CHAPTER ONE
INTRODUCTION

1.1 Background of Study

The demand for higher capacity and better Quality of Service (QoS) in wireless mobile communication systems has been increasing exponentially in the last decade. This is because of the user mobility and flexibility, particularly on the communication channel between Mobile Terminals (MT) and Base Station (BS) that cannot be provided in wired line. Unfortunately this wireless resourceis a bottleneck, which limits system capacity and performance due to multipath propagation problems in wireless channels (Adit, 2013). However, Mobile services have revolutionizedthe world, and promised to be keyin future transformation. The global mobile broadband industry has become an incredible spectacle to observe, from many competitors vying for the largest market share position to the amazing applications streaming into the market and the constant appearance of new devices.Mobile broadband access using the 3G and now the 4G/Long Term Evolution (LTE) networks has continued to expand as users continue to add tablets, modems and phones to use alternative communication methods and cloud based services. In longer term, with the increased availability of mobile devices such as tablets and smartphones, the amount of mobile data usedare likely to, at least, double yearly for the next few years(Kylie, etal 2015).

At the end of 2016, 65% of the world's population had a mobile related services subscription,accounting for a total of 4.8 billion unique mobile subscribers (GSMA, 2017). The total is set to reach 5 billion in mid-2017 and by 2020, almost 860 million new subscribers will be added, taking the global penetration rate to 73%.There were 3.8 billion smartphone connectionsat the end of 2016, accounting for half of total connections excluding Machine to Machine (M2M) worldwide. As with subscriber growth,developing markets and particularly Asia aredriving the current phase of smartphone growth.In developing markets, smartphone connectionsreached 47% of the total base at the end of 2016and was forecast to reach 62% by 2020 (GSMA, 2017).

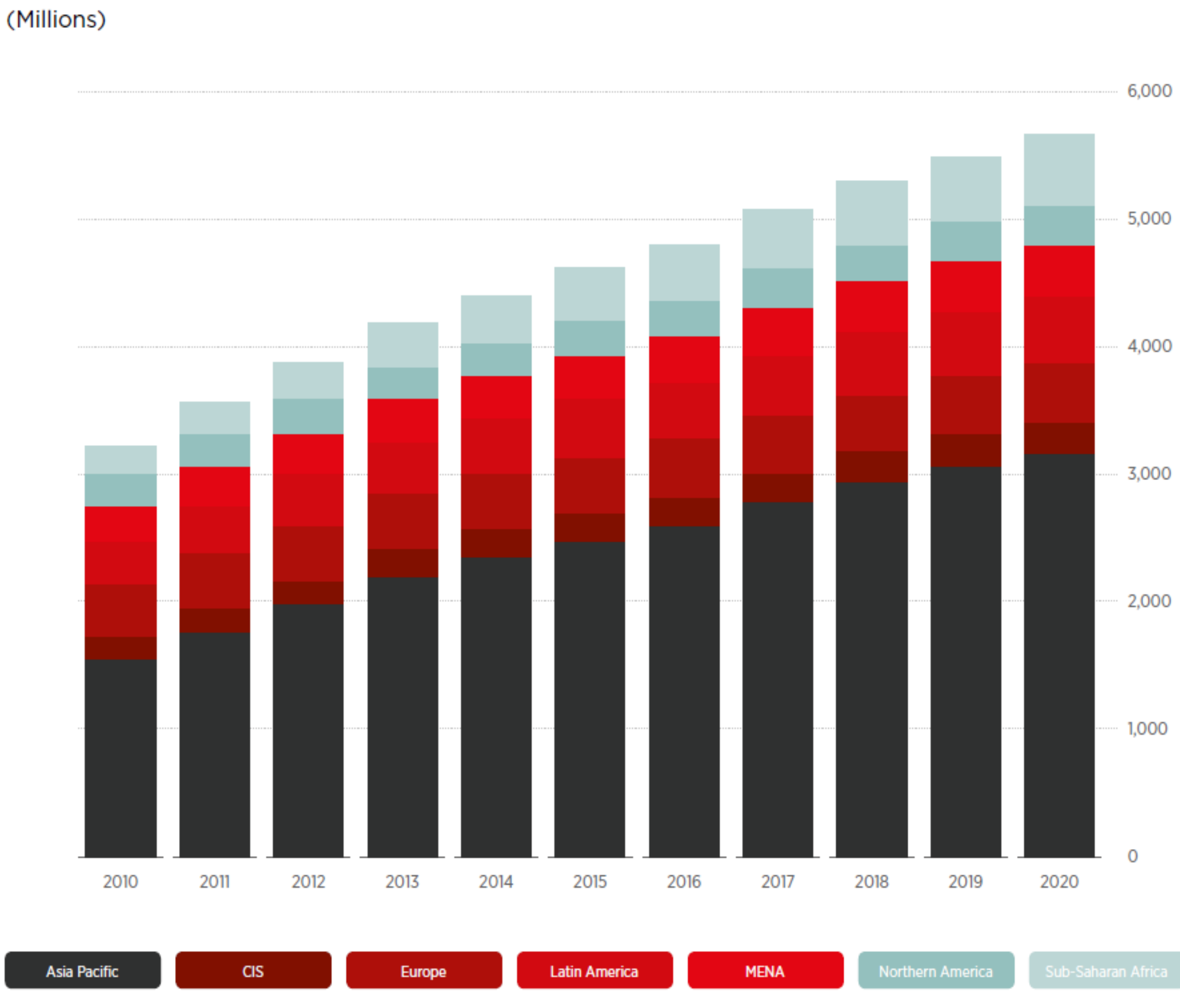


Figure 1.1 World subscribers by regions (GSMA 2017)

In Nigeria as at September 2016, the end of the third quarter, there were 153,271,581 subscribers, compared with 149,803,714 in June 2015, which represents a quarterly increase of 2.31%. The number of subscribers had therefore surpassed its previous peak of 152,123,172, attained in November 2015 (NCC, 2016). The yearly increase in total subscriber numbers was 1.73%; which was an increase compared to the yearly growth rate of 0.69% at the end of the previous quarter. As the number of subscribers increases and more applications of wireless communication are introduced, the problem of providing improved QoS continued to be a challenge. This statistics of wireless communication device subscribers continue to increase as the months go by as can be seen by the Nigerian communication chart shown in Fig. 1.1 (NCC, 2016).

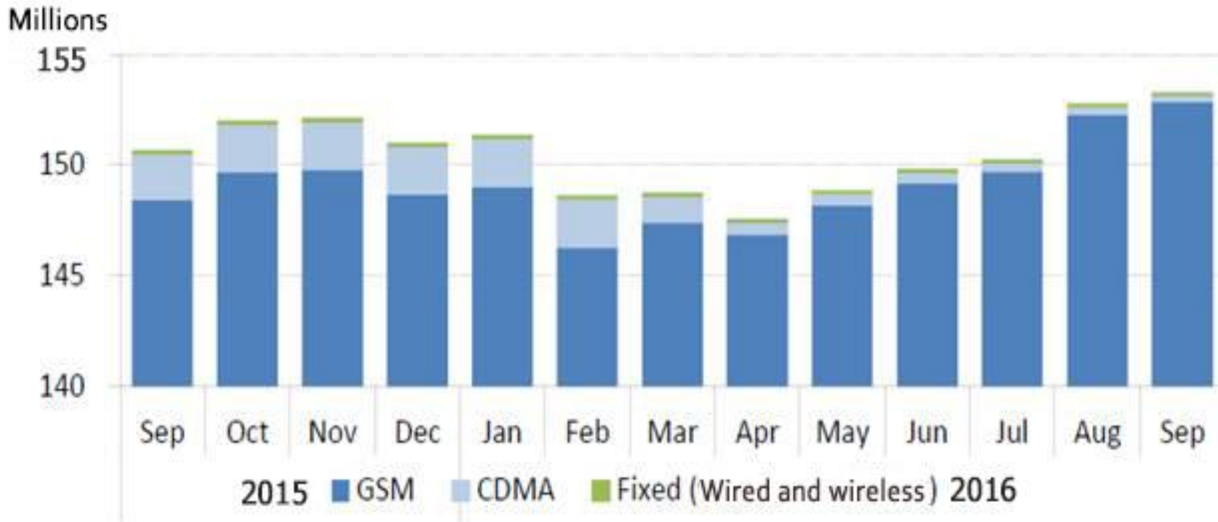


Figure 1.2Subcriber /Teledensity(NCC, 2016).

With the growing application of mobile phonesindiverse sectors; this in turn creates a greater demand on available mobile resources (channels). This means that there is an urgent need to properly and efficiently manage the wireless environment in other to ensure good Quality of Service (QoS) which would withstand the expected growth in number of mobile subscribers. This is the main focus of this research.The fundamental problem of the wireless channel is how to share the scarce communication resourceamong many mobile users (multiple-access) in order to accommodate as many users as possible with good (QoS). This has not been an easy task because unlike wired line communications, transmission of a signal through the wireless channels has beenvery challenging whereas the frequency spectrum allocation is very limited. However, these problems need to be solved using various new technologies in order to fulfil the ever increasing demand.

In the early 20th century, technological revolutions in the electrical andtelecommunications industry made wireless communication possible with the launch of first generation (1G) analogue cellular networks focusing on the real-time speech services. The concept of digital transmission was realized in 1991, the secondgeneration (2G) digital cellular network, called Global System for Mobile (GSM) communications was subsequently rolled out. GSM was designed to support voice as well as data communication,yet data transmission capabilities of GSM were rather limited. Improvements to enhance data transmission rates and reliability in GSM resulted in technologies like High Speed Circuit Switched Data

(HSCSD), General Packet Radio Service (GPRS) and Enhanced Data Rates for GSM Evolution (EDGE) promising data rates up to 236 kbps (Ali, 2010).

During the past decade or more, the world of telecommunications changed drastically for various technical and political reasons. The widespread use of digital technology has brought radical changes in services and networks. In addition, a strong drive towards wireless internet access through mobile terminals has generated the need for universal standard, which became known as the Universal Mobile Telecommunication System (UMTS) (Eheduru,2013). These new third-generation (3G) networks were developed byintegrating the features of telecommunications and Internet Protocol (IP)-based networks. Networks based on IP, initially designed to support data communication, have begun to carry streaming traffic like voice/sound, though with limited voice quality and delays that are hard to control (Jaana L., Achim W. and Tomas N., 2006). Commentaries and predictions regarding wirelessbroadband communications and wireless internet access are cultivating visions of unlimited services and applications that are available to consumers ‘anywhere, andanytime’. They (consumers) expect to surf the Web, check their emails, download files, make real time video-conference calls and perform a variety of other tasks through wireless communication links (Jaana, et al, 2006). They expect a uniform user interface that providesaccess to wireless links whether they are shopping at the mall, waiting at the airport, walking around town, working at the office or driving on the highway. The newgeneration of mobile communications is revolutionary not only in terms of radio access technology, but equally on the drive for newtechnical solutions are not the only motivation for UMTS. Requirements also come from expanded customer demands, new business visions and new priorities in life (Eheduru,2013).

Consequently, UMTS has met the challenge of continuously improving the end-user experience and service interaction by evolving its packet-data technology with High Speed Downlink Packet Access (HSDPA). Offering data speeds up to 14.4 Mbps; HSDPA is expected to become a preferred broadband access medium for end users, from mobile phones to laptops and tablets (Ali, 2010).

In UMTS, coverage and capacity are interdependent. Transmit power in downlink (cell coverage) is shared among users whereas each user adds to the overall interference that decreases the cell capacity. Moreover, the performance of HSDPA linkdepends exclusively on the radio channel conditions surrounding the mobile device. The better the channel conditions the higher the throughput. However, higher signal power levels needed to service the HSDPA userscan alsobe drawn from the BS. Therefore for service providers to sustain theincreasing demand for higher data rates and mobility with internet based applications and data centric services associated with HSDPA, efficient management of the transmitted signal energy level must be properly and efficiently managed in order to reduce interferences and reduction in QoS (Ali, 2000).

Many schemes have been suggested for power control in HSPA networks, which generally offer strategiesto reduce interference while maintaining efficient energy management system as well as data rates required for good Quality of Service.In 3G systems, HSPA has been chosen because theoretically it provides higher capacity compared with Frequency Division Multiple Access (FDMA) and Time Division Multiple access (TDMA) schemes (Ali, 2000).However, in order to achieve this "promised" high capacity, good techniques are needed to overcome several wireless impairments. This is why significant research works are currently being devoted to improve the performance of UMTS systems, such as interference cancellation or multiuser detection using smart antennas and power control, among others. Among these areas of research, power control is the most crucial aspect because it plays an important role in a UMTS system(Ali, 2000).

Power control is of great need in Wideband Code Division Multiple Access(WCDMA), because all users share the same bandwidth and as such a signal received by the base station (BS) from a nearby mobile station (MS) dominates the signal from a far-away MS, thus resulting in the so-called *near–far effect*. In the absence of power control, the capacity of the Direct Sequence Code Division Multiple Access (DS-CDMA) mobile system is very low, even lower than that of mobile systems based on FDMA. To overcome this problem, each MS cannot send signals with the same power, but rather transmit at power levels that are exactly enough for an efficient communication link. Transmission Power Control (TPC) is vital for capacity and performance in cellular communicationsystems, where high interference is always present due to frequency reuse. The basicintent is to control the transmission powers in such a way that the interference power from eachtransmitter to other co-channel users (users that share the same radio resource simultaneously)is minimized while preserving standard quality of service (QoS) among all users. Co-channelinterference management is important in any system employing frequency reuse. However, inCode Division Multiple Access (CDMA), there are interfering users both inside and outside a cell, which makes CDMA interferencelimited. Thus efficient TPC is essential in CDMA, especially in the uplink (from mobile tobase station communication) (Matti, 2005). The various challenges militating against improving QoS in WCDMA can be reduced with efficient transmit power management, which is the goal of this research work. The key performance indicators evaluated in this dissertation are call load, loop delay and dropped calls percentage.

1.2 Problem Statement

The WCDMA network also suffers from both intercellular (Adjacent channel) and intracellular (co-channel) interference, which is compounded by its spread spectrum technique and soft handover technology. This shortcoming requires an efficient power control system to reduce the impact of these interferences and invariably improve QoS which is the burning desire of all mobile service subscribers and service providers.

The ever increasing demand for wireless services accompanied with the desire for an improved QoS by consumers, has led to several researches being carried out in a bid to improve QoS as well as increase system capacity . These research efforts were aimed at proffering solutions that effectively mitigate existing problems associated with WCDMA communication systems. The problems that instigated this research work are:

- The near-far problem resultingfrom one user's transmission power becoming interference to others; which is as a result of distance dependent signal transmission in WCDMA.
- The Fixed Step Power Control (FSPC) scheme, which keeps power control step size values constant regardless of traffic load. This is faced with the problem not being able to track rapid changes in radio channel, coupled with the problem of feedback delay which makes the feedback information obsolete by the time it arrives the mobile terminal.
- Oscillation problem resulting from Adaptive step Power control, resulting from fixed 1dB or -1dB power update value.
- High outage probability in other power control schemes which leads to drop calls and interruptions in data transfer
- Furthermore, the impact of shadowing (resulting from obstruction by high rise buildings in densely populated areas) and varying weather conditions (such as rainy, harmattanetc) on the propagated signal are usually ignored when characterizing the propagation environment and thus leads to erroneous predictions of the rate of signal attenuation for

such environments which is required for an efficient modelling of propagation environment.

Therefore, the need to proffer a solution to these problems has necessitated this research work that is aimed at increasing channel capacity in WCDMA/HSPA network with reduced interference and reduced loop delay using Modified Adaptive Power Control Algorithm. An Modified Adaptive Power Control(MAPC) system is needed in order to reduce or completely eradicate challenges of poor QoS in UMTS networks.

1.3 Aim and Objectives of the Research

The aim of this research is to developa Modified Power Control Algorithm to improve QoS in UMTS (WCDMA/HSDPA) system.

The Specific objectives to achieve this aim include:

1. To carryout empirical measurement on QoS parameters to ascertain the level of received signal strength in WCDMA system.
2. To characterize the test bed environment(Onitsha and its metropolis) so as to know the effect of fading due to inadequate power control system.
3. To develop the mathematical models and algorithm for Modified Adaptive Power control (MAPC) system in a WCDMA network.
4. To simulate the developed models for the radio environment using MatLab environment.
5. To validate the developed algorithm for the Modified Adaptive Power control (MAPC) system.

1.4 Justification

A great deal of research has been channeled towards mitigating transmit power challenges so as to enable efficient use of radio resource as can be seen in most literatures reviewed in this work. Most schemes while trying to solve this problem employ complex power control algorithms that use up more bandwidth due to the use of additional power control bits resulting from complexities of the developedalgorithm. In conformity to 3GPP standard, the proposed technique requires the same information as in 3GPP specification, i.e. one bit per 0.667msec by the use of simple algorithm requiring less bandwidth, making it applicable to the practical world. Also, for most feedback based algorithms (i.e. closed loop) the time the power update command is calculated and the time it is applied in the transmitter constitute a delay as a result of such processes as SIR measurement and the transmission of the power control commands over the air interface. During this time, the radio channel and interference conditions might have changed considerably, which deteriorates the performance of power control. Many of the power control algorithms proposed in the literature were studied without taking the loop delay into account. However, the loop delay can cause increased oscillations of the SIR around the set point, and even make the power control algorithm unstable if it is ignored in the design of the algorithm. In this work, a Modified adaptive closed-loop algorithm was considered to help in mitigating the effects of the loop delay.

A common way to study power control algorithms has been the snapshotmethod (MattiRintamäki, 2005), where the link gains of the radio channel are assumed to be fixed, or change very slowly compared to the dynamics of the power control algorithm. This is not very realistic, because in practice the transmitted signals experience various kinds of attenuations resulting from multipath propagation and shadowing effect. In this work, the main focus was on this kind of dynamical radio environment, and these dynamics were taken into account in characterizing the propagation environment.

1.5 Scope

This research only focused on uplink transmission (i.e. from mobile station to the base station) and consideredboth empirical and analytical components of the system.The field measurement datawere collected from a single WCDMA network provider in Nigeria called GLO. Data were collected from a total of 5base stationsstudied for a period of six months. Coveringthethree seasons of the year namely: raining, harmattan and dry season. Signalto Interference Ratio (SIR) based evaluations were used to develop the algorithm as against Received Signal Strength (RSS) evaluations since WCDMA is interference limited. The developed algorithm was simulated using Matlab.The power control methodpresented in this dissertation can be applied to CDMA systems in generaland WCDMAin particular.

1.6 Dissertation Outline

This dissertation was explicitly concluded and organized in five chapters. Chapter one provided introduction of the focus of the research by elaborating on the background of the research, the problem statement, objectives, justification and scope of the research. In Chapter two a preview of previous works that gives the theoretical frame work for this research was done. Fundamentals of wireless communication, propagation environment, propagation models, UMTS architecture, Power controltechniques and algorithms were all reviewed in this Chapter.Chapter three presented the methodology used in achieving the objectives of this research, the research test bed used information, the presentation of empirical measured field data, the analysis of data collected, the characterization of the test bed environment, the chapter was concluded with the development of Modified Adaptive Power Control Algorithm (MAPC). Besides Chapter four presents the implementation of the developed Algorithm (MAPC) and the validation of the developed Algorithm. Finally, Chapter Five provides information on the conclusion of the work, contribution of the work to knowledge, recommendations and suggestion for further research work on power related issues in mobile communication system.

CHAPTER TWO

LITERATURE REVIEW

2.1 Fundamentals of Cellular Systems

Mobile communication radio networks are also known as cellular networks. These networks provide a wireless connection for communication, for the users within the radio range of the network. These regions of radio coverage are termed as cells. The length and dimensions of each cell are dependent upon the system configuration and the transmission power levels of its serving Base Station (BS). A cellular network constitutes multiple cells grouped together in a specific manner to form different tessellations. In wireless communication systems, especially considering the cellular networks, the radio resources are scarce and expensive. The goal is to use the available radio resources sensibly and repeatedly without compromising theoverall service performance of the system. The implementation of different radio access techniques, or the reuse of all set of radio resources (frequencies) after certain distance, can provide solutions to this problem (Sultan, 2010)

The cellular network basic infrastructure consists of Base Transceiver Stations (BTS) otherwise called base stations (BS), Mobile Stations (MS), and most likely also network elements that multiplex the traffic from multiple base stations to transport the traffic in the backbone network. Mobile stations are connected to the base stations via radio links, and the base stations in turn either connect to other base stations or other collective nodes.The terminology cell site is used for the location comprising the base station site equipment (transceiver, antennas, cables and mast). Cell relates to the coverage area of a base station antenna (Jari, 2010).

One of the ways commonly applied to increase the cellular system capacity is sectorizaton, in which a BS site is split in narrower coverage areas by directional antennas. Although sectorization requires more base station equipment, it is widely used in modern cellular systems, since it has been proven to reduce the overall interference in the network, and thus increase capacity. Sectorization has been seen particularly useful in areas with high traffic density(Jari, 2010).When the user is located at the cell edge, and is on the way to change to the coverage area of the neighboring cell, it is desired to maintain the connection during thetransfer to the new cell. The procedure used for serving seamless cell change (toprovide mobility) is called a handover. Basically, a handover is triggered when certain threshold values are reached in the received signal level from the base stations participating in the handover. Handover is called hard handover, when the connection an MT made to previous serving base station is disconnected before connecting to the new BS. In this case, some buffering may be needed in the network elements to maintain the handover seamlessly, and also the handover should occur in such a short time frame that it is hardly noticed by the user. In soft, or softer, handover connections are maintained in the cell edge region to two or more base stations, or sectors, respectively. Handovers may also be divided into inter-system or inter-frequency handovers, which are in practice called hard handovers(Jari, 2010).

The need of having a cellular network is to be able to get good coverage with mobility and at the same time to achieve enough user capacity for the whole system, without compromising the quality of the services provided by the system. These targets are met by distributing the large geographical area of interest into multiple smaller regions (or cells) each with its own set of allocated resources. However in actual practice a cell is overlapped by its adjacent cells at the edges. Still the regular shape of the cell must be known; "for systematic system design and adaptation for the future growth" (Rappaport, 2007). Hence, some of the possible geometrical structures for a cell can be: a quadrilateral (preferably a square or a rectangle), an equilateral triangle and a hexagon as shown in Fig 2.1.

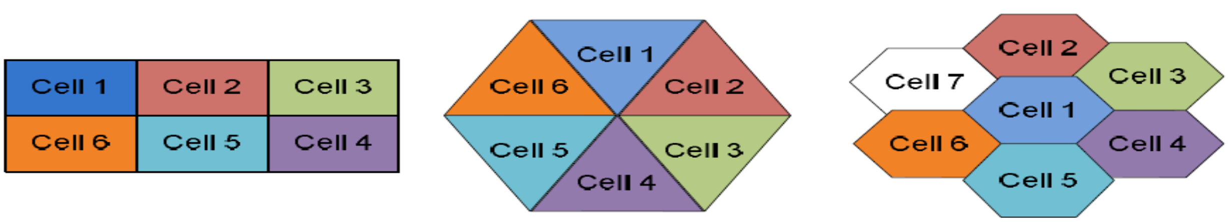


Figure 2.1: Different cellular structures (square, equilateral triangle, hexagon) (Sultan, 2010).

There are various types of cellular systems such as macro, micro and pico cells as shown in Fig 2.2

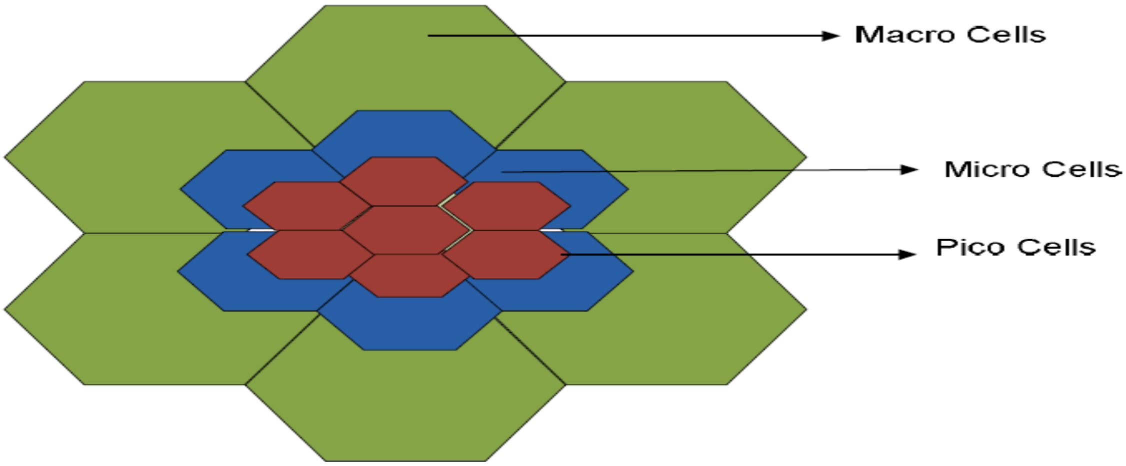


Figure 2.2: Combination of macro, micro and pico cells (Sultan, 2010).

- Macro cells have the largest horizontal radius ranging from 2 km up to several 20 km's. These types of cells provide the largest coverage region. The BS antenna associated with these cells is placed well above the rooftop level or at the height which provides clear line of sight (LOS) of the surrounding or the terrain. It is deployed in low traffic density areas such as highways, remote towns and villages.
- Micro cells have the coverage area less than the macro cells. They have the horizontal radius ranging from several hundred meters to few kilometers (i.e. 2 or 3 km). The height of the BS antenna associated with these cells is below the average rooftop level, It is deployed in high user traffic density such as urban streets and city centres (Sultan, 2010).
- Pico cells have very limited area to serve within their coverage zone. The pico cells are typically used for indoor applications. The behavior of pico cells could be analogous to WiFi or hotspots (Rappaport, 2007).

The horizontal radius of these cells: macro, micro and pico varies depending upon the BS antenna height, antenna gain and radio propagation conditions considering the interference level within the tolerable limits. Mostly, different types of cells are used in combination with each other in order to enhance or improve the coverage or capacity of the system (Sultan, 2010).

2.1.1 CellSectorization

The cells are sectored or split up into much smaller cells or sectors to enhance the capacity of the system by limiting the co-channel and adjacent channel interference. When the number of users in a large cell increases more than the threshold of the cell, the large area of cell is split or sectored into few sectors. Hence, this limits the interference levels within the tolerable limits and provides better manageability of the system. The cells are sectored, based on their serving antenna design i.e. the beam width of their BS antenna, as shown in Fig 2.3.

(a)

(b)

Figure 2.3: Graphical image of sectorial antennas serving 3 sectors [Source: Author]

The cells can be center excited as in case of omni-directional BS antenna, but in common practice the cells are corner or edge excited, as it provides better immunity to co-channel interference (Rappaport, 2007).

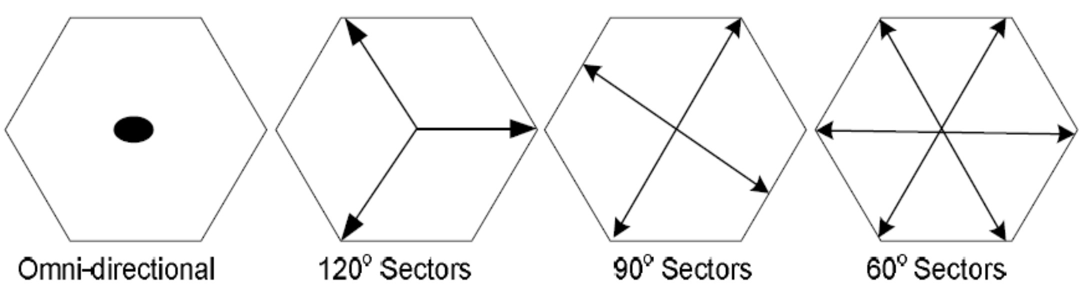


Figure 2.4: Cell sectoring through BS antenna beam width (Rappaport, 2007).

2.1.2. Cellular reuse concept

In a cellular network, the combination of two or more cells results in the formation of the clusters. In each cluster pattern, generally each cell is operating in a different group of radio frequency channels, and it is necessary that all the available groups of radio frequency channels are repeated in a single cluster. The clusters can be repeated as many times as necessary to provide coverage over the entire area but they should not overlap each other as shown in Fig 2.5 to avoid the interference (Sultan, 2010)

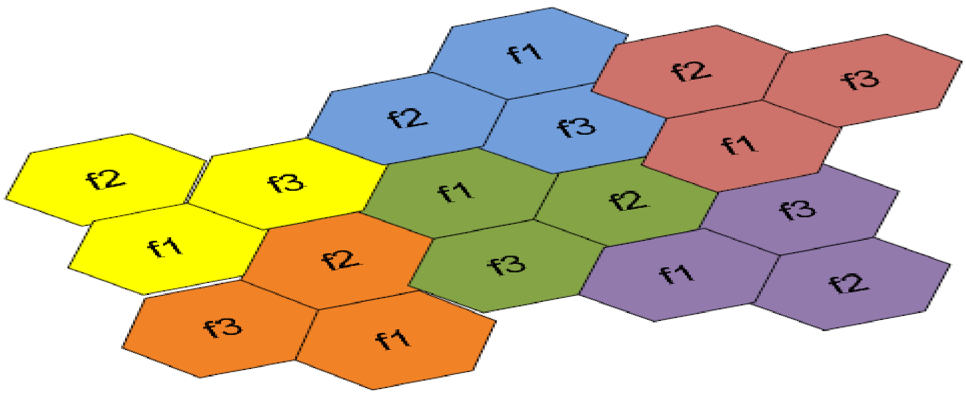


Figure 2.5: Six clusters of cells with cluster size of 3,(Sultan, 2010).

