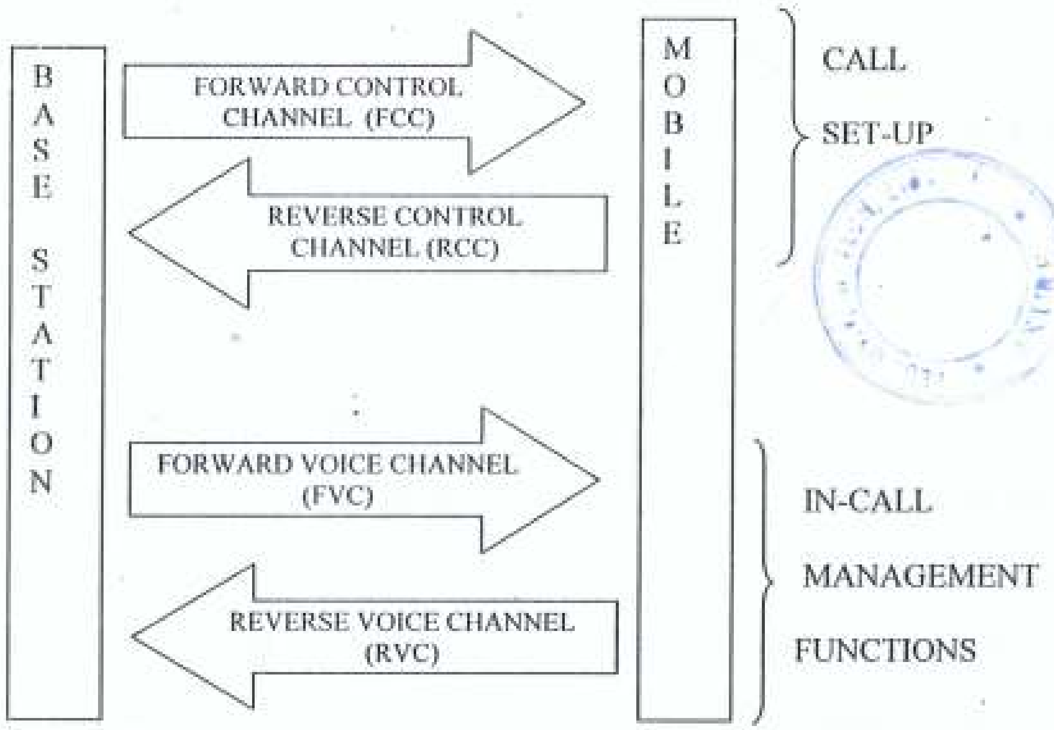

Fig. 2.5 Signaling channels.

The FCC is transmitted at all times so that a mobile entering the system can require system specific information e.g., which channels are allocated for voice traffic. The RCC is only active intermittently, e.g., when the BS moves from one BS to another (no conversation in progress) or the MS initiates a call.

2.5.5 SUPERVISION

While a call is in progress, a supervisory audio tone (SAT) is transmitted by the base station and looped back by the mobile. Both base station and mobile require the presence of the SAT on the received signal to enable the audio path. During call set-up, the base station informs the mobile which SAT to expect on the speech channel. If the SAT is incorrect, the mobile does not enable the audio path, but starts a timer, which, on expiring, returns the mobile to stand-by. Similarly, the base station expects to see its transmitted SAT returned and takes this a confirmation that the mobile is operating on the current channel.

2.5.6 CALL ORIGINATION

When a user makes an outgoing call, the number required is keyed into the mobile, or the required number is extracted from the short-code memory in the mobile. A SEND key is then pressed. This causes the mobile to perform a system access. To do this, the mobile first scans the network's access channel. The channel numbers of the access channels are transmitted as part of the overhead information on the paging channels. The mobile will choose two channels with the highest signal level and attempt to receive the overhead messages being transmitted. Should the mobile fail to receive these messages on the strongest channel, it tries again on the other channel. Contained in the overhead messages are parameters, which inform the mobile of the access procedure. Once the mobile has received these parameters, it checks to see if the access channel is in use. If it is available the mobile transmits it message.

When the mobile has sent its message to the network, it turns off its transmitter and remains on the access channel awaiting a message from the base station. For MS call originations, the received message from the base station is normally a speech channel allocation and contains the channel number and the SAT code. On receipt of the message, the mobile tunes to the required channel and starts to transpond the SAT. If the correct SAT is received at the BS, the audio paths are enabled and the user can hear the call being set-up.

2.5.7 CALL RECEIPT

When an incoming call for a MS is received, the MSC checks the current location of the mobile which has been obtained through the registration procedures. A paging call is then transmitted on the paging channel of all BSs in the mobile's current traffic area. When the MS receives a paging call, it accesses the network in the same way as for call originations, but the message sent to the BS informs the network that the access is as a result of receiving a page. The MS receives a speech-channel allocation from the BS, tunes to the new channel, and checks the SAT received. The BS then transmits on alert message to the MS, causing it to alert the user of the incoming call and to transmit a continuous signaling tone. When the user answers the call, the signaling tone is tuned off, the audio paths are enabled and the call proceeds.

2.5.8 POWER LEVELS AND POWER CONTROL

The transmit power levels used at a BS are chosen to give the required coverage area. The maximum effective radiated power (ERP) per channel is limited to 100W.

The mobile stations have a nominal power class, namely 1, 2, 3 and 4 with ERPs of 10W, 4W, 1.6W and 0.6W, respectively. However, classes 2 and 4 are used by the majority of MSs. It is the responsibility of the BS to instruct the MSs within its coverage area to adjust their transmitted power to the minimum level required for optimum performance of the BS. The power control facility on the other hand helps in reducing interference within the system. This is done by sending power control message, which is initiated by the BS. On receipt of the power control message from the BS, the mobile sends an acknowledgement to the Bs and selects the appropriate power level.

2.5.9 CALL TERMINATION

When a mobile user completes a call and replace the handset, the mobile transmits a long burst signaling tone to the BS, and then re-enters the control-channel scanning procedure. If the originator of a cell on the PSTN clears down, a release message is sent to the mobile, which responds by sending a burst signaling tone, after which it re-enters the control-channel scanning procedure.

2.6 CHOICE OF OPERATING FREQUENCY FOR MOBILE RADIO SYSTEMS

There are several factor that have to be considered in deciding what frequency band should be used for a particular type of radio communications service. For the specific application of interest, two-way mobile radio operations, communication is required over ranges that do not normally exceed a few tens of kilometers. Otherwise it would cause unnecessary interference to other users if the signals propagated were too far. It is evident that if mobiles are to communicate freely with their base, or with each other, throughout a given area (which may or may not be the total service area of the system) the transmitters involved must be able to provide adequate signal strength over the entire area concerned (Parsons, 1992). Hence operating frequencies must be chosen in a region of the radio frequency (RF) spectrum where it is possible to design efficient antennas of a size suitable for mounting on base station masts, on vehicles, and on hand-portable equipment. Since the mobile can move around freely within the area covered by the radio system, their exact location cannot be predicted per time. Hence the antennas must therefore radiate energy uniformly in all directions in the horizontal plane – technically this is known as 'omni-directional' radiation. It is also vital that the frequencies chosen are such that the transmitters used at base stations and mobiles can generate the necessary RF power while remaining fairly small in physical size.

For two-way mobile radio, particularly in urban areas, it is rare that the mobile antenna has a direct line-of-sight path to the base station. Radiowaves will penetrate into buildings to a limited extend and, because of diffraction, it will appear to bend slightly over minor undulations or folds in the ground. Fortunately, due to multiple scattering and reflection, the waves also propagate into built up areas, and although the signal strength is substantially reduced by all these various effects, sensitive receivers are able to detect the signals even in heavily built-up areas and within buildings. The choice of frequency is therefore limited by the need to minimize the losses due to buildings while continuing to satisfy the other constraints mentioned above.

For these reasons, traditional two-way mobile radio has developed almost exclusively around the VHF and UHF bands (Parsons, 1992). In a city, for example, there are many mobile users such as emergency services e.g. Fire Bridge, Police and the like. The central police control room receives report of incidents in the city area – often by emergency telephone calls. The control room radio operator puts out a call to a police officer, believed to be in the appropriate area, who may be on foot with a personal radio, or in a vehicle equipped with mobile radio. On receipt of the call the officer acknowledges it, investigates the incident and reports back by radio. Because of the nature of the work of the police, police force have radio channels exclusively allocated for their use and there is no mutual interference between them and other users who have been allocated different channels in the same frequency band.

The range over which signal propagates is also a fundamental condition since in order to use the available spectrum efficiently, it is necessary to re-allocate radio channels to other users operating some distance away. If in the example given above the message had been radiated on HF, then it is possible that the signal could have been detected at distances of several hundred kilometers away, where it would cause interference to other users. The VHF and UHF bands therefore represent an optimum choice for mobile radio because of their relatively short-range propagation characteristics and because radio equipment designed for these bands is reasonably compact and inexpensive.

There are many other services, however, which also operate in the VHF and UHF bands for example, television, marine radio, aero-mobile (including instrument for landing systems), and military radio. Several of these services have a 'safety of life' element and it is vital that their use is tightly regulated to ensure maximum efficiency and freedom from interference. The exact frequencies within the VHF and UHF bands that are allocated for various radio systems are agreed at meetings of the International

Telecommunications Union (ITU) and are legally binding on the member states. Every twenty years the ITU organizes a world administrative radio conference (WARC) at which regulations are revised and updated and changes in allocations and usage agreed.

In each country, a regulatory authority or body controls the use of the radio frequency spectrum. For example in UK, it is the Department of Trade and Industry, in Nigeria it is the National Communications Commission (NCC), and in the USA it is the Federal Communications Commission. Their job is to divide the usable radio frequency spectrum into individual channel and to license users for the use of a particular channel. Because of the attractive propagation characteristics of VHF and UHF, it is possible to allocate the same channel to different users in areas separated by distances of 50 – 100 kilometres with a substantial degree of confidence that, except under anomalous propagation conditions, they will not interfere with each other. The frequency allocated for mobile communication in Nigeria is between 800 – 1000 MHz. According to NCC (2003) proposal, allocated frequency for transmitter is between 890 – 915 MHz while the allocated frequency for receiver is between 935 – 960 MHz.

2.7 MOBILE RADIO POLARIZATION SYSTEM

An important consideration according to Frenzel (1989) in the transmission and reception of radiowaves is the orientation of the magnetic and electric fields with respect to the earth. He reported that a change in the state of the polarization of the radiowave causes signal fading. He stated also that the direction of the electric field usually specifies the polarization of the wave. If the electric field is parallel to the earth, the electromagnet wave is said to be horizontally polarized. However, if the electric field is perpendicular to the earth, then the wave is vertically polarized. Hence, antennas that are horizontal to the earth produce horizontal polarization, and antennas that are vertical to the earth produce vertical polarization.

In mobile communications, vertical polarization is always used (Parsons, 1992). At frequencies in the VHF band it is better than horizontal polarization because it produces higher field strength near the ground (Knight, 1969). Furthermore, mobile and hand-portable antennas for vertical polarization are more robust and more convenient to use. In an overall plan for frequency re-use, no worthwhile improvement can be achieved by employing both polarizations (as used in television broadcasting) because scattering in urban areas tends to cause a cross-polar component to appear. Although this may have some advantages, for example it is often inconvenient to hold the antenna of a hand-portable radio telephone in a truly vertical position, it is apparent that no general benefit would result from the transmission of horizontally polarized signals (Parsons, 1992).

The most important condition to fulfill in choosing the type of polarization to use is to ensure that both the transmitting and receiving antennas are of the same polarization (Frenzel, 1989). He reported that fulfilling this condition enhance optimum transmission and reception. He stated that theoretically, a vertically polarized wave will produce 0 V in an horizontal antenna and vice-versa. But during transmission over long distances, the waves have their polarization changes slightly due to the various propagation effects in free space. For this reason, even though polarization of the transmitting and receiving antennas may be mismatched, and a signal will typically be received, optimum results will take place when the polarization of the two antennas are matched.

2.8 RADIOWAVE PROPAGATION AND USES OF DIFFERENT FREQUENCY BANDS

The success of any communication depends on the influence of the propagation medium (Hall, 1989), be it dependent on sound waves radio waves or light. The Radio Regulations of the ITU (1986) limit the term "radio waves" to electromagnetic waves of frequencies arbitrarily lower than 3000 GHz. According to Parsons (1992), the part of the electromagnetic spectrum that includes radio frequencies extends from about 30 KHz to 300 GHz, although radio waves propagation is actually possible at frequencies down to a few KHz. By international agreement the radio frequency spectrum is divided into 'bands', each band being given a designatory name as in Table 2.1.

Table 2.1: Designations of Frequency Bands

Frequency Band	Frequency Range (Wavelength)	Propagation Modes
Extremely Low Frequency (ELF)	30 – 300 Hz or < 3 KHz ($\lambda > 100$ km)	Ground wave.
Very Low Frequency (VLF)	3 – 30 KHz (10 km $\leq \lambda \geq$ 100 km)	Earth – Ionosphere guided.
Low Frequency (LF)	30 – 300 KHz (1 km $\leq \lambda \geq$ 10 km)	Ground wave.
Medium Frequency (MF)	300 KHz – 3 MHz (100 m $\leq \lambda \geq$ 1 km)	Ground/Sky wave for short/long distance.
High Frequency (HF)	3 – 30 MHz (10 m $\leq \lambda \geq$ 100 m)	Sky wave, but limited, short-distance ground wave also.
Very High Frequency (VHF)	30 – 300 MHz (1 m $\leq \lambda \geq$ 10 m)	Space wave.
Ultra High Frequency (UHF)	300 MHz – 3 GHz (10 cm $\leq \lambda \geq$ 1 m)	Space wave.
Super High Frequency (SHF)	3 – 30 GHz (1 cm $\leq \lambda \geq$ 10 cm)	Space wave.
Extra High Frequency (EHF)	30 – 300 GHz (1mm $\leq \lambda \geq$ 10 mm)	Space wave.

Electromagnetic energy in the form of radio waves propagated outwards from a transmitting antenna and there are several ways in which these waves travel, much depending on the transmission frequency. Waves propagated via the layers of the ionosphere are known as ionospheric waves or sky- waves. Those that propagated over other paths in the lower atmosphere (the troposphere) are termed troposheric waves while those that propagate very close to the Earth's surface are known by the generic term ground-waves (Parsons 1992). Ground waves can be conveniently divided into space waves and surface waves. The space waves on the other hand, can be further sub-divided into:

(i) direct waves which propagate via the direct path between transmitting and receiving antennas and;

(ii) ground-reflected waves that reach the receiving antenna after reflection from the ground. Figure 2.6 gives a simple picture of the radiowave propagation mode. The surface waves are guided along the earth's surface and because the earth is not a perfect conductor, energy is extracted from the waves, as it propagates, to supply losses in the ground itself. The attenuation of this wave (sometimes known as the 'Norton surface wave') is therefore directly affected by the ground constants (conductivity and dielectric constants) along the transmission path.

The importance of each of these waves in any particular case depends upon the length of the propagation path and the frequency of transmission. Each frequency band will now be discussed in turn.

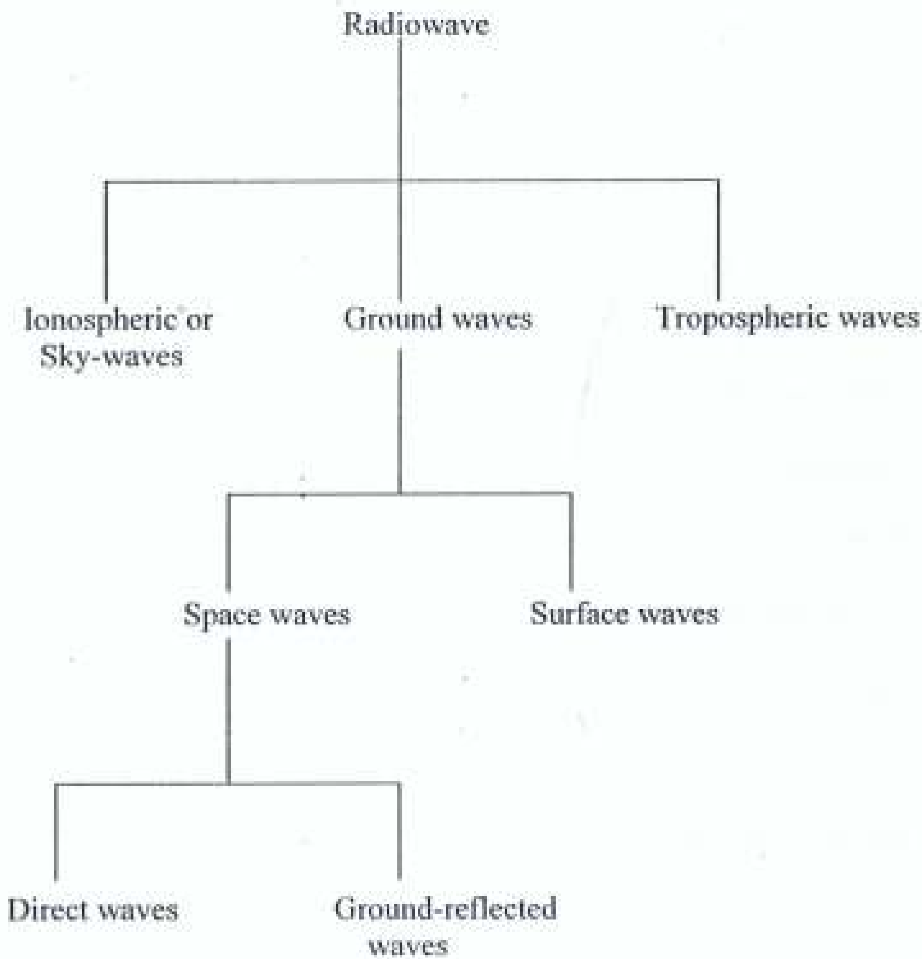

Fig. 2.6. Modes of radiowave propagation.

2.8.1 Extremely Low Frequency (ELF).

In the ELF range, the wavelength is very long. It is in range of above 10^5 m. Because of its very large wavelength, its requires the use of large antennas. The radiowave is propagated between the surface of the earth and ionosphere. It can penetrate deep into water and ground. Radiowaves in this frequency band do experience low attenuation, and high atmospheric noise level. The band is used for worldwide military and submarine communication.

2.8.2 Very Low Frequency (VLF).

In the VLF range, the wavelength is very long, typically 10^5 m, and antennas are therefore very large. The radiowaves are reflected from the ionosphere and a form of earth/ionosphere waveguide exists that guides the wave as it propagates. Because of diurnal variations in the height of the D-layer the effective height of the terrestrial waveguide also varies around the surface of the earth. The uses of VLF include long distance worldwide telegraphy and navigation systems. Frequencies in the VLF range are also useful for communication with submerged submarines. Also VLF is used for digital transmission but the data rate is extremely low because the available bandwidth in this frequency range is very small.

2.8.3 Low Frequency (LF), Medium Frequency (MF), and High Frequency (HF).

At frequencies in the LF and MF bands, groundwave propagation is the dominant mode and the radiation characteristics are strongly influenced by the presence of the earth. At LF, the surface wave component of the ground wave is successfully utilized for long distance communication and navigation. Physically, antennas are still quite large and high power transmitters are used. In the MF band, the increased bandwidth available allows it to be used for commercial AM broadcasting. Although the attenuation of the surface wave is higher than that of LF band, broadcasting over long distances is still possible particularly during the daytime. At night, skywave propagation via the ionospheric D-layer is possible in the MF band, and this leads to the possibility of interference between signals arriving at a given point, one via a groundwave and the other via a skywave path. The interference can be constructive or destructive depending upon the phases of the incoming waves and temporal variations in the height of the D-layer, which causes the signal to be alternatively strong and weak. This phenomenon, term fading, can also be produced by several other mechanisms and always occurs when energy can propagate via more than one path. In HF band, groundwave propagation also exists but here ionospheric or skywave is often the dominant feature.

2.8.4 Very High Frequency (VHF) and Ultra High Frequency (UHF).

Frequencies in the VHF and UHF bands are usually too high for ionospheric propagation to occur. In these bands, communications normally take place via the direct and ground-reflected components of the spacewave. Also in these bands, antennas are relatively small in physical size and can be mounted on mast several wavelengths above the ground. Under these conditions, the spacewave is predominant. Although the spacewave is often a negligible factor communication at lower frequencies it is the dominant feature of grounwave communication at VHF and UHF.

The bandwidth available is such that high quality frequency modulation (FM) radio and Television channels can be accommodated but propagation is normally restricted to points within the radio horizon and coverage is therefore essentially local. The bands are equally used for mobile radio communication. The analysis of spacewave propagation at VHF and UHF needs to take into account the problems of reflections both from the ground and from natural and man-made obstacles. Diffraction over hill tops and buildings, and refraction in the lower atmosphere are also important.

2.8.5 Super High Frequency (SHF) and Extremely High Frequency (EHF)

Frequencies in the SHF band are commonly termed microwaves. The propagation paths must have line-of-sight between the transmitting and receiving antennas, otherwise losses will be extremely high. The band is used for satellite communication, point-to-point terrestrial links, and short-range communication systems. The band is being used for satellite communication since its signals penetrate the ionosphere with little or no effect. The term millimeter wave (mm-wave) is often used to describe frequencies in the EHF band between 30 and 300 GHz. By comparing it with lower frequencies, enormous bandwidths are available in this part of the spectrum. Line of sight propagation is now predominant. In mm-wave band the most important effects that have to be taken into account are scattering by precipitation (rain and snow) and at certain frequencies, absorption by fog, water vapour and other atmospheric gases.

2.9 THE WIRELESS COMMUNICATION LINK.

All communications systems have the basic form shown in Fig. 2.7 while Fig. 2.8 shows the entire block diagram of a wireless communication link. The basic components are a transmitter, a communications (transmission) channel or medium, and a receiver. Quantization, coding and decoding are only performed in digital systems. In wireless communication links, there are three modes of transmitting information. They are: simplex, half duplex, and full duplex. In simplex mode transmission, information is communicated or transmitted in one direction only. A good example is in AM/FM radio. Another example is in a telemetry device transmits the collected data to a central computer. In half duplex transmission, two devices are involved that can exchange data or information alternatively. In other words, it permits transmission in either direction; however, transmission can occur in only one direction at a time. An example is human communication, in which master 'A' talks while master 'B' listens, then 'B' talks and 'A' listens. In full-duplex transmission, two devices exchange data or information simultaneously. This transmission mode requires the use of two channels. Most wireless links, e.g. mobile systems, are full duplex and include a transmitter and a receiver or transceiver at each end of the link. In most systems, a human generates a message that is inputted to the transmitter, which then transmits the message over the transmission or communications channel. The message is picked up by the receiver and is relayed to another human.

Fig. 2.7 The basic elements of any communications system.

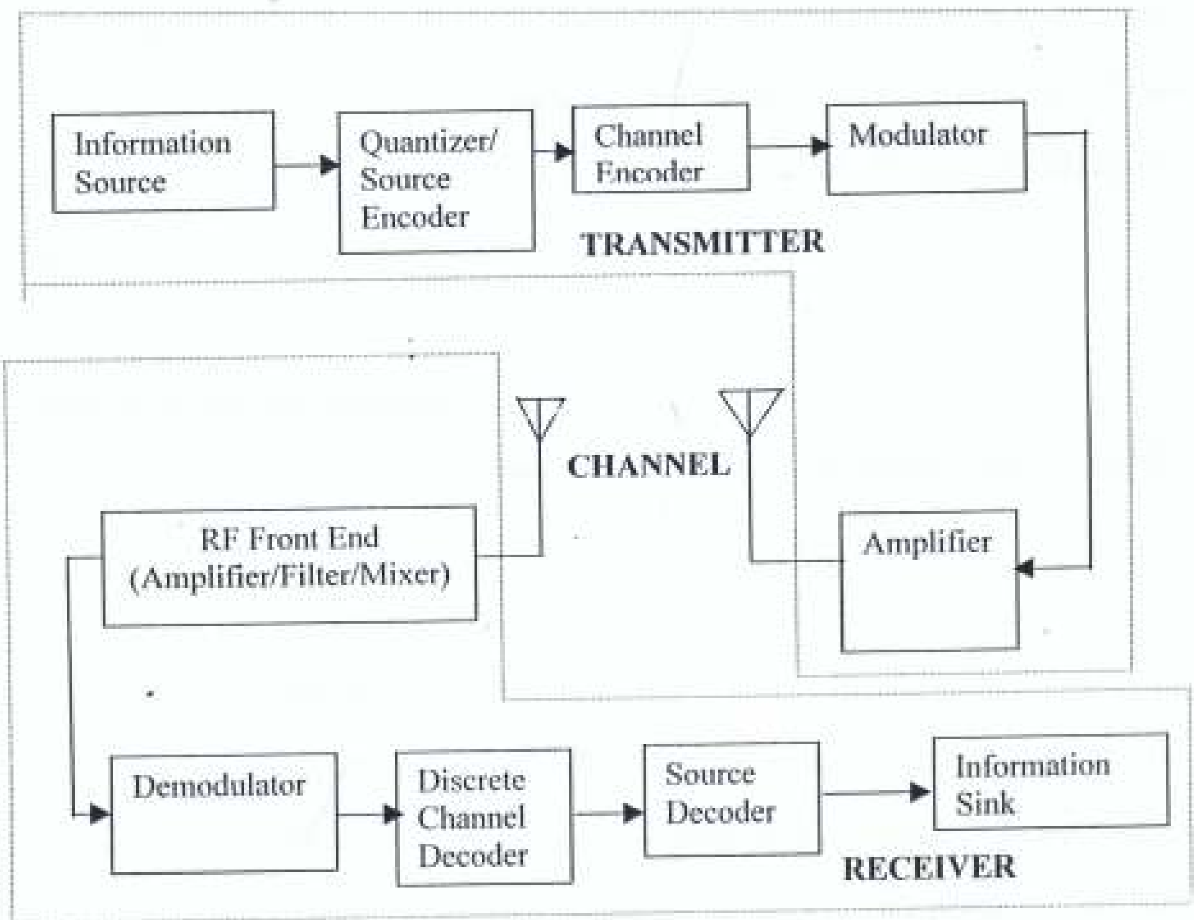

Fig. 2.8 Block diagram of a wireless communication link

2.9.1 THE TRANSMITTER

The transmitter is a collection of electronic components and circuits designed to convert the information into a signal suitable for transmission over a giving communication medium. It may be as simple as a microphone or as complex as a microwave radio transmitter.

2.9.2 THE RECEIVER

The receiver is another collection of electronic components and circuits that accept the transmitted message from the channel and convert it back into a form understandable by humans. Again it may be a simple earphone or a complex electronic receiver. The transmission of the message or information from the transmitter to the receiver via the transmission medium involves the use of MoDem (Modulation-Demodulation).

Modulation Systems in Mobile Communication

Various types of modulation can be used for mobile communications. These fall into two basic categories, analog and digital.

2.9.2.1 ANALOG MODULATION

In analog modulation formats, some parameters of the transmitted signal vary as a linear function of the amplitude of the original audio or video signal to be transmitted. Analog modulation schemes include amplitude, frequency, and phase modulation. Amplitude modulation (AM) occupies only about twice the bandwidth of the baseband signal but is sensitive to non-linearities in the amplitude response of the RF circuitry in the transmitter and the receiver, and to time-varying fading in the channel. Frequency and phase modulation (FM and PM, respectively) are relatively insensitive to amplitude non-linearities and provide higher SNR of the demodulated audio signal by spreading the signal over a bandwidth that is many times that of the original baseband signal.

2.9.2.2 DIGITAL MODULATION

In digital modulation formats, the signal to be transmitted is binary data that may or may not represent an analog signal that has been quantized and digitized. At any given time, the transmitter sends one of a discrete set of symbols, each of which represents one or more bits. In digital modulation each symbol typically occupies a finite time slot, and this requires the receiver to be synchronized to the transmitter so that the receiver demodulates each symbol in turn.

The simplest type of digital modulation is on-off keying (OOK), in which the carrier is turned on and off depending on the value of each bit. In Amplitude-shift keying (ASK), the amplitude of the transmitted signal is varied in discrete steps, with each level representing one or more bits. Frequency-shift keying (FSK) uses discrete frequencies as its symbols. A variation of this is AFSK, in which a carrier is modulated with a baseband FSK signal using one of the analog techniques, typically FM. Phase-shift keying or PSK uses a carrier of a constant nominal frequency and each symbol is represented by a different phase shift from a reference phase that is maintained for the symbol period. Differentially encoded PSK or DPSK is similar to PSK except that each symbol is represented by a phase shift relative to the previously transmitted signal. This is desirable in mobile systems where the phase of the received signal changes rapidly and it is difficult to maintain a constant phase reference. Quadrature-amplitude modulation (QAM) uses symbols that vary in both amplitude and phase. It can potentially provide many more symbols than the other techniques but it is very sensitive to changes in the channel and thus is difficult to implement for mobile systems. QAM is appropriate for fixed microwave and fiber-optic systems where it can support very high data rates.

2.9.3 THE TRANSMISSION MEDIUM

The transmission medium or communications channel is the medium by which the electronic signal is sent from one place to another. It is the physical path between transmitter and receiver in a communication network. The transmission media may be classified as guided or unguided. In both cases, communication is in form of electromagnetic waves. With guided media, the waves are guided along a physical path. Examples of guided media are twisted pair cable, coaxial cable and optical fibre all of which are used mostly for short distance communication.

On the other hand, the atmosphere and outer space are examples of unguided media, which provide a means for transmitting electromagnetic waves over a long distance but do not guide them. The medium of communication in mobile-radio environment is radio, which is unguided in nature.

Radio is the broad general term applied to any form of wireless communication from one point to another. Radio makes use of the electromagnetic spectrum where signals are communicated from one point to another by converting them into electric and magnetic fields that propagate readily over a long distances.

Although the medium supports the transmission of information, it also attenuates it or causes its fluctuations. Generally, all types of media whether guided or unguided degrades the signal and causes it to appear much lower in amplitude at the receiver. Hence considerable amplification of the signal is required at either the transmitter or the receiver or both.

One of the transmission impairments that responsible for the performance degradation in wireless communications is fading. According to Zoltan and Liu (2002), it was reported that fading is one of the distortions affecting signal transmitted in wireless communications. They said that the design of communication systems that offer reliable transmission without fading of any form is a challenging task in wireless communications. With this challenge in mind, this present work has set to find a means of combating fading in mobile wireless communication in Nigerian.

2.10 CAUSES OF RADIO SIGNAL FADING IN MOBILE ENVIRONMENT

There are various factors responsible for radio signal fading in mobile environment. According to parsons (1992), in mobile-radio communications environment there are times when the mobile unit will be in motion, and other times when the mobile unit will be stationary. When the mobile unit is moving, it moves at various speeds and travels in various directions. As the mobile units proceeds along its route, it passes many types of local scatters, including numerous other vehicles in motion. The presence of scatters along the path constitutes a constantly changing environment that introduces many variables that can scatter, reflect, and dissipate the propagated mobile-radio signal energy. This effect according to Lee (1982) often results in multiple signal paths that arrive at the receiving antenna displaced with respect to each other in time, space and phases. When this happens, it has the effect of lengthening the time allotted to a discrete portion of the signal or information, which normally causes signal fluctuation or fading at the receiving end. This effect is called multipath propagation.

2.10.1 MULTIPATH PHENOMENON

According to Morris (1983), radio energy do arrive the receiver via several paths simultaneously. A situation whereby various incoming radiowaves arrive from different directions with different time delays gives raise to multipath propagation as shown in Fig. 2. 9. The incoming radiowaves now combine vectorially at the receiving antenna to give a resultant signal, which can be constructive or destructive in nature depending on the distribution angles or phases among the component waves.

In mobile environment, the multipath phenomenon may occur as a result of hills, trees, buildings, etc, between the base station and the mobile station. In the process, the amplitude and phase of the reflected path may differ from the direct path. In the extreme case when the two signals are of equal amplitude but of opposite phases, they will cancel and there will be no received signal. This situation is referred to as total or complete fading. Whereas when there are destructive vectoral summations, it results in signal fluctuations or fading at the receiver.

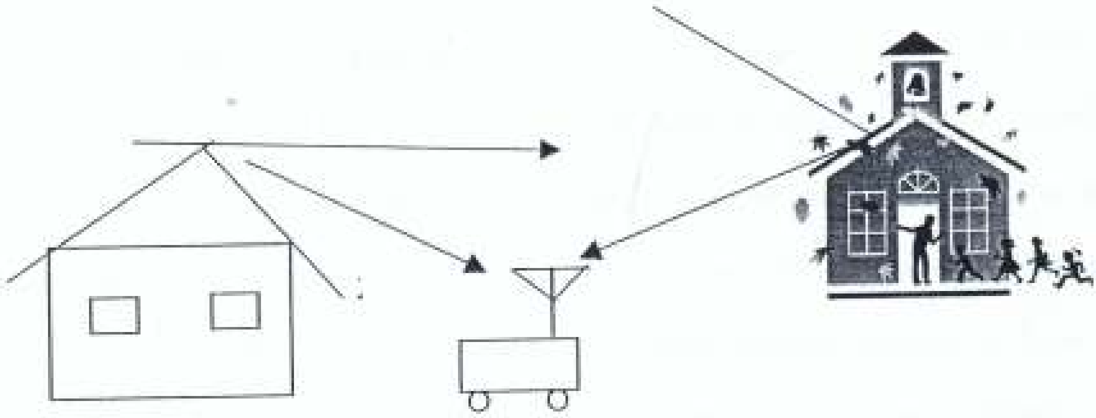

Fig. 2.9 Multipath Propagation

2.10.2 RECEIVER ANTENNAS SIZE

Another causes of fading in mobile communication is the antenna height of the mobile terminal which is usually very small, typically less than a few meters. As a result of its this small size, the antenna is expected to have very little clearance, so obstacles and reflecting surfaces in the vicinity of the antenna have a substantial influence on the propagation path.

2.10.3 SOME OTHER CAUSES OF SIGNAL FADING

Other causes of signal fading in mobile environment are changes in the state of the polarization produced by the earth's magnetic field. Another cause is the Doppler effect that occurs as a result of the relative motion existing between the transmitter and the receiver. Whenever relative motion exists between the transmitter and the receiver, there is an apparent shift in the frequency of the received signal as reported by Parsons (1992). This resulted frequency shifting in practice, causes the receiver to experience continuous and random fluctuations i.e. fading at the receiver. In addition, Morris (1983) reported that signal long-term variations or fading could be as a result of radiowave absorptions due to rain, fog or smog.

2.11 CURE FOR SIGNAL FADING

In an attempt to combat the adverse effects of fading, there have been a lot of approaches both theoretically and practically (Alamouti, 1998; Winter, 1987; Foschini, 1999 and Proakis, 1995). Theoretically, the most effective technique to mitigate or combat fading in wireless channel is transmitter power control (Alamouti, 1998). He reported that if the channel conditions as experienced by the receiver on one side of the link are known at the transmitter on the other side, the transmitter could predistort the signal in order to overcome the effect of the channel at the receiver. However, there are two fundamental problems with this theoretical approach as reported by Alamouti (1998). The first problem which infact is the major problem with this approach is the required transmitter dynamic range. This is because for the transmitter to overcome a certain level of fading, it must increase its power by that same level, which in most cases is not practicable. This is because of the radiation power limitations and the size and the cost of the amplifiers (Alamouti, 1998). The second problem is that the transmitter does not have any knowledge of the channel experienced by the receiver. Hence, the channel information has to be fed back from the receiver to the transmitter, which results in output degradation and considerable added complexity to both the transmitter and the receiver.

However, there is a practical approach that can be applied to combat fading effect in wireless channel. This is by the application of diversity schemes (Chinthananda *et al.*, 2001; Lee, 1982,Ranjan *et al.*, 2002; Zoltan and Liu, 2002; Ali and Mostafa, 2002; Liu, *et al.*, 2002 and Naguib *et al.*, 2000). Traditionally, research work in spatial diversity mainly focused on the receiving diversity. Infact, receive antenna diversity is being used in base stations to improve the reception in current cellular systems (Liu, *et al.*, 2002). However, transmit diversity at the transmitting end as just beginning to attract attention (Naguib *et al.*, 2000).

It has been reported that diversity may be employed either at the transmitter or the receiver (Winters, 1987; Fosschini, 1996; Fosschini and Gans, 1998; Fosschini *et al*., 1999; Chinthananda *et al*.; 2001; and Liu, *et al*., 2002). Chinthananda *et al*., (2001) and Liu, *et al*., (2002) 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. . In mobile-radio systems, it is generally most practicable to employ diversity at the base station rather than at the mobile units (Alamouti, 1998). He 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. So in transmitting from the mobile to the base station, diversity is achieved through a multiple – element receive antenna – "receiver diversity", while in transmitting from the base station to the mobiles, diversity is achieved through a multiple – element transmit antenna "transmit diversity" (Fosschini, 1996; Fosschini and Gans, 1998 and Fosschini *et al*., 1999).

2.12 DIVERSITY SCHEME

By definition, diversity is a method of transmission and/or reception where a single received signal is derived from combining a group of signal in an attempt to gain decibels (dB) or improve the signal strength (Data Communication Dictionary, 1976). The method works on the principle 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 (Suthuramen et al., 1993; Parsons, 1992 and Lee, 1982). That is, the method depends upon the fact that if we take two points separated by a few metres, the signal does not fade out simultaneously at the two points at the same rate.

There are many types of diversity schemes use in wireless communication system. Among them the following are the popular ones, namely space diversity, frequency diversity, polarization diversity, time diversity, directional (angle) diversity, and path diversity. Table 2.2 shows their features.

For this exercise, the space diversity technique was chosen to combat fading in mobile communication system in Nigeria because of its outstanding advantages compared to others. The technique will be applied at the base station because of the outstanding advantages that transmit diversity technique has over the receive diversity technique in mobile communication. According to Alamouti (1998), it was reported that diversity techniques is better applied at base stations to improve reception quality because it is cost effective; since a base station often serves hundreds to thousands of remote units. Therefore it is more economical to add equipment to base stations rather than the remote units.

Table 2.2: Features of each diversity scheme.

Diversity Scheme	Merits	Demerits
Space Diversity	*Easy to design. *Any numbers (N) of diversity branches are selectable. *Neither extra power nor bandwidth is necessary or required. *Applicable to macroscopic diversity.	*Hardware size could be large (depends on device technologies). *Large antenna spacing is necessary for microscopic diversity at the base station.
Frequency Diversity	*Any numbers of diversity branches (N) are selectable.	*N times more power and spectrum are necessary.
Polarization Diversity	*No space is necessary. *No extra bandwidth is necessary.	*Only two branch diversity schemes are possible. *3dB more power is necessary.
Time diversity	*No space is necessary. Any numbers of diversity branches (N) are selectable. *Hardware is very simple.	*N times more spectrums are necessary. *Large better memory is necessary especially when the delay constant is small.
Directional (Angle) Diversity	*Doppler spread is reducible	*Diversity gain depends on the obstacles around the terminal. *Applicable only to the receiver or terminal unit.
Path Diversity	*No space is necessary. *Neither extra power nor bandwidth is necessary.	*Diversity gain depends on the delay profile.

(Seiichi, 1997, PP.146).

2.13 HOW SPACE DIVERSITY WORKS

The space diversity technique works on the principle that if we take two points separated by few metres apart, the signal does not fade out simultaneously at the two points at the same rate. In mobile communication system, in order achieve space diversity at either the base station, at least two transmitting are required. These antennas are either to radiate out signal to mobile stations or to receive signal from mobile stations depending on whether the link is forward link or reverse link. By this there will be a direct link between the base station and the mobile terminal(s) in that particular network in respect of the location of the mobile station. The positioning of the antennas is very important. They need to be positioned in such a way as to cover the entire network. The shorter the distance between the antennas, the lower the probability that the mobile terminal experiences fading.

According to Sigma Wireless Technologies (2001), the separation of the antennas is frequency dependent. For instance, it was reported that, at 900 MHz, antennas are generally regarded as being at optimum separation at 2.75 metres while at 400 MHz; the optimum separation is at 5.5 metres. It was also reported by Sigma Wireless Technologies (2001), that in space diversity technique the lowest short term correlation coefficient, ρ, achievable with two antennas is approximately 0.7, which is adequate to achieve optimum diversity gain. It was also reported that, the lower the short-term correlation coefficient, ρ, the better the diversity gain (Braun, 1986 and Sigma Wireless Technologies, 2001). They reported that if these criteria are met by the antenna system, and the receivers receive equal amplitude signals on average, the signal strength would be increasing with increase in the number of receivers.

2.14 MOBILE RADIO PROPAGATION AND PATH LOSS MODELS

The general term *fading* is used to describe fluctuations in the envelope of a transmitted radio signal. However, when speaking of such fluctuations, one must consider whether a short observation interval (or small distance) has been taken, or whether a long observation interval (or large distance) has been taken. For a wireless channel, the former case will show rapid fluctuations in the signal's envelope, while the latter will give more of a slowly varying, average view – which is being referred to as large-scale path loss. In this work, this large-scale effect shall be considered.

Received power or its reciprocal, path loss, is generally the most important parameter predicted by large-scale propagation models. It is valuable to examine the three main propagation mechanisms that determine and describe path loss:

Reflection occurs when a radio wave collides with an object which has very large dimensions compared to the wavelength of the propagating wave. Reflections are very commonly caused by the surface of the earth and from buildings, walls, and other such obstructions.

Diffraction occurs when the radio path between the transmitter/receiver pair is obstructed by a surface with sharp edges. This causes secondary waves to arise from the obstructing surface. There is a possibility that the secondary waves can bend around the obstacle and provide an almost artificial LOS between transmitter and receiver. Like reflection, this phenomenon is dependent on: frequency, amplitude, phase, and the angle of arrival of the incident wave.