The idea of repeating clusters leads to the need for better management of frequency channels in the network. The frequency reuse or planning is the design process of selecting and allocating the available frequency channel groups (or frequencies) to all the BSs in a cellular network in a sensible manner. The margin of frequency reuse in cellular networks is defined by the frequency reuse factor, which defines how often the group of frequencies can be repeatedly utilized. It also provides the information about the repetition of the clusters. The frequency reuse factor depends upon the morphology and topology of the radio propagation environment and the implementation of radio network configuration (Rappaport, 2007).

A properly chosen frequency reuse factor assists in improving the overall spectral efficiency of the system. In Frequency Division Multiple Access-Time Division Multiple access (FDMA-TDMA) based networks such as Global System for Mobile Communication (GSM), the performance is entirely dependent on the frequency reuse efficiency. In GSM networks, the allocated frequency band is grouped into smaller frequency sub-groups and reused over the whole coverage area. The frequency reuse factor in this case provides the appropriate distance, after which the same frequency sub-group (that has been used earlier) could be reused in the nearby cell present in the different cluster. Thus, the frequency reuse distance in fact provides the cluster size i.e. after some long distance the same cluster of frequencies can be repeated (Lempiainen and Manninenl,2003).

In CDMA or WCDMA based networks such as Universal Mobile Telecommunication Systems (UMTS) the same frequency band is used in all cells. The cells and users are all separated from each other by unique pseudo random codes. The frequency reuse factor in these networks is always one. Therefore the capacity in these systems also depends on the available number of pseudo random codes. However, the capacity in WCDMA systems is interference limited, because all the users interfere with each other in both uplink and downlink resulting in co-channel interference (both in uplink and downlink) (Sultan, 2010)

2.1.3 Interferences in Cellular Systems

(a) Co-channel interference

Co-channel interference is caused by two users operating at the same frequency but located at some distance away. This is due to use of same frequency in two GSM or WCDMA or Long Term Evolution (LTE) cells at some distance away. This re-use of same frequency causes interference to another mobile at distant cell. In order to make re-use of the precious frequency spectrum, telecom operators employ RF planning and keep the power levels such that one cell's signal does not interfere with another cell's signal in the same band. If the levels are not properly maintained it creates a problem as the signal pass through RF filters easily as it is in the pass band of the designed filter.

In WCDMA networks, both the users and neighbouring BSs are distinguished from each other by unique pseudo random codes. However, these unique pseudo random codes lose their orthogonality(either partially or completely) due to the effects of multipath propagation and some other BSs transmit power related issues. Hence, the adverse effects of multipath propagation contribute to co-channel interference in both uplink and downlink directions as shown in Fig 2.6. Both the uplink and downlink co-channel interference as shown in Fig 2.6 can be categorized as inter-cell interference (or other cell interference) and intra-cell interference (or own cell interference), F1 is the BS (LempiainenandManninen, 2003).

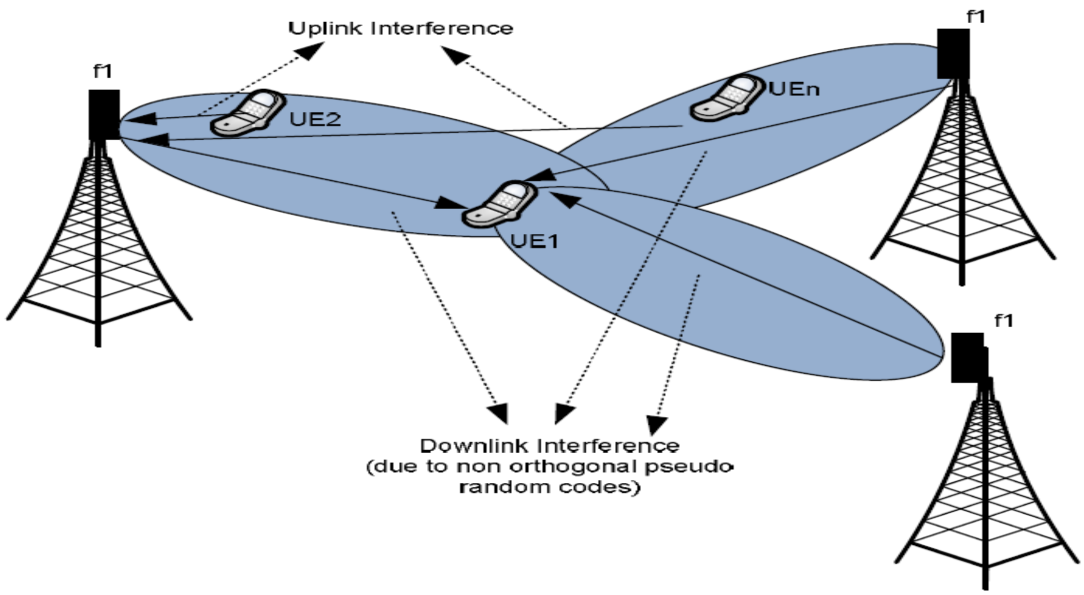


Figure 2.6: Uplink and downlink co-channel interference in WCDMA network (Lempiainenand Manninen, 2003).

(b) Adjacent Channel Interference

Adjacent Channel Interference is caused by adjacent channel frequency at some distance from the wanted carrier frequency. The other cell interference in uplink direction exists in the system because all the active UEs (user equipment) in the system transmit power in all directions. Although, the transmit power levels of the UE's are controlled by the power control commands from their serving BSs. However, transmit power of UEs from different (nearby) cells leaks into other cells and contribute in other cell interference in uplink. In downlink, the other cell interference is due to the leakage of transmit power from BSs in other cells. The own cell interference in the system is due to the rise in noise floor in uplink because of the different transmit power levels by different users in the network. Moreover, the channel interferences (i.e. own cell interference and other cell interference) are also at times bolstered by the characteristics of the radio propagation environment (Lempiainenand Manninen, 2003).

2.1.4 Handover in Wireless Communication System

The cellular concept presents the idea of mobility for users within different cells or network in a cellular system. In UMTS or in any network, the user based mobility issues are controlled by network based events called handovers (Panu, 2006). In UMTS, the handover

control supports different types of handover procedures such as HHO (hard handovers) only possible in HSPA, SHO (Soft handovers) and SFHO (Softer handovers) (Sultan 2010).
The term handover refers to the process of transferring an ongoing call or data session from one channel connected to the core network to another. There are different handover scenarios that are supported by Universal Mobile Telecommunication System Terrestrial Radio Access Network (UTRAN) .The type of handover is dependent on whether the handover is within the same node B, different node B, different UMTS frequencies or even handover between UMTS and GSM or Digital Cellular System (DCS) (Eheduru, 2013). The handover control can be divided into the following handover types:

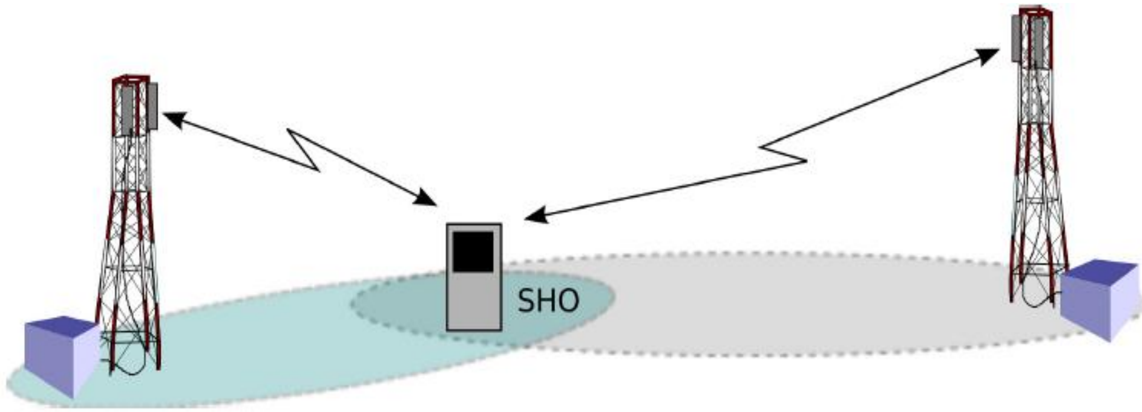
(i) Intra-system Handover: This occurs within a WCDMA system. It can be further subdivided into:

- Intra-frequency Handover, which is between cells belonging to the same WCDMA carrier.
- Inter-frequency Handover, which is between cells, operated on different WCDMA carriers.

(ii) Inter-system Handover: This takes place between cells belonging to two different Radio Access Technologies (RATs) or different Radio Access Modes (RAMs). This is very common between WCDMA and Global System for Mobile communications/Enhanced Data rates for GSM Evolution (GSM/EDGE)systems (Eheduru, 2013).

(iii) Hard Handover (HHO): Hard handover occurs when the radio links for a UE changes and there are no radio links that are common before the session is initiated and after the session is completed. It could be said to be a procedure in which all the old radio links of a UE are released before the new radio links are established (Eheduru, 2013).

(iv) Soft Handover (SHO): These are handover procedures in which the UE always keeps at least one radio link to the UTRAN. In soft handover, the UE is simultaneously controlled by two or more cells belonging to different Node BS of the same RNC or different RNCs (Eheduru, 2013).The SHO region is defined as the overlapping region between different cells. The users in SHO region utilize the resources of all the cells participating in SHO process. The readily participating cells are placed in an active set. However, the neighbour set or monitor set consists of the continuously monitored cells. The cells in neighbour or monitor sets replaces the bad performing cells in the active set. In certain situations, the SHO provides gain, known as macro diversity gain (Sultan, 2010).



BS **BS**

Figure 2.7: Soft handover between two cells(Jari, 2010)

(v) Softer handover (SfHO): In SfHO, a mobile user is simultaneously connected to two or more different cells/sectors controlled by the same BS (NodeB). SfHO is similar to the SHO procedure. However, in both SHO and SfHO, the mobile user shares resources from more than one cell thus reducing the overall radio capacity of the cell (and network also) if there is no efficient power control system (Sultan, 2010). BS

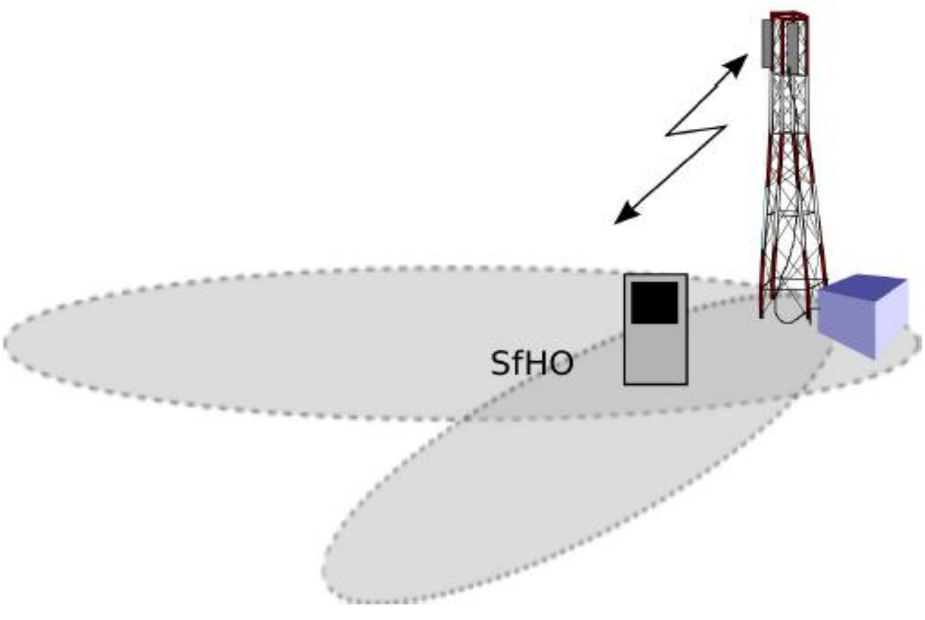


Figure 2.8: Softer handover between two sectors (Jari, 2010)

2.1.5. Congestion Control in Wireless Communication

The capacity in UMTS is interference limited. Therefore, a large number of users can overload the system resulting in the performance degradation. Congestion control mechanisms are used to keep air interface load below pre-defined thresholds. These control mechanism are employed in order to optimize the quality and capacity of the UMTS network (Lempiainenand Manninen, 2003). It is of paramount importance to keep the air interface load in WCDMA systems under predefined thresholds. This is because excessive loading prevents the network from guaranteeing the needed requirements. This could lead to the planned area of coverage not being provided, lower capacity than is required, degraded quality of service and an unstable network condition. Congestion control functions are divided into three (Eheduru, 2013).

(i) *Admission Control*: This handles all new incoming traffic and checks whether a new packet or circuit switched Radio Access Bearer (RAB) can be admitted to the system .Admission control consists basically of two parts. For Real Time (RT) traffic, i.e., the delay-sensitive conversational and streaming classes, it must be decided whether a UE is admitted into the network. If the new radio bearer would cause excessive interference to the system, access is denied. For None Real Time (NRT) traffic (less delay-sensitive interactive and background classes) the optimum scheduling of the packets (time and bit rate) must be determined after the RAB has been admitted. This is done in close cooperation with the packet scheduler.

(ii) *Load Control*:The task of load control is to avoid the overload condition by maintaining all the existing connections at defined level of quality. But in case of overload condition, the load control algorithm follows a well-defined set of rules to re-achieve the targeted load in order to avoid the deterioration in the performance of the system (H. Holma, A. Toskala, 2007).

(iii) *Packet Scheduling*: This handles all the NRT (Non-Real Time) traffic - i.e., packet data users. In general, it decides when a packet transmission is initiated and the bit rate to be used.

2.2 Multiple Access Technology in Wireless Systems

The main aim of designing any cellular communication radio network is always to provide uninterrupted QoS (quality of service) to all the active users in the cell, using all the available radio resources as efficiently as possible. Since the radio spectrum is scarce and expensive, the available radio resources are to be shared between all users in the system. In any mobile communication system, coverage and capacity are key parameters which are mainly dependent on the SIR and bandwidth of the access technology used to share the transmission medium (radio interface) (Ali, 2010). There are several different access techniques in which multiple users could send information through the common channel to the receiver. 2G systems used TDMA and FDMA techniques for radiointerfacewhereas Code Division Multiple Access(CDMA)technique was employed by 3G systems. In TDMA, all users transmit using the same frequency but the data are multiplexed in short consecutive time slots. In FDMA, the frequency spectrum is divided into small sub-frequency channels and user data are multiplexed on these channels at the same time (Ali, 2010).

In FDMA and TDMA the common channel is partitioned into orthogonal single-user sub-channels. A problem arises if the data from the users accessing the network are busty in nature. A single user who has reserved a channel may transmit data irregularly so that silent periods are even longer than transmission periods. For example, a speech signal may contain long pauses (Jaana, et al, 2006). In such cases TDMA or FDMA tend to be inefficient because a certain portion of the frequency - or of the timeslots - allocated to the user carries no information. An inefficiently designed multiple access system limits the number of simultaneous users of the common communication channel. One way of overcoming this problem is to allow more than one user to share the channel or sub-channel by the use of spread spectrum signals (Jaana,et al, 2006). In this method, each user is assigned a unique code sequence or signature sequence that allows the user's signals to be spread on the common channel. Upon reception, the various users' signals are separated by cross-correlating each received signal with each of the possible user signature sequences (Jaana,et al, 2006). By designing these code sequences with relatively little cross-correlation, the crosstalk inherent in the demodulation of the signals received from multiple transmitters is minimized. This multiple access method is called Code Division Multiple Access (CDMA) (Eheduru, 2013).In CDMA technique, all users transmit simultaneously in the same frequency channel but are separated by different orthogonal codes. The multiple access schemes are presented in Fig 2.9.

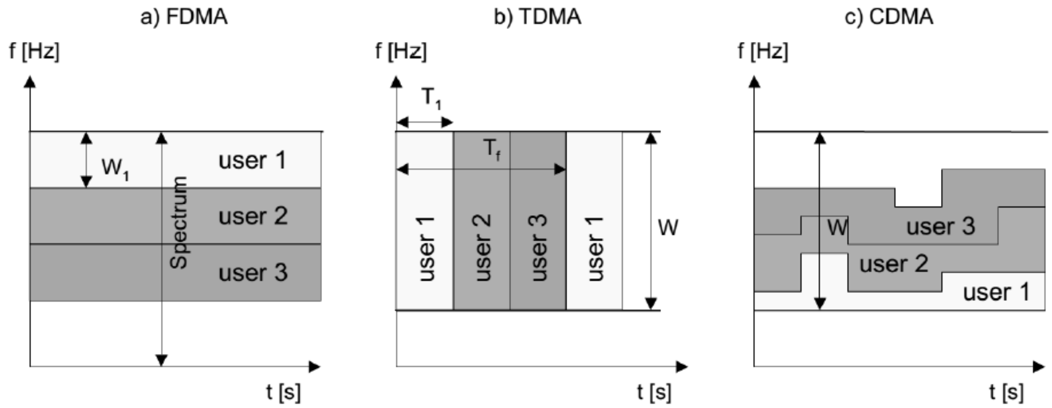


Figure 2.9: Multiple Access Schemes (Jaana, et al, 2006).

As part of 3GPP standardization, Wideband CDMA (WCDMA) was selected to be the radio interface for UMTS (Ali,2010). WCDMA is based on Direct Sequence CDMA (DS-CDMA) technology which has two modes of operation ; WCDMA-Time Division Duplexing (TDD) and WCDMA-Frequency Division Duplexing (FDD) (Eheduru, 2013).

2.3 Wireless Propagation Environment

In cellular communication systems, the radio propagation environment is defined as the surroundings of the path chosen by the radio signal to travel between the transmitter and the targeted receiver. There are different types of the propagation environments based on the terrain types i.e. if there is LOS (line of sight) path or the radio path is severely obstructed by buildings or other obstacles (Rappaport, 2007). The general categorization of the propagation environment is shown in Fig 2.10

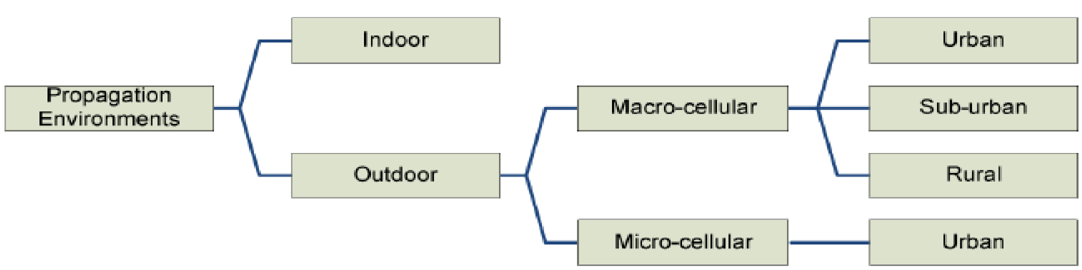


Figure 2.10: Classification of propagation environments (Ali, 2010).

The outdoor propagation environment is further divided into two; macro cellular and micro cellular. This division is based on the placement height of BS antenna. The outdoor macro cellular environment is further break down into urban, sub-urban and rural areas based on the morphology of the terrain and the density of the obstacles in the radio path. In macro cellular environment the height of the BS antenna is above the average roof top level. However, the height of BS antenna for micro cellular environment is below the roof top level. The micro cellular networks are usually deployed in the region with the large number of buildings and high user density. The Pico cellular deployment is used to provide cellular communication in indoor environment such as closed alleys, hallways, within buildings or malls. The BS antennas in indoor environment are deployed in such configuration, that they minimize the strong attenuation faced by the signal from the walls, floors, ceilings and other obstacles in the coverage area and improve the capacity of the system (Sultan, 2010).

2.3.1 Multipath Propagation

Multipath propagation occurs, when the same transmitted signal arrives to the receiver in different time instances. The mechanism that plays a role in multipath propagation includes: reflection, scattering and diffraction, which are illustrated in Fig. 2.11.

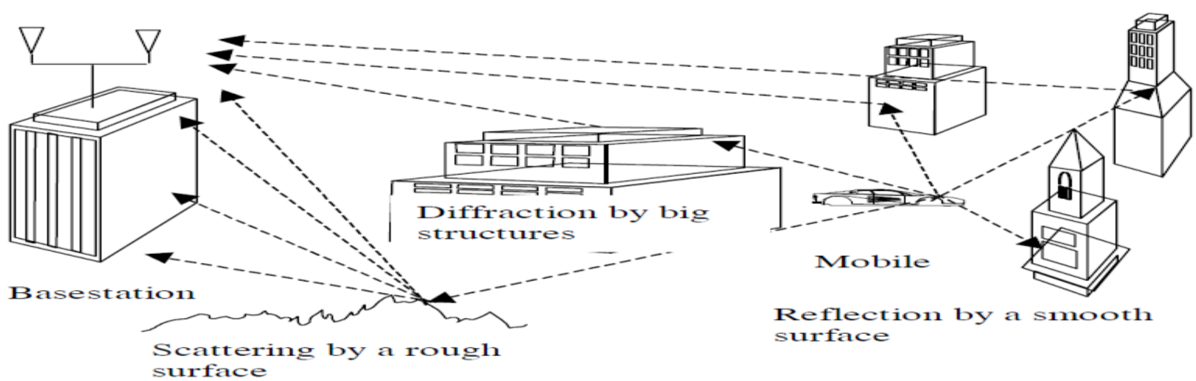


Figure 2.11: Illustration of wireless propagation mechanisms (Adit 2003).

Reflection occurs when a radio wave encounters a surface that is large relative to the wavelength of the signal. An example of reflection could be a ground-reflected signal from a base station to a mobile. Reflection causes a 180 degrees phase shift to the electromagnetic signal, which may cause signal cancellation to the reflected signal arriving at the receiver antenna with the LOS component. On the other hand, the path length of the reflected signal may cause noticeable delay relative to the unreflected signal. If the path delay equals to half a wavelength, the two signals are back in phase, and thus are received constructively in the receiver antenna (Stallings, 2001). When a radio wave encounters anobstacle that is in order of the signal wavelength or less, it scatters into several weaker components. In mobile communications, there are several obstacles in this size scale, such as lamp posts and traffic signs. Scattering is very hard to predict, because the amount and places of obstacles may vary a lot in time in every propagation environment (Stallings, 2001).

Diffraction occurs when the signal is passing a sharp edge that is large compared to the signal wavelength. Diffracted signal changes its direction but not its phase. Due to diffraction signal reception is possible even without a LOS component of the signal.Multipath propagation can be presented with impulse response, and the key figure describing multipath properties of a propagation environment is delay spread. Delay spread is the time difference of first arrived line-of-sight component and last arrived 'echo' of the signal. The multipath propagation effect is especially strong in urban environment with a lot of dynamics and high concentration of small obstacles (Stallings, 2001).

In CDMA systems, a RAKE receiver is used to mitigate multipath propagation effects. It tries to recover the signals from multiple paths and combine them with suitable delays. A RAKE receiver is illustrated in Fig. 2.12. First a transmitted data is spread with a spreading code and modulated for radio transmission. In the propagation channel multiple copies of the signal are generated with different time delays and attenuation factors. The receiver sees the multiple copies of the signal as a sum of multipath components, and demodulates the multipath propagated signal. In a RAKE receiver the demodulated chip stream is fed to multiple correlators with different delays. Each correlated component is then weighted with factors that are estimated from the propagation channel, and finally the weighted signals are combined as one (Stallings, 2001)

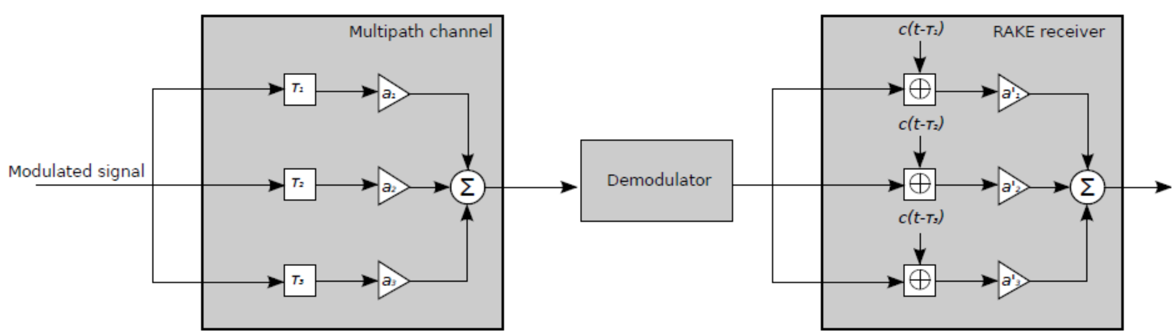


Figure 2.12: Rake receiver (Stallings, 2001).

2.4 Propagation Losses/Fading

Fading is described as the fluctuation of the amplitude of the mobile signal in a short period of time. Fading is caused by the addition of two or more versions of the same transmitted signal arriving at the receiver at different times. The effect of multipath fading on the amplitude and the phase of the received signal depend on the propagation time, intensity, speed and the bandwidth of the signal (Soheil,2000**).**The signals arriving at the base station are therefore a combination of signal paths with different amplitudes and time delays (phases). The superposition of these paths may be constructive or destructive, depending on the phase differences between all the arriving paths. If the user and structures that make up the propagation environment are stationary, the received signal level at a certain fixed point will be constant. However, this constant level may differ for different points, depending on the relative position between user and base station (spatial variation). When a user is in motion, the multipath mechanism is further complicated by continuous changes in the propagation paths, resulting in the received signal to fluctuate as a function of time (time variation). The received signal from a stationary user may also vary if one or more scattering or reflecting objects are in motion (Adit, 2003).

In addition to the rapid signal fluctuation, the received signal also decays dramatically with increasing transmitter-receiver separation distance because of severe path loss. This path loss also may vary from area to area due to the shadowing effect. Therefore, a signal propagating through a mobile channel will experience a large attenuation, shadowing variation, and multipath fading, which will result in an overall path loss. The total path loss$L(t)$ is calculated using equation (2.1) (propagation equation) expressed in dB (Adit, 2003)

$$L(t) = L_p(d) + m(t) + \beta(t) \tag{2.1}$$

Where,

$L_p(d)$ =Mean path loss as a function of the transmitter-receiver separation distance d

m(t) = Shadowing variation and

β(t) = fading fluctuation.

It will be more convenient for power control purposes to classify the overall path loss expressed in equation (2.1) into two categories:

- Large-scale propagation loss which is normally represented in terms of the mean path and its variation around the mean due to shadowing. The mean path loss and its variation are expressed in the first two terms of equation (2.1) respectively.

- Small-scale propagation loss that refers to rapid and dramatic changes of signal amplitude and phase due to the multipath phenomena. It is characterised by deep and rapid fades, which are very localised. Indeed, the fading characteristics of two signals received at locations distant from half a wavelength are statistically uncorrelated.

If the propagation loss is fairly constant over a large area, it is labelled as large-scale propagation loss. In the contrary, if the propagation loss changes dramatically within a small area, it is labelled as small-scale propagation loss. The adjectives small and large are defined as compared to the wavelength of the transmitted signal (Adit, 2003).

This classification is important because power control scheme to overcome the large-scale propagation loss is different from that for the small-scale propagation loss. The large-scale propagation loss can employ a slow open-loop power control while the small scale propagation loss uses a fast closed-loop algorithm. The two types of propagation loss are reviewed in more details below, which will help in understanding the importance of power control in wirelesscommunication.

2.4.1Large-Scale Propagation Loss

In an ideal situation where only the direct path between the transmitter and receiver exists, the received signal can be analytically determined using the free-space path loss formula. In this model, the mean path loss $L_p(d)$ is proportional to an nth power of distance d relative to a reference distance d_0, which is expressed in decibel (dB) as in equation (2.2) (Hata, 1980, Adit 2003):

$$L_p(d) = L_{d_0} + 10\eta\, Log_{10}(\frac{d_i}{d_0}) \quad (2.2)$$

Where,

L_{d_0} = the mean path loss at a reference distance d_0,

η= the path loss exponent and

d_i= distance whose path loss is measured

The value of path loss exponent ηdepends on carrier frequency, antenna height, and propagation environments. In urban areas, path loss exponent is shown to be n = 4 or greater.

Most empirical studies show that large-scale path loss has a log normal distribution due to shadowing. In this case, when the average received signal level is measured in dB, it follows a normal (Gaussian) distribution. Therefore $m(t)$ in (2.1) is a zero-mean Gaussian variable in dB with standard deviation σ*m*. Measurements have shown that a σ*m*between 6 and 10 dB is quite

common in most urban areas. The statistics of large-scale scale propagation loss are often required to determine various design parameters in a cellular mobile communications system, such as reliability of service, hand-off, and cell coverage (Adit, 2003).

Another important aspect of large-scale propagation statistics is that the mean path loss is reciprocal between the uplink and the downlink channels. Therefore, one can predict the large-scale path loss on the uplink using measurements of the downlink signal. This is a very important property, which is used to justify an open-loop power control device to compensate for the large-scale propagation loss.