Scattering occurs when the radio wave travels through a medium consisting of objects with dimensions that are small compared to the wave's wavelength. In such a case the number of such particles per unit volume are usually very large. Typically scattered waves arise when the radio wave meets rough surfaces or small objects in the channel.

These three propagation mechanisms are the propagation phenomenon aiding signal fluctuations or fading experiencing at the receiver as a result of multiple signals reaching the receiver.

2.15.1 FREE SPACE PATH LOSS MODEL

To obtain a more quantitative view of the effects of path loss, it is useful to consider a few examples. The simplest case of which is the path loss model for free space due to the fact that the influence of all obstacles is ignored. Further easing the analysis, consider the model to be *isotropic*, where the transmitting antenna signaling with power Pt, has its power radiate uniformly in all directions. Examining the path loss will tell us the amount of power available at the receive antenna a distance *r* meters away. This situation can be modeled as in Fig. 2.10 where the transmit antenna can be considered to be at the center of a sphere with radius *r*. The total power density on the sphere (also referred to as *flux density*) may be expressed as:

$$P_d = \frac{EIRP}{4\pi r^2} = \frac{P_t}{4\pi r^2} \quad (\text{Watts/m}^2) \text{ ---------------------------------- } (2.2)$$

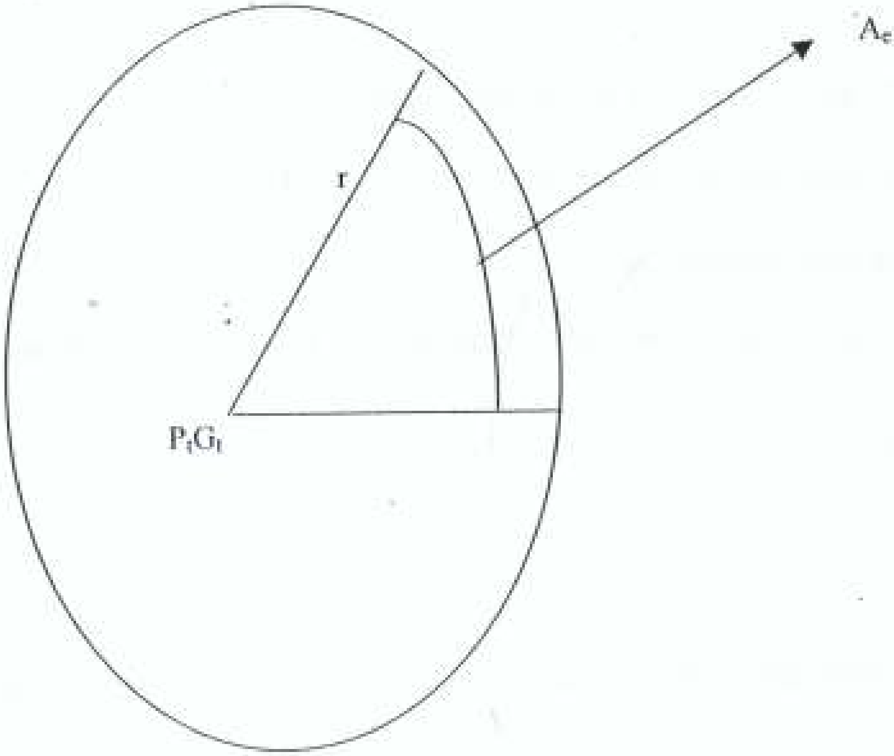

Fig. 2.10 Propagation in free space.

where $EIRP$ is the effective radiated power from an isotropic source and $4\pi r^2$ is the surface area of the sphere. In this model, the power at the receive antenna will be only a function of the transmitted power and the characteristics of the receive antenna:

$$P_r = P_d A_e = \frac{P_t A_e}{4\pi r^2} \quad \text{(Watts)} \text{ ------------------- } (2.3)$$

where A_e is the effective aperture of the receive antenna. As seen from (2), the received power P_d *is* inversely proportional to r^2. It so happens that the inverse-square relation is the ideal case due to the combination of free space, LOS, and isotropic assumptions. The effective aperture of an antenna (A_e) is generally related to its "Gain" G by

$$G = \frac{4\pi A_e}{\lambda^2} \text{ ------------------- } (2.4)$$

$$P_r = \frac{P_t G \lambda^2}{(4\pi r)^2} = \frac{P_t G_T G_R \lambda^2}{(4\pi r)^2} \text{ ------------------- } (2.5)$$

where G_T and G_R are the transmitter and receiver gains, respectively. Equation (2.5) is referred to as the Friis free space equation.

In mobile systems the received power may change several orders of magnitude over a fraction of a typical coverage area. This coupled with the fact that mobile systems employ low-power devices (order of milliwatts) leads to the choice of *dBm* (*dB* normalized to 1.0 mW) as the preferred unit for measuring power. Thus the path loss for the free space model may be expressed as:

$$L_P(dBm) = 10\log_{10}\left(\frac{P_t}{0.001P_r}\right) = -10\log_{10}\left(\frac{G_T G_R \lambda^2}{0.001(4\pi r)^2}\right) \text{ ---------- } (2.6)$$

2.15.2 PROPAGATION MODEL FOR NEAR EARTH'S SURFACE

When considering the more realistic model (compared to that of the highly ideal free space) near the Earth propagation, we must consider a direct wave, ground wave, and ground reflected wave component. This scenario is depicted in Fig. 5, along with its equivalent flat Earth model in Fig .2.11. The main assumptions that lead to the flat Earth model are the absence of the ground waves due to the height of the antenna when compared to that of the wavelength, and the lack of curvature of the Earth. From Fig. 2.11, the received signal E_s is given as:

$$E_r = E_d\left(1 - e^{-j\Delta\psi}\right) \quad \text{-- (2.7)}$$

where E_r is the direct wave, E_d is the total received field strength or signal and $\Delta\psi$ is the phase difference between the direct path and the reflected path.

The phase difference between the two waves is expressed thus (Parsons, 1992):

$$\Delta\psi = \frac{2\pi}{\lambda}\Delta R \quad \text{-- (2.8)}$$

Considering Fig. 2.11, the direct wave and the ground-reflected wave are represented respectively as AC and APC. From the figure now,

$$\Delta R = R_2 - R_1 \quad \text{-- (2.9)}$$

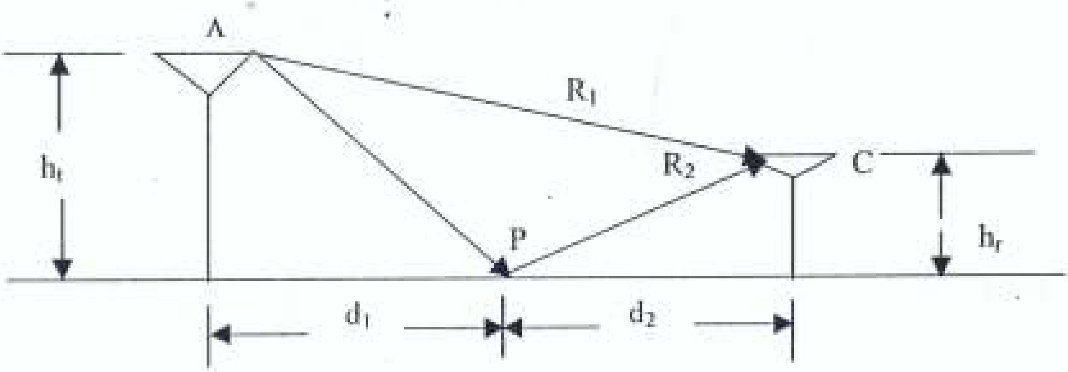

Fig. 2.11 Equivalent model of propagation close to Earth's surface.

R_1 = AC is the distance traveled by the direct ray or wave. The length AC from the figure is given as: $AC = \sqrt{\left[(h_t - h_r)^2 + d^2\right]}$, where $d = d_1 + d_2$

$$\therefore AC = R_1 = \sqrt{\left(d^2 + (h_t + h_r)^2\right)} = d\sqrt{\left(1 - \left(\frac{h_t - h_r}{d}\right)^2\right)} \text{ ------------------- } (2.10)$$

The distance traveled by the ground-reflected ray or wave is,

$$AP + PC = \sqrt{\left(h_t^{\,2} + d_1^{\,2}\right)} + \sqrt{\left(h_r^{\,2} + d_2^{\,2}\right)}$$

$$= d_1\left(\sqrt{\left(1 + \left(\frac{h_t}{d_1}\right)^2\right)}\right) + d_2\left(\sqrt{\left(1 + \left(\frac{h_r}{d_2}\right)^2\right)}\right)$$

Now let $\frac{h_t}{d_1} = \frac{h_r}{d_2} = \frac{h_t + h_r}{d}$

$$\therefore AP + PC = R_2 = d\sqrt{\left(1 + \left(\frac{h_t + h_r}{d}\right)^2\right)} \text{ -- } (2.11)$$

$$\Rightarrow \quad \Delta R = R_2 - R_1 = d\left[\sqrt{\left(1 + \left(\frac{h_t + h_r}{d}\right)^2\right)} + \sqrt{\left(1 + \left(\frac{h_t + h_r}{d}\right)^2\right)}\right]$$

$$\Delta R = d\left[\sqrt{1 + \frac{h_t^2 + 2h_t h_r + h_r^2}{d^2}} - \sqrt{1 + \frac{h_t^{\,2} - 2h_t h_r + h_r^{\,2}}{d^2}}\right] \text{ ------------------- } (2.12)$$

Apply binominal expression to equation (2.12) to get;

$$\Delta R = d\left[1 + \frac{1}{2}\left(\frac{h_t^{\,2} + 2h_t h_r + h_r^{\,2}}{d^2}\right) - \left(1 + \frac{1}{2}\left(\frac{h_t^{\,2} + 2h_t h_r + h_r^{\,2}}{d^2}\right)\right)\right]$$

$$\Delta R = d\left(\frac{4h_t h_r}{2d^2}\right) = \frac{2h_t h_r}{d} \text{ -- } (2.13)$$

put (2.13) in (2.8) to obtain;

$$\Delta\psi = \frac{2\pi}{\lambda}\left(\frac{2h_t h_r}{d}\right) = \frac{4\pi h_t h_r}{\lambda d} \quad \text{-- (2.14)}$$

Based on a direct path and a ground-reflected path shown in Fig. 2.11, Lee (1989) find an expression for the power received at the receiver as:

$$P_r = P_0\left(\frac{1}{4\pi d/_{\pi}}\right)^2 |E_S|^2 = \frac{|E|^2}{2\eta_0} \quad \text{-- (2.15)}$$

where $E_S = E\left(1 - e^{-j\Delta\psi}\right)$ from equation (2.8)

$$P_0 = P_t G_t G_r$$

η_0 = intrinsic impedance of free space

P_t = transmitted power

G_t = gain of the transmitting antenna

G_r = gain of the receiving antenna

Equation (2.15) can be rewritten as;

$$P_r = P_0\left(\frac{1}{4\pi d/_{\lambda}}\right)^2 |1 - Cos\Delta\Psi - jSin\Delta\Psi|^2 \quad \text{-- (2.16)}$$

since $\Delta\Psi$ is small, hence

$$Sin\Delta\Psi \approx \Delta\Psi = \frac{4\pi h_t h_r}{\lambda d} \quad \text{--(2.17)}$$

Also, $Cos\Delta\Psi \approx 1$ then putting (2.13) and (2.17) makes (2.16) becomes:

$$P_r = P_0\left(\frac{1}{4\pi d/_{\lambda}}\right)^2 \left|1 - 1 - j\frac{4\pi h_t h_r}{\lambda d}\right|^2 = P_0\left(\frac{1}{4\pi d/_{\lambda}}\right)^2 \left(\frac{4\pi}{\pi d} h_t h_r\right)^2$$

$$P_r = P_0\left(\frac{h_t h_r}{d^2}\right)^2 \text{ -- } (2.18)$$

Substituting the parameters for P_0 stated in (2.15) to get

$$P_r = P_t G_t G_r\left(\frac{h_t h_r}{d^2}\right)^2$$

$$\Longrightarrow \quad \frac{P_r}{P_t} = G_t G_r\left(\frac{h_t h_r}{d^2}\right)^2 \text{ -------------------------------- } (2.19)$$

In convenient logarithmic form equation (2.19) can be written as:

$$L_P = \log\left(\frac{P_r}{Pt}\right) = 10\log_{10} G_t + 10\log_{10} G_r + 20\log_{10} h_t + 20\log_{10} h_r - 40\log_{10} d \text{ ------ } (2.20)$$

From (2.20) we can write a "basic loss" between isotropic antennas as:

$$L_b(dB) = 20\log_{10} h_t + 20\log_{10} h_r - 40\log_{10} d \text{ ------------------------------- } (2.21)$$

This means that the loss increases by 40 dB each time the distance is multiplied by 10 (one decade). Another unfortunate aspect of (2.21) for path loss near the Earth's surface is the fact that, it is only a function of antenna heights and distance between transmitter and receiver. To be more precise, the path loss obtained by (2.21) is independent of the carrier frequency used to for the transmission. If the surface is undulating a correction factor, which is frequency dependent, must be included. Hence, equation (2.21) is not a precise accurate formula for predicting path loss.

2.15.3. EMPIRICAL PATH LOSS MODELS FOR MACROCELLS

Macrocells are generally large, providing coverage range on the order of kilometers, and used for out-door communication. Several empirical path loss models have been determined for macrocells. Two such models are outlined below, namely *Hata's model, which* was based on graphical path loss data provided by Okumura, and *Lee's model.*

Hata's model :

Hata's model was based on empirical data from measurements in Tokyo, Japan and has been claimed to give an accurate estimate of the path loss to within 1.0 dB when compared with the actual measurements (Lee, 1989). The model is useful for the following scenarios:

Carrier frequency: 150 MHz ≤ f_c ≤ 1500 MHz

Base station antenna height: 30 m ≤ h_t ≤ 200 m

Mobile station antenna height: 1 m ≤ h_r ≤ 10 m

Distance between base station and mobile: 1 km ≤ d ≤ 20 km

$$L_p\,(dB) = \begin{cases} A + B\log_{10} d & \text{for urban areas} \\ A + B\log_{10} d - C & \text{for suburban areas} \\ A + B\log_{10} d - D & \text{for open or rural areas} \end{cases} \qquad \text{---------} (2.22)$$

where ;

$$A = 69.55 + 26.16\log_{10} f_c - 13.82\log_{10} h_t - a(h_r)$$

$$B = 44.9 - 6.55\log_{10} h_t$$

$$C = 5.4 + 2\left[\log_{10}\left(\frac{f_c}{28}\right)\right]$$

$$D = 40.94 + 4.78\left[\log_{10} f_c^2 - 18.33\log_{10} f_c\right]$$

and

$$a(h_r) = \begin{cases} [1.11\log_{10} f_c - 0.7]h_r - 1.56\log_{10} f_c - 0.8 & \textit{for medium or small city} \\ 8.28[\log_{10}(1.5h_r)]^2 - 1.1 & \textit{for large city and } f_c \leq 200 \textit{ MHz} \\ 3.2[\log_{10}(11.75h_r)]^2 - 4.97 & \textit{for large city and } f_c \geq 400 \textit{ MHz} \end{cases}$$

Lee's model :

Lee's path loss model was based on empirical data chosen as to model a flat terrain. Large errors arise when the model is applied to a non-flat terrain. The received signal power in dB is expressed as:

$$\mu\Omega = 10\log_{10}\left[\mu_{\Omega 0}\left(\frac{d_0}{d}\right)^{\beta}\left(\frac{f_c}{f}\right)^{n}\alpha_0\right] \text{ ---------------------------------- } (2.23)$$

Two parameters are initially required to characterize the model: $\mu_{\Omega 0}$ (the power at a 1.6 Km point of interception) and the path loss exponent β. These two parameters are determined from empirical measurements and listed in tables such as that of Table 2. Subsequently the following nominal conditions are set when employing Lee's model:

f_c = 900 MHz

d_o = 1.6 km

base station or transmitting antenna height = 30.48 m

mobile station or receiving antenna height = 3.0 m

base station transmitter's power = 10 W

base station antenna gain = 6 dB above dipole gain

mobile station antenna gain = 0 above dipole gain

the following parameters must also be set:

f the actual carrier frequency

d distance between mobile station and base station antennas

α_0 correction factor

the parameter α_0 is basically used to account for different BS and MS antenna heights, transmit powers, and antenna gains. For instance, if the actual conditions differ from the nominal ones, then α_0 is computed via:

$$\alpha_0 = \alpha_1\alpha_2\alpha_3\alpha_4\alpha_5 \quad \text{------------} \quad (2.24)$$

where

$$\alpha_1 = \left[\frac{\text{new BS antenna height (m)}}{30.48\text{ m}}\right]^2 \quad \text{------------} \quad (2.25)$$

$$\alpha_2 = \left(\frac{\textit{new MS antenna height (m)}}{3\ m}\right)^\xi \quad \text{------------} \quad (2.26)$$

$$\alpha_3 = \left(\frac{\textit{new transmitter power}}{10\ W}\right)^2 \quad \text{------------} \quad (2.27)$$

$$\alpha_4 = \frac{\textit{new Bs antenna gain with respect to } \lambda_c/2 \textit{ dipole}}{4} \quad \text{------------} \quad (2.28)$$

α_5 = *different antenna gain correction factor at the MS* ------------ (2.29)

the value of n in (2.23) and ξ in (2.26) are also based on empirical data and recommended to take the following values:

Table 2.3: Parameters for Lee's path loss model.

Terrain	$\mu_{\Omega 0}$	β
Free Space	-45	2
Open Area	-49	4.35
North American Suburban	-61.7	3.84
North American Urban	-70	3.68
South American Urban	-64	4.31
Japanese Urban	-84	3.05

$$n = \begin{cases} 2.0 & \text{for } f_c < 450 \text{ MHz and in suburban or open area} \\ 3.0 & \text{for } f_c > 450 \text{ MHz and in urban area} \end{cases} \quad \text{-------------- (2.30)}$$

$$\xi = \begin{cases} 2.0 & \text{for MS antenna heigth} > 10 \text{ m} \\ 3.0 & \text{for Ms antenna heigth} < 3 \text{ m} \end{cases} \quad \text{-------------- (2.31)}$$

$$n = \begin{cases} 2.0 & \text{for } f_c < 450 \text{ MHz and in suburban or open area} \\ 3.0 & \text{for } f_c > 450 \text{ MHz and in urban area} \end{cases} \quad \text{-------------- (2.30)}$$

$$\xi = \begin{cases} 2.0 & \text{for MS antenna heigth} > 10 \text{ m} \\ 3.0 & \text{for Ms antenna heigth} < 3 \text{ m} \end{cases} \quad \text{-------------- (2.31)}$$

Finally, the path loss L_p is defined as the difference between the transmitted and received field strength can be expressed as:

$$L_p = P_t - \mu_{\Omega 0} \quad \text{-------------------------------------- (2.32)}$$

For the scenarios listed in Table 2, the path loss obtained from Lee's model can be reduced to:

$$L_p = \begin{cases} 85 + 20\log_{10}\left(\frac{r}{1.6km}\right) + 10n\log_{10}\left(\frac{f}{900MHz}\right) - \alpha_0 & \textit{Free Space} \\ 89 + 43.5\log_{10}\left(\frac{r}{1.6km}\right) + 10n\log_{10}\left(\frac{f}{900MHz}\right) - \alpha_0 & \textit{Open Area} \\ 101.7 + 38.410\log_{10}\left(\frac{r}{1.6km}\right) + 10n\log_{10}\left(\frac{f}{900MHz}\right) - \alpha_0 & \textit{Suburban} \\ 110 + 36.81\log_{10}\left(\frac{r}{1.6km}\right) + 10n\log_{10}\left(\frac{f}{900MHz}\right) - \alpha_0 & \textit{Philadelphia} \\ 104 + 43.1\log_{10}\left(\frac{r}{1.6km}\right) + 10n\log_{10}\left(\frac{f}{900MHz}\right) - \alpha_0 & \textit{Newark} \\ 124 + 30.51\log_{10}\left(\frac{r}{1.6km}\right) + 10n\log_{10}\left(\frac{f}{900MHz}\right) - \alpha_0 & \textit{Tokyo} \end{cases}$$

where r is in km and f is in MHz.

Because this model i.e. Lee's model is restricted to the stated places, hence it cannot be applied in this work since there is differences in the geographical factors in those places and Nigeria. More so the carrier frequency used in this model does not include the allocated frequency for mobile communication in Nigeria. However since *Hata's model* is general and since the carrier frequency range for it included the frequency range for mobile communication in Nigeria, its model shall be applied in this work.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 METHOD OF APPROACH

The following methods of approach are adopted to meet the objectives stated above. Detailed knowledge of the propagation path loss prediction and the antenna spacing prediction were understood. These entail the following activities.

(i) Literature survey.

(ii) Thorough examination of each propagation path loss prediction equation and the antenna spacing prediction equation about the work.

(iii) Model building, evaluation and analysis.

3.2 RESEARCH PROCEDURE

For this work, Figs. 3.1 - 3.3 were used as the basis or foundation. Fig. 3.1 shows the ideal situation when there is no propagation path loss or obstacle between the base station and the mobile station separated by unspecified distance, d_x kilometer. But in real practice, this cannot hold for mobile system as the communication can take place in either of the two ends at any time. Hence the real situation, which the propagated signals undergo in mobile environment, is as shown in Fig. 3.2. Under this condition, there is bound to be signal losses along the propagation path for both the forward and reverse links. The quality of the reception in each case depends on the obstacle between the base station (transmitter) and the mobile station (receiver) at each time since the

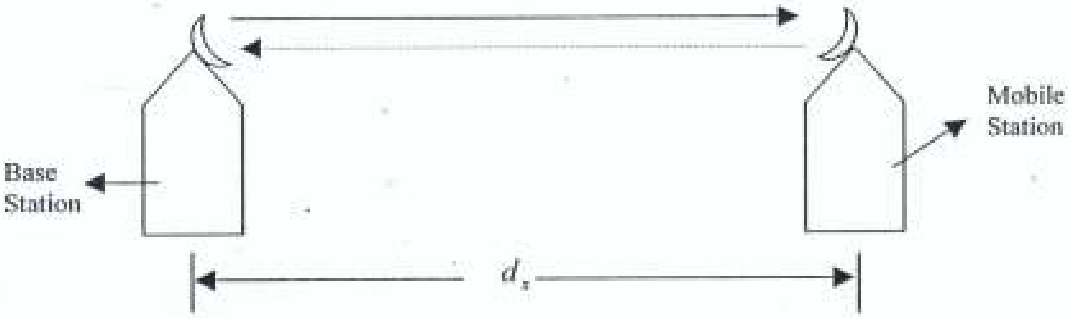

Fig. 3.1 Ideal transmitting situation.

Fig.3.2 Real transmitting situation.

KEY

——▶ FORWARD LINK

┈┈▶ REVERSED LINK

d_x Variable distance between the base and mobile stations.

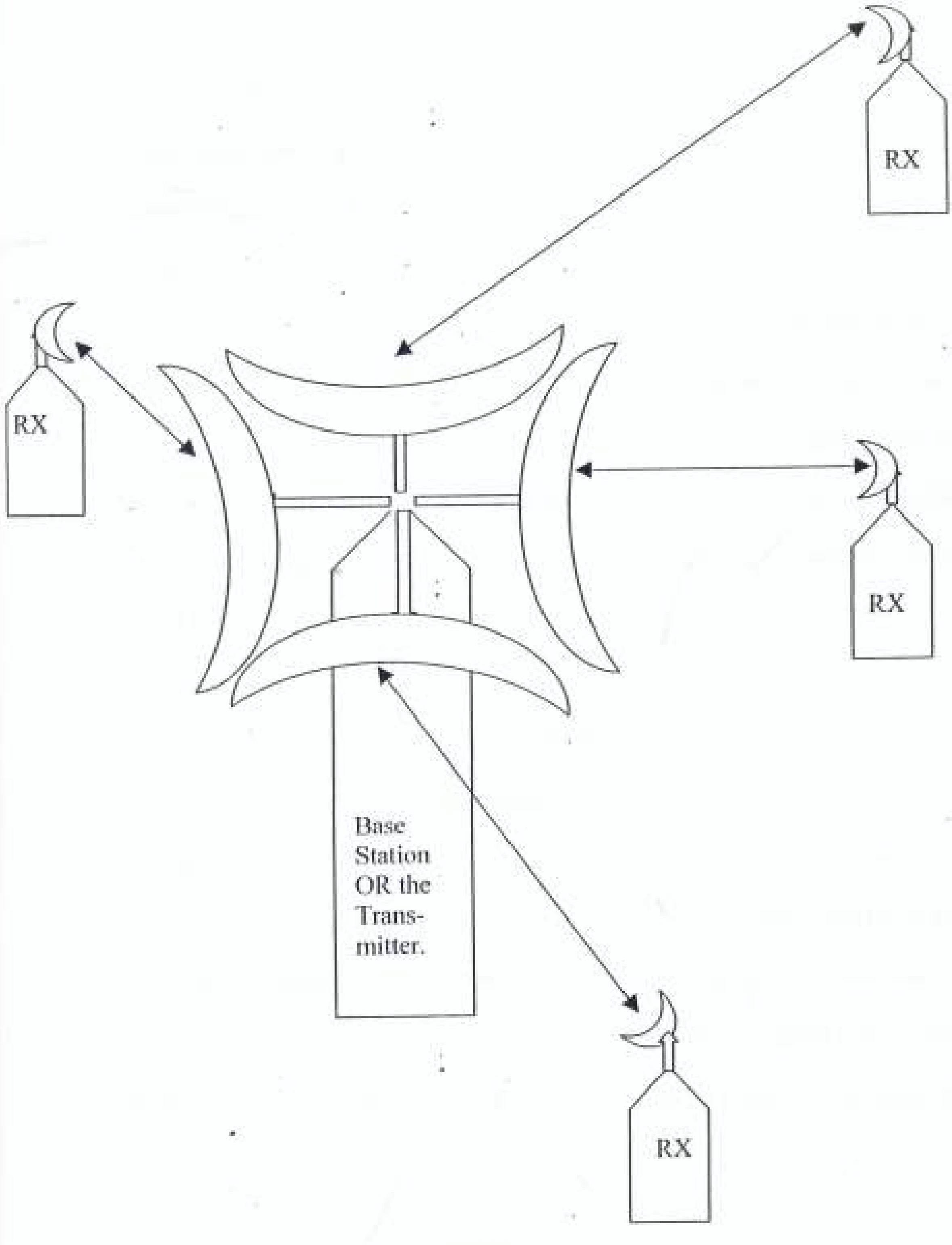

Fig.3.3. Space diversity technique.

mobile terminal is not fixed. Consequently, there will be signal losses along the path. Thus, these losses account for the fading or the fluctuations in the amplitude of the receiver signal at the receiving end.

In order to correct this anomalous transmission, there must be a means of ensuring a constant line of sight between both the base station and the mobile terminal. This is achieved by installation of two or more antennas at the base station as shown in Fig. 3.3. By this, there shall be a direct link between the base station and the mobile terminal irrespective of the location of the mobile station per time. Therefore Fig.3.3., now forms the basis of this work, which was modified into software for combating signal fading in mobile environment.

3.2.1 PATH LOSS PREDICTION MODEL

In an attempt to combat fading of radio signal, several methods of predicting propagation path loss over irregular terrain have appeared in literature. Some of the earlier techniques such as those due to Bullington (1947) and Egli (1957) as reported by Parsons edited by Hall (1989) are based on using the theoretical equations describing propagation in free space or over a plane earth and then including an additional term to account for diffraction losses. The propagation path characteristics are subjected to free space propagation when there are no obstacles around or between the base station and mobile station (Seiichi, 1997). In this case, the path loss is given as:

$$L_{pf}(dB) = 32.44 + 20\log_{10} f_c + 20\log_{10} d \quad \text{------------------------------------} (1)$$

where:

f_c = carrier frequency (MHz)

d = distance between the base station and the mobile station (Km)

According to Sigma Wireless Technologies (2001), it is reported that with this equation the losses increase by 6dB each time either the distance or the frequency is doubled. Moreso, since there are obstacles around or between the base station and the mobile station, free space propagation model will therefore not be appropriate for mobile systems. Hence, equation (1) becomes invalid.

On the other hand, when there are obstacles around or between the base station and mobile station, path loss is determined by many factors such as irregular configuration of the natural terrain and irregularly arranged artificial structures. So when the path between the transmitter and the receiver is blocked by a number of obstacles, it is necessary to resort to approximate methods of calculating diffraction loss since exact calculations then become very difficult.

A widely- quoted method developed for applications, which include urban areas, is that due to Okumura *et al.*, (1968) curves. These curves are called *Okumura curves*. Essentially this method is based on determining the free space path loss between the transmitter and the receiver, adding an urban loss and then adding or subtracting numerous correction factors to account for the nature of the terrain, the extent for urbanization, the heights of the antennas, carrier frequency, sea or lake areas and the street or road orientation.

Although *Okumura curves* are practical and effective when used to estimate coverage area for a system; it is not convenient to use them for the computational system designs including system parameter optimization. To solve this problem, Hata (1980) derived empirical formulas for the path loss that are fit to *Okumura curves*. The obtained formulas, called *Hata's equation,* are classified into three models – urban, suburban, and rural area models. This equation based on Okumura's work has been of great assistance in the application of the method over a restricted range of parameters. The results are as follows.

Urban areas:

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

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 antenna height.

$1 \le d \le 20$ (d in Km), d = distance between transmitter and receiver.

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

For a Small or Medium – size city;

$a(h_r) = (1.1\log f_c - 0.7)\, h_r - (1.56 \log f_c - 0.8)$ ---------------------------------- (2a)

where:

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

For a large city:

$$a(h_r) = 8.29(\log 1.54h_r)^2 - 1.1 : f_c \leq 200\text{MHz}, \text{ or}$$

$$3.2(\log 11.75h_r)^2 - 4.97 : f_c \geq 400\text{MHz} \text{ ------------------------------------ (2b)}$$

Suburban areas:

$$L_{ps} = L_p(urban) - 2\left[\log_{10}\left(\frac{f_c}{28}\right)\right]^2 - 5.4 \text{ (dB) ------------------------------------ (3)}$$

where:

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

Rural or Open areas:

$$L_{po} = L_p(urban) - 4.78(\log_{10} f_c)^2 + 18.33\log_{10} f_c - 40.94 \text{ (dB) ------------------- (4)}$$

where :

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

In order to make the equation suitable and applicable to Nigeria level of development and classification of areas, the urban areas that were classified as small city and large city is now changed to town and city respectively. While the rural area in the equation still remains as rural area, the suburban area was also changed to urban as applicable to Nigeria.

3.2.2 ANTENNA SPACE PREDICTION MODEL

The next step now, is to obtain another mathematical equation that can predict the distance between the antennas. For space diversity operation, the distance between antennas decides the correlation coefficient attainable. When a signal is subjected to fading its correlation coefficient (ρ), is equal to one i.e.ρ = 1 implies there is no diversity. When there is diversity, the correlation coefficient must be sufficiently small compared with one, i.e. $\rho < 1$. The smaller the value of ρ, the higher the signal strength received at the receiver (Braun, 1986).

Based on this conclusion, the CCIR - Recommendation 327-2 was choosing as the best antennas spacing prediction equation for this work. The CCIR - Recommendation 327-2 was given thus:

$$d_\lambda = 21.45\lambda\sqrt{(-\log_{10})\rho} \quad \text{---} \quad (5)$$

where:

d_λ = the spacing between antennas expressed in wavelengths of the operating frequency.

λ = the wavelength (m).

ρ = the correlation coefficient.

For the present work equation (5) was reviewed without damaging it by replacing d_λ with d_s and λ by v/f_c;

where :

d_s = the spacing between antennas in metre (m).

v = the velocity (3.0×10^8).

f_c = operating frequency (MHz).

Therefore we have:

$$d_s = \frac{21.45V}{f_c}\sqrt{(-\log_{10}\rho} \quad \text{---} \quad (6)$$

which is now the acceptable mathematical equation for the antenna spacing prediction in this present work.

3.3 THE MODEL

In order to have the prediction of both the propagation path loss and the antenna spacing at the base station that can correct signal fading simultaneously, this present work combines the two acceptable mathematical equations (i.e. Hata's equation and the CCIR -Recommendation) to develop a prediction application program that can perform the two functions simultaneously. This was achieved through a computer application program written in C++ programming language.

3.3.1 THE ORIGIN OF C++

C++ is an expanded version of C programming language. C is flexible and powerful. However, when a project data exceed a certain size, C reaches its limits. Depending on the volume of data, a program of 25,000 to 100,000 lines becomes hard to manage with C programming language (Schildt, 1992). In 1980, while at Bell Laboratories at Murray Hill, New Jersey, Bjarne Stroustrup addressed this problem by adding several extensions to the C language. Most additions made to C by Stroustrup support object-oriented programming, sometimes referred to as OOP. These features in C++, to use Stroustrup's words, "allow programs to be structured for **clarity, extensibility, and ease of maintenance without loss efficiency."** These object-oriented features in C++ as well as other advantages in it form the basis of its application in this work.

3.3.2 ADVANTAGES OF C++ PROGRAMMING LANGUAGE

Although C++ has some weaknesses, it has been observed that its advantages out-weigh its disadvantages. Some of these advantages were considered before C++ was found suitable for this work. These include:

- **Availability:**

  C++ can be used on a variety of computers ranging from personal computers to supercomputers.

- **Portability:**

  C++ is in the last stages of standardization, and this process has been closely followed by compiler vendors, ensuring quick availability of a common standard language.

- **Speed:**

  Even with the speed of modern computers there are problems for which efficiency of language is of paramount importance. C++ inherits the speed of C.

- **Generality:**

  Science and engineering now has extended beyond computation only into realms of graphics and robotics. The C++ language is not only suited for formulas and computations (FORTRAN's strong suit), it can be used effectively in data base and business applications (COBOL's strong suit).

- **Reusability:**

  Clearly it would be an advantage to use previously written code if it can be inserted into one's current project. The capability of easy re-use and modification of existing code to fit new problems is an important feature of the C++ language.

- **Object Orientation:**

  As computers have become larger and faster, they have been programmed to solve larger and more complex problems. Object Oriented Programming (OOP) is a strategy for simplifying the programming task, and is supported by the language features of C++.

Some disadvantages include:

- **Cryptic Syntax:**

  While having the English-like capability of a high level language, the speed of execution in C++ is inherited from C, and C++ retains some rather cryptic syntax to maintain compatibility.

- **Black box features:**

  Some features, such as input/output operations, are difficult for the novice to get a handle on.

- **A large overhead:**

  C++ was designed for large and very large applications. Learning a language, on the other hand, proceeds by building small programs at first. It sometimes seems that a programming problem is being attacked with a meat cleaver when a judicious scalpel might be more appropriate!

- **Difficult debugging:**

  Debugging C and C++ programs can be very frustrating. Errors in a C++ program may be very difficult to find because the compiler may not catch them until many lines later.

In summary, it would seem that the C++ language adheres to the classic economic dictum. C++ not only performs the mathematical calculations demanded by today's scientists, but also provides a means to program in the graphic environments of the modern PC, be they Windows or Mac or X on a UNIX system. Inexpensive compilers are readily available to the student in most venues.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 MODEL TESTING AND EVALUATION

In order to test and evaluate the performance of this work, the values of d_s and η obtained from it are compared with the practical values quoted by Sigma Wireless Technologies (2001) under similar conditions as shown.

The comparison shows that there is a deviation of 0.02 m between the antenna spacing value obtained in this work and that of Sigma Wireless Technologies (2001). The value obtained here is lower than the one quoted in the reference work by 0.02 m (2 cm). This low value suggests high performance ability than the reference work. This is because the closer the distance between the antennas apart, the higher the probability of the direct link between the transmitter or base station and the mobile terminal. Hence relatively to the accuracy and the acceptability of the reference work, it can be concluded that the results obtained in this study can compare favourably with reports in the available literature. Also, the data obtained from this study has confirmed the fact that the program is reliable and performed optimally.

Table 4.1: Comparison of past work with the present work.

Parameters	Sigma Wireless Technologies (2001) (Practical Result)	The Present Work (Application Program Result)
Carrier Frequency, f_c	850 MHz	850 MHz
Correlation coefficient, ρ	0.7	0.7
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

4.2 SIGNAL STRENGTH AT DIFFERENT CORRELATION COEFFICIENT VALUES

Fig. 4.1 shows the Signal Strength at different correlation coefficient values. From this figure, it is observed that the closer the value of correlation coefficient (ρ), to one i.e. $\rho \rightarrow 1$, the more the signal experiences fading and the lower the signal strength received at the receiver. However, the smaller the value of the correlation coefficient compared with one, the higher the signal strength received at the receiver. This correlates the findings of Braun (1986) who reported that the higher the correlation coefficient the lower the received signal.

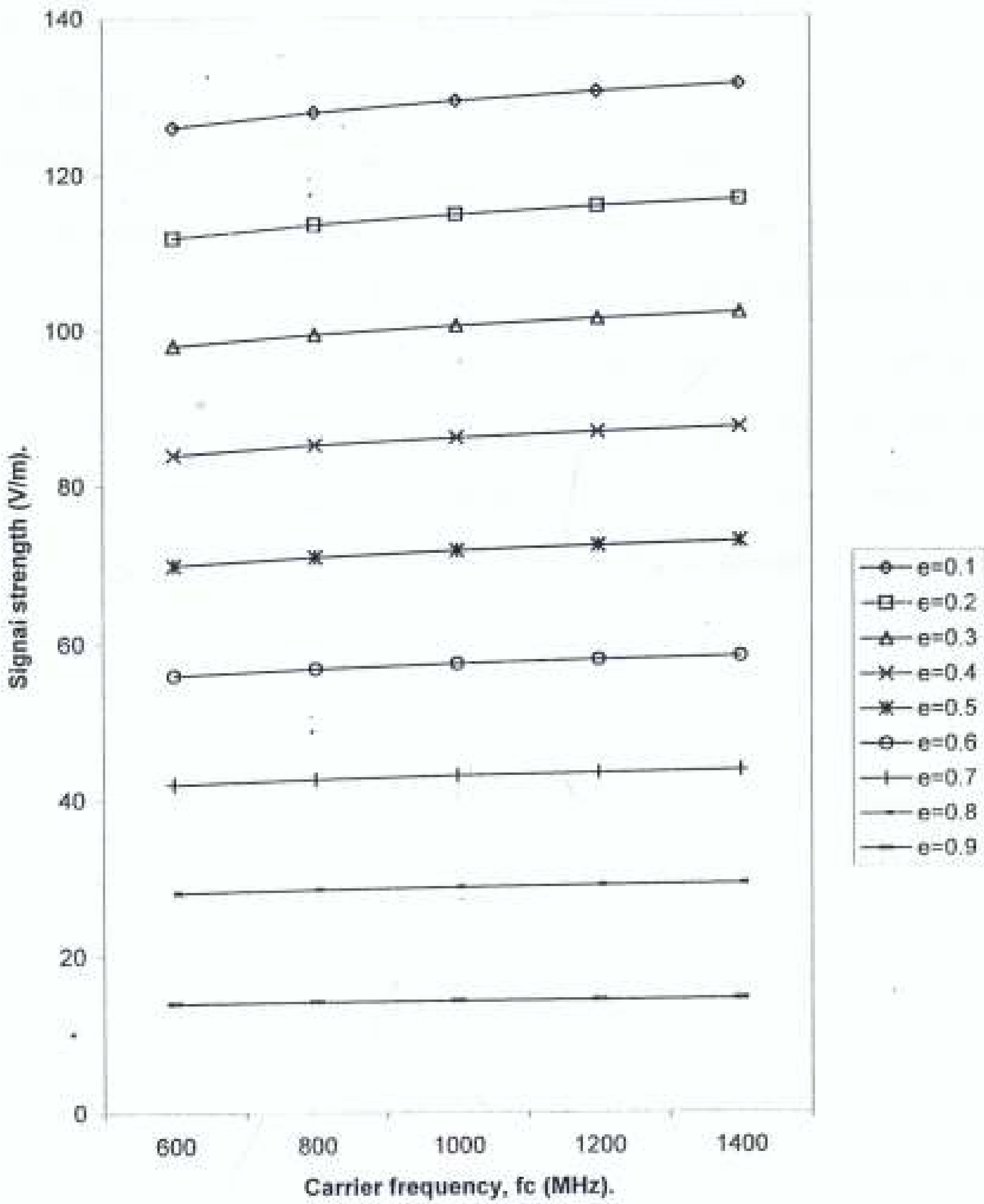

Fig. 4.1. Signal strength at different correlation coefficient values.

4.3 SIGNAL VARIATION WITH DISTANCE

Fig. 4.2 – Fig. 4.11 show the pictorial representations of the generated data from the program. The analysis of the data generated shows a significant variation in the signal losses with distance. The results reveal the fact that the longer the distance between the base station and the mobile station, the higher the signal losses and invariably the higher the signal fading experienced at the mobile station.

The figures also show the differences in the level of the signal losses when there is no diversity and when there is diversity. With the same carrier frequencies, it was observed that as the distance between the base station and the mobile station is increasing the rate of signal fluctuation or fading increases. Therefore, the work has established the fact that signal fading increases with increase in distance between the transmitter and the receiver. It further justifies the published research reports of both Lee (1982) and Sampei (1997).