2.4.2 Small-Scale Propagation Loss

Small-scale propagation model is important to explain the effect of multipath propagation not only on rapid amplitude fluctuation, but also on time dispersion of the received signal (time-shifted copies of the same signal). As has been mentioned earlier, the received signal is a superposition of all signal paths with various amplitudes, phases (or time delays), and angle of arrivals as a result of reflection, diffraction, or scattering of a transmitted signal through the propagation environment. There are two manifestations of multipath propagation:

• Amplitude fluctuation due to constructive or destructive superposition of the incoming signal paths (time-variant channel).

• Time dispersion (time spreading) of the received signal because of different arrival time instants of different paths (Adit, 2003).

A mathematical model to describe the received multipath signal can be determined as follows. Let the transmitted signal be $x(t)$ which can be expressed asin equation (2.3) (Adit, 2003).

$$x(t) = s(t)e^{j(2\pi fct)} \quad (2.3)$$

Where$s(t)$ is the complex baseband signal with bandwidth W, $f_c = c/\lambda$ is the carrier frequency, c is the speed of light, and λ is the wavelength of the radio frequency (RF) signal. The received signal $r(t)$ as the superposition of L multipath components can be expressed as in equation (2.4)

$r(xt) = \sum_{l=1}^{L} C_l s(t - \tau_l)\, e^{j2\pi[(f_c + f_D \cos\psi_l)t - f_c\tau_l]}$ (2.4)

Where,$C_l$is the fraction of the *l*th path of the incoming signal amplitude, $\tau_l$is the *l*th path delay, f_D= *v/*λ is the maximum Doppler spread, and ψ*l*is the direction of the *l*thscatterer with respect to the mobile velocity vector, *v*. The small-scale propagation loss can be evaluated in both the time domain and frequency domain.

(a) Time Domain Small Scale Propagation Loss

In the time domain, multipath fading comes from two different aspects: time spreading of the signal and time varying of the channel.Also in the signal time spreading aspect, the multipath fading is classified into frequency selective fading and a frequency nonselective (flat) fading. While in the channel time-varying aspect, the multipath fading can either be a fast fading or a slow fading.

- **The Time spreading of signal loss**

The time spreading of signal due to multipath channel can be characterized by using a multipath-intensity profile, S(τ) versus time-delay, τ. The multipath delay spread, τ_m, is defined as the difference of time-delay between the first arrival of multipath component (τ = 0) and the last arrival component ($\tau = \tau_m$). All signal paths arriving at the receiver can be considered as a wide-sense stationary uncorrelated scattering (WSSUS) model (Adit, 2003). When the channel has $\tau_m$greater than the symbol time, T_s, the multipath channel will exhibit a frequency-selective fading. Intersymbol interference occurs when the received multipath components of a symbol extend beyond the symbol-time duration.

In addition to ICI (Inter chip interference) distortion, a signal transmitted through a frequency-selective fading channel will suffer from amplitude fluctuation due to constructive and destructive superposition of multipath components. A channel with $\tau_m << T_s$is called a frequency nonselective or flat-fading channel, in which all multipath components of the received symbol arrive at nearly the same time-instant and fall within the symbol-time duration, hence only amplitude fluctuation experienced by the received signal (no ICI distortion).

In the frequency domain, a channel is characterized by a spaced-frequency correlation function, |ρ(Δ*f*)|, which is the Fourier transform of *S*(τ) and behaves as the channel's frequency transfer function. The frequency correlation function can be thought of as the channel frequency-response. The channel coherence bandwidth, W_0 is defined as the frequency within which the channel passes all the spectral components with approximately equal gain and linear phase. A channel is said to exhibit frequency selective fading if W_0 is much less than the signal bandwidth W, because the signal's spectral components is affected by the channel with unequal channel gains resulting in signal distortion. If $W_0 >> W$ the channel is said to have a frequency nonselective fading because all signal's spectral components have an equal channel gain. Bearing in mind that $\tau_m$and W_0 are reciprocally related, in that a channel with a large multipath delay-spread will have a low coherence-bandwidth.

The relationship between the time spreading of signal represented by multipath intensity profile (time domain) and channel coherence bandwidth (frequency domain) is shown in Fig.2.13.

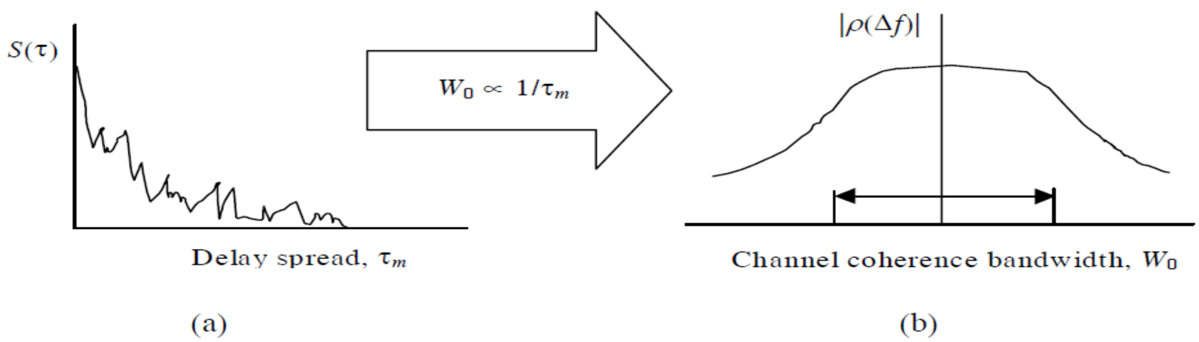


Figure 2.13: Relationship between time spreading of signal and channel coherence bandwidth: (a) Multipath intensity profile; (b) Spaced-frequency correlation (Adit, 2003).

In a frequency-selective fading channel, the signal degradation (distortion) is not only the loss of Signal Noise Ratio (SNR) due to amplitude fluctuation, but also ICI distortion due to a large delay spread. It is important to see the impact of a frequency selective channel on a CDMA signal. In most cases, when the spreading gain is large enough, a frequency selective channel will only lead to ICI, in which the multipath components extend on a number of chips smaller than the spreading factor (the number of chip per symbol). During a symbol interval, there will be mostly ICI and a little amount of inter symbol interference (ISI) at the beginning and the end of the symbol interval. In this case, the Rake receiver will make use of frequency diversity of the various multipath components and will provide very good performance. In other words, if one multipath component is affected by a deep fade, it is unlikely that the other multipath components will experience the same fading condition. However, the existing ICI even though it is small will lead to additional multiple access interference and therefore, power control is important even though not as crucial as in a flat fading situation. For flat fading channels, only one resolvable multipath component exists for each symbol and power control plays an important role because the rake receiver cannot make use of frequency diversity. In practice, CDMA systems employ several techniques to combat various effects of multipath fading (Adit, 2003).

A summary of multipath fading characterization, types of degradation, and mitigation techniques viewed in the time and frequency domains when the effect of fading is considered as a signal time-spreading is shown in Table 2.1.

Table 2.1 Manifestation of multipath fading as time spreading of signal (Adit, 2003).

Characterisation	Frequency selective fading	Flat fading
Time domain	$\tau_m >> T_s$	$\tau_m << T_s$
Frequency domain	$W_0 << W$	$W_0 >> W$
Signal degradation	ISI, loss of SNR	Loss of SNR
Mitigation	Channel equalization, spread spectrum (Rake),Orthogonal Modulation (OFDM).	Diversity, error control, power control.

ii. Time Varying of the Channel Signal Loss

The time varying manifestation of multipath fading can be seen in the time domain as a result of the motion between the transmitter and the receiver. We can also consider that the time variation of the channel is equivalent to the spatial variation because the channel time variation depends on the relative positions between the transmitter and the receiver (spatial variation). The time varying channel in the time domain can be characterized by the spaced-time correlation function, $\rho(\Delta t)$, defined as the autocorrelation function of the channel as shown in Fig. 2.14(a). Using the spaced-time correlation function of the channel, we can define the channel coherence time, T_0, as the time duration over which the channel response is time-invariant due to high autocorrelation within that time duration (Adit, 2003).

If the channel coherence time T_0 is much less than the symbol-time duration Ts, the channel is referred to as a fast fading channel, which implies that the channel exhibits time variation within a symbol-time duration. If $T_0 >> T_s$, the channel is defined as a slow fading channel, or the channel remains time-invariant for at least within a symbol-time duration. A symbol transmitted through a slow fading channel will not be distorted because the channel gain is approximately constant during a symbol period. However, a time variation of a slow-fading channel will result in a loss of SNR due to signal fluctuation over several symbols. In a fast-fading channel, a transmitted symbol suffers from unequal channel gains within the symbol period, leading to a pulse-shape distortion. The problems caused by such distorted pulses are not only a loss of SNR, but also loss of symbol synchronization and difficulties of designing a matched filter (Adit, 2003).

When viewed in the frequency domain, the time-variation of the channel can be characterized by the Doppler spread of the channel. The Doppler power-spectral density, $S(\upsilon)$, defined as the spectral broadening or Doppler spread of the channel, is used as a measure of fading rapidity of a time-varying channel. The Doppler power-spectral density can be expressed as (Adit, 2003).

$$S(\upsilon) = \begin{cases} \frac{1}{\pi f_D \sqrt{1-\left(\frac{\upsilon}{f_D}\right)^2}} & |v| \leq f_D \\ 0, & \text{otherwise} \end{cases} \qquad (2.5)$$

Where, $f_D$is the maximum Doppler spread, and υ is Doppler-frequency shift. The Doppler power-spectral density as a function of υ described in equation (2.5) has a bowl shape as shown in Fig 2.14.(b).

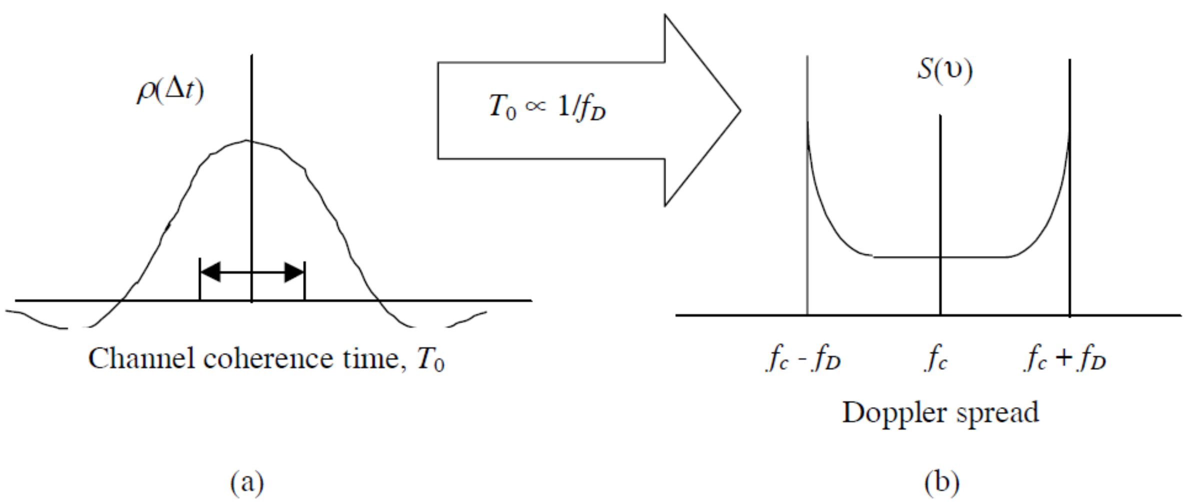


Figure 2.14: Relationship between Doppler spread and channel coherence time: (a) Spaced time correlation function; (b) Doppler power spectral density.

(b) Frequency Domain Small Scale Propagation Loss

The multipath fading in frequency domain is considered as the frequency response of a channel (transfer function) and as the Doppler spread of a channel. While frequency selectivity of a channel can be easily understood using the frequency response, time selectivity (fading rapidity) is more obvious from the Doppler spread evaluation (Adit, 2003).

In frequency domain, a time-varying channel is said to exhibit a fast-fading mechanism if $f_D >> W$ because the fading rate (represented by f_D) is higher than the symbol rate represented by the signal bandwidth, W). A fading channel with $f_D << W$ is referred to as a slow-fading channel. Viewed in frequency domain, fast fading causes a pulse-shape distortion on the transmitted symbol because the channel fading rate is higher than the signal bandwidth. Of course fast fading also causes the loss of SNR due to amplitude and phase fluctuation. The mitigation techniques that can be used to combat fast fading are error control and interleaving, robust modulation, and the use of signal redundancy to increase the signaling rate. Ideally, power control could be used to compensate for the loss of SNR. However, the problem of power control command delay, makes it unsuitable for fast fading applications.

On the other hand, a slow fading channel may only suffer from the loss of SNR and can be mitigated by power control. It is important to note that in a slow fading channel, the use of error-control coding is not effective due to long burst errors. In this case, the required time frame to interleave the symbol errors will be prohibitively long. Therefore, power control applications are complementary with error-control: the former is effective for slow fading and the later is good for fast fading (Adit, 2003).

Table 2.2 summarises the fading characteristics, types of degradation, and mitigation techniques viewed in time and frequency domains when the effect of fading is considered as a time-variation of the channel.

Table 2.2 Manifestation of multipath fading as time varying of channel (Adit, 2003).

Characterisation	Fast fading	Slow fading
Time domain	$T_0 >> T_s$	$T_0 << T_s$
Frequency domain	$f_D << W$	$f_D >> W$
Signal degradation	Loss of SNR, pulse-shape distortion, synchronization problem.	Loss of SNR
Mitigation	Error control and interleaving, robust modulation.	Diversity, error control, power control.

Fig.2.15 showsthe distinction between fast and slow fading.In a NLOS (Non-Line of sight) situation, when there is no direct signal path component, the amplitude variations are quite large and the phases of the components have random uniform distribution. In such a fading channel, amplitude is modeled by Rayleigh distribution and, therefore, is also referred to as Rayleigh fading. However, in a LOS situation, the amplitude has distribution due to the presence of a direct strong component and such a fading is known as Ricean fading (Eheduru, 2013). Typically, in UMTS, a slow fading margin of 8-9 dB is taken into account for path loss calculations (Lempiainen and Manninen, 2003).

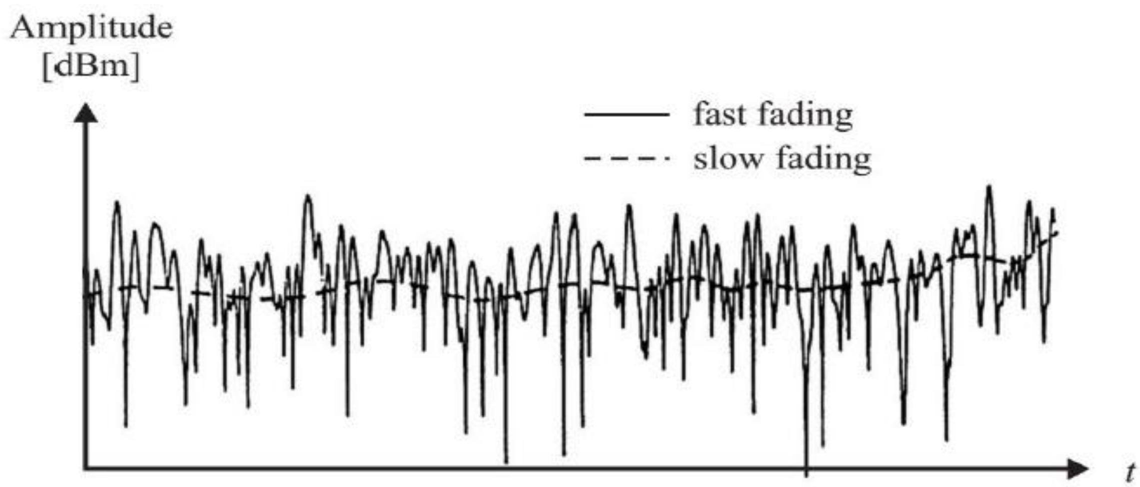


Figure 2.15: Fast Fading and Slow Fading(Eheduru, 2013).

In practice, a mobile wireless channel may exhibit one or more fading behaviours depending on the environment where the radio wave propagates. A mobile user may also experience different fading conditions when it moves from area to area. Therefore, to obtain reliable performance in a wireless communication system, various techniques to mitigate different effects of fading channel should be used. Table 2.3 shows the characteristics the fading channel models in the time and frequency domains. Following this necessary classification of wireless channels and the study concerning the effectiveness of power control on different channel types, we will concentrates next on the problem of power control in a flat fading situation. Indeed, we have seen that it is in this context that not only power control is effective, but also it is the only way to recover a signal affected by a long deep fade (Adit, 2003).

Table 2.3 Fading channel characteristics (Adit, 2003).

Channel models	$T_0 >> T_s$	$T_0 << T_s$
$W >> W_0$	Time-frequency Frequency-selective fading.	Frequency-selective time-nonselective fading.
$W << W_0$	Time-selective frequency-nonselective fading	Time-frequency frequency-nonselective fading

2.5 Propagation Models

A propagation model is needed to estimate the path loss between the mobile station and base station. This need occurs for example in the network dimensioning phase. Propagation models are divided into empirical, semi-empirical and deterministic models. Empirical models are based on measurement campaigns: the measurement statistics are turned into mathematical models. Semi-empirical models rely on physical phenomena, such as diffraction, refraction and reflection, and combine these with field measurements. Deterministic models, such as ray tracing and ray launching, have a basis on the electromagnetic theory, therefore providing more accuracy in path loss calculations in cost of computational power requirement (Jari, 2010).

In wireless communication Engineering, One of the most important parameters to evaluate the performance of any wireless communication system is the behavior of radio signal path between the transmitter and the receiver. It is because the strength of the radio signal is significantly altered by the morphology of the radio path. The radio path can be LOS and/or non-line of sight (NLOS) with some density of the obstacles in it. Thus, the propagation models are used to predict the average received signal strength at some distance from the transmitter. Though there exist various path loss models, the most commonly used ones for WCDMA due its high range of frequency include: Free space model, COST-231 Hata model and Electronic Communication Committee (ECC-33) model. The following section describes some of the commonly used propagation models.

2.5.1 Free Space Propagation Model

The simplest and fundamental propagation model is the free space propagation model, which explains the behavior of signal attenuation for the LOS radio path with no obstacles in between. The free space propagation loss depends on the distance from the transmitter and the frequency in use. Satellite communication systems and microwave line-of-sight radio links typically undergo free space propagation (Rappaport, 2007).

Calculating free space transmission loss requires a faithful representation of the transmitter and receiver characteristics. Assuming we have a transmitter with power P_t coupled to an antenna which radiates equally in all directions. At a distance *d* from the transmitter, the radiated power is distributed over an area of $4\pi d^2$, so that the power flux density, S, is(Rappaport, 2007).

$$S = \frac{P_t}{4\pi d^2} \quad (2.6)$$

Transmission loss for such a system depends on how much of this power is captured by the receiving antenna. If the effective aperture of the antenna is A_r, then the power which can be delivered to the receiver (assuming no mismatch or feeding losses) is simply (Rappaport, 2007).

$$P_r = SA_r \quad (2.7)$$

The effective area of the isotopic receiving antenna, A_r,is (Rappaport, 2007).

$$A_r = \frac{\lambda^2}{4\pi} \quad (2.8)$$

Substituting equation (2.6) and (2.8) into equation (2.7) will result in equation (2.9)

$$P_r = \frac{P_t}{4\pi d^2}\left(\frac{\lambda^2}{4\pi}\right) = P_t\left(\frac{\lambda}{4\pi d}\right)^2 \quad (2.9)$$

The free space path loss between isotropic antennas which is $\frac{P_t}{P_r}$, can be expressed as in equation (2.10).

$$\frac{P_t}{P_r} = \left(\frac{4\pi d}{\lambda}\right)^2 \qquad (2.10)$$

Where, $\lambda = \frac{c}{f}$

Rationalizing equation (2.10) gives the generic free space path loss, L_p, formula which is given as in equation (2.11):

$$L_p = 32.5 + 20\,Log_{10}(d) + \; 20\,Log_{10}(f) \qquad (2.11)$$

Where,*f* = frequency of transmission in MHz and *d* = distance in km.

However with the advancements in wireless communication systems and the use of modern technologies there is need for much more sophisticated propagation models which could predict the true nature of the received signal strength considering all the important and complicated details of the radio propagation environment (Sultan 2010).

2.5.2 COST- 231 Hata model

The Hata model took into consideration frequencies at 1.5GHz and below which could not be used for most WCDMA frequencies, this limitation as well as the interest in personal communications systems operating near 1.9GHz made the European Cooperation in the field of Scientist and Technical research (COST) organization to perform propagation measurements to extend the Hata model to 2GHz. This extended Hata model is applicable for frequencies from 1.5 to 2GHz. The COST-231 Hata model apart from being designed for frequency band covering 1.5 to 2GHz also contains corrections for urban, urban and rural (flat) environments,
(Ekpenyong, Isabona and Ekong, 2010).

The basic equation for the path loss, P_L, in dB is expressed as in equation (2.12). (COST Action 231, 1999)

$$P_L = \; 46.3 + 33.9\log_{10}(f) - \; 13.82\log_{10}(h_b) - \; ah_m + \; (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) + Cm \qquad (2.12)$$

Where,

f = frequency in MHz

d = distance between AP and Customer-Premises Equipment (CPE) antennas in km,

h_b = AP antenna height above ground level in meters (m).

The perimeter Cm is defined as 0 dB for urban or open environments and 3 dB for urban environment. The perimeter,ah_m is defined for urban environments as expressed in equation (2.13).

$$ah_m = 3.20(\log_{10} 11.75h_r))^2 - 4.97, \quad when\, f > 400MHz \quad (2.13)$$

While for urban or rural (flat) environmentsah_m is given in equation (2.14).

$$ah_m = (1.1 \log_{10} f - 0.7)h_r - (1.56\log_{10} f - 0.8) \quad (2.14)$$

Where,

h_r = CPE antenna height above ground level.

From equations (2.13) and (2.14) the path loss exponent,n_{cost}, of the prediction made by COST-231 is given by equation (2.15)

$$n_{cost} = (44.9 - 6.55\, Log_{10}(h_b))/10 \quad (2.15)$$

To evaluate the applicability of the COST-231 model for the 3.5GHz band, the model predictions are compared against measurement for three different environment namely, rural (flat), suburban and urban.

2.5.3 ECC – 33 Path Loss Model

Although the Hata Okumura model is widely used for UHF bands, its accuracy is questionable for higher frequencies (Hata, M., 1980). The COST-231 model extended its use up to 2GHz but it was proposed for mobile systems having Omni-directional antennas sited less than *3m* above ground level. A different approach was taken by the Electronic communication Committee (ECC) which extrapolated the original measurements by Okumura and modified its assumptions. The path loss equation for ECC-33 modelis defined as in equation (2.16).(ECC, 2003)

$$P_L = A_{fs} + A_{bm} - G_b - G_r \quad (2.16)$$

Where,

A_{fs} = Free space attenuation

A_{bm} = Basic median path loss

G_b= BSheight gain factor

G_r = Terminal (CPE) height gain factor.

They are individually defined as in equations (2.17), (2.18), (2.19), (2.20)and (2.21).

$$A_{fs} = 92.4 + 20LogF + 20Log_{10}d_i \quad (2.17)$$

$$A_{bm} = 20.41 + 7.894Log_{10}f + 9.83Log_{10}d_i + 9.56[Log_{10}f]^2 \quad (2.18)$$

$$G_b = Log_{10}\left(\frac{h_b}{200}\right)[\,13.958 + 5.8Log_{10}(d_i)]^2 \qquad (2.19)$$

And for medium city environments it expressed as in equation (2.20). (Doble, J., 1996),

$$G_r = [42.57 + 13.7Log_{10}F][Log_{10}(h_m) - 0.585] \qquad (2.20)$$

And for large city it is expressed as in equation (2.21).

$$G_r = 0.759h_m - 1.862 \qquad (2.21)$$

Where,

f = frequency in GHz

d_i = distance between base station and mobile station in km

h_b = BS antenna height in meters

h_m = Mobile antenna height in meters.

2.6 UMTS Network Architecture

The UMTS system consists of a number of logical network elements that each has a defined functionality. In the standards, network elements are defined at the logical level, but this quite often results in a similar physical implementation, since there are a number of open interfaces (Jorge, 2009). The network elements can be grouped based on similar functionality, or based on which sub-network they belong to.

Functionally, these elements are grouped into the Radio Access Network (RAN, UMTS Terrestrial RAN - UTRAN) and the Core Network (CN). The UTRAN handles all radio-related functionality. Whereas, the CN is responsible for switching and routing calls and data connections to external networks. The system is completed by the User Equipment (UE) or 3G terminal, which interfaces with the user and the radio interface. The high-level architecture is shown in Fig 2.16.

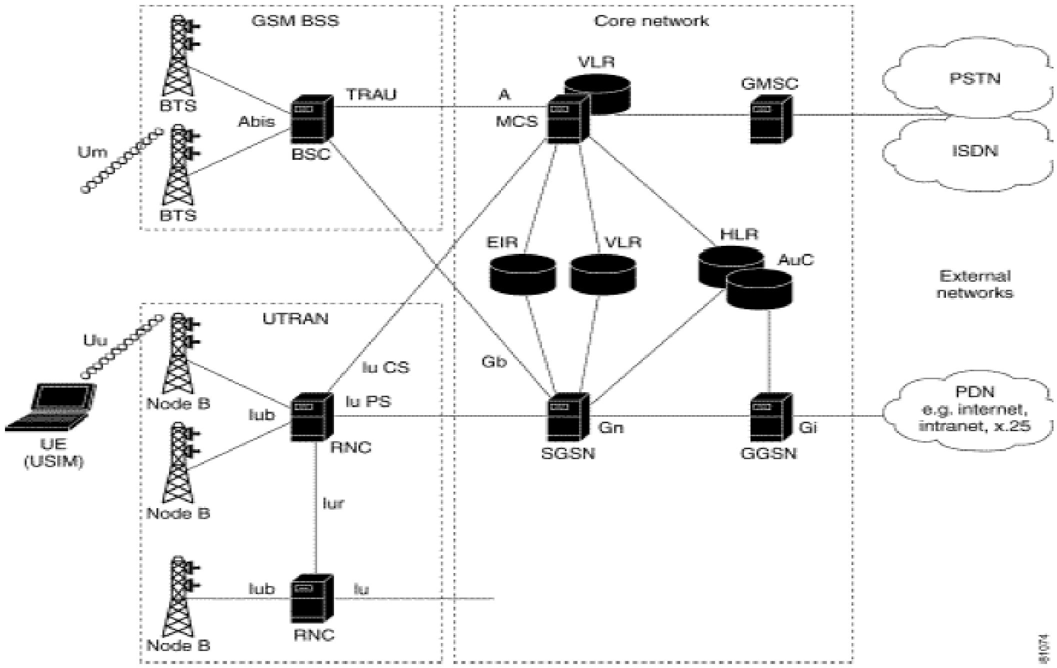


Figure 2.16.UMTS System Architecture(Jorge, 2009).

From a specification and standardisation point of view, both UE and UTRAN consist of completely new protocols, the designs of which are based on the needs of the new WCDMA radio technology. On the contrary, the definition of CN is adopted from GSM. This gives the system with new radio technology a global base of known and rugged CN technology that accelerates and facilitates its introduction, and enables such competitive advantages as global roaming.

Another way to group UMTS network elements is to divide them into sub-networks. The UMTS is modular in the sense that it is possible to have several network elements of the same type. In principle, the minimum requirement for a fully featured and operational network is to have at least one logical network element of each type. The possibility of having several entities of the same type allows the division of the UMTS into sub-networks that are operational either on their own or together with other sub-networks, and that are distinguished from each other with unique identities. Such a sub-network is called a UMTS Public Land Mobile Network (PLMN). Typically, one PLMN is operated by a single operator, and is connected to other PLMNs as well as to other types of network, such as Integrated Services Digital Network(ISDN), Public

Switched Telephone Network (PSTN), the internet, and so on. Fig 2.16 shows elements in a PLMN and, in order to illustrate the connections, also external networks(Jorge, 2009).

2.6.1 UMTS Terrestrial Radio Access Network (UTRAN) Architecture

The UTRAN architecture is depicted in Fig. 2.17. UTRAN consists of one or more Radio Network Sub-systems (RNSs). An RNS is a sub network within UTRAN and consists of one RNC and one or more Node BS. RNCs may be connected to each other via an Iur (Link between two RNC) interface. RNCs and Node BS are connected with an Iub (Link between Node B and RNC) Interface. During Release 7, work study on the support of small RNSs was done, meaning use of co-located RNC and Node B functionalities in a flat architecture, and that was found feasible without mandatory specification changes.