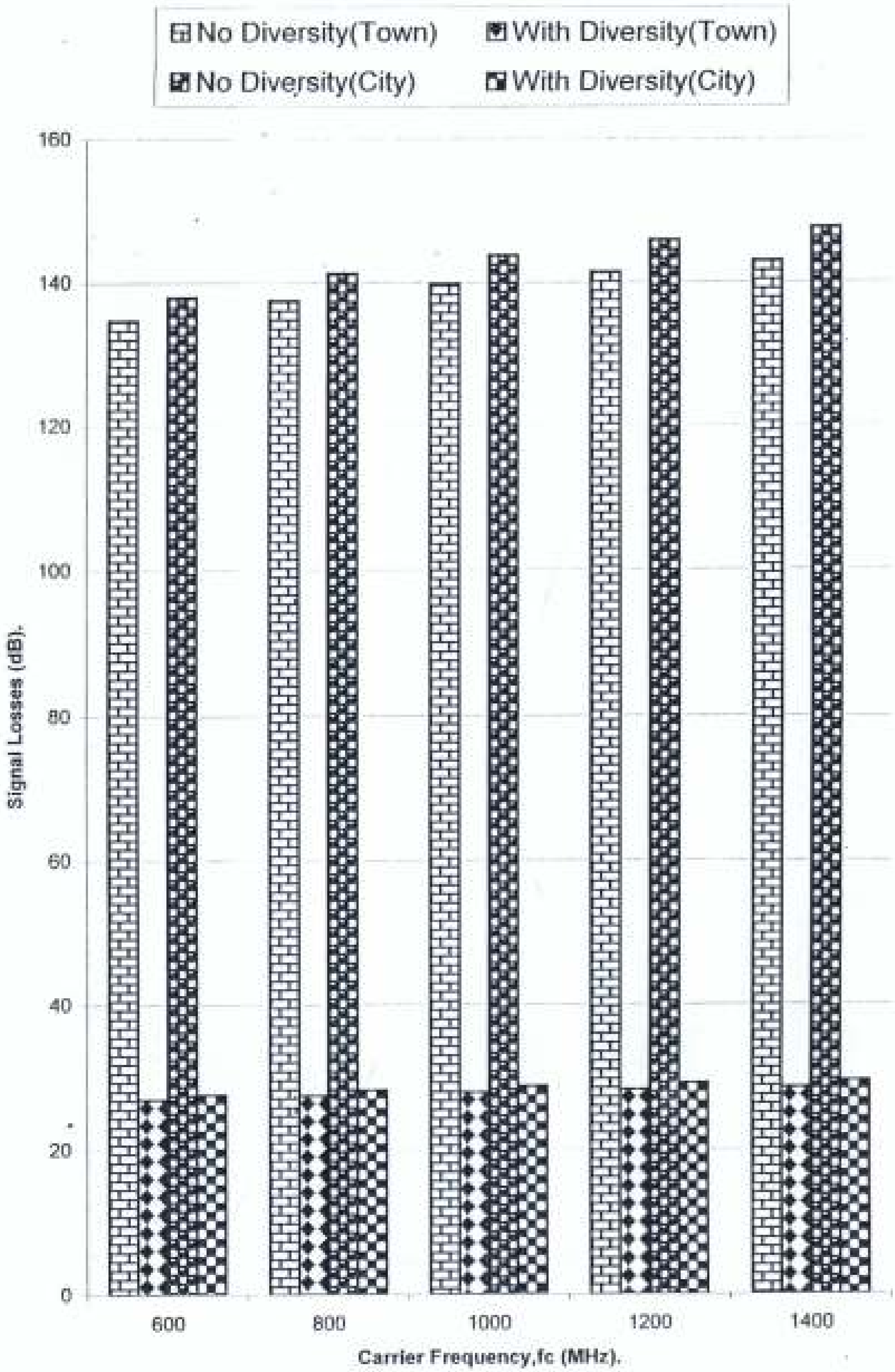

Fig.4.2. Signal Losses at a distance of 4km between the base station and the mobile station for Town and City.

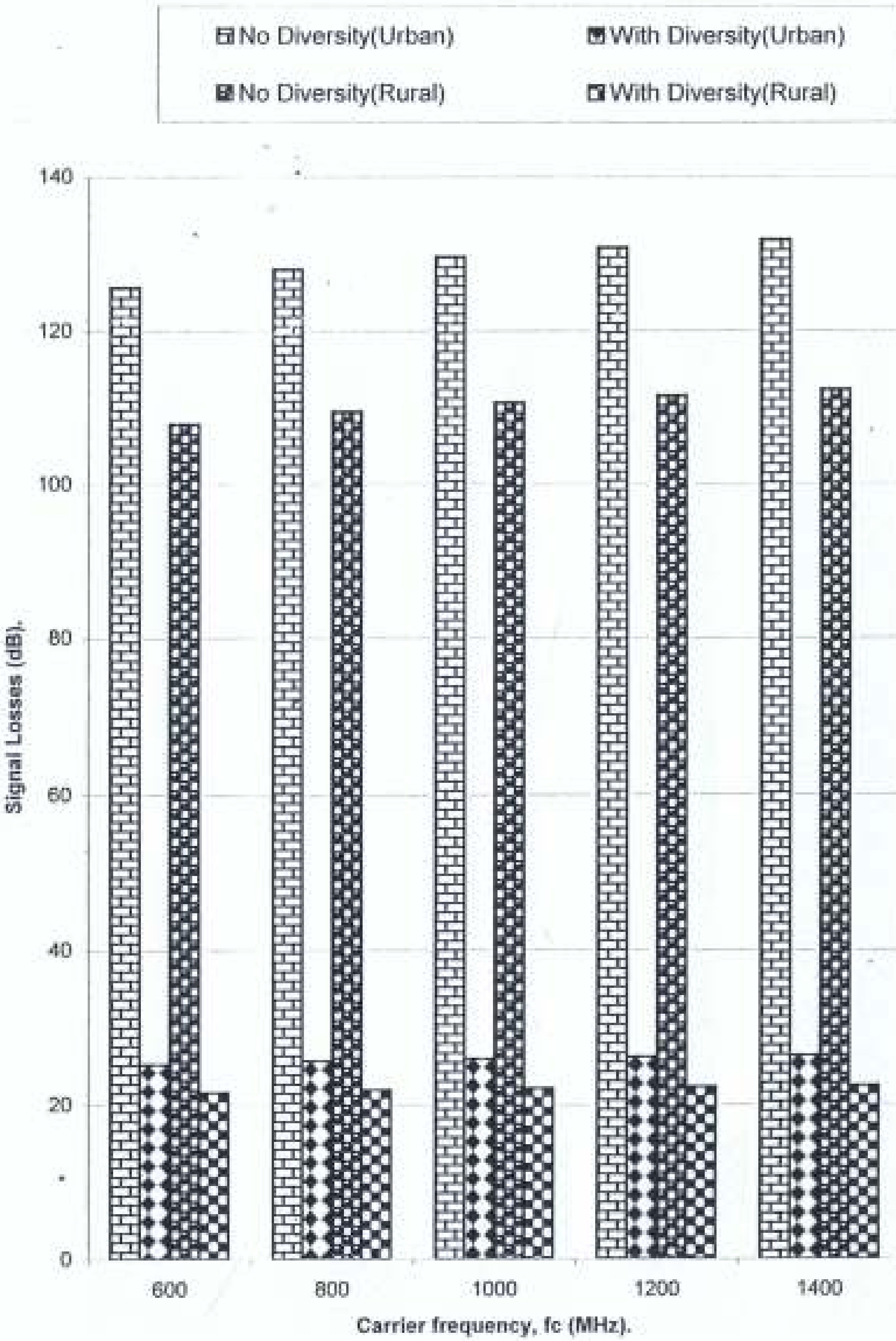

Fig.4.3. Signal Losses at a distance of 4km between the base station and the mobile station for Urban and Rural areas.

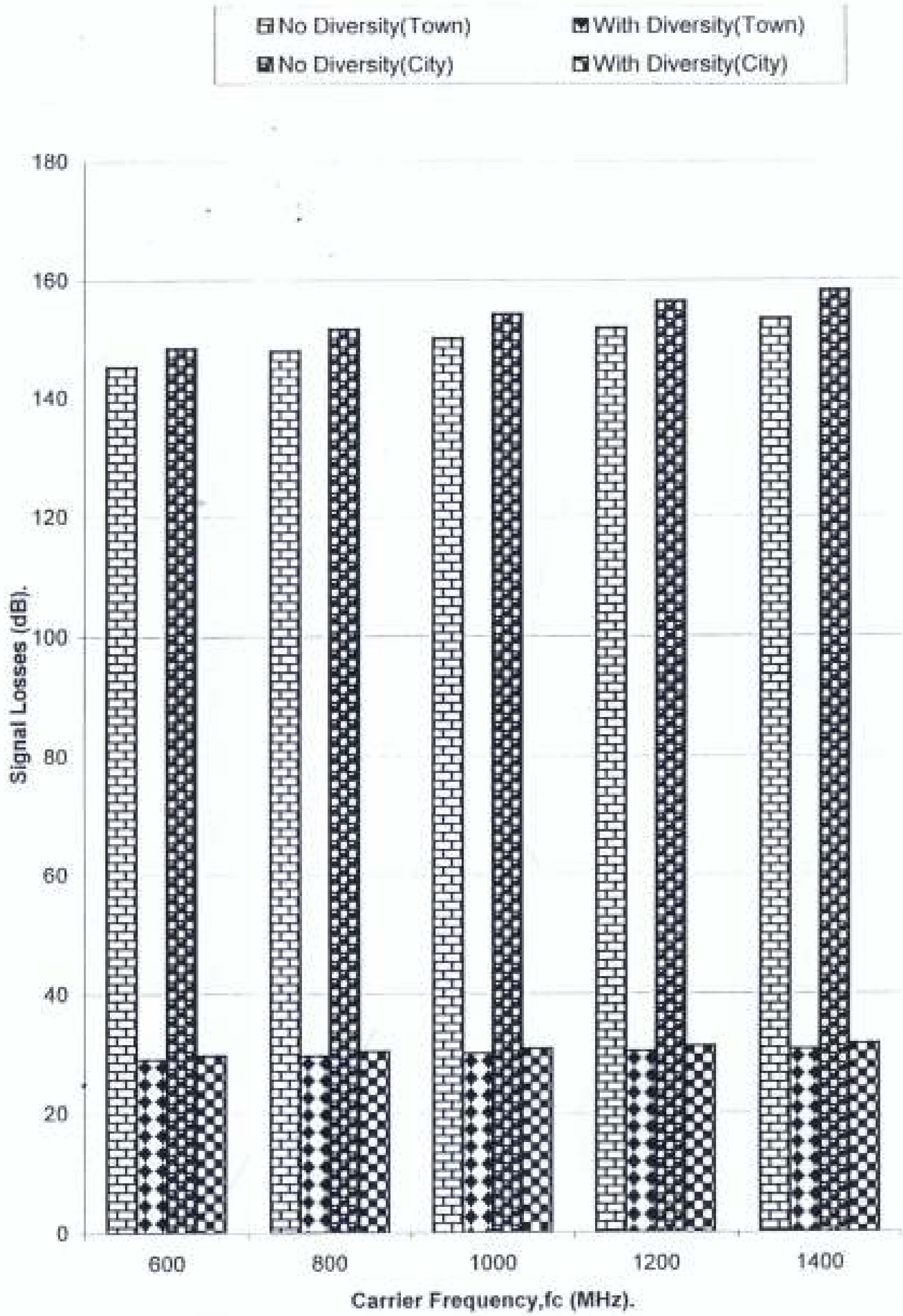

Fig.4.4. Signal Losses at a distance of 8km between the base station and the mobile station for Town and City.

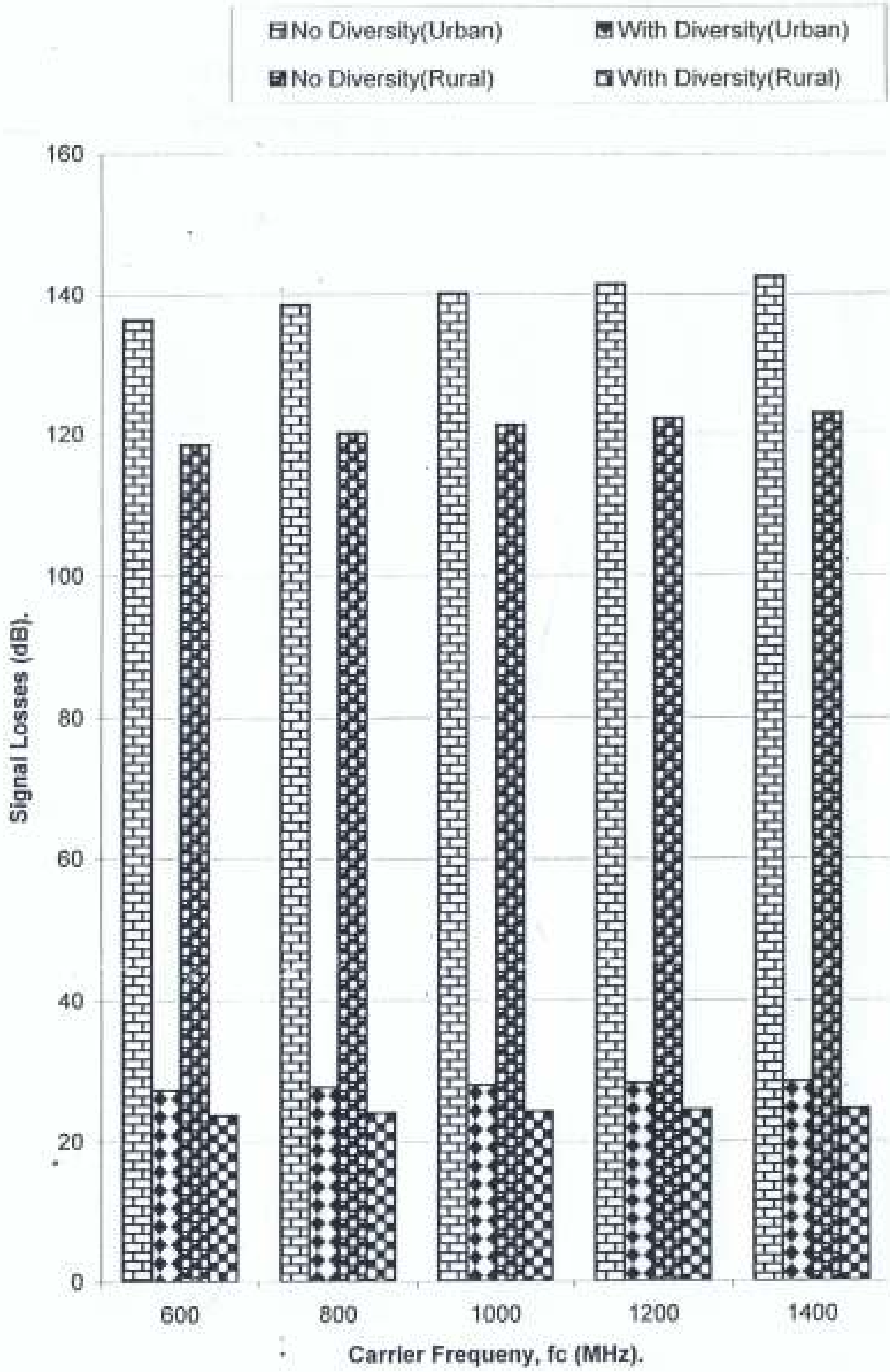

Fig.4.5. Signal Losses at a distance of 8km between the base station and mobile station for Urban and Rural areas.

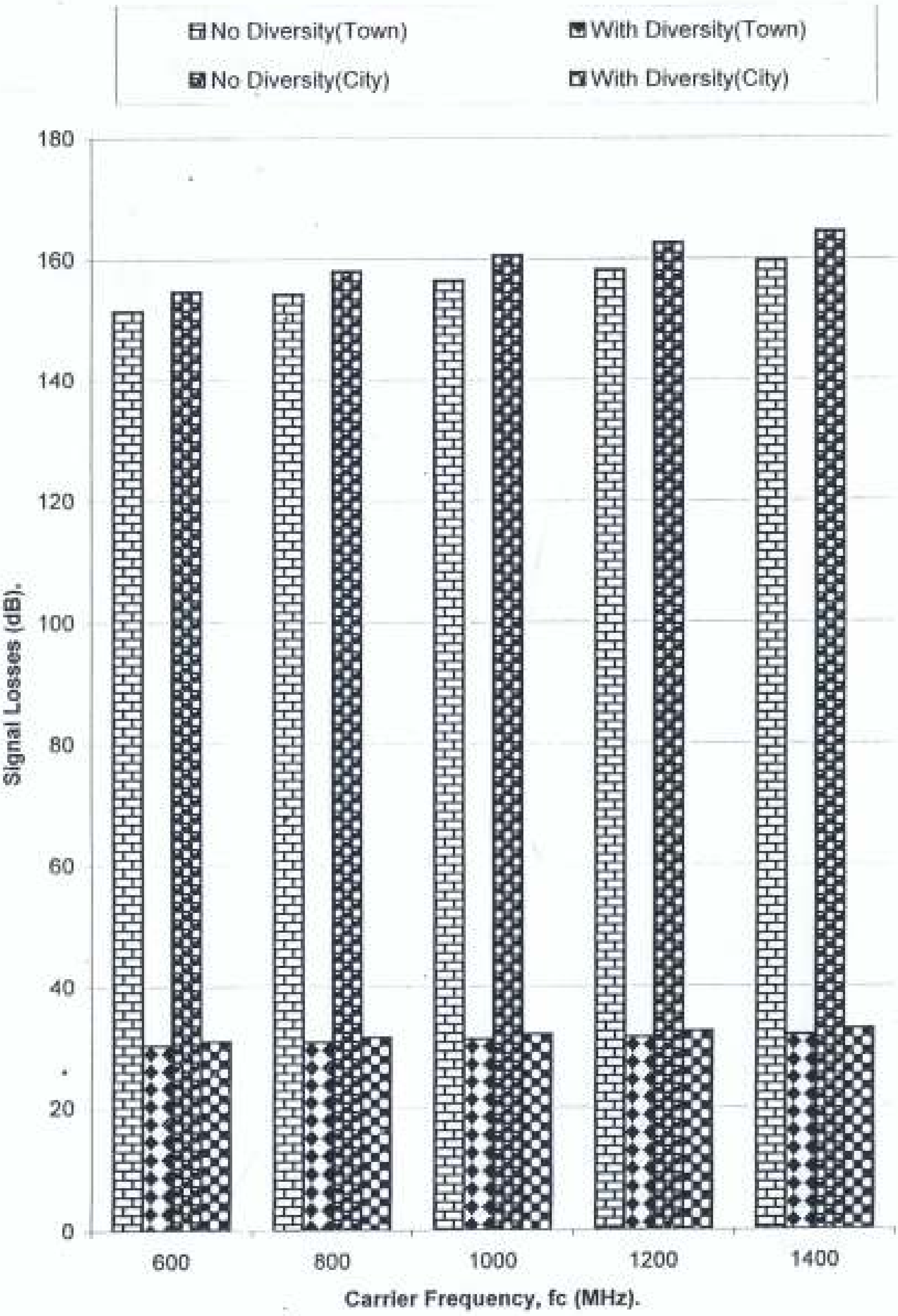

Fig. 4.6. Signal Losses at a distance of 12km between the base station and the mobile station for Town and City.

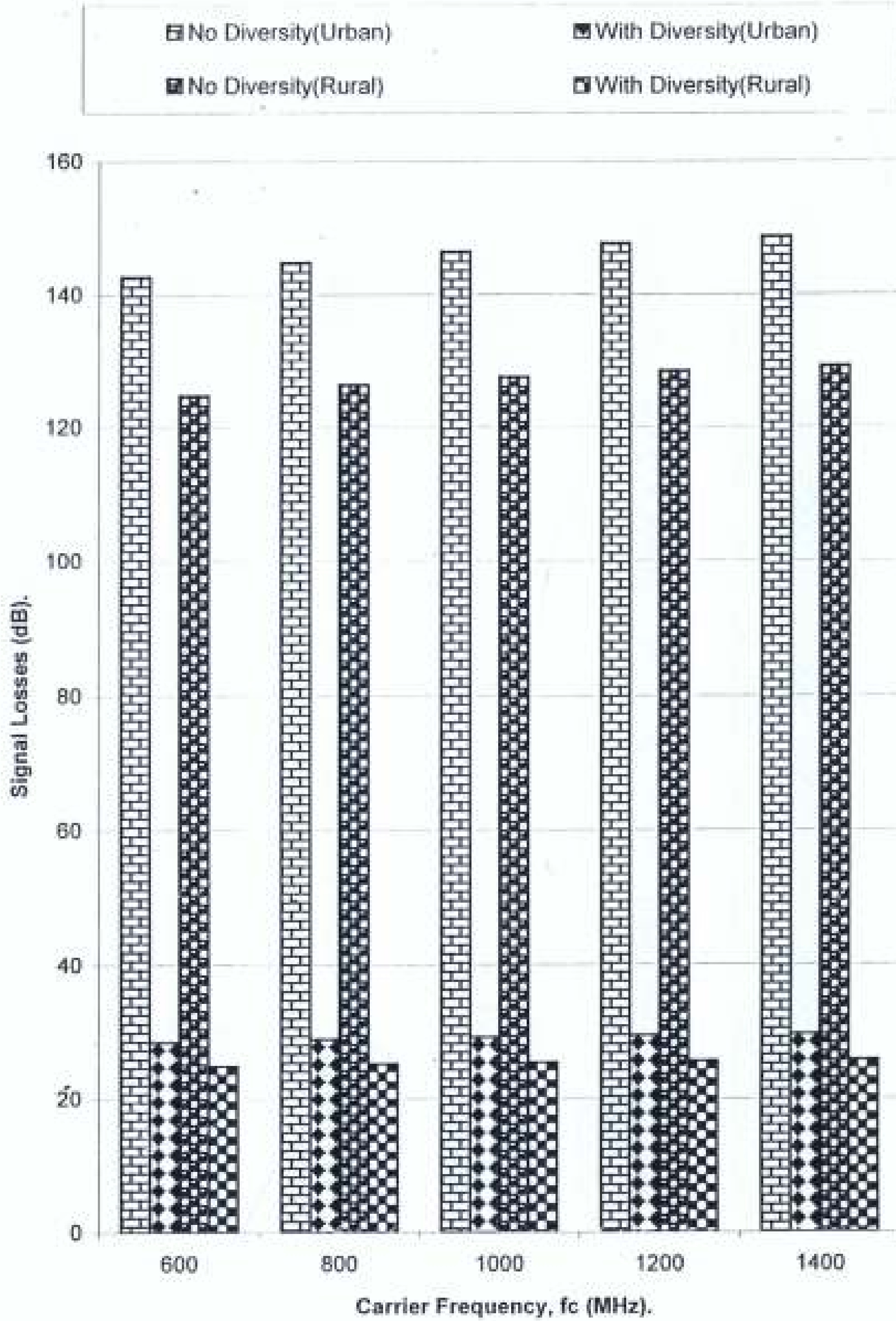

Fig.4.7. Signal Losses at a distance of 12km between the ase station and the mobile station for Urban and Rural areas.

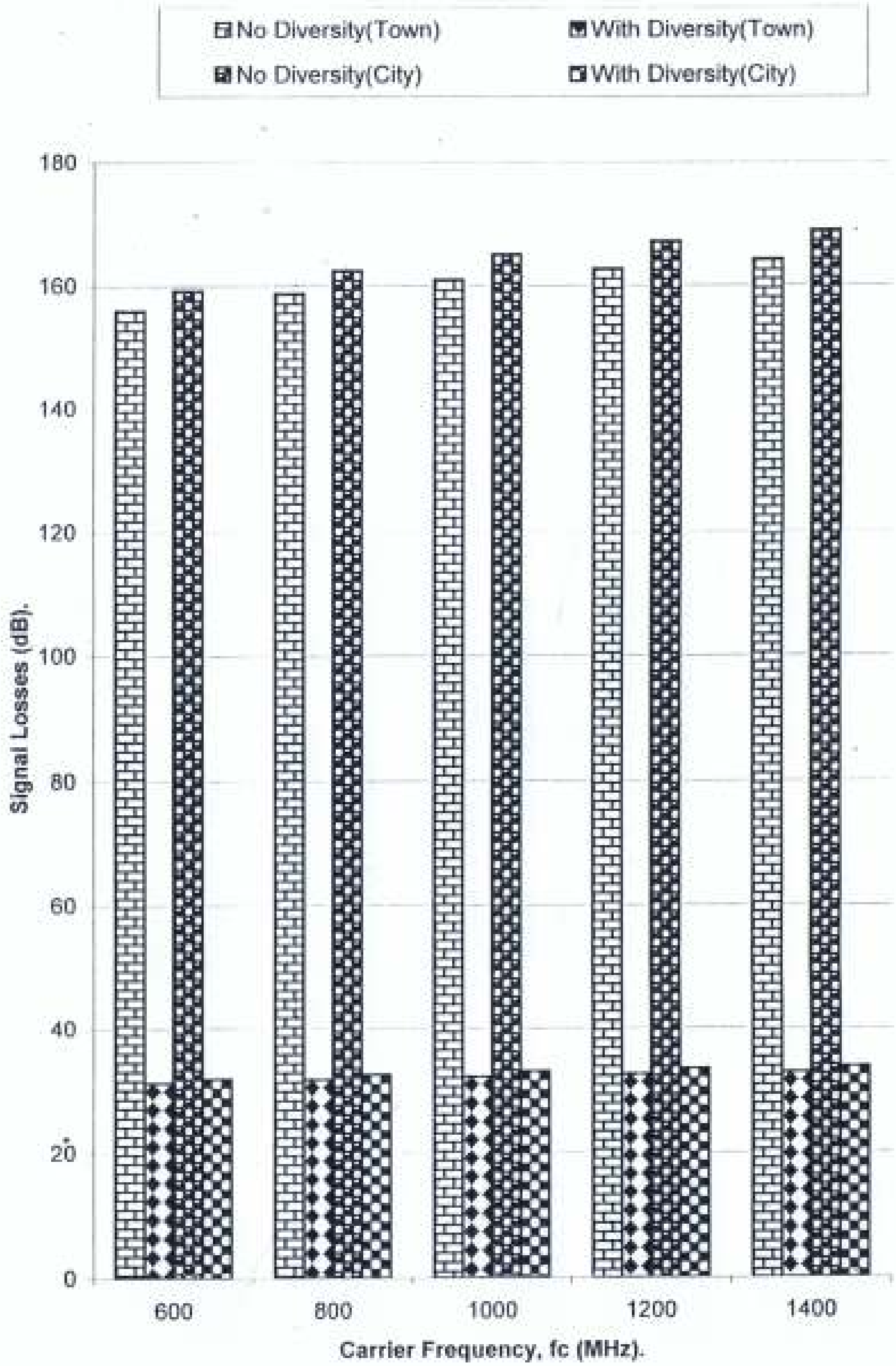

Fig.4.8. Signal Losses at a distance of 16km between the base station and the mobile station for Town and City.

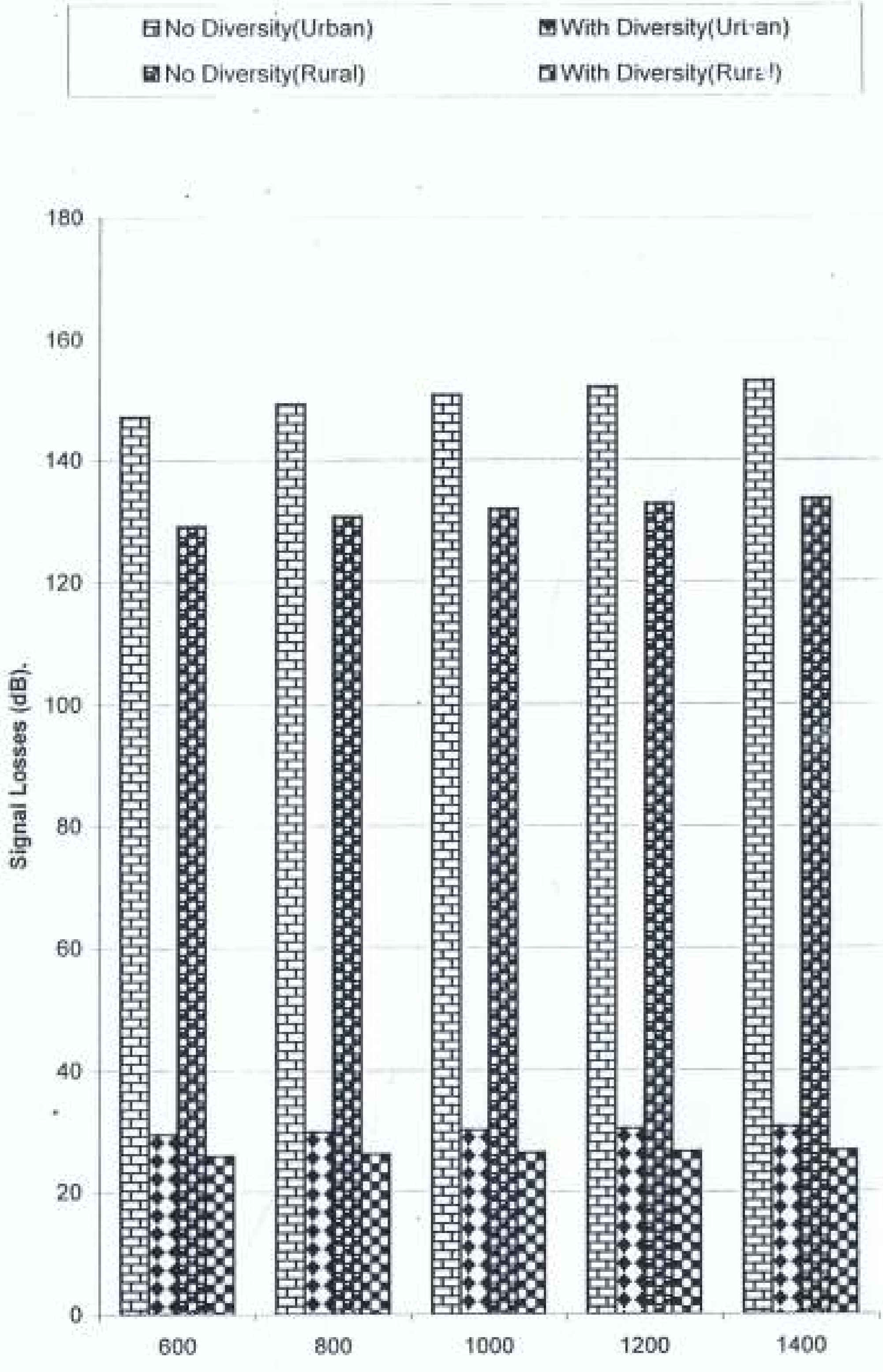

Fig.4.9. Signal Losses at a distance of 16km between the base station and the mobile station for Urban and Rural areas.

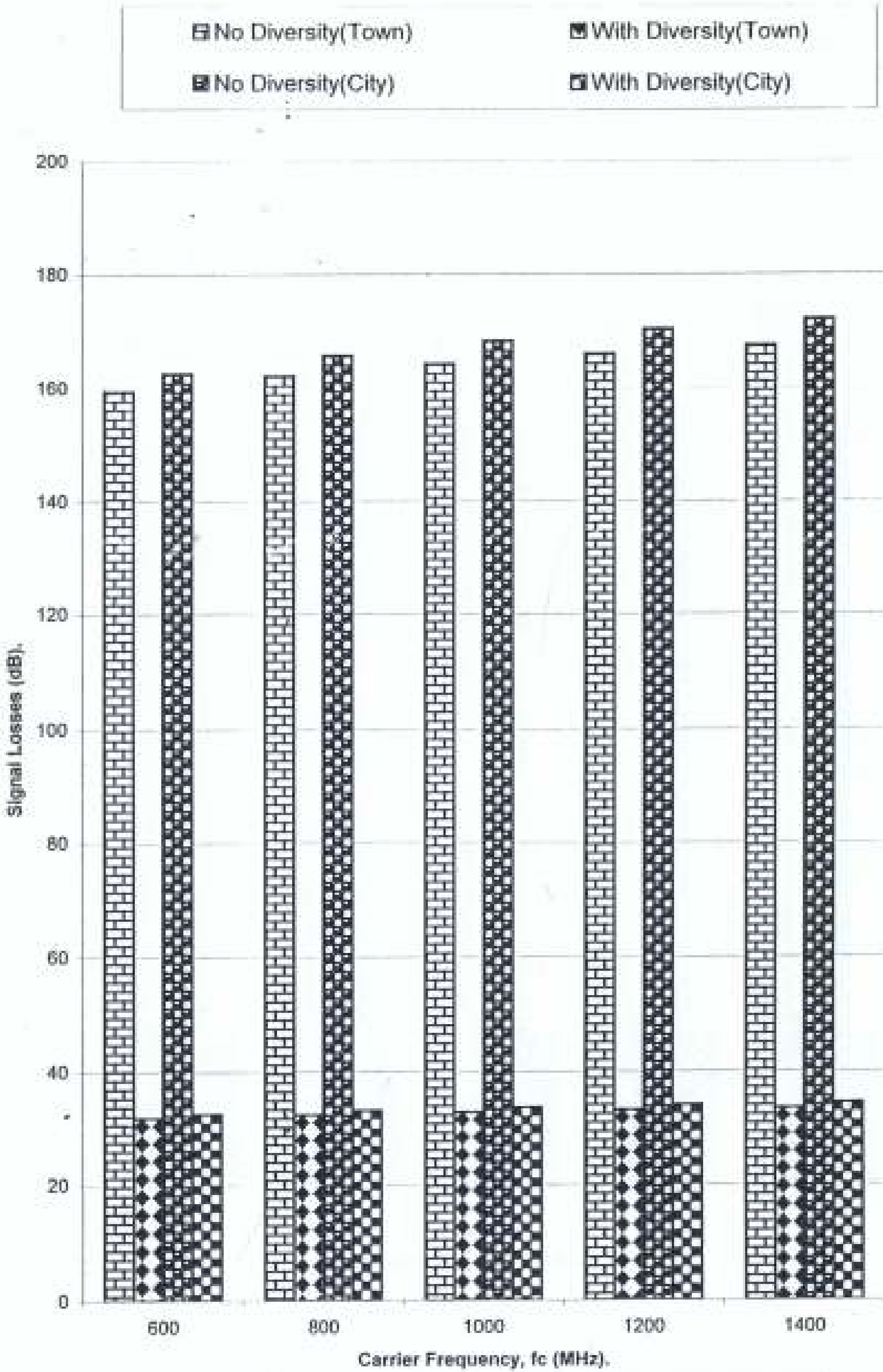

Fig.4.10. Signal Losses at a distance of 20km between the base station and the mobile station for Town and City.

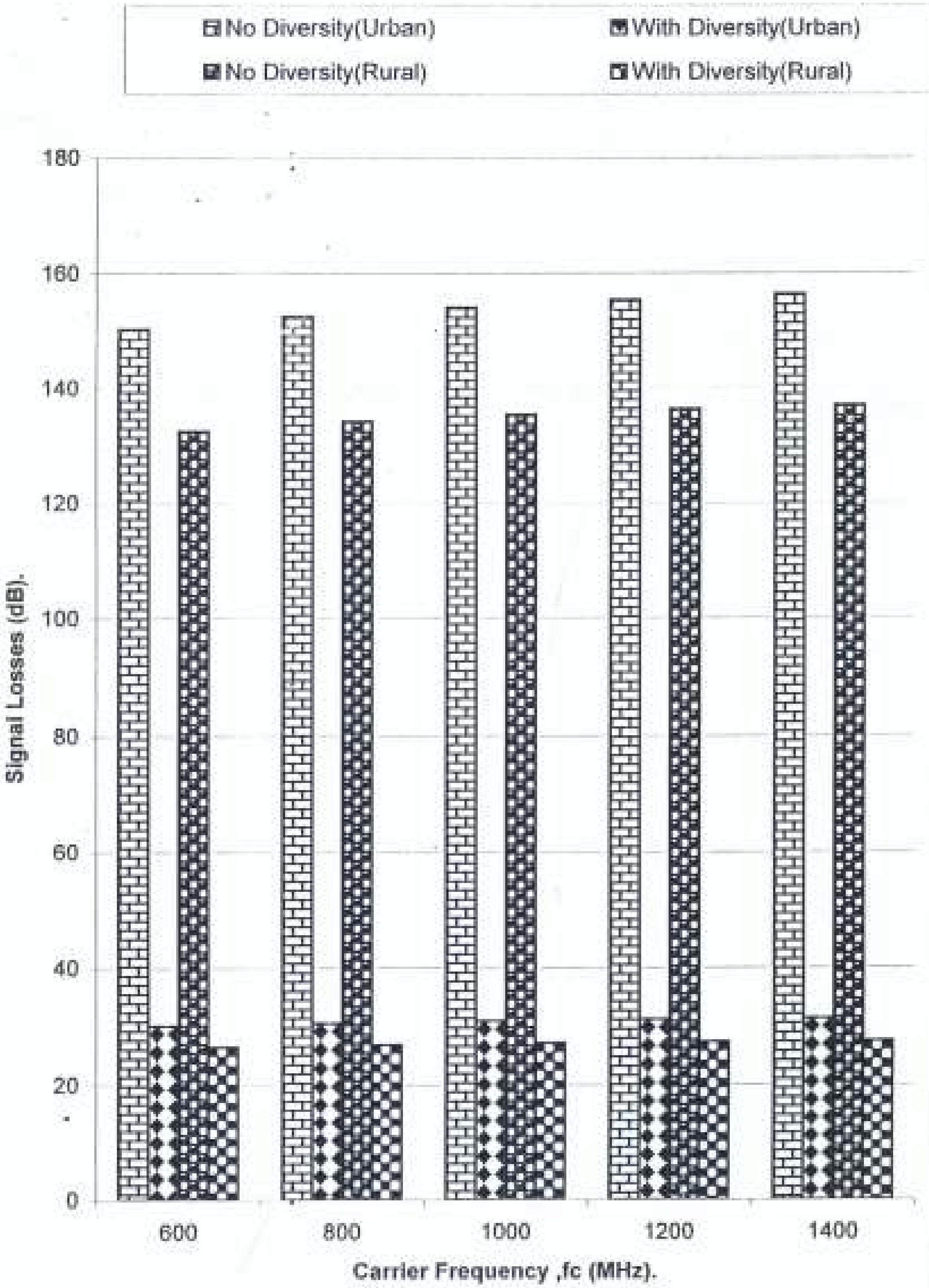

Fig.4.11. Signal Losses at a distance of 20km between the station station and the mobile station for Urban and Rural areas.

4.4 SIGNAL DEVIATION LOSSES WITH CARRIER FREQUENCY.

The results of this study show an improved and better signal deviation losses in the received signal as the carrier frequency is increasing (Fig. 4.13 – Fig. 4. 16). The figures show the deviation losses against the carrier frequency at different distances between the transmitter and the receiver. From these figures, it was observed that the deviation losses increase with carrier frequency with the application of the space-diversity technique in this study. This agrees with the findings in all the available literatures that have deduced that, diversity scheme is an effective means of combating fading in an outdoor environment.

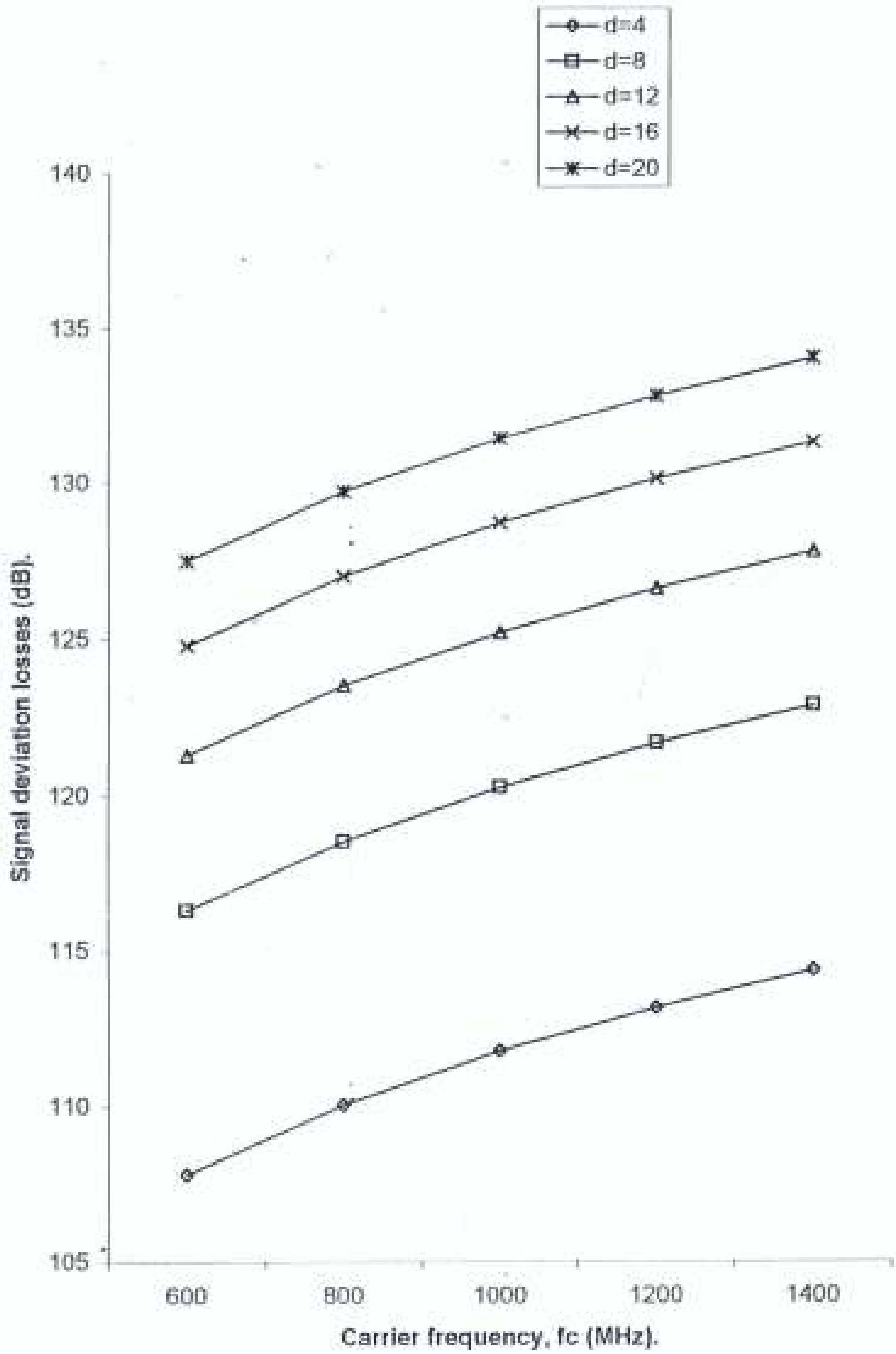

Fig. 4.12. The graph of signal deviation losses against the carrier frequency for town.