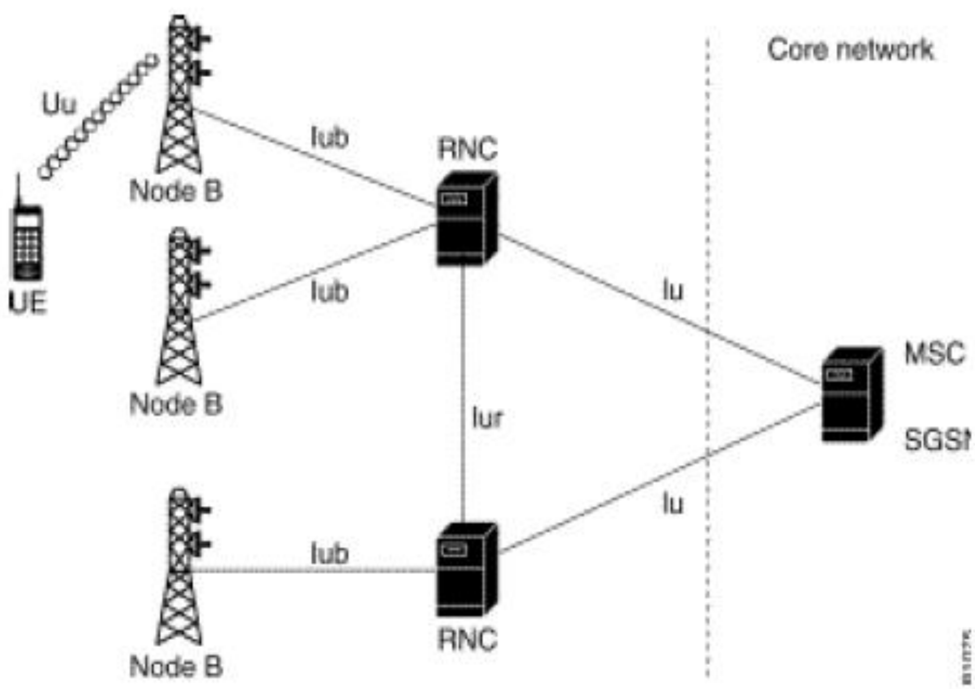


Figure 2.17**.**UTRAN architecture(Jorge, 2009).

The Node B

The Node B converts the data flow between the Iub and Link between UE and Node B (Uu) interfaces. It also participates in radio resource management (RRM). It logically corresponds to GSM Base Station but the term “Node B” was initially adopted as a temporary term during the standardization process and then never changed.

Traditionally, the Node B's have minimum functionality, and are controlled by an RNC. However, this is changing with the emergence of High Speed Downlink Packet Access (HSDPA), where some logic (e.g. retransmission) is handled on the Node B for lower response times. The utilization of WCDMA technology allows cells belonging to the same or different Node Bs and even controlled by different RNC to overlap and still use the same frequency (the effect is utilized in soft handovers).Since WCDMA often operates at higher frequencies than GSM, the cell range is considerably smaller compared to GSM cells, and, unlike in GSM, the cells' size is not constant (a phenomenon known as "cell breathing"). This requires a larger number of Node Bs and careful planning in 3G networks. Power requirements on Node Bs and UE are much lower(Jorge, 2009).

A full setup used contains: a cabinet, an antenna mast and actual antenna. An equipment cabinet contain, for instance, power amplifiers, digital signal processors, back-up batteries and air conditioner equipment. A Node B can serve several cells, also called sectors, depending on the configuration and also on the type of antenna. The most common configuration includes omni cell (360°), 3 sectors (3x120°) or 6 sectors (3 sectors 120° wide overlapping with 3 sectors of different frequency) (Jorge, 2009).

2.6.2The Radio Network Controller (RNC)

The RNC is the network element responsible for the control of the radio resources of UTRAN. It interfaces the CN (normally to one MSC and one SGSN) and also terminates the Radio Resource Control (RRC) protocol that defines the messages and procedures between the mobile and UTRAN. It logically corresponds to the GSM BSC. The RNC controlling one Node B (i.e. terminating the Iub interface towards the Node B) is indicated as the Controlling RNC (CRNC) of the Node B. The CRNC is responsible for the load and congestion control of its own cells, and also executes the admission control and code allocation for new radio links to be established in those cells. In case one mobile-UTRAN connection uses resources from more than one RNS, the RNCs involved have two separate logical roles:

- Serving RNC (SRNC). The SRNC for one mobile is the RNC that terminates both the Iu (link between RNC and CN) link for the transport of user data and the corresponding RAN application part (RANAP) signaling to/from the CN (this connection is referred to as the RANAP connection). The SRNC also terminates the RRC1 Signaling, i.e. the signaling protocol between the UE and UTRAN. It performs the L2 processing of the data to/from the radio interface. Basic Radio Resource Management operations, such as the mapping of Radio Access Bearer (RAB) parameters into air interface transport channel parameters, the handover decision, and outer loop power control, are executed in the SRNC. The SRNC may also be the CRNC of some Node B used by the mobile for connection with UTRAN. One UE connected to UTRAN has one and only one SRNC.

- Drift RNC (DRNC). The DRNC is any RNC, other than the SRNC, that controls cells used by the mobile. If needed, the DRNC may perform macro diversity combining and splitting. The DRNC does not perform L2 processing of the user plane data, but routes the data transparently between the Iub and Iur interfaces, except when the UE is using a common or shared transport channel. One UE may have zero, one or more DRNCs. One physical RNC normally contains all the CRNC, SRNC and DRNC functionality.

UTRAN Interfaces

The following open interfaces are the UTRAN interfaces:

- Iub interface: The Iub connects a Node B and a RNC. UMTS is the first commercial mobile telephony system where the Controller-Base Station interface is standardized as a fully open interface (Jorge, 2009). Like the other open interfaces, open Iub is expected to motivate further competition between manufacturers in this area. It is likely that new manufacturers concentrating exclusively on Node Bs will enter the market.
- Iur interface: The open Iur interface allows soft handover between RNCs from different manufacturers and, therefore, complements the open Iu interface.
- Iu interface: This connects UTRAN to the CN and is similar to the corresponding interfaces in GSM, A (CS) and Gb (PS), the open Iu interface gives UMTS operators the possibility of acquiring UTRAN and CN from different manufacturers. The enabled competition in this area has been one of the success factors of GSM(Jorge, 2009).

2.6.3 General Protocol Model for UTRAN Terrestrial Interfaces

Protocol structures in UTRAN terrestrial interfaces are designed according to the same general protocol model. This model is shown in Fig 2.18. The structure is based on the principle that the layers and planes are logically independent of each other and, if needed, parts of the protocol structure may be changed in the future while other parts remain intact.

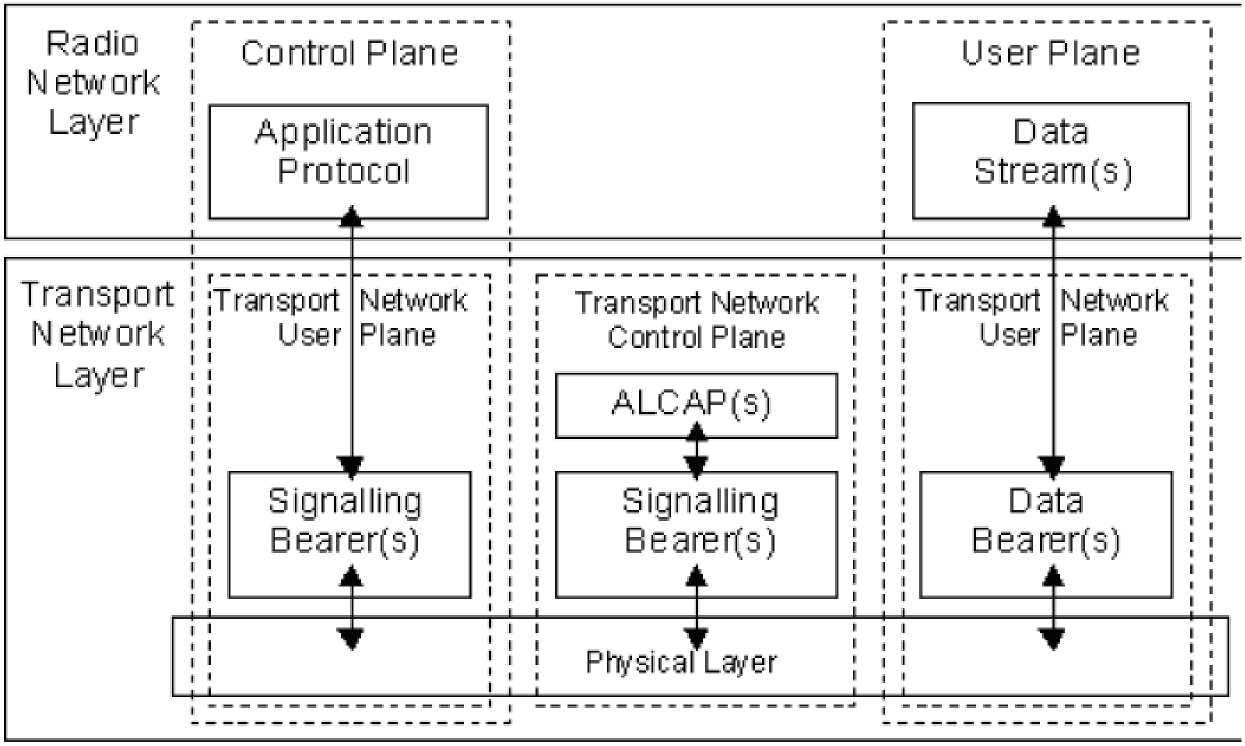


Figure 2.18**.**General protocol model for UTRAN terrestrial interfaces (Jorge, 2009).

- **Horizontal Layers**

The protocol structure consists of two main layers, the Radio Network Layer and the Transport Network Layer. All UTRAN-related issues are visible only in the Radio Network Layer, and the Transport Network Layer represents standard transport technology that is selected to be used for UTRAN but without any UTRAN-specific changes.

- **Vertical Planes**

Control Plane is used for all UMTS-specific control signalling. It includes the Application Protocol (i.e. RANAP in Iu, Radio Network System Application Part (RNSAP) in Iur and Node B Application Part (NBAP) in Iub), and the Signalling Bearer for transporting the Application Protocol messages.The Application Protocol is used, among other things, for setting up bearers to the UE (i.e. the RAB (Radio Access Bearer) in Iu and subsequently the Radio Link in Iur and Iub). In the three plane structure the bearer parameters in the Application Protocol are not directly tied to the User Plane technology, but rather are general bearer parameters.The signaling Bearer for the Application Protocol may or may not be of the same type as the Signaling Bearer for the ALCAP (Access Link Control Application Part). It is always set up by operation and maintenance (O&M) actions.

All information sent and received by the user, such as the coded voice in a voice call or the packets in an internet connection are transported via the User Plane. The User Plane includes the Data Stream(s), and the Data Bearer(s) for the Data Stream(s). Each Data Stream is characterized by one or more frame protocols specified for that interface.Transport Network Control Plane. It is used for all control signaling within the Transport Layer. It does not include any Radio Network Layer information. It includes the ALCAP protocol that is needed to set up the transport bearers (Data Bearer) for the User Plane. It also includes the Signaling Bearer needed for the ALCAP(Jorge, 2009)

The Transport Network Control Plane is a plane that acts between the Control Plane and the User Plane. The introduction of the Transport Network Control Plane makes it possible for the Application Protocol in the Radio Network Control Plane to be completely independent of the technology selected for the Data Bearer in the User Plane When the Transport Network Control Plane is used, the transport bearers for the Data Bearer in the User Plane are set up in the following fashion. First, there is a signaling transaction by the Application Protocol in the Control Plane, which triggers the setup of the Data Bearer by the ALCAP protocol that is specific for the User Plane technology.

The independence of the Control Plane and the User Plane assumes that an ALCAP signaling transaction takes place. It should be noted that ALCAP might not be used for all types of Data Bearers. If there is no ALCAP signaling transaction, then the Transport Network Control Plane is not needed at all. This is the case when it is enough simply to select the user plane resources e.g. selecting end-point addresses for IP transport or selecting a preconfigured Data Bearer. It should also be noted that the ALCAP protocol(s) in the Transport Network Control Plane is/are not used for setting up the Signaling Bearer for the Application Protocol or for the ALCAP during real-time operation.

The Signaling Bearer for the ALCAP may or may not be of the same type as that for the Application Protocol. The UMTS specifications assume that the Signaling Bearer for ALCAP is always set up by O&M actions, and do not specify this in detail.Transport Network User Plane. The Data Bearer(s) in the User Plane and the Signaling Bearer(s) for the Application Protocol also belong to the Transport Network User Plane. As described in the previous section, the Data Bearers in the Transport Network User Plane are directly controlled by the Transport Network

Control Plane during real-time operation, but the control actions required for setting up the Signaling Bearer(s) for the Application Protocol are considered(Jorge, 2009).

2.6.4 UMTS Transport Channels

The UMTS radio interface has logical channels that are mapped to transport channels. The data generated at higher layers is carried over the air with transport channels, which are mapped in the physical layer to different physical channels. The physical layer is required to support variable bit rate transport channels to offer bandwidth-on-demand services, and to be able to multiplex several services to one connection. There are two types of transport channels: common and dedicated channels (Eheduru, 2013)

- **Dedicated Transport Channel**

The dedicated transport channel or Dedicated Channel (DCH) carries all the information intended for the given user coming from layers above the physical layer, including data for the actual service as well as higher layer control information. The content of the information carried on the DCH is not transparent to the physical layer, thus higher layer control information and user data are treated in the same way. Naturally the physical layer parameters set by UTRAN may vary between control and user data. The dedicated transport channel carries both the service data, such as speech frames, and higher layer control information, such as handover commands or measurement reports from the terminal. In WCDMA a separate transport channel is not needed because of the support of variable bit rate and service multiplexing (Holmaand Toskala, 2007). The dedicated transport channel is characterized by features such as fast power control, fast data rate change on a frame-by-frame basis, and supports soft handover.

- **Common Transport Channels**

Common channels do not have soft handover but some of them can have fast power control. There are six common transport channels:

(i) *Broadcast Channel* (BCH): BCH is a transport channel that is used to transmit identification information specific to the UTRA network or for a given cell, such as access codes, access slots, etc. the BCH is sent with a low fixed data rate. The BCH must be decoded by all the mobiles in the cell, therefore relative high power is allocated to broadcast the BCH. The BCH is mapped into the PCCPCH (primary common control physical channel).

(ii) *Forward Access Channel* (FACH): FACH is a downlink transport channel that carries control information to terminals known to be located in the given cell. The FACH can also carry packet data. The FACH is mapped into the SCCPCH (secondary control physical channel).

(iii)*Paging Channel* (PCH): PCH is a downlink transport channel that carries paging signals within the location area, which alerts mobiles about incoming calls, SMS and data connections. The PCH is mapped into the SCCPCH.

(iv)*Random Access Channel* (RACH): RACH is an uplink transport channel intended to be used to carry control information from the terminal, such as requests to set up a connection. It can also be used to send small amounts of packet data from the terminal to the network. The RACH is mapped into PRACH (physical random access channel).

(v) Uplink Common Packet Channel (CPCH): CPCH is an extension to the RACH channel that is intended to carry packet-based user data in the uplink direction. It is used for fast power control, and also provides additional capacity beyond the capacity of the RACH. The CPCH is mapped into the PCPCH (physical common packet channel).

(vi)*Downlink Shared Channel* (DSCH): DSCH is a transport channel intended to carry dedicated user data and/or control information; it can be shared by several users. In many respects it is similar to the forward access channel, although the shared channel supports the use of fast power control as well as variable bit rate on a frame-by-frame basis. The DSCH is mapped to the PDSCH (physical downlink shared channel) (Tolstrup, 2008).

Table 2.4 shows the set of physical channels available to each transport channel.

Table 2.4Transport channels for UMTS (Eheduru, 2013).

Transport channel	Type	Uplink	Downlink
Broadcast Channel (BCH)	Common		•
Paging Channel (PCH)	Common		•
Random Access Channel (RACH)	Common	•	
Forward Access Channel (FACH)	Common		•
High Speed Downlink Shared Channel (HS-DSCH)	Common		•
Dedicated Channel (DCH)	Dedicated	•	•
Enhanced Dedicated Channel (E-DCH)	Dedicated	•	

2.6.5 UMTS Logical Channels

Logical channels are used to transfer data between the RLC and MAC layers. The MAC layer provides the mapping between logical channels and transport channels. They define the type of information being transferred. They are categorized as either *control* or *traffic*.

1) **Controlchannels**: Control channels include the BCCH, PCCH, CCCH, DCCH, MCCH and MSCH. These logical channels are responsible for transferring RRC signaling messages. Traffic channels include the CTCH, DTCH and MTCH. These logical channels are responsible for transferring application data. The DTCH is the only logical channel able to transfer application data in both the uplink and downlink directions (Eheduru, 2013).

- *Broadcast Control Channel* (BCCH): This channel broadcasts information to the mobiles for system control, system information about the serving cell and the monitored set (neighbor list). The BCCH is carried by the BCH or FACH.
- *Paging Control Channel* (PCCH): This is a downlink channel that transfers paging information. The PCCH is carried by the PCH.
- *Dedicated Control Channel* (DCCH): A point-to-point bidirectional channel that transmits dedicated control information between a UE and the RNC. This channel is established during the RRC connection establishment procedure.
- *Common Control Channel* (CCCH): A bidirectional channel for transmitting control information between the network and UEs. This logical channel is always mapped onto RACH/FACH transport channels. A long UTRAN UE identity is required (U-RNTI,

which includes SRNC address), so that the uplink messages can be routed to the correct serving RNC even if the RNC receiving the message is not the serving RNC of this UE.

- *MBMS Control Channel (MCCH) and MBMS Scheduling Channel* (MSCH):MCCH and MSCH are point-to-multi-point logical channels used by UE that support the Multimedia Broadcast/Multicast Service (MBMS). The majority of MBMS control plane information is sent on the MCCH. The MSCH is used to send scheduling information to indicate when specific MBMS services are transmitted. System information on the BCCH informs UE of the information necessary to read the MCCH and MSCH. Both logical channels can be read from either RRC Idle mode or RRC Connected mode. MBMS procedures can also make use of other logical channels and more general RRC messages, e.g. the MBMS counting procedure which allows the network to estimate the number of MBMS UE within a cell can use the Cell Update message and the CCCH or DCCH logical channels (Eheduru, 2013).

2) Traffic Channels:

- *Dedicated Traffic Channel* (DTCH): This is a point-to-point channel, dedicated to one UE, for the transfer of user information. A DTCH can exist in both uplink and downlink.
- *Common Traffic Channel* (CTCH): This is a downlink-only channel, used to transmit dedicated user information to a single mobile or a whole group of mobiles(Holma and Toskala, 2007).

Mapping Between Logical Channels and Transport Channels

The mapping between logical channels and transport channels is shown in Fig. 2.19. The following connections between logical channels and transport channels exist:

- PCCH is connected to PCH
- BCCH is connected to BCH and may also be connected to FACH
- DCCH and DTCH can be connected to either RACH and FACH, to CPCH and FACH, to RACH and DSCH, to DCH and DSCH, or to a DCH and DCH.
- CCCH is connected to RACH and FACH
- CTCH is connected to FACH.

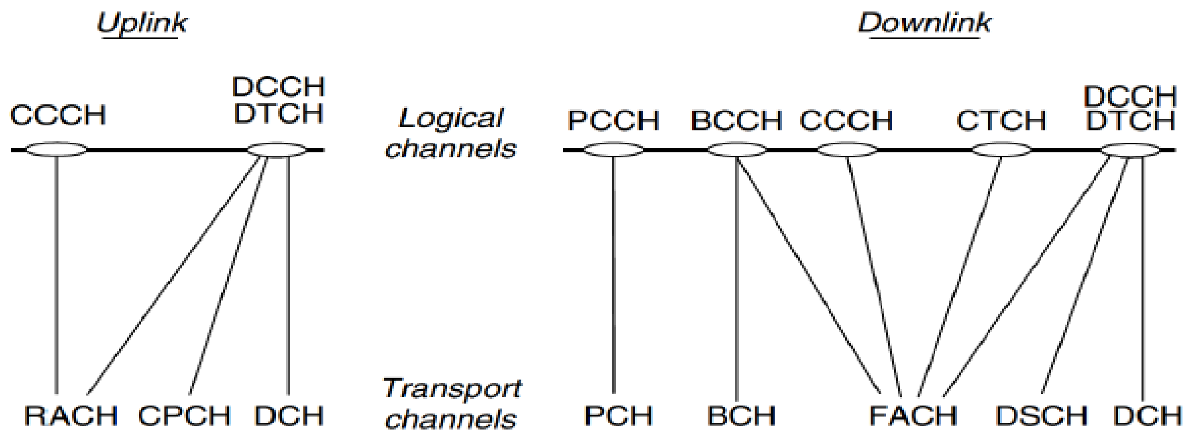


Figure 2.19**:** Mapping between logical and transport channels, UL and DL directions(Holma andToskala, 2007).

2.6.6 UMTS Physical Channels

Physical channels are used to transfer data across the air-interface. They are categorized as either common or dedicated. Common channels can be used by more than a single UE, whereas dedicated channels can be used by only a single UE. Common channels include the SCH, CPICH, P-CCPCH, S-CCPCH, PICH, AICH, PRACH, HS-PDSCH, HSSCCH, E-AGCH and MICH. Dedicated channels include the DPDCH, DPCCH, FDPCH, HS-DPCCH, E-DPDCH, E-DPCCH, E-RGCH and E-HICH. The transport channels are mapped into physical channels. Table 2.5 presents the set of physical channels.

Table 2.5Transport channels mapped onto physical channels (Eheduru, 2013)

Transport channel	Physical channel
RACH	Physical Random Access Channel (PRACH)
FACH	Secondary Common Control Physical Channel (S-CCPCH)
BCH	Primary Common Control Physical Channel (P-CCPCH)
PCH	Secondary Common Control Physical Channel (S-CCPCH)
HS-DSCH	High Speed Physical Downlink Shared Channel (HS-PDSCH)
DCH	Dedicated Physical Data Channel (DPDCH)
E-DCH	Enhanced Dedicated Physical Data Channel (E-DPDCH)

(a) *Common Pilot Channel* (CPICH*):*This isan unmodulated code channel, which is scrambled with the cell-specific primary scrambling code. The function of the CPICH is to aid the channel estimation at the terminal for the dedicated channel and to provide the channel estimation reference for the common channels when they are not associated with the dedicated channels or not involved in the adaptive antenna techniques. UTRA has two types of common pilot channel; which are*primary* and *secondary*. The difference is that the Primary CPICH is always under the primary scrambling code with a fixed channelization code allocation and there is only one such channel for a cell or sector. The Secondary CPICH may have any channelization code of length 256 and may be under a secondary scrambling code as well. The typical area of Secondary CPICH usage would be operations with narrow antenna beams intended for service provision at specific 'hot spots' or places with high traffic density.

(b) *Synchronization Channel* (SCH):This is needed for cell search and consists of two channels, the *primary* and *secondary* synchronization channels. The Primary SCH uses a 256-chip spreading sequence identical in every cell. The Secondary SCH uses sequences with different code word combination possibilities representing different code groups. Once the terminal has identified the secondary synchronization channel, it has obtained frame and slot synchronization as well as information on the group the cell belongs to. There are 64 different code groups in use, pointed out by the 256 chip sequences sent on the secondary SCHs.

(c) *Common Control Physical Channel* (CCPCH): There are two types of CCPCHs, the *primary* and the *secondary*. The PCCPCH continuously broadcasts the system identification (the BCH) and access control information. The SCCPCH transmits the FACH (forward access channel), and provides control information, as well as the PACH (paging channel).

(d) *Random Access Channel* (RACH): This is typically used for signaling purposes, to register the terminal, after power-on to the network or to perform location update after moving from one location area to another or to initiate a call. The RACH that can be used for initial access has a relatively low payload size, since it needs to be usable by all terminals. The ability to support 16 kbps data rate on RACH is a mandatory requirement for all terminals regardless of what kind of services they provide.

(e) Acquisition Indicator Channel (AICH): This is used to indicate the reception of the random access channel signature sequence from the base station. The AICH uses an identical signature sequence as the RACH on one of the downlink channelization codes of the base station to which the RACH belongs. Once the base station has detected the preamble with the random access attempt, then the same signature sequence that has been used on the preamble will be echoed back on AICH. As the structure of AICH is the same as with the RACH preamble, it also uses a spreading factor of 256 and 16 symbols as the signature sequence.

(f) *Paging Indicator Channel* (PICH): PICH provides terminals with efficient sleep mode operation. The paging indicators use a channelization code of length 256. The paging indicators occur once per slot on the corresponding physical channel, the Paging Indicator Channel (PICH). Each PICH frame carries 288 bits to be used by the paging indicator bit, and 12 bits are left idle. PICH indicates the paging group the mobile belongs to. This enables the mobiles to be able to monitor the PCH (paging channel) when its group is paged, and in the meantime the mobile can 'sleep' and preserve its battery.

(g)*MBMS Indicator Channel* (MICH): This is used to broadcast MBMS Notification Indicators (NI) across the entire coverage area of a cell. A positive NI is used to trigger UE which have activated a specific MBMS service to decode control information on the MCCH. The MCCH logical channel is always transferred using the FACH transport channel and the S-CCPCH physical channel. This means that the MICH is always associated with a S-CCPCH which includes at least one FACH transport channel. This is in contrast to the PICH which is always associated with a S-CCPCH which includes one PCH transport channel. A single cell can have a maximum of one FACH transport channel carrying MCCH information and so there is a maximum of one MICH per cell.

(i) *Dedicated Physical Channel* (DPCH): This can be used to transfer user plane data and control plane signaling in both the uplink and downlink directions. The DTCH and DCCH logical channels are mapped onto the DCH transport channel when using the DPCH physical channel. The uplink DPCH includes the Dedicated Physical Control Channel (DPCCH) and the Dedicated Physical Data Channel (DPDCH). It may also include the High Speed Dedicated Physical Control Channel (HSDPCCH), the Enhanced Dedicated Physical Control Channel (E-DPCCH) and the Enhanced Dedicated Physical Data Channel (E-DPDCH). The HS-DPCCH is used for HSDPA connections whereas the E-DPCCH and E-DPDCH are used for HSUPA connections. The downlink DPCH uses Fractional Dedicated Physical Channel (FDPCH) to replace DPCCH and DPDCH when both the user and control plane signaling are transferred using one or more HS-PDSCH. The F-DPCH reduces the requirement for downlink resources in terms of both transmit power and channelization codes (Holma and Toskala, 2007).

Table 2.6 Physical Channels of the UMTS Network (Holma and Toskala, 2007).

Physical channel	Type	Uplink	Downlink
Synchronous Channel (SCH)	Common		•
Common Pilot Channel (CPICH)	Common		•
Primary Common Control Physical Channel (P-CCPCH)	Common		•
Secondary Common Control Physical Channel (S-CCPCH)	Common		•
Paging Indication Channel (PICH)	Common		•
Access Indication Channel (AICH)	Common		•
High Speed Physical Downlink Shared Channel (HS-PDSCH)	Common		•
E-DCH Absolute Grant Channel (E-AGCH)	Common		•
MBMS Indicator Channel (MICH)	Common		•
Physical Random Access Channel (PRACH)	Common	•	
High Speed Shared Control Channel (HS-SCCH)	Common	•	
Dedicated Physical Data Channel (DPDCH)	Dedicated	•	•
Dedicated Physical Control Channel (DPCCH)	Dedicated	•	•
Fractional Dedicated Physical Channel (F-DPCH)	Dedicated		•
E-DCH Relative Grant Channel (E-RGCH)	Dedicated		•
E-DCH Hybrid ARQ Indicator Channel (E-HICH)	Dedicated		•
High Speed Dedicated Physical Control Channel (HS-DPCCH)	Dedicated	•	
E-DCH Dedicated Physical Data Channel (E-DPDCH)	Dedicated	•	
E-DCH Dedicated Physical Control Channel (E-DPCCH)	Dedicated	•	

2.7 Power Control in Mobile Communication

Power control is a very important issue in WCDMA, it reduces interference and power consumption of the transmission and therefore it needs to be addressed in relation with throughput maximization. Transmission powers represent a key degree of freedom in the design of wireless networks. In both cellular and ad hoc networks, power control helps with several functionalities such as:

• **Interference management**: Due to the broadcast nature of wireless communication, signals interfere with each other. This problem is particularly acute in interference-limited systems, such as CDMA systems where perfect orthogonality among users are difficult to maintain. Power control helps ensure efficient spectral reuse and desirable user experience.

• **Energy management**: Due to limited battery power in mobile stations, handheld devices, or any "nodes" operating on small energy budget, energy conservation is important for the lifetime of the nodes and even the network. Power control helps minimize a key component of the overall energy expenditure of both MS and BS.

• **Connectivity management**: Due to uncertainty and time variation of wireless channels, even when there is neither signal interference nor energy limitation, the receiver needs to be able to maintain a minimum level of received signal so that it can stay connected with the transmitter and estimate the channel state (Mung, Prashanth and Tian,2008). There is some common phenomenon in WCDMA system like fading of the signal, intracell interference and random nature of the wireless channel that deteriorate the signal quality to achieve the required QoS. And the most important issue is the near far problem that is mobile stations that are closer to the base station can dominate the mobile stations that are far away from the base stations. Power control helps maintain logical connectivity for a given signal processing scheme an well as improved link quality.

Transmission power control (TPC) is vital for capacity and performance in cellular communication systems, where high interference is always present due to frequency reuse. The basic intent is to control the transmission powers in such a way that the interference power from each transmitter to other co-channel users (users that share the same radio resource simultaneously) is minimized while preserving sufficient quality of service (QoS) among all users (Matti, 2005).

2.7.1 Power Control in Downlink and Uplink Transmission

On the Base station –to-Mobile station (BS-to-MS) link or downlink channel (forward link), the spread signals for the entire MSs created from the same BS and simultaneously are transmitted through the same channel. Therefore the entire signals transmitted by a particular BS and propagate over the same channel and undergo the similar attenuation before reaching the MS. Orthogonal codes can be utilized in the forward link channel. There are theoretically no MAI and Near-Far problems in the forward link when orthogonal sequences are used. Therefore, via orthogonal spreading sequence, there is no longer any crucial problem and no PC is required in single cell systems. In multiple cell systems, moreover, PC in forward link is essential in order to rectify the users atboundaries of the cell. These users may experience interference from neighbour cells since users in dissimilar cells are not mutually orthogonal from each other (Tekbiyik, 2007). Interference from an adjacent cell fades independently from the given cell and may degrade the system performance. If this happens forward link PC is required toprepare adequate power level for bordered users suffering from high interference.Assuch appropriate transmission powers can minimize the interference of nearby cells. This process is prepared at the BS by allowing the distant users to transmit at higherlevel than those located near the BS. PC is required in forward link in order toequalize and control the ICI to the heavily loaded cells. This also reduces the co-channel interference cells by upgrading the necessary transmission power level.

In principle, the downlink signals to different users could be made orthogonal by using proper spreading codes. Unfortunately, the orthogonality of the downlink signals is lost in practice due to multipath propagation. Thus, allocating different powers for different users in downlink could cause a near-far situation at the mobile stations. For this reason, the dynamic range of downlink power control is usually much smaller than in uplink, typically of the order of 20-30 dB.The uplink transmission in WCDMA may suffer a near-far difficulty if powercontrol is not used. This occurs because the signals of the different mobile stations propagate through different radio channels before reaching their serving base station (Matt, 2005).

In the MS-to-BS link or uplink (reverse link), different users transmit their signals at different times and from different locations. Synchronization is often very difficult and almost impossible to set. Due to missing synchronization, orthogonal spreading sequences may not be applied in the reverse link as their orthogonality will fail. Therefore different fading channels lead to unequal received power level at the BS. This therefore hinders us from using orthogonal spreading sequences. Due to unequal received power levels in the uplink that influences of MAI and Near-Far problem becomes evident.

The fundamental problem in uplink is the Near-Far problem. Strong interference reduces the power level of bordered users. If detected strength levels at the BS are not the same, the relating receiver cannot be able to distinguish the weak user's signal because of other users with higher power levels disturbance. Thus, uplink requires the use of power control to modify the transmission powers and compensate the varying channel attenuations, in order that signal from different MS are received with the same powers at the BS. Therefore, power control is the basic requirement in the reverse link of WCDMA system. It is very important to be able to keep the disturbance acceptable for all users and get important capacity progress in WCDMA systems. Due to the importance of power control in MS-to-BS link, power control at uplink was investigated in this thesis and an enhanced step size power control algorithm developed. Uplink power control is critical for the capacity of CDMA systems (Matt, 2005)

2.7.2 Power Control Techniques

There are several proposed power control techniques employed in wireless communication, the WCDMA system basically employs two mechanisms to manage power transmission control:

- ✓ open-loop power control,
- ✓ closed-loop power control,

Open- Loop Power Control

The open loop power control function is implemented in both directions (uplink and downlink). In uplink direction, the open loop power control function sets the initial transmit power levels for the UE and in downlink direction it determines the transmit power levels for the downlink channels. The open loop power control uses the measurement reports of the UE about the received power from the BS, and it then decides how to set the transmit downlink power levels (Sultan, 2010). The open-loop power control is designed to ensure that the received powers from all users are equal in average at the base station. In the open-loop algorithm, the mobile user can compute the required transmit power by using an estimate from the downlink signal (no feedback information is needed). This is because the large-scale propagation loss is reciprocal between uplink and downlink channels Fig. 2.20 illustrates the OPLC applied in the uplink. In this case the UE estimates the transmission signal strength from the received power level of the pilot signal from the base station and make the adjustment of the transmitting power in a certain level that is inversely proportional to the pilot signal strength. Consequently the stronger the received pilot signal, the lower the UE transmitted power (Hossain et al, 2007). This is because the large-scale propagation loss is reciprocal between uplink and downlink channels.

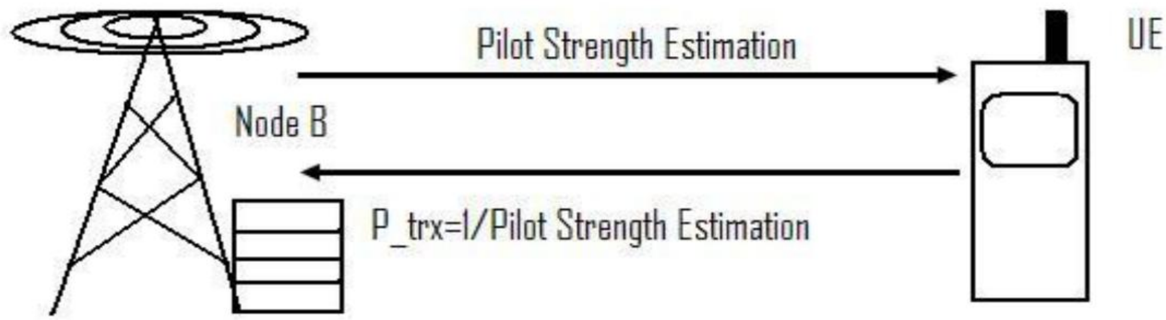


Figure 2.20: Open Loop power Control (Hossain et al, 2007)

Fig. 2.21 shows how an open-loop power control algorithm solves the near far problem in the reverse link of a CDMA system (Aditt, 2003).

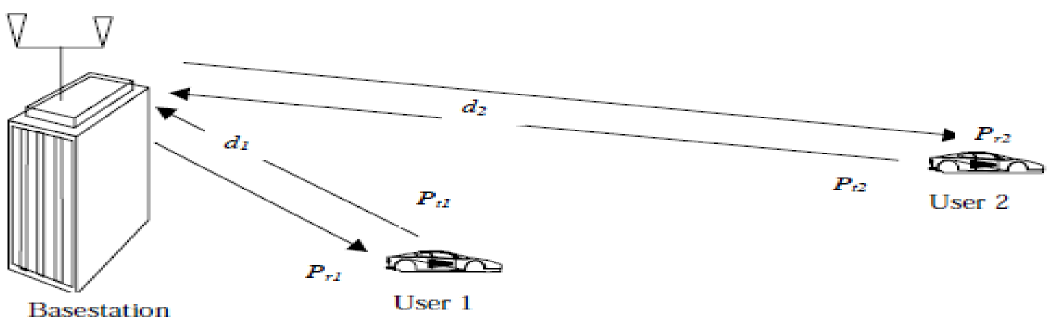


Figure 2.21 Mechanism of open-loop power control (Adit, 2003)

In Fig. 2.21, user 1 located at distance $d_1$from the base station receives a power level Pr_1.This power level is higher than that received by user 2, Pr_2, who is located at distance d_2 from the base station because $d_1 < d_2$. Therefore to deliver an equal power received at the base station, user 2 must transmit a higher power level than user 1 or $P_{t2} > P_{t1}$. The procedure to determine the transmit power can be expressed as:

$$P_t = - P_r + P_{off} + P_p, \qquad (2.22)$$

Where P_t(dBm) is the required transmit power for a mobile user, P_r(dBm) is the received power at the mobile, P_{off}(dB) is the offset power parameter, and P_p(dB) is the power adjustment parameter. The offset power parameter is used to compensate for different frequency bands, i.e. P_{off}= –76 dB for the 1900 MHz and P_{off}= –73 dB for the 900 MHz frequency band (Adit, 2003).The power adjustment parameter is used to compensate for differences with regard to different cell sizes and shapes, basestation transmit power, and receiver sensitivities.

However, it is important to obtain a good method of the downlink signal measurement. If the measurement period is too short, rapid fluctuation due to multipath may still exist and may not give an accurate result for the mean power measurement. On the other hand if measurement period is too long it may average out the effect of shadowing and therefore open-loop power control may not compensate for the shadowing effect (Adit, 2003).

Closed-Loop Power Control

Closed-loop power control aims at eliminating the received signal fluctuation due to small scale propagation loss. In contrast to the large-scale propagation loss, the small-scale propagation loss is uncorrelated between uplink and downlink. Therefore, to control the uplink fading, the uplink channel information must be estimated at the base station and then fed back to the mobile station, so that the mobile station can adjust its transmit power according to the fed back information (Adit, 2003).

The CLPC system is further divided into two different processes, both operating in parallel to each other; inner loop and outer loop power control.

The inner loop power control is also known as the fast closed loop power control. The fast closed loop controls the transmission power levels for UE and BS based on the received signal-to-interference ratio (SIR) level at BS and UE, to combat fading characteristics of the radio channel (Sulatan, 2010). The TPC (transmit power control) commands are sent by UE and BS providing the information either to increase or decrease the transmission power levels. In UMTS both in uplink and downlink directions, the UE and BS measures the received SIR to compare it with the target SIR levels, set earlier by outer loop power control. If the measured uplink SIR is greater than the target SIR, the BS requests the UE to lower its transmission power. Similarly, if the measured uplink SIR is lower, then the UE increase its transmission power to attain the target SIR. In downlink the BS changes the transmission power levels in response to the TPC commands from the UE.

The outer loop power control provides the target SIR level for the inner loop power control. The outer loop power control adjusts the target SIR to achieve the desirable BLER (block error rate) for the particular service (voice or data) carried out by the UE. The change in the mobile speed or the multipath propagation environment also results in the adjustment of the target SIR (Sulatan, 2010). A closed-loop power control model for the reverse link is shown in Fig. 2.22.

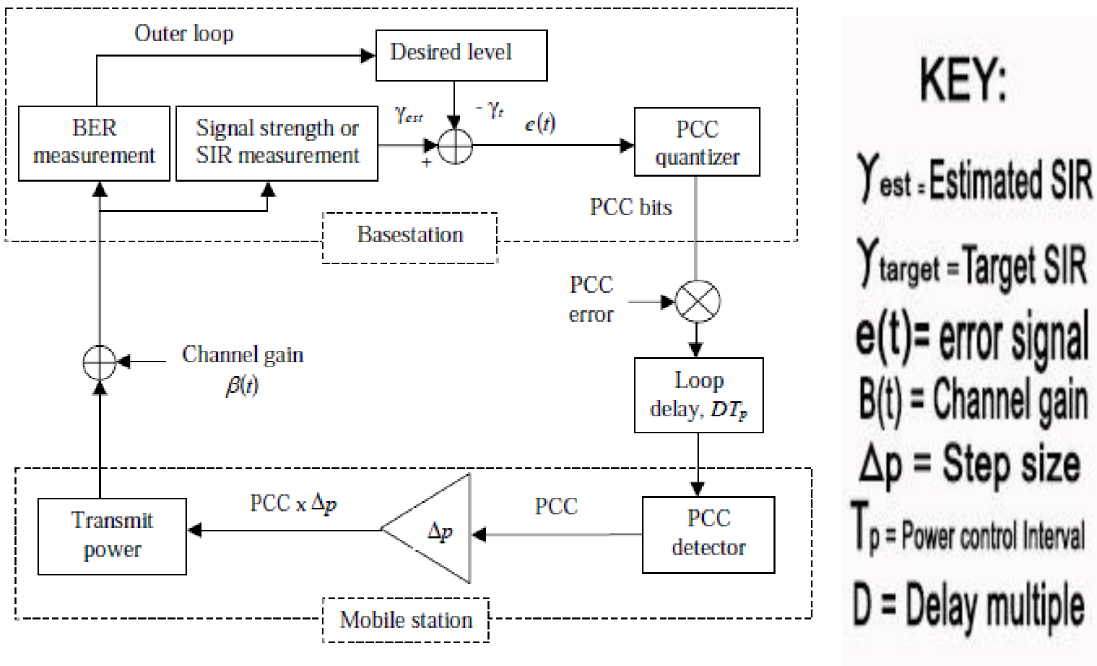


Figure 2.22 Closed-loop power control model (Adit, 2003)

In this model, the signal strength or SIR is first estimated at the base station for every time slot, T_p, which corresponds to one power control interval. In Fig 2.22 this estimated quantity is represented by γ_{est}. Then it is compared with the desired or the target level γ_t.The difference between the estimated SIR or signal strength and the target level is then quantised and sent to the mobile user via the downlink channel as a binary representation of PC command (PCC) bits. The command bits are multiplexed with the user data. The mobile users then extract the PCC bits from the downlink data stream and use them to adjust their transmit power (Adit, 2003).

Due to the downlink channel impairments, the PCC bits received by the mobile user can be in error. The PCC bit error is modelled as a multiplicative quantity with opposite bit polarity. A delay is also introduced by the control loop. This delay is called the feedback loop delay and is expressed in a multiple, D, of power control interval T_p, where D is an integer. After the PCC bits are recovered by the mobile user, they are used to adjust the transmit power by the required step size, PCC x Δp. Due to feedback delay, however, the mobile transmit power (after adjustment) may not compensate the current channel condition because at the time the mobile adjusts the power, channel conditions may have already changed in a fading situation. This problem is what the open-loop PC tends to correct.

To avoid positive feedback, a strength-and-SIR-combined power control scheme is proposed in (Zhang, Zhang, and Ko, 2000). In this scheme, SIR is used to control the desired signal quality, while signal strength is used to control the interference level. For example when a user's SIR is below the required threshold but its signal strength is already high (above the threshold), that user cannot increase its transmit power. Alternatively, power control should be operated together with another technique, such as call admission control (CAC) in order to prevent positive feedback by assuming that the maximum system capacity is not exceeded. Another possible technique to reduce the possibility of positive feedback, a soft dropping technique can be used. With this technique, a user who needs a high transmit power to combat deep fades can decrease its target SIR, which is quite possible for a CDMA system at the expense of a graceful performance degradation (Adit, 2003).

2.7.3 Power Control Computation

Power control measurements may be categorized in to several classes accordingto the variable that is measured to evaluate the power level (Novakovic, 2000).Bit-Error-Rate-based (BER-based), signal-to-interference-based (SIR-based), and strength-based are well known than the others. Bit-error-rate is the element of controlling the power inBER-based PC method. BER is defined as an average number of missed bitscompared to original sequence of bits (Rappaport, 2007).In signal-to-Interface-ratio based PC, the measured element is signal-to-noise-ratio (SIR) where disturbance includes channel noise and multi-user interference. A critical aspect regarding SIR-based PC is theprobability of occurrence of positive feedback. Positive feedback arises in a situation where one mobile has to increase its transmission power to provide the desired SIR toward the BS. Nevertheless, the increase in its power also causes an increase ininterference to other MSs so that others are also obliged to increase their power. Alsoin strength-based PC schemes, the strength of a received signal at the BS from a MSis the factor that defines whether it is higher or lower than the appropriate strengthlevel. Thereafter, the command will be sent from the BS to rectify the transmissionpower level accordingly. It should be noted that two types of PC updaters exist. Thefirst type could be identified as those that are fixed in the transmission power stepsize (known as fixed step size type), and those that are adapted to the channelvariation in the transmission power step size (known as adaptive step size method).

It is shown in Ariyavisitakul (1994) that power control based on SIR appears to perform better than that based on the signal strength. SIR-based power control, however, has the potential for positive feedback that may occur when the number of active users exceeds the maximum CDMA system capacity. In this situation, an increase of transmit power from any user will increase interference to other users, which in turn, are forced to increase their power, and so on. This is why this work adopted SIR-based power control.

2.7.3.1 SIR-Based Power Control

The goal of the power control is to assign minimal transmit power to the forward and reverse link such that every user experiences maximum signal-to-interference ratio. For a user equipment requesting access to the system, the received SIR is estimated and compared with the target SIR. A request for increase in the transmitted power is sent to the mobile if the estimated SIR is below the target SIR, while a request for decreasing the transmitted power is sent to the mobile if the estimated SIR is above the target SIR.

The SIR experienced at each measurement point is estimated as expressed in equation (2.23).

$$SIR_{estimate} = \frac{Received\ \ power}{Interference} = \frac{P_r}{I} \qquad (2.23)$$

Where I = Intra cell interference(I_{intra}) + Inter cell Interference(I_{inter})

The transmitted power of each mobile station is adjusted at each iteration to maintain target signal to interference ratio, $SIR_{k,target}$for class k. The new power control level is executed every 10ms and the new power level is evaluated as expressed in equation (2.24) (Hossain et al, 2007)

$$P_{tx\,k_{new}} = P_{tx\,k_{old}} \frac{SIR_{k_{target}}}{SIR_{k_{cur}}} \qquad (2.24)$$

Where, SIR_{kcur} is the current SIR experienced by the mobile station of class k. The actual SIR experienced by each user, are evaluated after each power control iteration. Power request that cannot be satisfied may result in outage. In order to compensate for power control error, the SIR target value is taken to be 1dB greater than the required value. After each power control iteration the actual *SIR* values experienced by the each user is evaluated. If the *SIR* is lower than the target value, $SIR_{k_{target}}$, the system increases its transmitted power provided sufficient Base Station Power is available. If the system resources are insufficient, that call is dropped. The users with the lowest SDD values and Real-Time services are considered first. The users with high SDD values and Non-Real Time services are considered last. If a user has a *SIR* value higher than the transmit power allocated to that user is reduced (Hossain et al, 2007)

2.7.4Development of PowerControl Algorithm for Wireless Network

Signal fading due to multipath radio propagation severely degrades the performance of wireless systems and imposes high transmitter power requirements. Since the characteristics of the mobile channel changes rapidly, the transmitter and the receiver cannot be configured to operate at their optimum performance levels and therefore, they fail to exploit the full potential of the wireless system. Generally, any enhancements to the system that can improve the delivery of high-speed data, voice and video over mobile devices while increasing the battery life are challenging topics for consideration.

In the absence of power control, a Base Station (BS) would receive a much stronger signal from a Mobile Station (MS) that is geographically close to it than from a MS that is farther away. This is so called the near-far problem. In this case, power control schemes on the up-link or the reverse-link attempt to adjust the transmitted power of each MS so that the nominal received power from each MS to the BS is almost the same. Using as low transmitted energy as possible is the primary design goal for the developers of mobile systems. Strictly speaking, in wireless communications systems, this is important for increased battery life and reduction of interference. In an unbalanced and unmanaged system with an inadequate power control scheme, performance degradation and reduction in the channel capacity are vastly evident. The basic idea behind any adaptive transmission is to maintain a constant ration of energy per bit over noise power Eb/N0 at the receiver by varying the transmitter power level or adjusting the transmitted rate or coding. This procedure ensures an adequate SIR for all mobiles using simple algorithm.

There are several proposed methods of power control algorithms that were suggested recently. Power control algorithm can be categorized in many different aspects. This section reviewed some of this algorithm; although the review did not follow chronological order of their deployment.

a) Fixed Step Power Control (FSPC) Algorithm

The fixed step size power control algorithm or command is embedded in 1 bit, meaning either a single step increment or decrement of the output power, which is easier to implement and leads to less control bits overhead. However, the fixed step leads to oscillations with high variance around the $SIR_{target}$and thus restrains the capability of the power control algorithm to follow radio interface variations. The fixed step size power control procedures are described with the following steps:

- ✓ The base station estimates the received SIR from a particular mobile.
- ✓ The estimated SIR is compared with the corresponding SIR target.
- ✓ If the estimated SIR is lower than the target, then the base station sends an "up" Transmission power control (TPC) command. Otherwise, a TPC "down" command will be sent.
- ✓ The mobile station obeys the command by increasing or decreasing the transmit power on a fixed step size typically 1dB

The updated transmit power can be represented as expressed by equation (2.25), (Ariyavisitakul, 1992).

$$p_i(t+1) = P_i(t) + \delta sign(\gamma^t(t) - \gamma(t) \quad (2.25)$$

Where,

$P_i(t)$ = Transmission power

$\gamma^t(t)$ = SIR target

$\gamma(t)$= Measured SIR of user *i* at time *t*

δ= fixed step size

The term sign is the sign function as expressed in equation (2.26).

$$Sign(x) = \begin{cases} 1, if\ x \geq 0 \\ -1, if\ x < 0 \end{cases} \quad (2.26)$$

It can be noted that sign (SIR_{target}-SIR_{est}) = -1 is equivalent to a TPC power up command which can be represented by bit 0. From (2.25), it can be observed that the transmit power will be increased or decreased by δ (power control step size) on every time slot. The transmitted power will always change even when there is no change in the channel and this causes oscillations with variations around the SIR_{target} in a slow-varying radio environment. In addition to this, when the channel changes rapidly, the fixed step size is unable to adequately control the power to compensate for the changes.

b) Distributed SIR Balancing Algorithms

Distributed versions of the SIR balancing problem draw a lot of attention in the 1990's. The starting point was to find iterative algorithms that would be suitable for distributed operation, and would solve the eigenvalue problem in the noiseless case, 0 noisy case. The underlying assumption was that the channel power gains would change slowly compared to the dynamics of the power control iterations, and thus the convergence was mainly studied in a static "snapshot" scenario. The first proposal was the *Distributed Balancing* (DB) algorithm proposed in the work of (Zander, 1992). It is implemented as shown:

- Calculates the optimal transmit power assignment for each mobile within the cell, taking into consideration all the neighbouring cells
- The optimal transmit power assignment for a mobile is proportional to the ratio of the total received power of the mobile to the link gain between its base station and itself

It is described as in equation (2.27).

$$p_i(t+1) = \beta p_i(t)\left(1 + \frac{1}{\gamma_i(t)}\right), \beta > 0, t = 0,1, \dots \dots \qquad (2.27)$$

Where,

p_i= Transmit power by mobile unit

β= Update rate

γ_i= Estimated power.

For a feasible system, the DB algorithm converges to the optimal power vector $\boldsymbol{p}*$with probability one (Zander, 1992). However, it suffers from poor convergence speed. Moreover, an improper selection of parameter β may result in ever-increasing (or decreasing) powers. The correct selection of β requires a normalization procedure, which is not possible to do in a completely distributed manner. DB algorithm gives the best achievable performance, but it is relatively difficult to implement.

i) The Modified DB (M-DB) Algorithm

An improvement to the DB algorithm in terms of convergence speed was proposed in the works of Grandhi, Vijayan, Goodman (1994). They proposed a modified version of the DB algorithm and called it the *Distributed Power Control* (DPC) algorithm. However, since the term DPC is used for another algorithm (described later), the algorithm of (Grandhi, et al, 1994)is called the *Modified DB (M-DB) Algorithm*. It is described as in equation (2.28).

$$p_i(t+1) = \beta \frac{p_i(t)}{\gamma_i(t)}, \beta > 0. t = 0,1, \dots \dots . n \quad (2.28)$$

The convergence of the M-DB algorithm to the optimal power vector and SIR balance has been proven in the noiseless case (Grandhi, et al, 1994). Also, the convergence speed was shown to be faster than with the DB algorithm. However, the problem of cleverly choosing the step size factor (β)still remained.

ii) The Distributed Power Control (DPC) Algorithm

From control theory viewpoint, the DPC algorithm is an integrating P-controller. The convergence of the DPC algorithm in the case where the power updates occur asynchronously was proven in (Mitra, 1993). The DPC algorithm has received wide attention in the research community since it was published. In all practical systems the transmission powers are limited as in equation (2.29)

$$0 \le p \le p_{\max} \quad (2.29)$$

Where **0** is a vector with all-zero elements and $\boldsymbol{p}_{max} = [p_1^{max}, p_2^{max}, \dots \dots . . p_N^{max}]^T$ denotes the maximum transmission power of each transmitter. To take these limitations into account, the distributed constrained power control (DCPC) algorithm was suggested in (Grandhi, Zander, Yates, 1995).And expressed in equation (2.30).

$$p_i(t+1) = p_i(t) \frac{\gamma^t}{\gamma_i(t)}, t = 0,1, \dots . \quad (2.30)$$

Where γ_i is the estimated transmit power, γ^t actual transmit power as time increases.

iii) The Distributed Constrained Power Control (DCPC) Algorithm

$$P(t+1) = \min \left\{ P_i \max, p(t) \frac{\gamma_i^t}{\gamma_i(t)} \right\}, \text{t} = 0, 1\dots \quad (2.31)$$

With DCPC it can happen that some transmitters are transmitting with the maximum power, thus producing maximum interference to other users, but still do not achieve their SIR target. Therefore it might be beneficial to lower the transmission power when link quality is bad.

c) Distance Based Power Allocation Algorithm

The distance-based power allocation algorithm (DBPA) (Lagrange, Nuaymi and Godlewski, 2001) uses the distance between base station and each mobile station to allocate transmitted power to each of its served mobiles. No correction or feedback is provided; hence it is an open–loop power control mechanism. If power control is not employed (*i.e.*, the transmitted power is same for all users), the most constrained value of the signal-to-interference ratio (SIR) is for a user at the boundary of the cell. Thus, more transmitted power should be allocated to mobiles that have poor channel conditions. The DBPA algorithm computes the transmitted power of mobile m according as in equation (2.23).

$$p_m = k x_{a_m}^n m \qquad (2.32)$$

Where,

$$x_{a_m}^n m = \begin{cases} \frac{d_{a_m m}}{R}, if\ d_{a_m m} > d_{min} \\ \frac{d_{min}}{R}, if\ d_{a_m m} \le d_{min} \end{cases} \qquad (2.33)$$

$k =$ Positive constant

$n =$ Real positive value

$R =$ Maximum bass station-to-mobile distance

$d_{a_m m}$ = Distance between mobile m and its assigned base station

In order to avoid having very small transmitted powers for mobiles close to the base stations, the same transmit power is assigned to all mobiles whose distance $d_{a_m} m$ is less than a certain threshold value d_{min} .

d) Blind Adaptive Closed-Loop Power Control

Blind Adaptive Closed-Loop Power Control (BA-CLPC) is an algorithm in which the step sizes are adjusted to cope with the user mobility. The algorithm adapts its step size based on the logic of increasing the step size by 0.25 if two TPC commands with the same sign are consecutively detected. If alternative TPC commands are detected, then the step size will be reset to 1dB (Lagrange et.al, 2001).

e) The Adaptation method

The adaptation method proposed here is referred to as the *Adaptive Step* (AS) method.

It was derived as expressed in equation (2.34).

$e(t) = \gamma^t(t) - \gamma(t)$ and $u(t) = \text{sign}(e(t))$. (2.34)

Equally, the sign change check, $a(t, x)$, is defined as inequation (2.35).

$$a(t, x) = \frac{1}{2}[1 + xu(t)\,u(t-1)],\ x\epsilon\{-1,1\} \quad (2.35)$$

Note that the sign change check, $a(t, x)$, has ranges as in equations (2.36) and (2.37).

$$a(t,1) = \begin{cases} 1, & if\ u(t)=u(t-1) \\ 0, & if\ u(t)\neq u(t-1) \end{cases} \quad (2.36)$$

$$a(t,-1) = \begin{cases} 0, & if\ u(t)=u(t-1) \\ 1, & if\ u(t)\neq u(t-1) \end{cases} \quad (2.37)$$

The AS method can be described as expressed in equation (2.38)

$$\bar{e}(t) = a(t,1)\,\bar{e}(t-1) + \delta_e u(t) \quad (2.38)$$

Where $\bar{e}(t)$ is the reconstruction of $e(t)$ and δ_e is a parameter controlling the speed of the update, which can assume any value depending on the designer. While not readily seen from equation (2.38), the idea of the adaptation method is very intuitive: if the two latest commands have the same sign, the reconstruction of $e(t)$ is updated by δ_e to the direction of the last command $u(t)$ so as to increase the step size of the next power update. If the two latest commands have different signs, a zero crossing must have happened in the signal $e(t)$ and the reconstruction also crosses zero.

i) Speed Adapted Closed Loop power Control (SA-CLPC)

The speed adapted closed-loop power control algorithm was presented by (Taaghol, 2004), in this algorithm the step size is selected based on user speed estimation. The idea was based on the hypothesis that there is an optimum fixed step size for each of the user speed. This algorithm requires an accurate speed estimator to be installed at the User Equipment (UE). The estimated speed was then used to select the optimal step size corresponding to the UE speed based on a lookup tableas shown in Table 2.7:

Table 2.7: The optimal step size for each user speed (Taaghol, 2004).

Speed(Km/h)	5	10	20	30	40	50	70
$\delta_{optimal}$	1.0	1.5	2.0	2.5	2.5	3	3

Although the performance of SA-CLPC relies significantly on the speed estimator, Taaghol (2004) showed that it was not critical to know the exact speed. It could work as long as the user speed could be correctly categorized into a speed range. For example, user peed range of 7.1 to

13 km/h would be put into the speed category of 10kh/h and be assigned 1.5 step size. The author showed that the performance of SA-CLPC with imperfect speed estimation performed very similar to that obtained by perfect speed estimation.

ii) Multiple Step SIR Based Power Control (MSPC)

The multiple step SIR based power control is a closed–loop power control algorithm in which feedback from the mobile is used to adjust the transmitted power of the base station. The update is based on the average SIR received at the mobile, and the adjustments usually occur in multiple steps, which explain the name (Chang and Ren, 1994). The steps involved in the operation of the MSPC algorithm are:

1) The mobile stations measure the SIR over time and compare them with a pre-determined threshold.

2) If the observed SIR is larger than the threshold, then the mobile sends a power–down command to the base station. Otherwise, it sends a power–up command.

3) The base station interprets the command from step 2 and updates the transmit power accordingly.