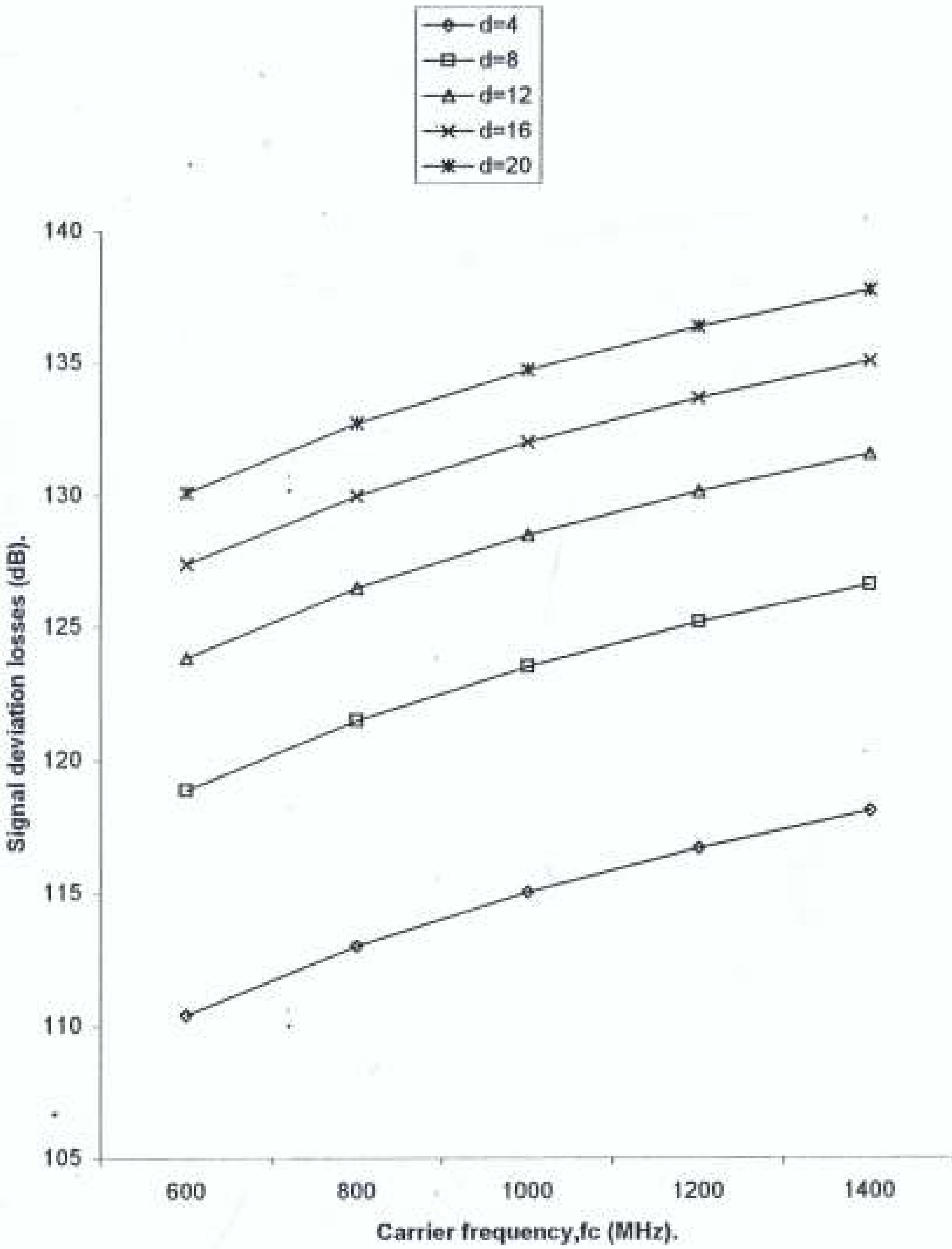

Fig.4.13. The graph of signal deviation losses against carrier frequency for city.

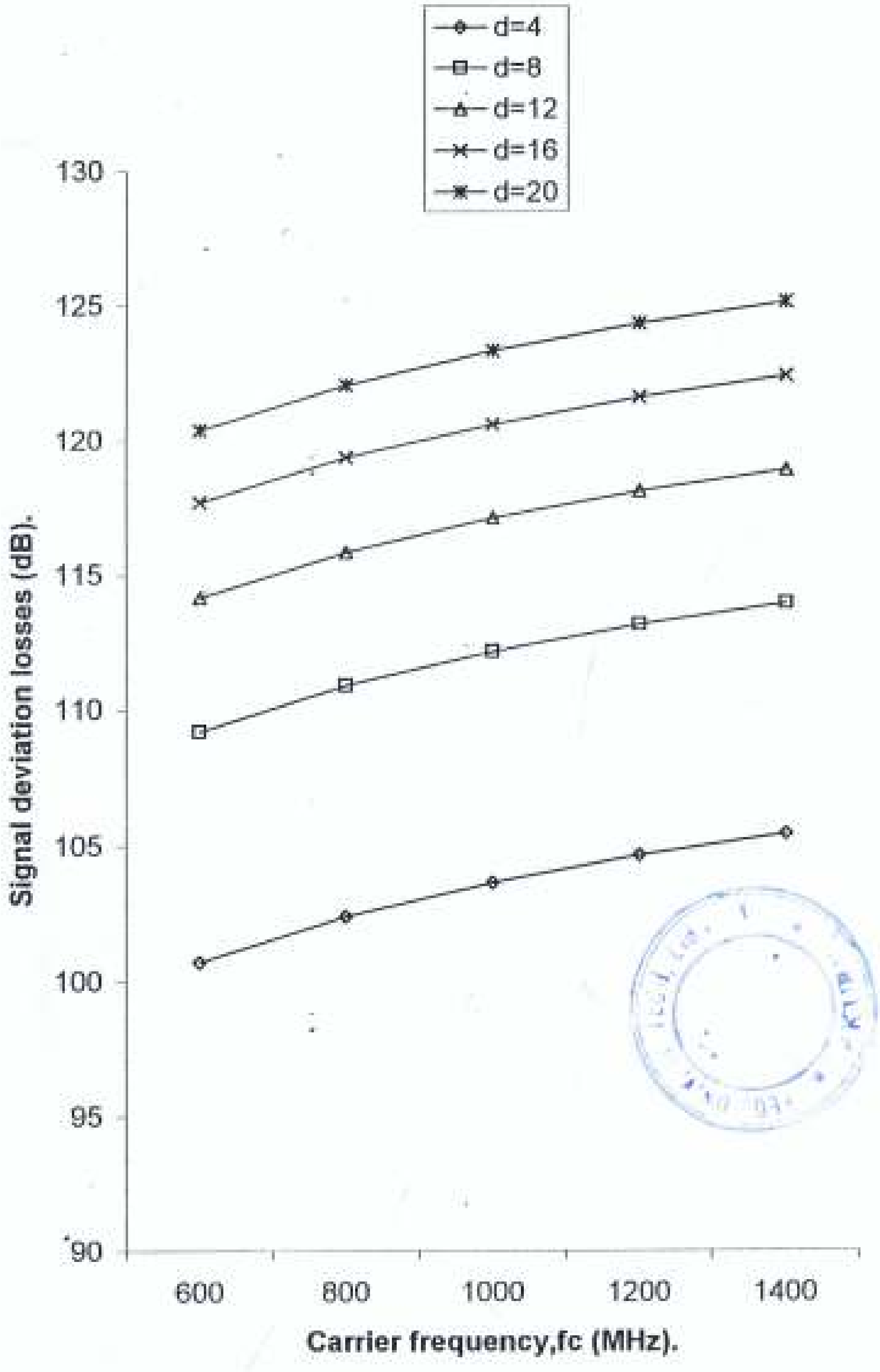

Fig.4.14. The graph of signal deviation losses against carrier frequency for urban area.

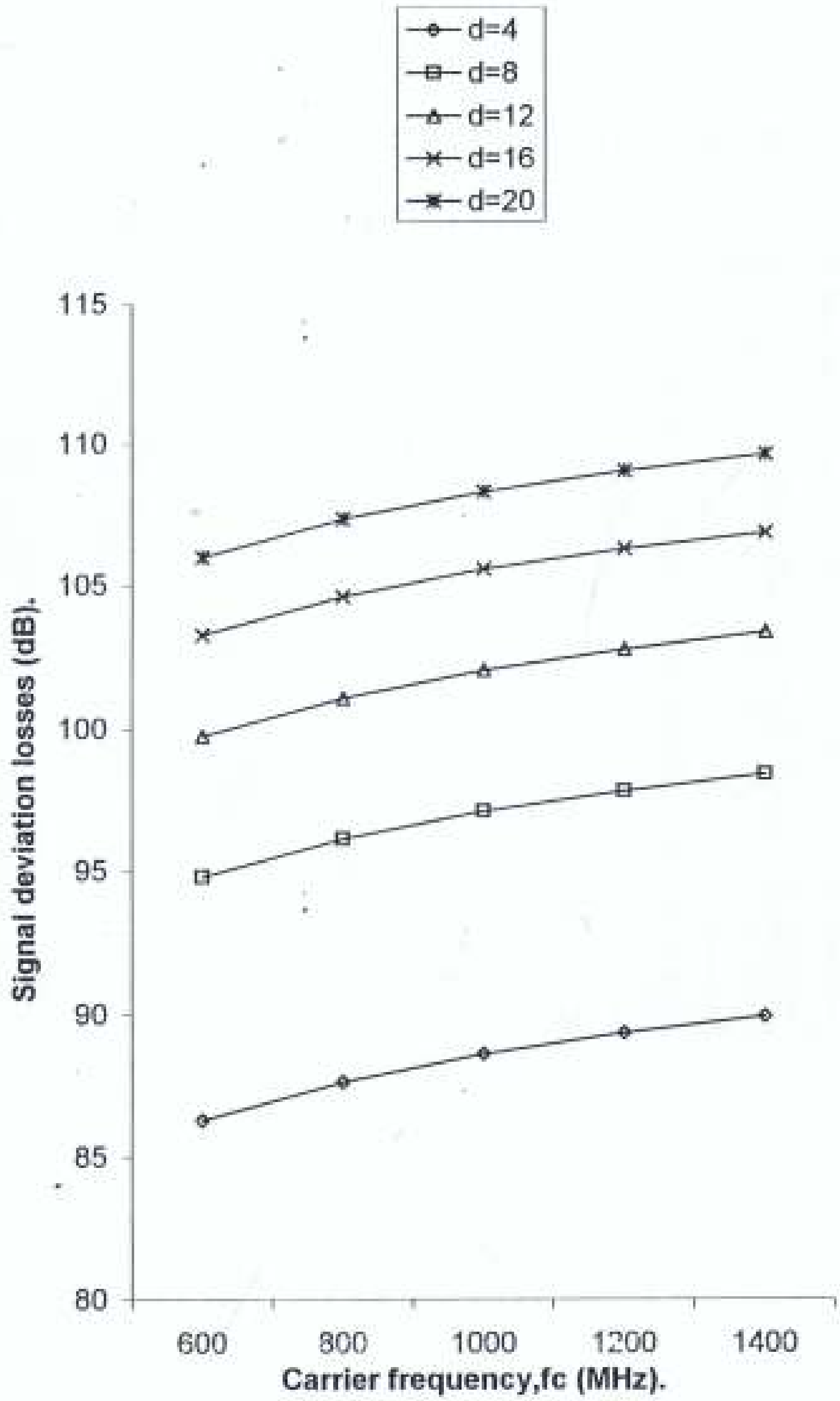

Fig.4.15. The graph of signal losses against carrier frequency for rural area.

4.5 VARIATION OF ANTENNA SPACING WITH CARRIER FREQUENCY

Table: 4.2: Antenna Spacing, d_s (m) at distance, d = 8.0 km.

Antenna Spacing, d_s (m) for different Values of ρ at constant Values of $h_t = 33m$, and $h_r = 5m$										
f_c (MHz)	$\rho=$ 0.1	$\rho=$ 0.2	$\rho=$ 0.3	$\rho=$ 0.4	$\rho=$ 0.5	$\rho=$ 0.6	$\rho=$ 0.7	$\rho=$ 0.8	$\rho=$ 0.9	$\rho=$ 1.0
600.0	10.73	8.97	7.76	6.77	5.88	5.05	4.22	3.34	2.29	0.00
650.0	9.90	8.28	7.16	6.35	5.43	4.66	3.90	3.08	2.12	0.00
700.0	9.19	7.69	6.45	5.80	5.04	4.33	3.62	2.86	1.97	0.00
750.0	8.58	7.17	6.20	5.41	4.71	4.04	3.38	2.67	1.84	0.00
800.0	8.04	6.72	5.82	5.07	4.41	3.79	3.17	2.50	1.72	0.00
850.0	7.57	6.33	5.47	4.78	4.15	3.57	2.98	2.36	1.62	0.00
900.0	7.15	5.98	5.17	4.51	3.92	3.37	2.81	2.23	1.53	0.00
950.0	6.77	5.66	4.90	4.27	3.72	3.19	2.67	2.11	1.45	0.00
1000.0	6.44	5.80	4.65	4.06	3.53	3.03	2.53	2.00	1.38	0.00
1050.0	6.13	5.12	4.43	3.87	3.36	2.89	2.41	1.91	1.31	0.00
1100.0	5.85	4.89	4.23	3.69	3.21	2.76	2.30	1.82	1.25	0.00
1150.0	5.60	4.68	4.05	3.53	3.07	2.64	2.20	1.74	1.20	0.00
1200.0	5.36	4.48	3.88	3.38	2.94	2.53	2.11	1.67	1.15	0.00
1250.0	5.15	4.30	3.72	3.25	2.82	2.42	2.03	1.60	1.10	0.00
1300.0	4.95	4.14	3.58	3.12	2.72	2.33	1.95	1.54	1.06	0.00
1350.0	4.77	3.99	3.45	3.01	2.62	2.25	1.87	1.48	1.02	0.00
1400.0	4.60	3.84	3.32	2.90	2.52	2.16	1.81	1.43	0.98	0.00
1450.0	4.44	3.71	3.21	2.80	2.43	2.09	1.75	1.38	0.95	0.00
1500.0	4.29	3.59	3.10	2.71	2.35	2.02	1.69	1.33	0.92	0.00

The Table 4.2 above shows the relationship between the carrier frequency, f_c, the correlation coefficient, ρ, and the antenna spacing d_s. From the table, it is observed that the lower the values of both the carrier frequency, f_c, and the correlation coefficient, ρ, the higher the value of the antenna spacing d_s. However, since the carrier frequency normally used for mobile communication is in the higher part of the UHF band (for example the frequency range for mobile system currently in Nigeria is from 800 – 1000 MHZ), it is obvious that space diversity technique is practicable at the base station since the antenna spacing is not all that wide compared with those at lower frequencies.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

As set out in the objective, the study has developed an application computer program for radiowave propagation path loss and antenna spacing predictions. The developed program is tested and found to be reliable and accurate in combating signal fading in an outdoor environment.

This study has also revealed that the signal loss deviation increases with both the carrier frequency and the distance between the transmitter (base station) and the receiver (mobile station) when the space-diversity technique is applied. This is contrary to the data observed when the space-diversity technique is not applied.

5.2 RECOMMENDATION

The general observation of the signal losses deviation when the space-diversity technique is not applied shows that the longer the distance between the transmitter and the receiver the lower the strength of the signal at the receiver. However with the application of space-diversity technique in this work, it is observed that the quality or strength of the signal at the receiver improves even as the distance between the transmitter and the receiver increases. Hence if the technique used in this work is applied to our mobile systems in Nigeria, the advantages that will be derived from it will be many. Firstly, it will bring about the long desired rural area development. Secondly, the mass migration of people from rural areas to urban areas will be reduced if not totally eradicated. Thirdly, it will enable the people in the rural areas to reach others and to be reached. Lastly, the major problem of signal fading in mobile system in this country will be greatly reduced if not totally eradicated.

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APPENDIX I

Table: A. Signal Losses at distance, d = 4.0 km for Town and City.

Signal Losses (dB) at Constant Values of $h_t = 30m$, $h_r = 5m$ and $\rho = 0.2$				
$f_c\,(MHz)$	TOWN		CITY	
	NO DIVERSITY (dB)	WITH DIVERSITY (dB)	NO DIVERSITY (dB)	NO DIVERSITY (dB)
600.0	134.7742	26.9548	137.9761	27.5952
650.0	135.5466	27.1093	138.8854	27.7771
700.0	136.2617	27.2524	139.7274	27.9455
750.0	136.9275	27.3855	140.5112	28.1022
800.0	137.5503	27.5101	141.2445	28.2489
850.0	138.1353	27.6271	141.9332	28.3866
900.0	138.6869	27.7374	142.5826	28.5165
950.0	138.2087	27.8417	143.1969	28.6394
1000.0	139.7037	27.9407	143.7796	28.7559
1050.0	140.1745	28.0349	144.3339	28.8668
1100.0	140.6234	28.1247	144.8624	28.9725
1150.0	141.0524	28.2105	145.3675	29.0735
1200.0	141.4631	28.2926	145.8510	29.1702
1250.0	141.8570	28.3714	146.3148	29.2630
1300.0	142.2355	28.4471	146.7604	29.3521
1350.0	142.5997	28.5199	147.1891	29.4378
1400.0	142.9506	28.5901	147.6023	29.5205
1450.0	143.2893	28.6579	148.0010	29.6002
1500.0	143.6164	28.7233	148.3862	29.6772

APPENDIX I

Table:B. Signal Losses at distance, d = 4.0 km for both Urban and Rural Areas.

Signal Losses (dB) at Constant Values of $h_t = 30m$, $h_r = 5m$ and $\rho = 0.2$				
$f_c\,(MHz)$	URBAN AREA		RURAL AREA	
	NO DIVERSITY (dB)	WITH DIVERSITY (dB)	NO DIVERSITY (dB)	NO DIVERSITY (dB)
600.0	125.8777	25.1755	107.8651	21.5730
650.0	126.4380	25.2876	108.3456	21.6691
700.0	126.9533	25.3907	108.7803	21.7561
750.0	127.5232	25.5046	109.1760	21.8352
800.0	127.9618	25.5924	109.5384	21.9077
850.0	128.3716	25.6743	109.8721	21.9744
900.0	128.7560	25.7512	110.1805	22.0361
950.0	129.1969	25.8394	110.4669	22.0934
1000.0	129.5354	25.9071	110.7337	22.1467
1050.0	129.8560	25.9712	110.9830	22.1966
1100.0	130.1604	26.0321	111.2168	22.2434
1150.0	130.4502	26.0900	111.4365	22.2873
1200.0	130.7932	26.1586	111.6436	22.3287
1250.0	131.0551	26.2110	111.8391	22.3678
1300.0	131.3060	26.2612	112.0241	22.4048
1350.0	131.5465	26.3093	112.1995	22.4399
1400.0	131.7776	26.3555	112.3661	22.4732
1450.0	132.0577	26.4115	112.5246	22.5049
1500.0	132.2702	26.4540	112.6756	22.5351

APPENDIX I

Table: C. Signal Losses at distance, d = 8.0 km for Town and City.