4) The power control updates usually take place in multiple fixed-size steps (Chang and Ren, 1994).

iii) Adaptive Step Size Power Control

Adaptive-Step size Power Control (ASPC) algorithm was proposed by (Nuaymi, Lagrange and Godlewski, 2002) if the mobile station detects the same TPC from a base station in a set of consecutive slots, the step dedicated to this mobile is increased. On the contrary, if alternative sequences of up and down TPCs of a mobile are received by a mobile station, the step size dedicated to this mobile is reduced. The Adaptive Step Power Control (ASPC) is a closed– loop power control mechanism that was originally proposed for uplink transmission using adaptive step sizes as opposed to fixed step sizes, in order to achieve faster convergence towards the target SIR. This is described by Nuaymi et al (2002) as expressed in equation (2.39).

$$P\ (t + 1) = \min\ \{p\ \max,\ p\ (t) + \delta\bar{e}(t)\} \qquad (2.39)$$

The algorithm was implemented using the following steps:

- ✓ The mobile stations measure the observed value of the SIR at each iteration and compare them with a pre-set threshold value.

- ✓ If the observed SIR is larger than the threshold, then the mobile sends a power–down command to the base station. Otherwise, it sends a power–up command.
- ✓ The first power update command is interpreted as a fixed step modification, as suggested in (Chang andRen, 1994). However, adapt the step size is adapted dynamically if successive feedback commands request additional change in the power level in the same direction, to ensure faster convergence.
- ✓ The base station interprets the power control command from each mobile station and updates the transmit power accordingly.
- ✓ The power control updates take place in multiple steps of different sizes (Nuaymiet al, 2002).

Adaptive power control algorithms reduce oscillations around the SIR_{target}. However, the limited amplifier precision prevents transmitters from using very low power control steps; therefore, oscillations are not totally eliminated(Kim et al, 1998, Nourizadeh et al 2000, and Lee and Cho 2003).

2.8. Review of related works

Power control as a radio resource management variable plays a vital role in efficient radio transmission and reception. It helps with several functionalities such as Interference management, Energy management and Connectivity management. Power control in wireless networks has been systematically studied since the 1970s. Thanks to the tremendous growth of cellular networks and its transformative impacts on society, extensive research on cellular network power control has produced a wide and deep set of results in terms of modelling, analysis, and design. It has attracted extensive research and several techniques have been propounded and implemented to improve both user experience and enable the continuous evolution and significant impact of the digital cellular technology. Comparative reviews of some of these techniques were done in this work.

The work presented by Adit (2003) considered a SIR-based power control algorithm, with main focus on the uplink. A new SIR estimator for CDMA systems was proposed using an auxiliary spreading sequence method. The proposed SIR estimator was employed at the base station to estimate the SIR, which served as a control parameter in the power control algorithm. The work also investigated the effects of system parameters such as: step size, power-update rate, feedback delay, SIR measurement error, and command error on the Bit Error Rate (BER) performance of power control. Their observation showed that feedback delay was the most critical parameter that caused serious problems in the loop and to solve the problem they proposed to use channel prediction at the base station. The proposed channel predictor utilised fading statistics to predict the future channel conditions and thus the SIR. By using a channel predictor a predictive power-control algorithm was developed, which could eliminate the effect of feedback delay. Adit(2003) further explored the use of a diversity reception technique using antenna arrays at the base station so as to solve to the problems linked to the use of power control in a real system affected by multiple access interference under fading conditions. There are certain short falls arising from the work done by Adit(2003), for instance, the effect of the downlink channel bit error rate on the performance of power control was investigated under a Gaussian distribution assumption of the command error, but in a real system, the downlink channels are also under fading conditions in which burst errors occured (Adit, 2003). It would have been better if the effect of burst errors of the command bits transmission on the performance of power control were considered. Also, the coefficients of channel predictor were computed using a direct matrix inversion method under the assumption that the autocorrelation function of fading channel were known. In practice, this is not the case as autocorrelation of fading channel needed to be estimated. Therefore a recursive method would have been desirable to reduce the computational complexity, which was not investigated in the study.

The work by Mung, Prashanthand Lan(2008) provided a comprehensive survey of the models, algorithms, analysis, and methodologies in power control. It starts with the classification of the wide range of power control problem formulations, and progresses from the basic formulation to more sophisticated ones. After surveying the key formulations, their relationships with each other, and the key properties of convexity and decomposability the authors studied in details the following outline: basic formulations, starting with the simplest case of power control with fixed equilibrium SIR targets; control of transient behaviours and admission; joint control of power and SIR assignment; extensions to opportunistic and non-cooperative power control, respectively; joint power control and beam forming, base station assignment, frequency allocation, and scheduling, for both fixed SIR and variable SIR cases. Each case study started with an overall introduction and concludes with a discussion of open problems. The authors also highlighted the use of mathematical language and tools in the study of power control, including optimization theory; control theory; game theory; and linear algebra; with practical implementations of some of the algorithms in operational networks discussed. An analysis of the open problems presented at the end of most chapters especially in the area of power control in cellular networks showed that there are still many under-explored directions and unresolved issues that remain theoretically challenging and practically important (Mung, et al, 2008).

The performance of multiple air-to-air repeaters parallel in a single cell was studied byJari (2010). Firstly, network coverage was studied with varying number of repeaters in rural macro-cellular environment. Secondly, the received signal quality was studied as the ratio of desired signal and interference and noise in suburban environment with different number of repeaters, and with different repeater distances to the base stations. Also, an alternative repeater configuration was studied in both the scenarios to see the effect of repeater antenna locations and directions on the system performance. From the result gotten, the network coverage was noticed to improve in rural macro-cell with multiple repeaters, but the number of repeaters was limited. In urban macro-cell, the studied multi-repeater configurations provided minor improvements in the received signal quality. Both, the number of repeaters, and the distance to the serving base station were shown to have effect on the multi-repeater performance,Jari (2010). Additionally, it was noticed that the alternative repeater configuration provided poor coverage improvement in the rural scenario, but in suburban scenario it provided the best results. It was then inferred from this research that utilizing multiple repeaters in severely shadowed regions within the same mother cell would be a considerable alternative to denser Base Station (BS) site deployment, in cost-optimization point of view. It is important to note that all the scenarios studied in this work had idealized terrains with homogenous repeater and base station site distributions. Preferably, the simulations carried out in this work could have been done with different kind of scenarios and multi-repeater configurations. A review of the system shows that this system could suffer from noise rise in the uplink if repeater gain is not properly set. Thus, the results of this thesis should be verified with real-life measurements to some extent, so that the results could be confirmed to be suitable for application.

Certain closed loop power control algorithms for CDMA cellular communicationsystems were proposed by Matti (2005). To cope with the random changes of the radio channel and interference, certain adaptive algorithms are considered that utilize ideas from self-tuning control systems. A new approach to enhance the performance of closed-loop power controlin limited-feedback-case was presented, and power control algorithms based on the new approachwere proposed. The inherentloop delay associated with closed loop power control can be included in the design processand thus alleviated by the proposed methods. Even though the proposed adaptive algorithms in this work can improve the closed-loop PC performance it can do this using only local information, thus in some cases where a part of the link gain matrix may be, at least partially, known a more extensive technique is employed.

The thesis by Sultan (2010), studied the deployment of repeaters for two different topologies i.e. nominal clover leaf topology and triangular topology. Though the study was further narrowed to explain the behaviour of some Key Performance Indicators (KPI) in the network, when Electrical Down Tilt (EDT) angle is varied at the serving antenna of the Node B. The results showed that for both nominal clover leaf topology and triangular topology the introduction of repeaters improves the overall performance of network, while in absence of repeaters, coverage gaps in the network and the interference levels were seen to be high. Note that most of the results analyzed were averaged since the results were extracted from the data gathered from the simulations and numerical calculations. The simulation scenarios were static though made to look as real as possible they still present some form of inaccuracies and short comings.

The work by Shun-Ren (2007) investigated the UMTS discontinuous reception (DRX) mechanism for MS power saving. The DRX mechanism considered is controlled by two parameters namely: the inactivity timer threshold $t_I$and the DRX cycle t_D. The DRX mechanism is controlled by two parameters: the inactivity timer threshold $t_i$and the DRX cycle t_D. Analytical analysis and a simulation model were proposed to study the optimal $t_i$and$t_D$selections that maximize the MS power saving under the given mean packet waiting time constraint. The work devised an adaptive algorithm called dynamic DRX (DDRX) which dynamically adjusts the $t_i$and$t_D$values to enhance the performance of UMTS DRX.

Transmission schemes based on distributed power control was developed and analysed by Fredrik (2003) for cellular DS-CDMA systems. The schemes were designed to provide various QoS, while assuring global stability and rapid convergence. An iterative algorithm which handles congested situations by autonomously removing radio connections was proposed for this. An analysis of the proposed system shows that a time dependent model was assumed hence makes the analysis deterministic. This cannot reasonably capture all effects of the channel and traffic characteristics, thus a practically achievable capacity might be lower than the figures assumed in this work.

Akhilesh, Rajeev andPrajatanta (2016) did a comparative study between Modified Adaptive Step Power Control (MASPC) algorithm and Novel Adaptive Step Power Control (NASPC) algorithm for efficient use of power between mobile and base station, both the algorithm uses dynamic step size for increase the performance of the system. From the work it was observed that novel adaptive step power control algorithm reduces instability but the probability of a considerable outage degrades its performance, while in the modified adaptive step power control algorithm, results showed that it was better in terms of stability as well as speed while also increasing system performance. Notable from this work is the important feature of MASPC which is that it achieves zero percentage outage at only three (3) iteration while NASPC achieves it at sixty (60) iteration.

Rasha, Mohammed and Haala(2016) simulated the performance of WCDMA with power control as the focal point using Matlab software program. The parameters which were taken into consideration were: Multipath fading, modulation and power control rate. After the execution of the simulation, it was observed that a decrease in data rate decreased the Bit Error Rate (BER) and whenever there was a decrease of the Doppler Frequency, the BER would also decrease and lastly whenever there is an increase of multipath, the BER would decrease.

The thesis by Eheduru (2013) studied the effect of location on channel fading in an indoor environment for the purpose of planning for UMTS/HSDPA indoor network coverage. The study was carried out using a building with a transmitter (comprising a VNA and a quarter-wave monopole antenna) and a receiver (comprising an SA and a monopole antenna). Different typical indoor environments were measured to evaluate the extent of signal losses due to noise and reflection during propagation. The results from the measurement showed that the amount of reflection and thus losses during wave propagation in corridors increased with increasing distance between the transmitter and receiver. It was also observed that measurements taken in narrower corridors had a lower received total power than those on wider corridors; this was as a result of increased reflection from walls. Furthermore, it was found that the amount of reflections and fading increased with the increase in vertical distance between the transmitter and receiver on different floors. These loses between floors were seen to be much greater than those between walls or rooms. From this study the author was able to infer that radio wave obstacles in an indoor environment do have tremendous impact on the UMTS/HSDPA network. An exception to this study is the neglect of the material composition of the walls, floors, doors and ceilings in the building. It is very important to put building construction materials into consideration when analyzing path loss and fading in any indoor building.

Tondare (2015) provided an overview of the different power allocation schemes adopted in cellular system along with power control mechanisms. The exact impact of the power control mechanisms was analyzed by reviewing some fundamental approaches which showed the impact of the power control schemes on the design of energy efficient design.

Sandeep, Sumit andSiddhant(2015) in their work compared various power control algorithms such as: Fixed Step Power Control (FSPC), Adaptive Step Power Control (ASPC), and Modified Adaptive Step Power control (MASPC).It was realized that some had better advantages over the other. There were able to deduce that MASPC gives far better stability to the communication system than that of ASPC at the expense of increased complexity.

2.9 Research Gap

Numerous research efforts have been channeled towards mitigating the degrading effect of inefficient power control. The trend has been a shift from the conventional fixed step algorithms/models to more efficient adaptive algorithms/models. An analysis of these models (as seen insection 2.7.4 and section 2.8 of this dissertation) led to the development of an enhanced and better performing model with a unique approach.

An enhanced adaptive technique is developed which intelligently deals with the high oscillation variance experienced by most developed models/algorithms. In this work, a policy similar to other power control techniques with thresholds was defined, with the exception that the thresholds in this work were set based on several regions of operation. Simulation results obtained showed how the oscillation variance was effectively mitigated.

Often times most sophisticated models performed poorly due to loop delay which was usually not considered while designing such models. The technique utilized in this work not only adapts to the changing channel but also includes a Time Delay Compensation (TDC) scheme to remove the effect of delays in the output powers from the measurements in the closed-loop power control. The TDC scheme was based on the fact that after issuing a power control command, the resulting output powers are known to the algorithm, and can be pre-calculated and used in the measurements.

Power control algorithms are often studied using a snapshot method, i.e. a scenario where the link gains of the radio channel were assumed to be fixed, or change very slowly compared to the dynamics of the power control algorithm. This is not very realistic and pragmatic, because in practice the transmitted signals experience various kinds of fading, noise and interference which implies a dynamic radio environment. In this dissertation, the dynamics of this kind of environment is also taken into account in the design of the Modified power control algorithm.

CHAPTER THREE

METHODOLOGY AND SYSTEM ANALYSIS

3.1 Methodology

It is very essential in the design of any system for wireless application that the propagation environment and wireless channel be properly studied and understood. A precise characterisation and modelling of the channel is indispensable for designing efficient broadband wireless communication systems as well as for assessing their system performance. Two different approaches have always been used to investigate the nature of mobile radio channels. One approach is to try to get a comprehensive impression of the channel by its background in terms of physics. Another approach is to carryout field measurements of real channels so as to develop an empirical path loss model. In either case one can only develop a model based upon statistical descriptions of the channel.

The approach adopted in this work is to model the existing channel and also accurately characterise the propagation environment based on empirical data obtained from field measurements carried out on the test bed considered. This approach yields a better model of the propagation environment. An algorithm is developed based on simulation results obtained from the measurements carried out on the test bed considered. In order to validate this work, the developed algorithm was compared with other existing power control algorithms so as to visibly see the improved performance of the developed model over other existing algorithms.

3.1.1 Experimental Measurement Environment

Most mobile communication systems operate in complex propagation environments that are notaccurately modelled by free-space path loss. A number of path loss models have been developed over the years to predict path loss in typical wireless environments, such as large urban macro cells, urban microcells, and, more recently, indoors of buildings. These models are mainly based on empirical measurements over a given distance in a given frequency range and a particular geographical area or building. However, applications of these models are not always restricted to an environment in which the empirical measurements were made, which makes the accuracy of such empirically-based models applied to more general environments somewhatquestionable. Nevertheless, many wireless systems use these models as basis for performance evaluation.

The field measurements were carried out in the urban city of Onitsha. Onitsha is an urban city located in South East Nigeria in Anambra State and situates on Latitude 6.15^0, Longitude 6.79^0, with elevation 57 meters above sea level and a population of 561,066 (world atlas, 2016). Onitsha is a metropolitan city known for its river port, and as an economic hub for commerce, industry, and education. The Onitsha environ is predominantly comprise of two to fourstorey buildings, a few trees with random settlers. The google map of Onitsha is shown in Fig. 3.1.

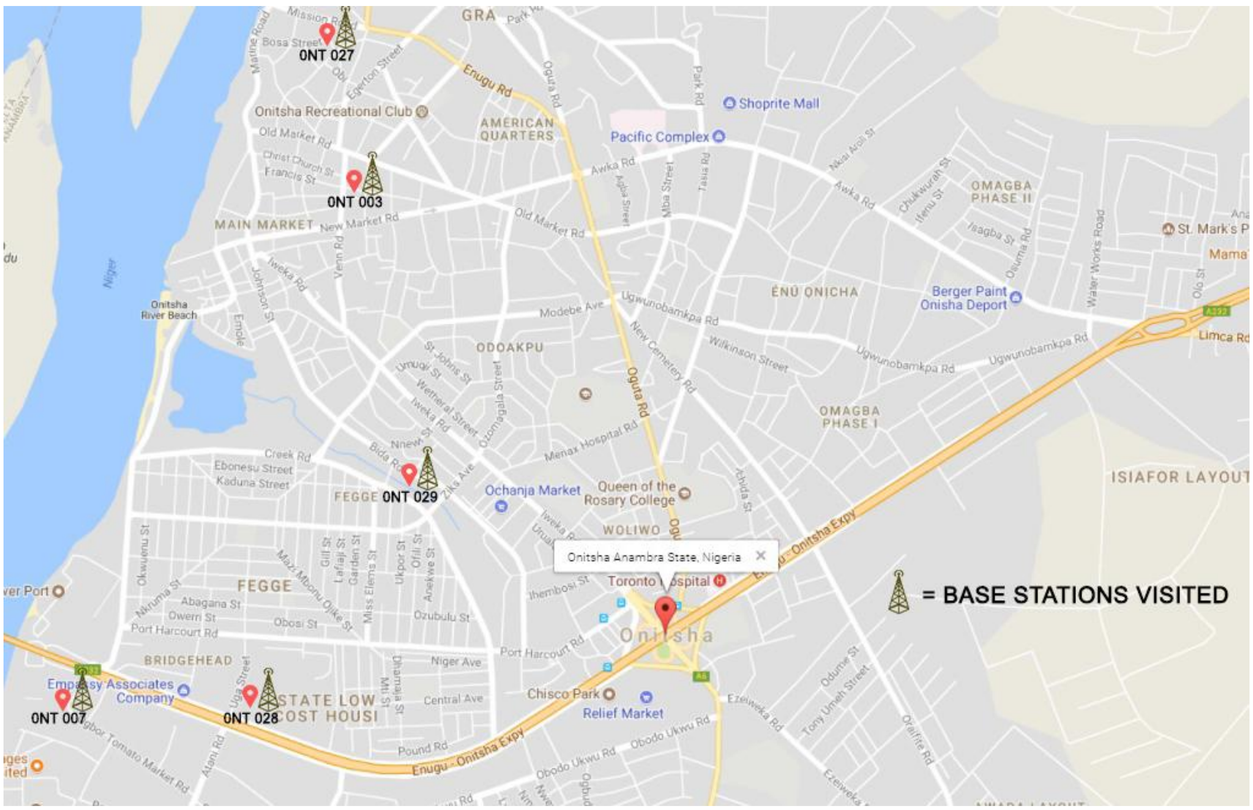


Figure 3.1: Google map view of Onitsha

The measurements were carried out at different months of the year, such as June 2016, December 2016 and repeated in January 2017 using existing WCDMA cellular mobile network belonging to Globacom Nigeria, a networkOperator operating at 2112 MHz band.A total of five base stations located in this urban environment were considered for this measurement as indicated in the Google map, see fig. 3.1. Table 3.1 shows the period the measurements were carried out and details of the days the measurements were taken are shown in Appendix A.

Month	Period covered	Time
June	2^{nd} – 30^{th} June 2016	8am – 2pm
December	2^{nd} – 30^{th} December, 2016	8am – 2pm
January	3^{rd} – 23^{rd} January, 2017	8am – 2pm

Table 3.1 Table showing dates and time of measurements carried out

Appendix F1 to F5 showthe snap shots of the base stations visited. Each of the BS used is a sectorized cellular system which has 3 sectors containing sectorized antennas tilted accordingly to achieve a 360^0 cell coverage. These three sectors each serves a sector for the cell and measurements were taken starting from any sector in the drive test region. A detailed particulars of these base stations is provided in Table 3.2. Cell splitting technique is in use in most of the areas visited and so the drive test range was typical of distances less than 2km for each base station.

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Table 3.2: Parameters of Globacom BSs Covered in the drive test at Onitsha

BS Designation	BS Model/ Type	BS Height of antenna (m)	Azimuth (degrees)	Carrier Frequency (MHz)	BS Transmit Power (dBm)	Location / Latitude and Longitude (degrees)
ONT 027	HUAWEI (WCDMA)	36	180	2112	44.7	Mbanugo street, by Enugu road, Onitsha. (0609.3167^0 /00647.1154^0)
ONT 003	HUAWEI (WCDMA)	24	120	2112	44.7	Venn road by new market road, Onitsha. (0609.3167^0 /00647.1154^0)
ONT 029	HUAWEI (WCDMA)	24	240	2112	43.0	Creek road Onitsha. (0609.3167^0 /00647.1154^0)
ONT 028	HUAWEI (WCDMA)	24	120	2112	43.0	School road, Housing estate, Fegge Onitsha. (0609.3167^0 /00647.1154^0)
ONT 007	HUAWEI (WCDMA)	24	120	2112	44.7	Con oil filling station by bridge head, Onitsha. (0609.3167^0/ 00647.1154^0)

Source: Globacom Mobile Transmitter Operator Onitsha.

3.1.2 Equipment (Instruments) used During Measurement

Table 3.3 presents a description of the instruments and tools used.

Table 3.3: List of instruments and tools used

S/N	Type of Equipment	Model	Quantity Used
1.	USB Global Positioning System (GPS) Global Sat BU 353	BU-353	1
2.	Software Activator/Processing Unit (USB License Dongle)	KEYLOK2	1
3.	Compass Andriod Package Kit (APK)	Version 2.1.1	Software
4.	The Operation/Monitoring Unit (Laptop computer)	Intel Core i5-6260U	1
5.	Samsung galaxy S5 phone	SM-G900FD	1
6.	Transmission Evaluation and Monitoring System	Version 16.01	Software
7.	Geographical Information System software (Map Info)	Version 15.2	Software
8.	Google Earth	Version 7.1.8.3036	Software
9.	Vehicle	Toyota Hilux pick up van	1
10.	Power Inverter	1kVA inverter	1

3.1.3 Experimental Measurement and Data Collection

The hardware setup for the experiment was grouped into the user interface hardware and network interface hardware. A complete drive test software, the Transmission evaluation and monitoring system (TEMS) Kit was connected in a special way to represent the user interface design and it composed of one mobile station, a GPS antenna, USB dongle (which contain the software license), all connected to a laptop computer. The laptop computer has a TEMS Investigation

Drive Test Software installed which has to detect all connected hardware and provides interface to investigate/monitor the radio network during the drive test. The Map information (Map Info) was used for mapping and location analysis. The GPS was used alongside the map info to provide accurate drive route images and their coordinates for easy location of the base stations. Google earth was used to access satellite and aerial imagery of the base station location. The dongle is programmed with a product key or other cryptographic protection mechanism and attaches via electrical connector to an external bus of the computer. Without the dongle, the software (TEMS) may run only in a restricted mode, or will not run at all. The compass was used to obtain the azimuths of the base stations visited. The laptop computer uses the inverter as a backup power supply. The network interface design is the BTS (Base Transceiver Station) which is the source of the radio network under evaluation.

The data collected from this field measurement include the received signal strength from each base station visited, active and neighbouring cell information. The received signal strength measured from the base stations served as the main data for characterizing the environment, while the data for both active and neighbouring cells served as indicators/guide on which cell is being monitored and the next possible cell that the call could be handed over to. The key Performance Indicators (KPI's) considered in the entire network include: Call setup success rate, and dropped call percentage.

A series of drive test was carried out to actually capture the received signal strength variation in the area under study. Drive testing is a method of measuring and assessing the coverage, capacity and Quality of Service (QoS) of a mobile radio network. The technique required the use of a motor vehicle containing mobile radio network air interface measurement equipment (Placed at 1.5m above ground level) that can detect and record a wide variety of the physical and virtual parameters of mobile cellular service in a given geographical area. There are different categories of drive test and they are categorized based on the type oftest to be conducted. The three (3) categories include:

(i) *Network benchmarking*: This drive test involves the use of sophisticated equipment to test different network technologies and service types simultaneously to very high accuracy, so as to provide directly comparable information regarding competitive strengths and weaknesses. Benchmarking results are usually used in marketing campaigns and givemobile network operators access to accurate competitive data on the performance and quality level of both their competitors and themselves.

(ii) *Optimization and troubleshooting*: This type of drive test is typically used during the rollout phases of new networks and also to aid in finding specific problems reported by consumers during the operational phase of the network lifecycle. Results from this test are normally used to diagnose the root cause of some problems such as dropped calls, missing neighbour cell assignments, etc.

(iii)*Service quality monitoring*:In this type of drive test, the focus is on end user experience of the quality of service. Usually, test calls are made across the network to a fixed test unit to assess the relative quality of various services. Service quality monitoring is typically carried out in an automated fashion, using devices that run largely without human intervention carried in vehicles that regularly ply typical drive testing routes.

For the purpose of this work, the service quality monitoring drive test was employed. The data obtained from the base stations were based on automated logs outputted from the investigation/monitoring software (TEMS). The system was queried to output readings of the Received Signal Strength Indicator(RSSI) from a distance of 100m (as the starting or reference point) and then readings were taken at 100m intervals up to a distance of 1200m. Due to the presence of several micro cells in the area, quick handovers to neighbouring cells deterred any effort to carry out purely single cell verification; rather a combination of both single cell and cluster cell verification was employed (i.e. a situation where more than one cell is monitored on a drive test).

The measured received signal levels (in dBm) for each cell site used was shown in Appendix A and their average value for each monthwas shown in Tables 3.4 to 3.6. Due to variations in the measurements of the received signal strength, the mean values are used for the model development. The tables showing the Received signal strengths are shown in this section while the map-info images gotten from the drive test is shown in Appendix D.

Table 3.4: Average Measured Data from Globacom WCDMA BSs in June 2016

Distance (m)	Base Stations				
	ONT027 RSS (dBm)	**ONT007** RSS (dBm)	**ONT003** RSS (dBm)	**ONT028** RSS (dBm)	**BONT029** RSS (dBm)
100	-47.20	-40.20	-51.00	-59.00	-50.00
200	-59.40	-47.10	-59.40	-59.16	-58.20
300	-58.20	-50.30	-50.80	-67.15	-61.50
400	-62.70	-45.80	-62.70	-79.26	-69.90
500	-68.50	-60.00	-65.50	-86.18	-64.30
600	-70.60	-76.30	-68.50	-89.26	-72.00
700	-73.10	-72.50	-75.10	-91.20	-73.90
800	-75.00	-65.50	-77.80	-92.22	-73.10
900	-80.00	-71.50	-84.40	-97.55	-78.20
1000	-78.10	-85.40	-82.10	-99.58	-81.30
1100	-85.00	-96.00	-90.40	-105.65	-86.10
1200	-89.00	-88.20	-88.10	-112.15	-90.10

Table 3.5: Average Measured Data from Globacom WCDMA BSs in December 2016

Distance (m)	Base Stations				
	ONT027 RSS (dBm)	**ONT007** RSS (dBm)	**ONT003** RSS (dBm)	**ONT028** RSS (dBm)	**ONT029** RSS (dBm)
100	-50.20	-41.40	-50.60	-58.80	-55.60
200	-58.20	-44.70	-51.00	-58.95	-63.50
300	-57.10	-45.30	-64.10	-69.25	-65.30
400	-62.30	-51.40	-66.50	-80.18	-68.60
500	-64.40	-62.80	-71.10	-88.25	-67.80
600	-69.10	-60.10	-71.20	-86.15	-70.40
700	-71.00	-69.30	-74.50	-90.05	-70.80
800	-73.10	-73.40	-79.10	-92.85	-76.10
900	-77.10	-78.30	-83.10	-98.99	-80.00
1000	-76.80	-78.10	-82.50	-101.28	-78.90
1100	-84.20	-84.30	-89.60	-107.89	-87.10
1200	-91.20	-91.80	-90.10	-108.15	-91.20

Table 3.6: Average Measured Data from Globacom WCDMA BSs in January 2017

Distance (m)	Base Stations				
	ONT027 RSS (dBm)	**ONT007** RSS (dBm)	**ONT003** RSS (dBm)	**ONT028** RSS dBm)	**ONT029** RSS (dBm)
100	-56.80	-42.30	-49.10	-61.20	-55.50
200	-55.00	-42.30	-53.60	-63.48	-68.30
300	-59.30	-46.30	-65.50	-67.60	-65.10
400	-77.40	-53.10	-64.50	-83.65	-71.60
500	-66.60	-57.20	-69.70	-87.26	-74.10
600	-68.70	-63.10	-72.60	-89.28	-72.10
700	-72.10	-71.20	-75.40	-88.78	-73.40
800	-72.10	-74.10	-78.10	-92.52	-74.90
900	-78.30	-78.50	-82.40	-98.21	-79.90
1000	-80.10	-80.10	-81.30	-99.83	-83.10
1100	-86.50	-85.20	-87.20	-107.10	-88.30
1200	-90.10	-90.30	-90.40	-116.33	-92.10

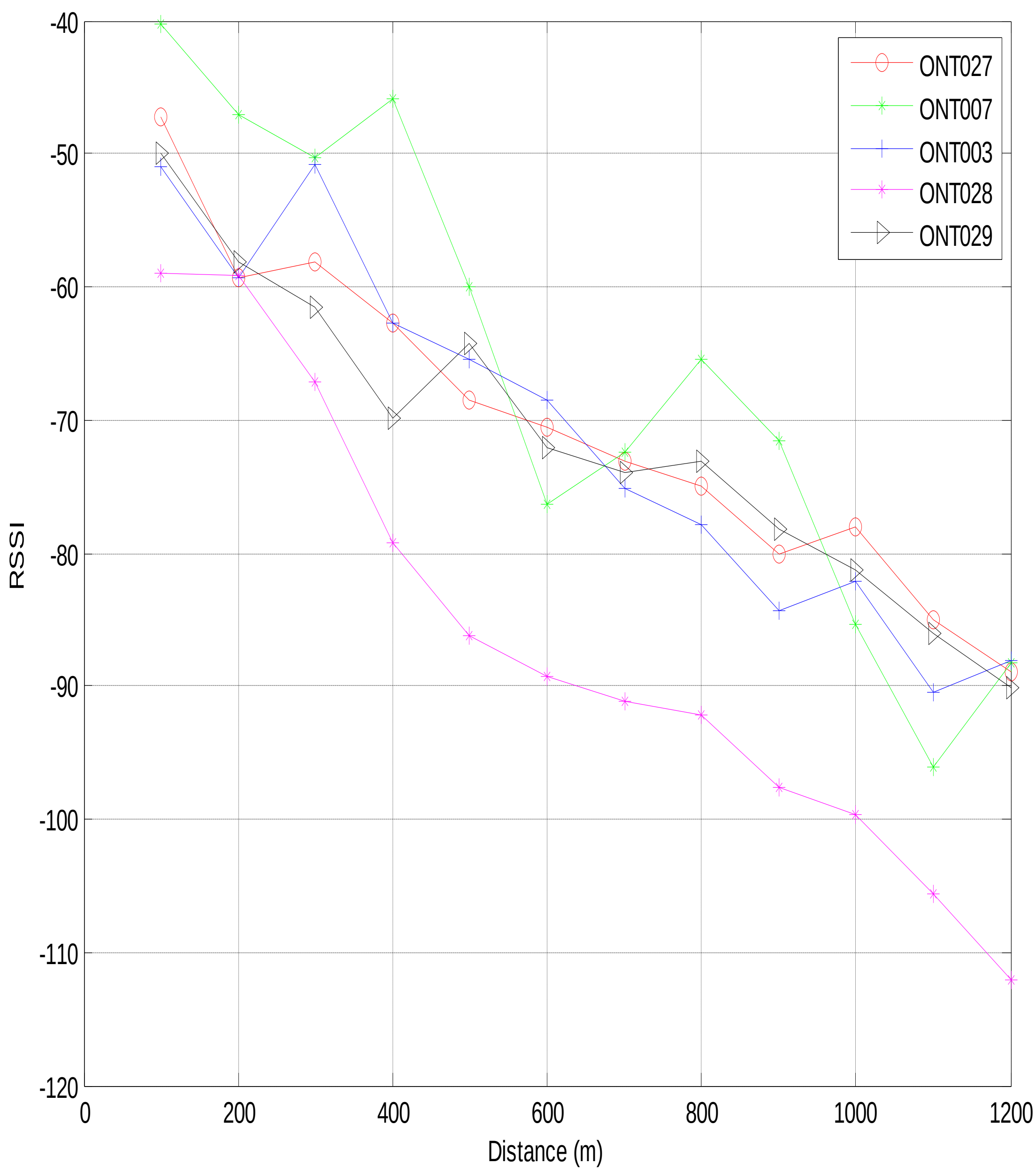

Figure 3.2: Plot of RSSI for the five base stations visited in the month of June 2016

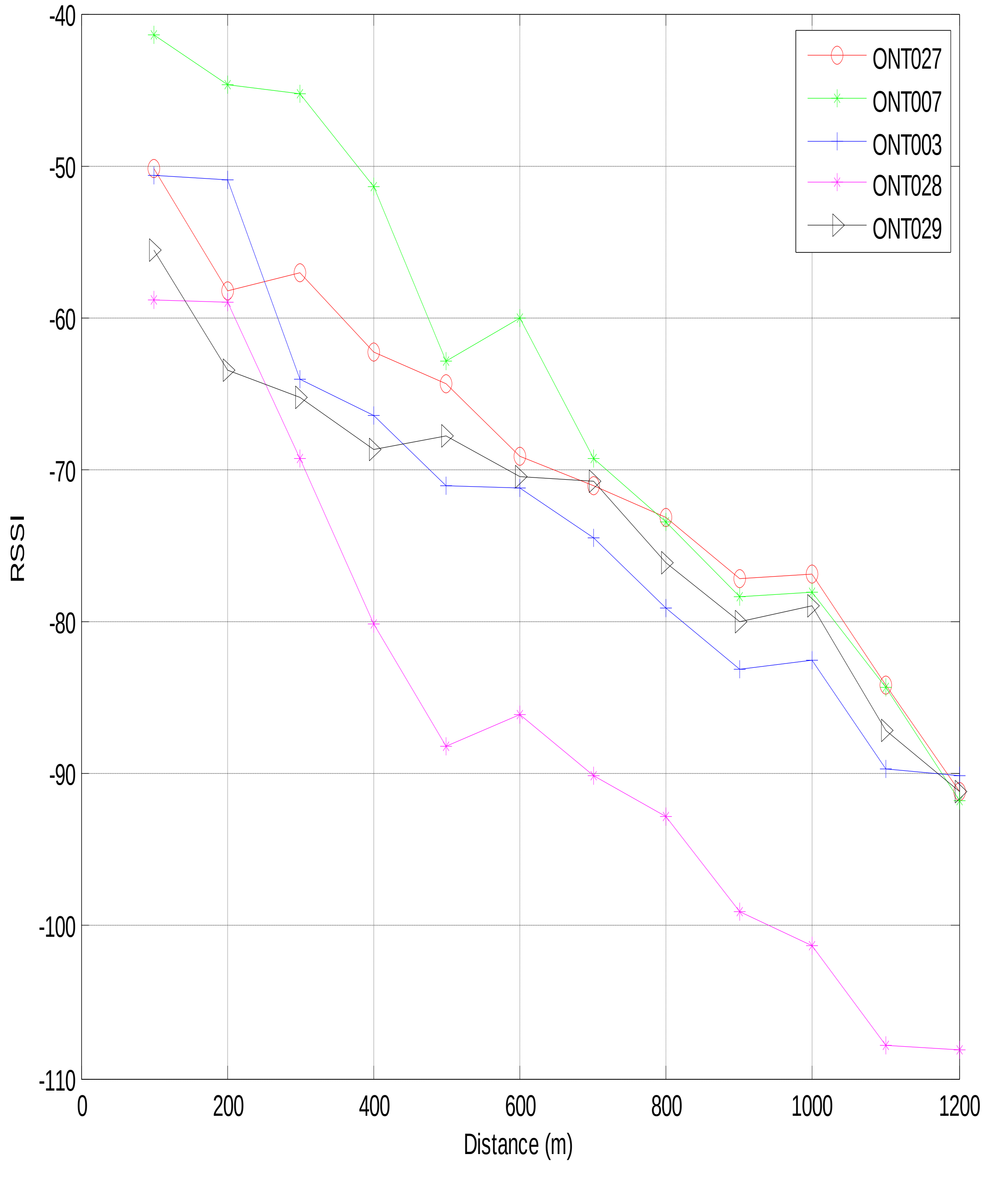

Figure 3.3: Plot of RSSI for the five base stations visited in the month of December 2016

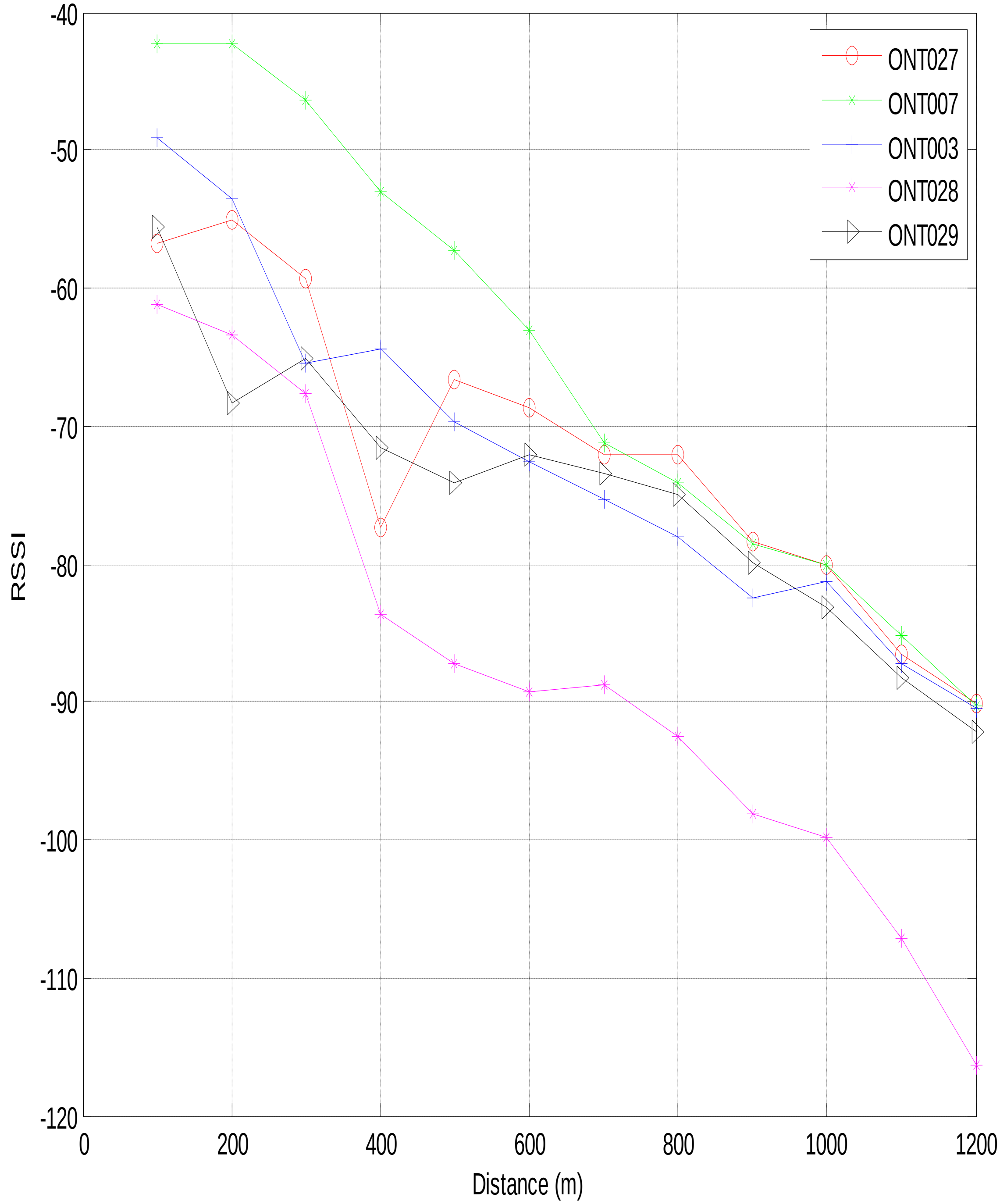

Figure 3.4: Plot of RSSI for thefive base stations visited in the month of January 2017

3.2 Experimental Environment Characterization

In cellular networks, a signal is propagated to and from a base station. When a signal is transmitted through space, it gets weaker with the distance travelled, resulting in the received power being significantly less than the transmitted power. This phenomenon is referred to as propagation signal power attenuation. The propagation path between the transmitter and the receiver may vary from BS to BS and from simple line-of-sight (LOS) to very complex one due to diffraction, reflection and scattering resulting from either natural or artificial obstacles (Doble, 1996). For such environments, the propagation path may be modelled as a randomly varying propagation path and in many instances, there exist more than one propagation path leading to multipath propagation. Such environments are characterized by fading effects such as: shadowing, multipath fading and path loss.

These fading effects are best described (in a large scale) by the path loss exponent which defines the rate of change of attenuation that the signals suffers as it propagates from the transmitter to the receiver. The average large-scale path loss for an arbitrary transmitter to receiver separation is expressed as a function of distance as in equation (3.1), (Smith andDalley, 2000):

$$P_L(dB) = P_L(d_0) + 10\eta Log_{10}(\frac{d_i}{d_0}) \tag{3.1}$$

Where,

$P_L(d_o)$ = Estimated path loss

d_0 = Reference distance,

η = Path loss exponent

d_i= Distance between MS and BS.

It was shown by Erceg et al (1999) that for any value of distance*di*, the path loss $P_L(dB)$is a random variable with a log-normal distribution about the mean value due to shadowing effect. To compensate for shadow fading, the path loss beyond the reference distance can be written as in equation (3.2):

$$P_L(dB) = P_L(d_0) + 10\eta Log_{10}\left(\frac{d_i}{d_0}\right) + \varsigma \tag{3.2}$$

Where ς is the shadowing factor and also a Gaussian random variable (with values in dB) and modeled as log normal with zero mean and standard deviation σ (also in dB). The standard deviation of the shadowing factor is known as the location variability.

The standard deviation is given as in equation (3.3), (Erceg, et al 1999).

$$\sigma = \sqrt{\sum \frac{(P_L(d_i) - P_L(d_0))^2}{N}} \quad (3.3)$$

Where $P_L(d_i)$ is the measured path loss at distanced_i, $P_L(d_o)$is the estimated path loss using (3.1) and N is the number of measured data points.

The path loss exponent η, is obtained from measured data by applying the method of linear regression analysis (Azubogu, 2011) (or method of least squares) such thatthe sum of squared errors is as in equation (3.4).

$$e(\eta) = \sum_{i=1}^{m} (P_L(d_i) - P_L(d_o))^2 \quad (3.4)$$

Making $P_L(d_o)$ *in* equation (3.1) the subject of formula and substituting into equation (3.4) gives as expressed in equation (3.5).

$$e(\eta) = \sum_{i=1}^{m} (P_L(d_i) - P_L(d_0) - 10\eta Log_{10}(\frac{d_i}{d_0}))^2 \quad (3.5)$$

The value of η which minimizes mean square error can be obtained by equating the derivative of $e(\eta)$ to zero. Differentiating (3.5) with respect to η and equating to zero gives:

$$\frac{\delta e(\eta)}{\delta n} = -20\, Log_{10}(\frac{d}{d_0}) \sum_{i=1}^{m} (P_L(d_i) - P_L(d_0) - 10\eta Log_{10}\left(\frac{d_i}{d_0}\right)) = 0$$

$$\sum_{i=1}^{m} (P_L(d_i) - P_L(d_0) - 10\eta Log_{10}\left(\frac{d_i}{d_0}\right)) = 0$$

$$\sum_{i=1}^{m} (P_L(d_i) - P_L(d_o)) = \sum_{i=1}^{m} (10\eta \log_{10}(\frac{d_i}{d_o})$$

$$\sum_{i=1}^{m} (P_L(d_i) - P_L(d_o)) = \eta \sum_{i=1}^{m} (10 \log_{10}(\frac{d_i}{d_o})$$

Making η subject of formular is as expressed in equation (3.6).

$$\eta = \frac{\sum_{i=1}^{m} (P_L(d_i) - P_L(d_o))}{\sum_{i=1}^{m} (10 \log_{10}(\frac{d_i}{d_o}))} \quad (3.6)$$

Where,

$P_L(d_i)$is the average path loss which is the difference between the transmitting power (P_t) in dB and received power (P_r) in dBm,

$P_L(d_o)$= the path loss at close-in reference distance otherwise known as reference path loss,

$d_o$is close-in reference distance,

d_i is distance at intervals from the BS to MS.

Table 3.7 shows the typical values of path loss exponent for most environments.

Table 3.7: Typical Pathloss Exponents for various environments (Rappaport, 2008)

Environment	**Pathloss Exponent,** η
Free Space	2
Urban cellular/PCS	2.7 to 4.0
Shadowed urban cellular/PCS	3 to 5
Indoor LOS	1.6 to 1.8
Obstructed Indoor	4 to 6
Obstructed in factories	2 to 3

Applying equation (3.6) and (3.3) to Tables 3.4 to 3.6 using Matlab program, the Path loss exponent and shadowing factor for each site is obtained as shown in Table 3.8.

Table 3.8: Path loss exponent and shadowing factor for each site

Base Station	**Rainy Season (June)**		**Harmattan Season (December)**		**Dry Season (January)**	
	Path loss Exponent	**Shadowing Factor**	**Path loss Exponent**	**Shadowing Factor**	**Path loss Exponent**	**Shadowing Factor**
ONT027	3.23	7.53	2.68	6.48	2.09	5.36
ONT007	3.65	9.13	3.27	8.26	3.18	8.13
ONT003	2.81	6.99	3.07	7.37	3.23	7.61
ONT028	3.81	9.28	3.86	9.35	3.70	9.04
ONT029	3.04	7.22	2.40	5.74	2.68	6.24

To estimate the performance of wireless channels, propagation models are often used (Moltechanov, Koucheryavy and Harju, 2003). Path loss models represent a set of mathematical equations and algorithms which are applied for radio signal propagation prediction in certain environments. They describe the signal attenuation between a transmitting and a receiving antenna as a function of the propagation distance and other parameters which provide details of the terrain profile required to estimate the attenuating signal (Ekpenyong, Isabona andEtim, 2010).

Using BS ONT028 as reference (ONT 028 was used in modeling Onitsha path loss because it has the highest signal attenuation due to shadowing effect),the path loss model is determined using the information provided in Table 3.8.

From the information provided by Table 3.8 the empirical path loss model for Onitsha urban can be obtained as expressed in equation (3.2).

$$P_L(dB) = P_L(d_0) + 10\eta Log_{10}\left(\frac{d_i}{d_0}\right) + \varsigma$$

From Table 3.8, the average Path loss exponent for ONT 028 was found to be 3.79 with an average Shadow factor of 9.22 dB and $P_L(d_o)$which is the path loss at close-in reference distance otherwise known as reference path loss is obtained as expressed in in equation (3.7).

$$P_L(d_o) = P_t - P_r \qquad (3.7)$$

$= (43.04 - (-59.63) = 102.67$dB.

Where, P_r is the reference received signal strength at d = 100m.

$$P_t = transmit\ power\ of\ ONT\ 028$$

Therefore the empirical Path loss for ONT 028 is as expressed in equation (3.8).

$$P_L(dB) = P_L(d_0) + 10\eta Log_{10}\left(\frac{d_i}{d_0}\right) + \varsigma \qquad (3.8)$$

Substituting the values above into (3.7)gives:

$$P_L(dB) = 102.67 + 10(3.79)Log_{10}\left(\frac{d_i}{d_0}\right) + 9.22$$

$$P_L(dB) = 111.89 + 37.9Log_{10}\left(\frac{d_i}{d_0}\right)$$

The empirical path loss model for Onitsha urban is then obtained as expressed in equation (3.9).

$$P_L(dB) = 111.89 + 37.9Log_{10}\left(\frac{d_i}{d_0}\right) \qquad (3.9)$$

This is the efficient path loss model determined for Onitsha urban in this work.

The signal strength received by the mobile equipment, Samsung S5, as shown in Tables 3.4 to 3.6 depends largely upon shadow fading, multipath fading, distance of the Mobile Unit (MU) from the Base Transceiver Station (BTS), presence of obstacles in the paths taken for the drive tests and varying weather conditions.

Natural and man-made structures such as high rise buildings, office structures or clustered trees in the environment characterized, with sizes ranging from a few meters to tens of meters, dramatically influence the wireless propagation channel and give rise to shadowing effect. These features are usually similar or greater in size than the wavelength of the transmitted signal and may both block, scatter or reflect the radio signal. These contributions reach the Mobile by way of multiple paths, in addition to that of the direct signal.

Also, the presence of precipitation such as rain and fog in the propagation path during the months of June and December respectivelyintroduces major attenuation to the propagation channel.

The absorption of propagation signal by atmospheric rain, snow or iceare caused by rain fade and are prevalent at high frequencies. This results in the degradation of the transmitted signal due to the electromagnetic interference of the leading edge of a storm front. Rain fade can be caused by precipitation at the uplink or downlink location. However, it does not need to be raining at a location for it to be affected by rain fade, as the signal may pass through precipitation many miles away, especially if the antenna has a low azimuth. About 5 to 20 percent of signal attenuation as a result of rain fade is caused by rain, snow or ice on the uplink or downlink antenna reflector or feed horn (Das,Maitra, and Shukla, 2010). Since rain is a non-homogeneous process in both time and space, specific attenuation varies with location, time and rain type. For instance, the path loss exponent obtained during rainy season (June) varied with base station which showed that at different locations, depending on the intensity of rain fall in such an area, the signal attenuation varied.

Rain attenuation modeling is usually done in terms of Drop Size Distribution (DSD) (Crane, 1996, Thurai et al, 2007). Rain DSD varies with rain rate as well as with location and thus the same rain rate can correspond to different DSD. The DSD depends strongly upon the local climate of the region studied (Maitra, 2004).

Wind in itself doesn't affect the propagated signal but it does put an external force (wind loading) on the antenna system that can cause it to move or come out of alignment. As can be seen in Table 3.8 there was no much loss during the dry season (which is mostly windy and sunny) compared to the other seasons except for some sites which could be as a result of antenna misalignment or shadowing effect due to natural obstructions in the propagation path.The solution to this is to install antenna systems to withstand local wind patterns. Most antenna systems are designed to withstand wind gusts up to 177 kmph (varies by manufacture). Hence, in addition to the expected distance power decay, two main effects are characteristic in mobile propagation: shadowing and multipath. This leads to a reduction in power density (attenuation) as the signal propagates through space, and this phenomena is known as path loss.

As depicted in the plots of Figs 3.2 to 3.4, it is evident that the signal loss in the environment showed a generally increasing trend with distance. It was also shown that the received signal strength varied with distance and also with the season of the year. These varying results shows that different seasons of the year plays a major role in signal degradation/attenuation and should be considered during cell planning and verification.

These observable variations are often neglected when characterising the propagation environment. This has been factored into this work and the impact of shadowing was also considered.

The model obtained was also compared with other existing models so as to see the variation and acceptability. Due to the frequency limitation of COST-231 Hata model to 2GHz which is below the frequency of the WCDMA network studied in this work, the comparison was limited to only free space and ECC-33 model.

- **free space path loss**

The free space path loss equation as expressed in equation (2.11) is as expressed in equation (3.10).

$$P_L(dB) = 32.4 + 20Log_{10}f + 20Log_{10}d_i \qquad (3.10)$$

Where,

f = frequency in MHz

d_i = distance in km

This equation shows the relationship between the path loss, the frequency and distance of the transmission medium.

Using the following test parameters: $f = 2112MHz$

$$P_L(dB) = 32.4 + 20Log_{10}2112 + 20Log_{10}d_i$$

$$P_L(dB) = 32.4 + 66.49 + 20Log_{10}d_i$$

The free space path loss model for Onitsha urban is given as in equation (3.11).

$$P_L(dB) = 98.89 + 20Log_{10}d_i \quad (3.11)$$

- **ECC-33 Path loss model**

The path loss equation for ECC-33 model (Electronic Communication Committee (ECC), 2003) from equation (2.16) is:

$$P_L = A_{fs} + A_{bm} - G_b - G_r$$

Where,

A_{fs} = the free space attenuation

A_{bm} = the basic median path loss

G_b, = the *BS* height gain factor

G_r = the terminal height gain factor

They are individually defined as were expressed in equations (2.16), (2.18) and (2.19)

$$A_{fs} = 92.4 + 20Log_{10}f + 20Log_{10}d_i$$

$$A_{bm} = 20.41 + 7.894Log_{10}f + 9.83Log_{10}d_i + 9.56(Log_{10}f)^2$$

$$G_b = Log_{10}\left(\frac{h_b}{200}\right)(13.958 + 5.8Log_{10}(d_i))^2$$

And for urban city environments (Doble, J.,1996), it is expressed as in (2.20),

$$G_r = (42.57 + 13.7Log_{10}f)(Log(h_m) - 0.585)$$

And for mega city:

$$G_r = 0.759h_m - 1.862$$

Where f is the frequency in GHz

h_b is the BS antenna height in meters

h_m is the mobile antenna height in meters

h_m =1.5m, h_b = 24m, $f\ =\ 2.112\ GHz$

$$A_{fs}\ =\ 92.4 + 20Log_{10}2.112 + 20Log_{10}d_i$$

$$A_{fs}\ =\ 92.4 + 6.53 + 20Log_{10}d_i$$

$$A_{fs}\ =\ 98.89 + 20Log_{10}d_i$$

$$A_{bm}\ =\ 20.41 + 7.894Log_{10}2.122 + 9.83Log_{10}d_i +\ 9.56(Log_{10}f)^2$$

$$A_{bm}\ =\ 20.41 + 2.56 + 9.83Log_{10}d_i +\ 9.56(Log_{10}2.112)^2$$

$$A_{bm}\ =\ 20.41 + 2.58 + 9.83Log_{10}d_i +\ 1.01$$

$$A_{bm}\ = 24 + 9.83Log_{10}d_i$$

$$G_b\ =\ Log_{10}\left(\frac{h_b}{200}\right)(\,13.958 + 5.8Log_{10}(d_i))^2$$

$$G_b\ =\ Log_{10}\left(\frac{24}{200}\right)(\,13.958 + 5.8Log_{10}(d_i))^2$$

$$G_b\ =\ -0.92\ (13.958 + 5.8Log_{10}(d_i))^2$$

$$G_b\ =\ -0.92\ (194.83 + 161.91Log_{10}(d_i) + 33.64\{Log_{10}(d_i)\}^2)$$

$$G_b\ =\ -179.24 - 148.96Log_{10}(d_i) - 30.95\{Log_{10}(d_i)\}^2$$

$$G_r = [42.57 + 13.7Log_{10}F][Log(h_m) -\ 0.585]$$

$$G_r = [42.57 + 13.7Log_{10}2.112][Log(1.5) -\ 0.585]$$

$$G_r = 47.02\ (-0.4089) =\ -19.23$$

Substituting the values into equation(2.16) given as

$$P_L\ =\ A_{fs}\ +\ A_{bm}\ -\ G_b\ -\ G_r$$

Will give equation (3.12).

$$P_L\ =\ 98.89 + 20Log_{10}d_i\ +\ 24 + 9.83Log_{10}d_i -\ (-179.24 - 148.96Log_{10}(d_i) - 30.95\{Log(d_i)\}^2) - (-19.23)$$

$$P_L\ =\ 321.36 + 178.79Log_{10}(d_i) + 30.95\{Log_{10}(d_i)\}^2 \quad (3.12)$$

Using Matlab, the values from the various path loss models are computed and tabulated in Table 3.9.

Table 3.9: Comparison of Path loss models

Distance (Km)	**Free Space Model (dB)**	**Developed model (dB)**	**ECC-33 Path loss Model (dB)**
0.1	78.89	111.89	173.52
0.2	84.91	123.29	211.51
0.3	88.43	129.97	236.33
0.4	90.93	134.70	255.11
0.5	92.87	138.38	270.34
0.6	94.45	141.38	283.21
0.7	95.79	143.91	294.40
0.8	96.95	146.11	304.32
0.9	97.98	148.05	313.24
1.0	98.89	149.79	321.36
1.1	99.72	151.35	328.81
1.2	100.47	152.79	335.71

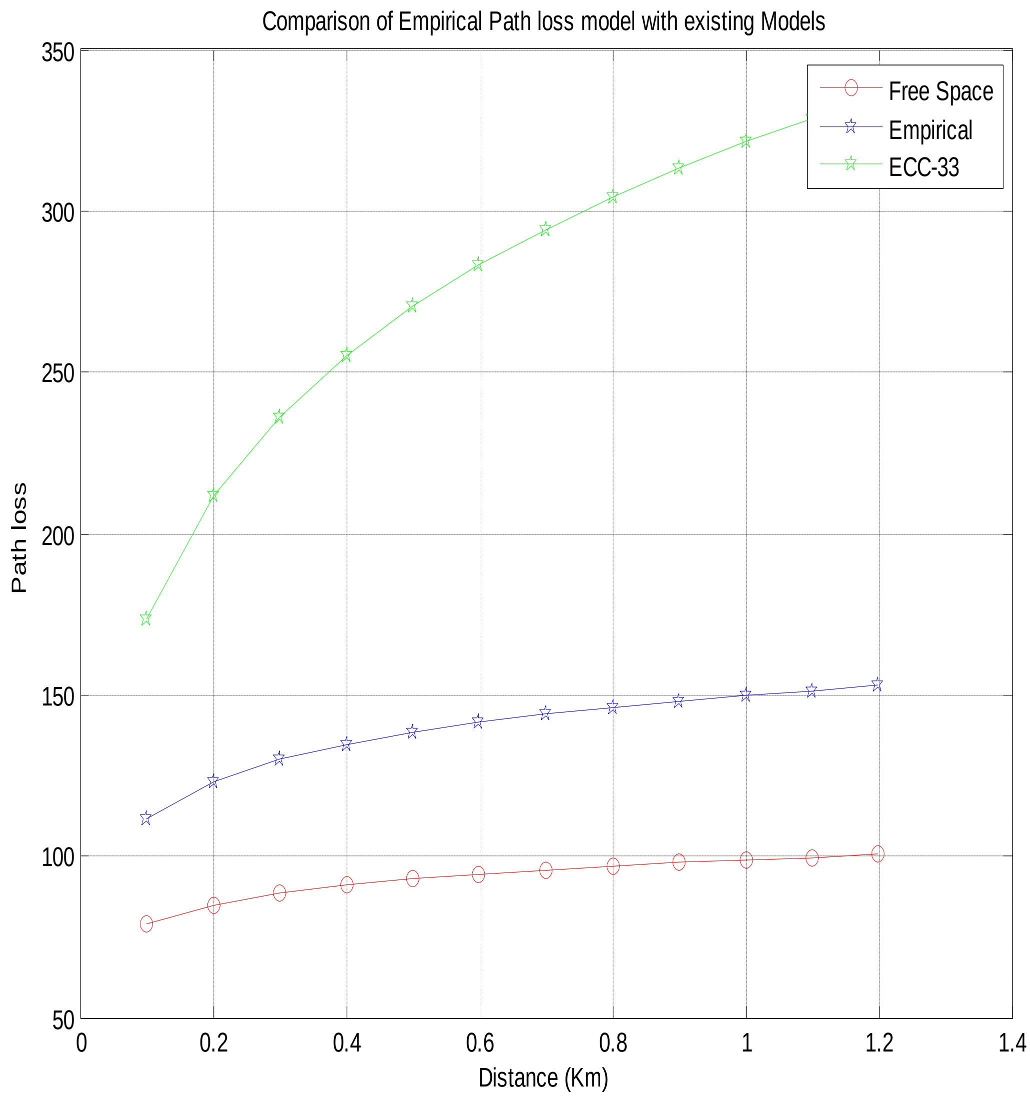

Figure 3.5: Graph showing the comparison of various Path Loss Models

It was shown that the efficient path loss model determined for Onitsha urbanis as expressed in equation (3.8).

$$P_L(dB) = 111.89 + 37.9Log_{10}\left(\frac{d_i}{d_0}\right)$$

Comparisons between the model and that predicted by ECC-33 and other traditional models have shownsome variations. These variations show that the ECC-33 model or any existing model cannot fit in effectivelyinto an environment other than that for which it was developed. To make such models appropriate fordifferent environments, they must be corrected. This can only be done by carrying out field measurementsin the environment. The measured data were then used to correct an existing model or to develop a newmodel for the environment.