Signal Losses (dB) at Constant Values of $h_t = 30m$, $h_r = 5m$ and $\rho = 0.2$				
f_c (MHz)	TOWN		CITY	
	NO DIVERSITY (dB)	WITH DIVERSITY (dB)	NO DIVERSITY (dB)	NO DIVERSITY (dB)
600.0	145.3779	29.0756	148.5798	29.7160
650.0	146.1503	29.2301	149.4892	29.8978
700.0	146.8655	29.3731	150.3311	30.0662
750.0	147.5313	29.5063	151.1150	30.2230
800.0	148.1541	29.6308	151.8482	30.3696
850.0	148.7391	29.7478	152.5370	30.5074
900.0	149.2907	29.8581	153.1863	30.6373
950.0	149.8124	29.9625	153.8006	30.7601
1000.0	150.3074	30.0615	154.3834	30.8767
1050.0	150.7782	30.1557	154.9377	30.9875
1100.0	151.2271	30.2454	155.4662	31.0932
1150.0	151.6561	30.3312	155.9712	31.1942
1200.0	152.0668	30.4134	156.4547	31.2910
1250.0	152.4607	30.4922	156.9185	31.3837
1300.0	152.8392	30.5678	157.3641	31.4728
1350.0	153.2034	30.6407	157.7929	31.5586
1400.0	153.5544	30.7109	158.2061	31.6412
1450.0	153.8930	30.7786	158.6047	31.7210
1500.0	154.2201	30.8440	158.9899	31.7980

APPENDIX I

Table: D. Signal Losses at distance, d = 8.0 km for both Urban and Rural Areas.

Signal Losses (dB) at Constant Values of $h_t = 30m$, $h_r = 5m$ and $\rho = 0.2$				
$f_c\,(MHz)$	URBAN AREA		RURAL AREA	
	NO DIVERSITY (dB)	WITH DIVERSITY (dB)	NO DIVERSITY (dB)	NO DIVERSITY (dB)
600.0	136.4814	27.2963	118.4688	23.6938
650.0	137.0417	27.4084	118.9494	23.7899
700.0	137.5570	27.5114	119.3840	23.8768
750.0	138.1270	27.6254	119.7798	23.9560
800.0	138.5655	27.7131	120.1422	24.0284
850.0	138.9753	27.7951	120.4758	24.0952
900.0	139.3597	27.8719	120.7842	24.1569
950.0	139.8006	27.9601	121.0706	24.2141
1000.0	140.1391	28.0278	121.3374	24.2675
1050.0	140.4597	28.0919	121.5868	24.3174
1100.0	140.7642	28.1528	121.8205	24.3641
1150.0	141.0540	28.2108	122.0403	24.4081
1200.0	141.3969	28.2794	122.2473	24.4495
1250.0	141.6589	28.3318	122.4428	24.4886
1300.0	141.9097	28.3819	122.6278	24.5256
1350.0	142.1503	28.4301	122.8033	24.5607
1400.0	142.3814	28.4763	122.9699	24.5940
1450.0	142.6614	28.5323	123.1284	24.6257
1500.0	142.8739	28.5748	123.2794	24.6558

APPENDIX I

Table:E. Signal Losses at distance, d = 12.0 km for Town and City.

Signal Losses (dB) at Constant Values of $h_t = 30m$, $h_r = 5m$ and $\rho = 0.2$				
f_c (MHz)	TOWN		CITY	
	NO DIVERSITY (dB)	WITH DIVERSITY (dB)	NO DIVERSITY (dB)	NO DIVERSITY (dB)
600.0	151.5807	30.3161	154.7826	30.9565
650.0	152.3531	30.4706	155.6920	31.1384
700.0	153.0683	30.6137	156.5339	31.3068
750.0	153.7340	30.7468	157.3177	31.4636
800.0	154.3568	30.8714	158.0510	31.6102
850.0	154.9419	30.9884	158.7397	31.7480
900.0	155.4935	31.0987	159.3891	31.8778
950.0	156.0152	31.2030	160.0034	32.0007
1000.0	156.5102	31.3020	160.5861	32.1172
1050.0	156.9810	31.3962	161.1405	32.2281
1100.0	157.4299	31.4860	161.6690	32.3338
1150.0	157.8589	31.5718	162.1740	32.4348
1200.0	158.2696	31.6539	162.6575	32.5315
1250.0	158.6635	31.7327	163.1213	32.6243
1300.0	159.0420	31.8084	163.5669	32.7134
1350.0	159.4062	31.8812	163.9957	32.7991
1400.0	159.7572	31.9514	164.4089	32.8818
1450.0	160.0958	32.0192	164.8075	32.9615
1500.0	160.4229	32.0846	165.1927	33.0385

APPENDIX I

Table: F. Signal Losses at distance, d = 12.0 km for both Urban and Rural Areas.

Signal Losses (dB) at Constant Values of $h_t = 30m$, $h_r = 5m$ and $\rho = 0.2$				
f_c (MHz)	URBAN AREA		RURAL AREA	
	NO DIVERSITY (dB)	WITH DIVERSITY (dB)	NO DIVERSITY (dB)	NO DIVERSITY (dB)
600.0	142.6842	28.5368	124.6716	24.9343
650.0	143.2445	28.6489	125.1522	25.0304
700.0	143.7598	28.7520	125.5868	25.1174
750.0	144.3298	28.8660	125.9826	25.1965
800.0	144.7683	28.9537	126.3450	25.2690
850.0	145.1781	29.0356	126.6786	25.3357
900.0	145.5625	29.1125	126.9870	25.3974
950.0	146.0034	29.2007	127.2734	25.4547
1000.0	146.3419	29.2684	127.5402	25.5080
1050.0	146.6625	29.3325	127.7896	25.5579
1100.0	146.9670	29.3934	128.0233	25.6047
1150.0	147.2568	29.4514	128.2431	25.6486
1200.0	147.5997	29.5199	128.4501	25.6900
1250.0	147.8617	29.5723	128.6456	25.7291
1300.0	148.1125	29.6225	128.8306	25.7661
1350.0	148.3531	29.6706	129.0061	25.8012
1400.0	148.5842	29.7168	129.1727	25.8345
1450.0	148.8642	29.7728	129.3312	25.8662
1500.0	149.0767	29.8153	129.4822	25.8964

APPENDIX I

Table: G. Signal Losses at distance, d = 16.0 km for Town and City.

Signal Losses (dB) at Constant Values of $h_t = 30m$, $h_r = 5m$ and $\rho = 0.2$.				
$f_c (MHz)$	TOWN		CITY	
	NO DIVERSITY (dB)	WITH DIVERSITY (dB)	NO DIVERSITY (dB)	NO DIVERSITY (dB)
600.0	155.9817	31.1963	159.1835	31.8367
650.0	156.7541	31.3508	160.0929	32.0186
700.0	157.4692	31.4938	160.9349	32.1870
750.0	158.1350	31.6270	161.7187	32.3437
800.0	158.7578	31.7516	162.4519	32.4904
850.0	159.3428	31.8686	163.1407	32.6281
900.0	159.8944	31.9789	163.7901	32.7580
950.0	160.4162	32.0832	164.4043	32.8809
1000.0	160.9111	32.1822	164.9871	32.9974
1050.0	161.3820	32.2764	165.5414	33.1083
1100.0	161.8309	32.3662	166.0699	33.2140
1150.0	162.2598	32.4520	166.5749	33.3150
1200.0	162.6705	32.5341	167.0585	33.4117
1250.0	163.0645	32.6129	167.5223	33.5045
1300.0	163.4430	32.6886	167.9679	33.5936
1350.0	163.8072	32.7614	168.3966	33.6793
1400.0	164.1581	32.8316	168.8098	33.7620
1450.0	164.4967	32.8994	169.2085	33.8417
1500.0	164.8239	32.9648	169.5936	33.9187

APPENDIX I

Table: H. Signal Losses at distance. d = 16.0 km for both Urban and Rural Areas.

Signal Losses (dB) at Constant Values of $h_t = 30m$, $h_r = 5m$ and $\rho = 0.2$				
$f_c(MHz)$	URBAN AREA		RURAL AREA	
	NO DIVERSITY (dB)	WITH DIVERSITY (dB)	NO DIVERSITY (dB)	NO DIVERSITY (dB)
600.0	147.0851	29.4170	129.0725	25.8145
650.0	147.6455	29.5291	129.5531	25.9106
700.0	148.1607	29.6322	129.9878	25.9976
750.0	148.7307	29.7461	130.3835	26.0767
800.0	149.1693	29.8339	130.7459	26.1492
850.0	149.5791	29.9158	131.0795	26.2159
900.0	149.9635	29.9927	131.3880	26.2776
950.0	150.4044	30.0809	131.6743	26.3349
1000.0	150.7428	30.1486	131.9411	26.3882
1050.0	151.0634	30.2127	132.1905	26.4381
1100.0	151.3679	30.2736	132.4243	26.4849
1150.0	151.6577	30.3315	132.6440	26.5288
1200.0	152.0007	30.4001	132.8510	26.5702
1250.0	152.2626	30.4525	133.0466	26.6093
1300.0	152.5134	30.5027	133.2316	26.6463
1350.0	152.7540	30.5508	133.4070	26.6814
1400.0	152.9851	30.5970	133.5736	26.7147
1450.0	153.2651	30.6530	133.7321	26.7464
1500.0	153.4776	30.6955	133.8831	26.7766

APPENDIX I

Table: I. Signal Losses at distance, d = 20.0 km for Town and City.

Signal Losses (dB) at Constant Values of $h_t = 30m$, $h_r = 5m$ and $\rho = 0.2$.				
f_c (*MHz*)	TOWN		CITY	
	NO DIVERSITY (dB)	WITH DIVERSITY (dB)	NO DIVERSITY (dB)	NO DIVERSITY (dB)
600.0	159.3953	31.8791	162.5972	32.5194
650.0	160.1677	32.0335	163.5065	32.7013
700.0	160.8829	32.1766	164.3485	32.8697
750.0	161.5486	32.3097	165.1323	33.0265
800.0	162.1714	32.4343	165.8656	33.1731
850.0	162.7565	32.5513	166.5543	33.3109
900.0	163.3080	32.6616	167.2037	33.4407
950.0	163.8298	32.7660	167.8180	33.5636
1000.0	164.3248	32.8650	168.4007	33.6801
1050.0	164.7956	32.9591	168.9550	33.7910
1100.0	165.2445	33.0489	169.4836	33.8967
1150.0	165.6735	33.1347	169.9886	33.9977
1200.0	166.0842	33.2168	170.4721	34.0944
1250.0	166.4781	33.2956	170.9359	34.1872
1300.0	166.8566	33.3713	171.3815	34.2763
1350.0	167.2208	33.4441	171.8103	34.3621
1400.0	167.5717	33.5144	172.2234	34.4447
1450.0	167.9104	33.5821	172.6221	34.5244
1500.0	168.2375	33.6475	173.0073	34.6015

APPENDIX I

Table: J. Signal Losses at distance, d = 20.0 km for both Urban and Rural Areas.

Signal Losses (dB) at Constant Values of $h_t = 30m$, $h_r = 5m$ and $\rho = 0.2$				
$f_c(MHz)$	URBAN AREA		RURAL AREA	
	NO DIVERSITY (dB)	WITH DIVERSITY (dB)	NO DIVERSITY (dB)	NO DIVERSITY (dB)
600.0	150.4988	30.0998	132.4862	26.4972
650.0	151.0591	30.2118	132.9668	26.5934
700.0	151.5744	30.3149	133.4014	26.6803
750.0	152.1443	30.4289	133.7971	26.7594
800.0	152.5829	30.5166	134.1596	26.8319
850.0	152.9927	30.5985	134.4932	26.8986
900.0	153.3771	30.6754	134.8016	26.9603
950.0	153.8180	30.7636	135.0880	27.0176
1000.0	154.1565	30.8313	135.3548	27.0709
1050.0	154.4771	30.8954	135.6041	27.1208
1100.0	154.7816	30.9563	135.8379	27.1676
1150.0	155.0713	31.0143	136.0577	27.2115
1200.0	155.4143	31.0829	136.2647	27.2529
1250.0	155.6762	31.1353	136.4602	27.2920
1300.0	155.9271	31.1854	136.6452	27.3291
1350.0	156.1677	31.2335	136.8206	27.3641
1400.0	156.3987	31.2798	136.9872	27.3975
1450.0	156.6788	31.3358	137.1457	27.4292
1500.0	156.8913	31.3783	137.2968	27.4594

APPENDIX II

PROJECT C++ (MR POPOOLA J.J, M.ENG PROJECT)

SPACE-DIVERSITY TECHNIQUE FOR COMBATING SIGNAL FADING IN MOBILE COMMUNICATION SYSTEM IN NIGERIAN

```
# include<iostream.h>
# include<math.h>
# include<stdlib.h>
# include<iomanip.h>
# include<conio.h>
# include<ctype.h>
#define SPACE_VELOCITY 3E8

void calculate_path_loss (int fc);
 long double compute_path_loss_sm_city (int fc);
 long double compute_path_loss_large_city (int fc) ;
 long double compute_path_loss_suburban_areas (int fc);
 long double compute_path_loss_open_areas (int fc) ;
 long double lpsm,lpl,lps,lpo,ahrsm,ahrl,ds,e,newlpsm,dsnew;
  char accept;
  int hr,d,ht;
  long fc1,d1;
 long double compute_correction_factor_sm_city (int fc);
  long double compute_correction_factor_large_city (int fc) ;
  long double compute_distance_between_antenna_ds (int fc);
long double compute_new_distance_between_antenna_dsnew (long double
lpold,long double dsold,int fc);
            void error_message ( );
  void welcome_message ( );
```

APPENDIX II

```
main ( )

{

 long fc;
  welcome_message ( ); //THE PROJECT TITLE
 receive_fc:  //THIS MODULE ACCEPT THE VALUE OF THE TRANSMITTING
ANTENNA (fc)
 cout<< "\n          Enter the value          \n";
 cout<< "\n    of the transmitting frequency...\n";
  cout<< "\n NB .....150 <= fc <= 1500.....\n";
 cin>>fc;
  if ((fc<150)||(fc>1500)) {
  error_message ( );
  goto receive_fc;
          }
  calculate_path_loss (fc);//THIS MODULE ACCEPTS VARIABLE VALUES AND COMPUTE
RESULTS
         cout<<"\n\n\n...... COMPUTE MORE VALUES ? ....\n" ;
         cout<<"\n...TYPE (Y) FOR YES & (N) FOR NO.......\n" ;
         cin >>  accept;
                    if((accept=='Y')||(accept=='y'))goto receive_fc;
         else
         cout<<"########.....PROGRAM TERMINATES.....#######"  ;

         }
  void calculate_path_loss (int fc)
{
char choice,choice1;
```

APPENDIX II

```
receive_ht: //This module accepts the value of the height of the transmitting
antenna (ht)
cout<<"\n Enter the value of the height of the";
out<<"\n   transmitting antenna...ht(m)\n";
cout<<"\n NB:30<=ht<=200\n";
cin>>ht;
 if((ht<30)||(ht>200)){
 error_message ( );
 goto receive_ht;
         }
 receive_d:  //This module accepts the value of the distance between base and
mobile station (d)
          cout<<"\n     Enter the value of the distance ";
cout<<"\n between base station and mobile station...d(km)";
cout<< "\n NB:1 <= d <= 20\n";
cin>>d;
 if((d<1)||(d>20)){
 error_message ( );
 goto receive_d;
         }
long d=d*1000;
receive_hr:  // This module accepts the value of the height of the receiving
antennas(hr)
cout<<"\n Enter the value of the height of the receiving antennas...hr(m)";
cout<< "\n NB .....1 <= hr <= 10.....\n";
cin>>hr;
 if((hr<1)||(hr>10)){
 error_message ( );
```

```
goto receive_hr;
}
  receive_e:  //This module accepts the value of the correlation coeficient (e)

cout<<"\n Enter the value of correlation coefficient e........\n";
cout<<"\n NB......0 <= e <= 1......\n";
cin>>e;
if((e<0)||(e>1)){
error_message ( );
goto receive_e;
}
cout<<"\n 1.......Compute path loss for Urban areas..........";
cout<<"\n 2.......Compute path loss for Suburban areas.......";
cout<<"\n 3.......Compute path loss for Rural areas ...........";
cout<<"\n ......Enter your choice....1,2,3\n";
cin>>choice;
if(choice=='1'){
cout<<"1......Compute path loss for small or medium city\n";
cout<<"2...Compute path loss for large city.........\n";
cout<<"........Enter your choice 1,2.......\n";

cin>>choice1;
          if(choice1=='1'){
           lpsm= compute_path_loss_sm_city (fc);
                                    cout<<"\n path loss for small or medium city....
"<<setprecision(7)<<fabs(lpsm)<<"dB";
                                    ds= compute_distance_between_antenna_ds(fc);

dsnew=compute_new_distance_between_antenna_dsnew(lpsm,ds,fc);
```

APPENDIX II

```
cout<<"\n at e="<<e<<" loss path,distance between antenna
is="<<dsnew/1e6<<'m';
        }
                if(choice1=='2'){

                 lpl =compute_path_loss_large_city (fc);

        cout<<"\n Path loss for large city... "<<setprecision(7)<<fabs(lpl)<<"dB";
                ds= compute_distance_between_antenna_ds(fc);

dsnew=compute_new_distance_between_antenna_dsnew(lpl,ds,fc);
                cout<<"\n at e="<<e<<" loss path,distance between antenna
is="<<dsnew/1e6<<'m';

                }
        }
                        if(choice=='2'){
                        lpsm= compute_path_loss_sm_city (fc);
         lps=compute_path_loss_suburban_areas (fc) ;
         cout<<"\n Path loss suburban areas.... "<<setprecision (7)<<fabs
(lps)<<"dB";
                        ds= compute_distance_between_antenna_ds (fc);
                dsnew=compute_new_distance_between_antenna_dsnew
(lps,ds,fc);
                cout<<"\n at e="<<e<<" loss path,distance between antenna
is="<<dsnew/1e6<<'m';


                        }
```

APPENDIX II

```
                    if(choice=='3'){

lpsm= compute_path_loss_sm_city (fc);
        lpo=compute_path_loss_open_areas (fc);

        cout<<"\n Path loss for rural areas.... "<<setprecision
(7)<<fabs(lpo)<<"dB";
                ds= compute_distance_between_antenna_ds (fc);
                dsnew=compute_new_distance_between_antenna_dsnew
(lpo,ds,fc);
                cout<<"\n at e="<<e<<" loss path,distance between antenna
is="<<dsnew/1E6<<'m';

                    }

return;
        }
 long double compute_path_loss_sm_city (int fc)
        {
        long double ahrsm=compute_correction_factor_sm_city (fc);
                lpsm=69.55+26.16*log10(fc)-13.82*log10(ht)-ahrsm+(44.9-
6.55*log10(ht))*log10(d);
        return lpsm;
        }

        long double compute_path_loss_large_city (int fc)
                {
                ahrl=compute_correction_factor_large_city (fc) ;
                lpl=69.55+26.16*log10(fc)-13.82*log10(ht)-ahrl+(44.9-
6.55*log10(ht))*log10(d);
```

APPENDIX II

```
        return lpl;
        }
    long double compute_path_loss_suburban_areas (int fc)
        {
        lps=lpsm-2*pow((log10(fc/28)),2)-5.4;
        return lps;
        }

        long double compute_path_loss_open_areas (int fc)
        {
        lpo=lpsm-4.78*pow((log10(fc)),2)+18.33*log10(fc)-40.94;
        return lpo;

        }

    long double compute_correction_factor_sm_city (int fc)
        {
        ahrsm=(1.1*log10(fc)-0.7)*hr-(1.56*log10(fc)-0.8);
        return ahrsm;
        }

    long double compute_correction_factor_large_city (int fc)
        {
         if (fc<=200)
        ahrl=8.29*pow((log10(1.54*hr)),2)-1.1;
        if(fc >= 400)
        ahrl=3.2*pow((log10(11.75*hr)),2)-4.97;
        if((fc>200)&&(fc<400)) {
        error_message();
            exit(0);
```

```
                }
                return ahrl;
                }
                void error_message ( )
                {
                cout<<'\a';
                cout<<"..........ERROR ! !! !!!..........."<<'\n';
                cout<<"\n This value is not within the expected range\n";

cout<<"\n============================================================
=";
                return;

}
        long double compute_distance_between_antenna_ds (int fc)
{
ds=(21.45*SPACE_VELOCITY*sqrt((-1*log10(e))))/fc ;
return ds;
}

long double compute_new_distance_between_antenna_dsnew (long double
lpold,long double dsold,int fc)
        {
            long double   lpnew=(lpold*e)/1;
cout<<"\n new lp is..."<<fabs(lpnew)<<"dB";
        dsnew= (dsold*lpnew)/lpold  ;
return dsold;
        }

  void welcome_message ( )
```

APPENDIX II

```
{

cout<<"################################################################\n\n\n";

cout<<"=========MR POPOOLA J.J  M.ENG
PROJECT=============\n\n\n\n";
cout<<"TITLE:- SPACE-DIVERSITY TECHNIQUE FOR COMBATING
.\n";
cout<< "------- SIGNAL FADING IN MOBILE COMMUNICATION.----
\n\n";
cout<<"--- SYSTEM IN NIGERIA --\n\n";


cout<<"################################################################\n\n";
for(long count=-90000000;count<=90000000;count++);
clrscr();
return;
}
```