3.3 Development of the Modified Adaptive Power Control (MAPC) model

The MAPC algorithm is simply the combination of the FSPC, the ASPC, and the DCPC algorithms.

The FSPC and AS algorithm aredescribed respectively as in equations (2.25) and (2.34).

$$P(t+1) = P(t) + \delta sign(\gamma^t\,(t) - \gamma(t)),$$

$$P(t+1) = \min\{p\ \max, p(t) + \ \delta\bar{e}(t)\}\text{and}$$

$e(t) = \gamma^t\,(t) - \gamma(t)$ and $u\,(t)$ = sign $(e(t))$

Considering uplink, the base station generates the commands $u(t) \in \{-1,1\}$. Just like the FSPC algorithm, the commands are transmitted to the mobile station, which applies Adaptive Step to generate a reconstruction $\bar{e}_G(t)$of the PC misadjustment, and then updates its power as in the ASPC algorithm, but using the reconstructed value instead of the true $e(t)$. This is described as in equation (3.12).

$$\bar{e}_G(t) = a(t,1)\bar{e}_G(t-1) + \delta_e u\,(t) \qquad (3.12)$$

Where,

δ_e = update parameter

$a(t,1)$= Parameter to implement sign change.

The idea employed here is such that if the two latest TPC commands have the same sign(e.g. if u (t) = u (t-1) = +1), the reconstruction of $e(t)$ is updated by δ_e to the direction of the last command $u(t)$ so as to increase the step size of the next power update. If the two latest commands have different signs (e.g. if u (t) ≠ u (t-1)), a zero crossing must have happened in the signal $e(t)$, and the reconstruction also crosses zero.

The condition for the change in sign is applied mathematically like in the AS method as expressed in equation (3.13).

$$a(t,1) = \begin{cases} 1, & if\ u(t)=u(t-1) \\ 0, & if\ u(t)\neq u(t-1) \end{cases} \qquad (3.13)$$

The performance of the MAPC algorithm depends on the selection of the update parameterδ_e. If very small δ_e is selected, then the reconstruction cannot track the actual maladjustment$e(t)$. This can happen for example during a deep fade in the radio channel. On the other hand, if δ_e is too big, then the advantage of the "fine-tuning" provided by the adaptation method to the power control algorithm is significantly reduced. To circumvent these problems, the update parameter is adapted to meet varying conditions.

The reason for adapting the step size in the first place is to make the transmission power to change faster if the consecutive TPC commands have the same sign. To adapt the update parameter the FSPC algorithm is considered. In the FSPC algorithm, the PC step size δ is fixed and the best situation is achieved when the commands (power updates) generated by the FSPC algorithm are consecutive+1's and -1's, since in this case the PC maladjustment$e(t)$ oscillates between the opposite sides of the origin at consecutive samples. The amplitude of this oscillation depends on the step size. Now, consider that we could decrease the step size applied at the transmitter, while maintaining the consecutive up-down command flow. In this case the amplitude of the oscillation of the PC maladjustment would be decreased. If the continuous up-down command flow breaks, the step size could be increased again. This can be achieved based on the following modification of the update parameter as expressed in equation (3.14).

$$\delta_e(t) = \delta_e(t-1) + \delta_G u(t)\, u(t-1) \quad (3.14)$$

Where, δ_G controls the rate of change of the update parameter $\delta(t)$, which is now time-varying. The idea behind this method is that the update parameter is decreased every time the two most recent PC commands have different signs, otherwise it is increased. In this way the algorithm tries to find the smallest update step size that still leads to consecutive up-down PC command flow. To prevent the update step size from growing too large, it should be limited. A limit of 1 dB was used in all the simulations and$\delta_G = 0.01$. The cell load is given as the number of mobile users per cell at a given instant of time.

With this, the developed model for the MAPC algorithm is given as in equation (3.14).

$$P(t+1) = P(t) + \delta \bar{e}_G(t) \quad (3.14)$$

Where,

$$\bar{e}_G(t) = a(t,1)\bar{e}_G(t-1) + \delta_e u(t) \quad \text{and} \quad \delta_e(t) = \delta_e(t-1) + \delta_G u(t)\, u(t-1)$$

Fig. 3.11 shows the flow chart for the implementation of the Modified Adaptive Power Control algorithm, using the following steps:

(a) The mobile stations measure the observed value of the SIR at each iteration and compare them with the pre-set lower and upper critical threshold values.

(b) If the observed SIR is smaller than the lower critical threshold, then the mobile sends a power–up command to the base station, also if it is greater than the upper critical a power-down command is sent. The first power update command is interpreted as a fixed step modification; however, the MAPC algorithm dynamically adjusts the step size if successive feedback commands request additional change in the power level in the same direction.

(c) If the observed threshold is between the lower and the upper critical threshold values, then the mobile does not send any control signal to the base station. Thereby eliminating oscillations observed at low outage percentage of Multiple Step Power Control (MSPC) algorithm.

(d) The increment size is chosen larger than the decrement size. This ensures that mobiles in outage can quickly come out of outage.

(e) Once the mobiles are active and not in the buffer region, the smaller decrement size brings the mobile back into the buffer region.

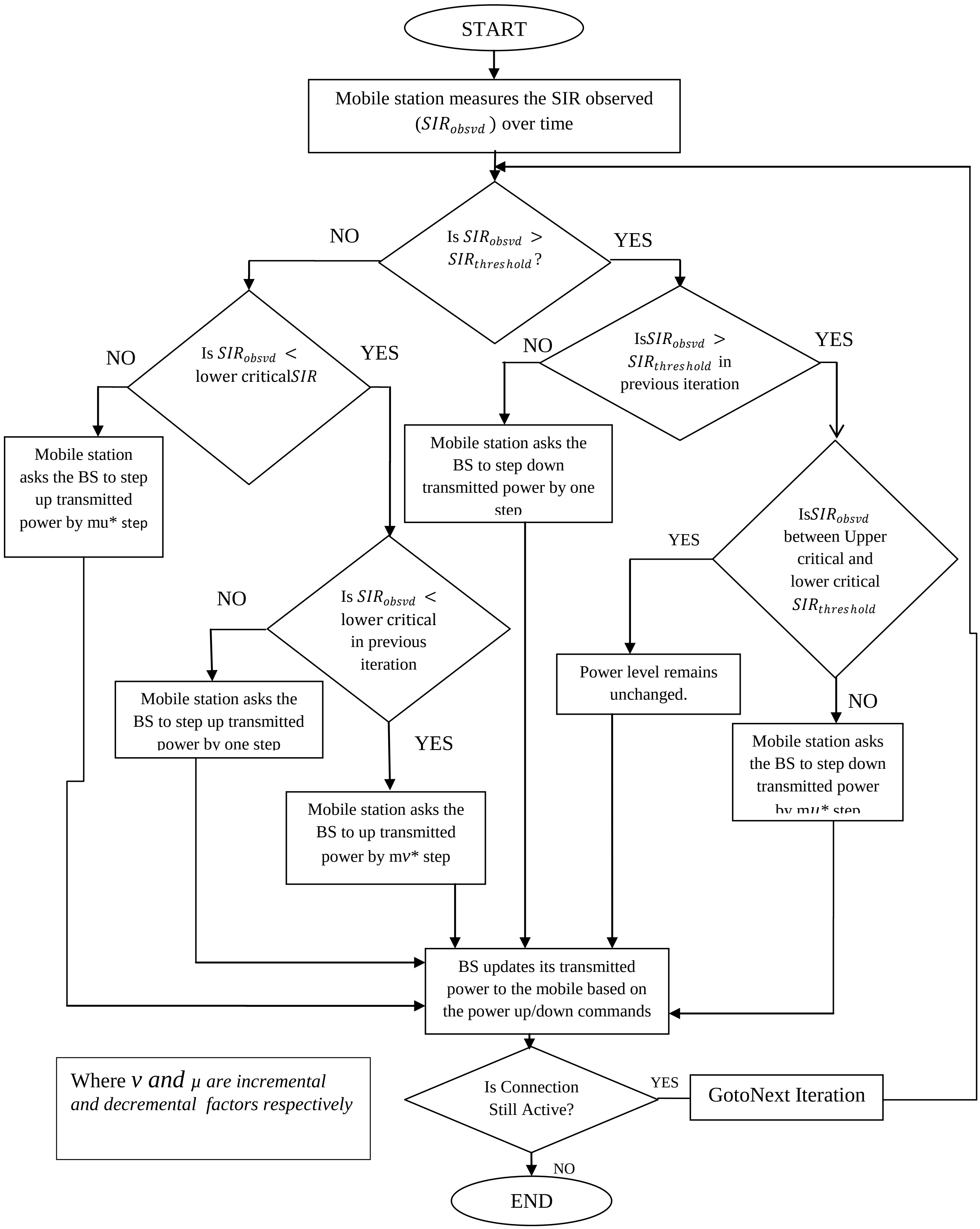

Figure 3.6: Flow chart for the implementation of the MAPC algorithm

The pseudo-code for the simulation is as in Algorithm 1.

Algorithm 1: MAPC Algorithm Pseudo-codes.

1. Initialize number of iterations

2. Initialize number of mobiles

3 Generate uniformly distributed vector of mobile-to-base station distance

4. Generate a vector of link–gains from each mobile to the base station based on a log-normal distribution with zero–mean and standard deviation = 6 dB

5. Allocate initial power for each mobile at the base station

6. Initialize SIRthreshold = −14 dB

7. Initialize ν (increment factor), μ (decrement factor), δ (step size), flag (previous iteration feedback information)

8. Initialize buffer region

9. for i = 1 to iterations

• *for j = 1 to mobiles*

• *Calculate SIRobserved at each mobile*

• *Compare SIRobserved with SIRthreshold*

if (SIRobserved ≤ SIRthreshold)

• *Increment outage counter(i)*

• *if (previously in outage)*

• *Adjust (increase) power by νδ*

• *elseif (previously not in outage or returning from outage)*

• *Adjust (increase) power by δ*

• *elseif (initial power allocation caused this outage)*

• *Adjust (increase) power by νδ*

• *elseif (SIRobserved>SIRthreshold + buffer)*

• *if (previously not in outage)*

• *Adjust (decrease) power by μδ*

• *elseif (previously in outage)*

• Adjust (decrease) power by δ

• elseif (initial power allocation caused this "non–outage")

• Adjust (decrease) power by δ

• else

• Do nothing if the SIRobserved is in the buffer region

• end

end

10. Calculate the outage percentage using outage counter and the number of mobiles

11. Plot outage percentage versus number of iterations

3.4 Performance Parameters and Measure

Rate of Convergence and Outage are important performance parameters. Rate ofconvergence measure gives the responsiveness of an algorithm. It gives the speed with which an algorithm canconverge to the desired power level. Outagegives the ratio of number of mobiles having power levels lower than the required power level to the total number of mobiles in the system using same channel. It also gives the system availability for particular Quality of Service.

The performance of the system was tested under different load conditions. The load of the system was changed by just increasing the number of users. But in these simulations the load was fixed at the time of power control. Another important system parameter that was changed was the gain matrix. The distance of each user under each cell is random, so the gain matrix changes in every run and the simulations waseffected for different gain matrices.

CHAPTER FOUR

IMPLEMENTATION, RESULTS AND DISCUSSIONS

4.1 Model Implementation

This chapter presents the simulation and the simulation results for this work. Uplink of FDD WCDMA 3G system was considered. In a FDD-CDMA system, a physical channel is defined by its code and its frequency. The methods considered in this work applied to downlink and TDDsystems after some slight adaptations. Power control was only applied at Layer 1 (inner closed-loop PC). Circuit switched systems (e.g., voice service) was considered. A rather simple simulation model was used. This allows comparisons between the Power Control algorithms. A maximal transmitted power limitation was also considered. For each mobile, the best-received base station is selected as its corresponding one. The Mobiles mobility, the initiation and termination of communications were also simulated. A discrete event simulation is considered.

The system model considered the effect of Additive White Gaussian Noise AWGN and the effect of Rayleigh and multi path fading. The specific simulated environment and the performance metrics used to measure and compare performance were also described. It also looked at the performance comparison of some of the power control algorithms. The performance evaluation was done using Matlab simulator, and the comparison was made under the condition of multi-traffics WCDMA system. The simulation was conducted using the parameters given in Table 4.1. The performance metrics considered during the simulation were presented in the following section.

4.2 Simulation Testbed

The simulation program was implemented in Matlab. It had seven cells in a hexagonal pattern, where the cell radius was 50 m and base station height was 24 m. At the centre of each cell, a base station with an omnidirectional antenna was located. The thermal noise at the base station receiver was -113 dBm Mobiles were uniformly distributed over the seven cells. The chip rate is 5 Mchip/s as in WCDMA. The target bit-energy tointerference-spectral-density ratio (Eb=Io) was 6 dB for every user. In the beginning of the simulation, the users were assigned velocities randomly between v_{min} km/h and v_{max} km/h and a random direction of movement. These were not changed during simulation. The maximum transmit power of mobile was 250 mW (24 dBm). Each mobile will connect to the closest base station and ideal handovers are assumed in the sense that each user connects to the base station with the least channel attenuation at all times. The servicemodelled in this simulation was 12.2 kbps voice services with 100% activity factor. The initial transmit power is based on the open-loop power control.

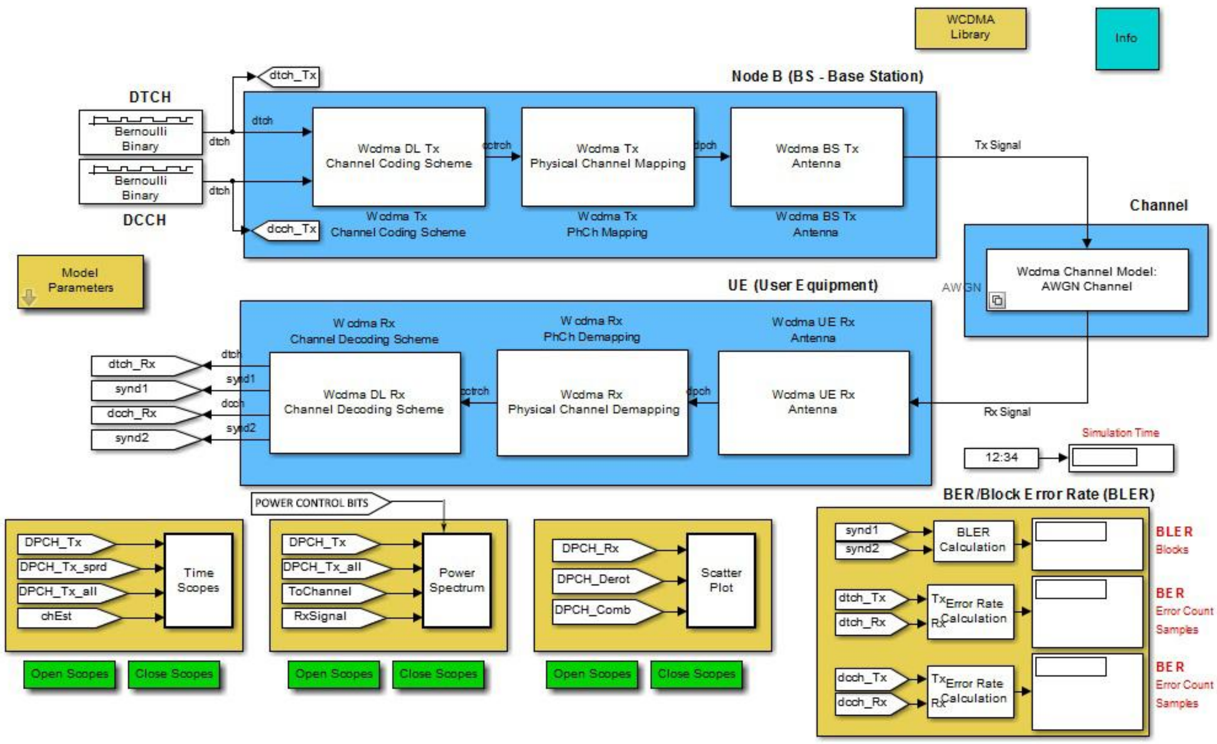

Figure 4.1 Physical Layer simulation model of a WCDMA Communication System

The model in Fig. 4.1 shows part of the frequency division duplex (FDD) downlink physical layer of the third generation wireless communication system known as wideband code division multiple access (WCDMA) in Matlab/Simulink environment.

The physical layer is in charge of providing transport support to the data generated at higher layers. This data is exchanged between the higher layers and the physical layer in the form of transport channels. There can be up to eight transport channels processed simultaneously. Each transport channel is associated with a different transport format that contains information on how the data needs to be processed by the physical layer. The physical layer processes this data before sending it to the channel.The model has seven main sub-systems, whose functions are summarized below:

(a) *WCDMA DL Tx Channel Coding Scheme*: The WCDMA DL Tx Channel Coding Scheme sub-system processes each transport channel independently according to the transport format parameters associated with it. This sub-system implements the following functions:

- Cyclic redundancy code (CRC) attachment
- Transport block concatenation and segmentation
- Channel encoding
- Rate matching
- First interleaving
- Radio frame segmentation

The different transport channels are then combined to generate a coded combined transport channel (CCTrCH). The CCTrCH is then sent to the WCDMA Tx Physical Mapping sub-system

(b) *WCDMA Tx Physical Mapping*: This sub-system implements the following functions: Physical channel segmentation, Second interleaver, Slot builder.The output of this sub-system constitutes a dedicated physical channel (DPCH), which is passed to the WCDMA BS Tx Antenna Spreading and Modulation sub-system

(c) *WCDMA BS Tx Antenna*: The WCDMA BS Tx Antenna sub-system performs the following functions: Modulation,Spreading by a real-valued orthogonal variable spreading factor (OVSF) code,scrambling by a complex-valued gold code sequence,power weighting,pulse shaping.

(d) *WCDMA Channel Model*: The WCDMA Channel Model sub-system simulates a wireless link channel containing additive white Gaussian noise (AWGN) and, if selected, a set of multipath propagation conditions. You can modify the multipath profile with the Propagation conditions environment parameter.

(e) *WCDMA UE Rx Antenna*: The received signal at the WCDMA UE Rx Antenna sub-system is the sum of attenuated and delayed versions of the transmitted signals due to the so-called multipath propagation introduced by the channel. At the receiver side, a Rake receiver is implemented to resolve and compensate for such effect. A Rake receiver consists of several rake fingers, each associated with a different received component. Each rake finger is made of chip correlators to perform the 105spreading, channel estimation to gauge the channel, and a derotator that, using the knowledge provided by the channel estimator, corrects the phase of the data symbol. The sub-system coherently combines the output of the different rake fingers to recover the energy across the different delays.

(f) *WCDMA Rx Physical Channel Damping*: This decodes the signal by performing the inverse of the functions of the WCDMA DL Tx Channel Coding Scheme sub-system

(g) *WCDMA DL Rx Channel Decoding Scheme*: The WCDMA Rx Physical Channel Demapping and the WCDMA DL Rx Channel Decoding Scheme sub-system decode the signal by performing the inverse of the functions of the WCDMA DL Tx Channel Coding Scheme sub-system, described above.

Table 4.1: Simulation Parameters (Globacom Nigeria)

S/N	**Parameter**	**Value**
1.	Chip rate, W	5M chips/s
2.	BS thermal noise, N_o	-113 dBm
3.	Data rate, R_k	144Kbps, 253Kbps,384Kbps
4.	Voice activity factor, v_k	0.65, 1
5.	Signal bit energy over noise spectral density, E_b/N_o	3-7dB
6.	Transmitting antenna gain, G_{tx}	11dBi
7.	Base station height	24m

Table 4.2 Simulation Assumptions

S/No	Paremeter	Value
1.	$SIR_{threshold}$	-14dB
2.	$SIR_{threshold}$(Lower critical)	-14.5dB
3.	$SIR_{threshold}$(Upper critical)	-13.5dB
4.	u (decremental factor)	Determined by the algorithm
5.	v (incremental factor)	Determined by the algorithm
6.	δ (fixed step size)	1
7.	δ_G(Update speed controller)	0.01

4.3 The DevelopedModified Adaptive Power Control (MAPC) Algorithm

The developed Modified Adaptive Power Control (MAPC) algorithm was done according to the steps listed in section 3.3 of chapter three and pseudo code given therein. The assumptions and values used for the various parameters were explained.

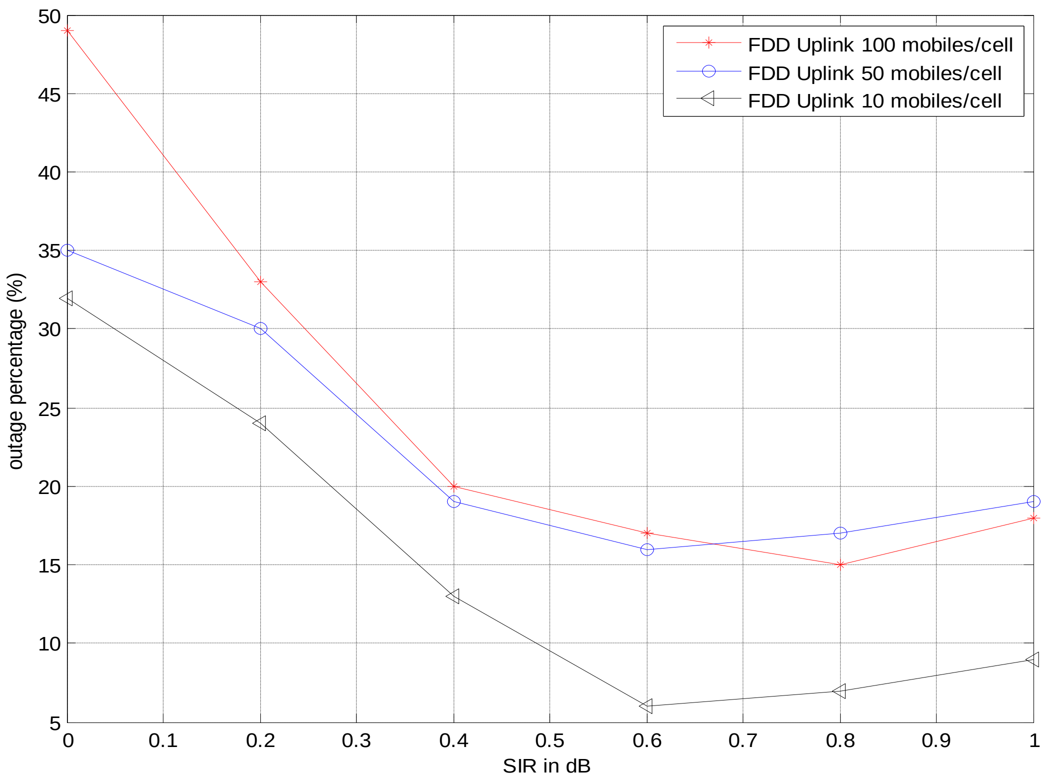

Figure 4.2: Impact of various SIR margin on the outage probability

In Fig 4.2, the impact of various values of SIR margin on the outage probability when the MAPC algorithm is used for uplink in the FDD mode was presented. Cell loads are respectively 10, 50 and 100 mobiles/cell for uplink FDD. The minimum outage probability is reached with a 0.6 dB SIR margin for the three loads, and therefore, system maximum capacity is reached with a 0.6 dB SIR margin. A 0.5dB margin was used in this work which was close to the optimal value (0.6dB) so as to obtain a trade-off with increasing channel capacity and minimal power increase. The selected SIR margin was equal to the half of the conventional fixed step power control step which could be justified by the fact that within the stable phase, the majority of user's SIRs oscillate around $SIR_{threshold}$with a standard deviation around 0.5dB. Therefore with a threshold value of-14dB, our buffer region is: (-14dB $\pm$ 0.5dB). Thus the upper critical $SIR_{threshold}$= -13.5dB and the Lower critical $SIR_{threshold}$= -14.5dB.

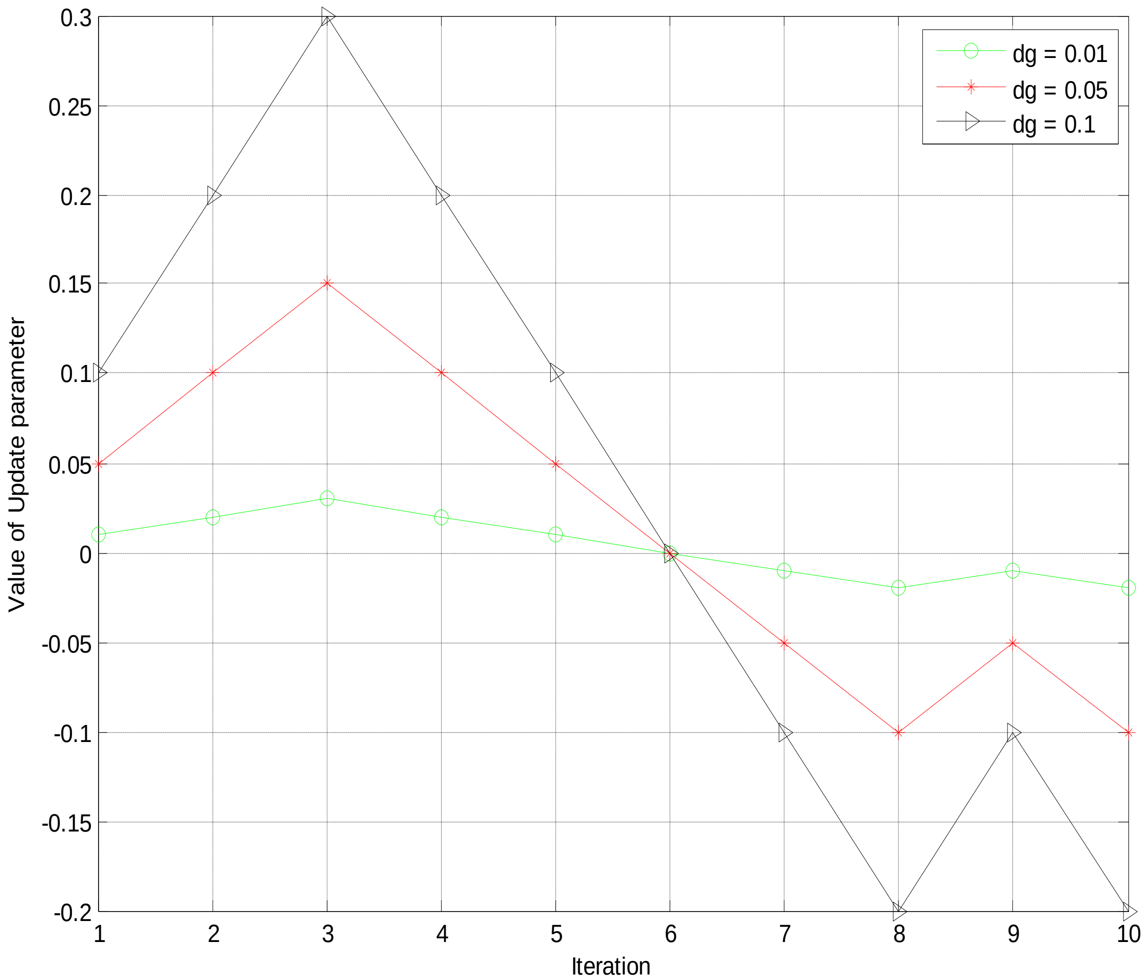

Figure 4.3: Impact of Update speed controller (δ_G) on the MAPC algorithm

The impact of the update speed controller on the MAPC algorithm is shown in Fig 4.3 for ten different iterations. The idea that wasemployed in selecting the update speed controllerwas to find the smallest update step size that still leads to consecutive up or down PC command flow without increasing the update parameter (δ_e) beyond its limit (1dB) quickly. The values tested were: 0.01, 0.5 and 0.1. Though other values could be used depending on ones choice of update speed rate.This figure shows that the optimal value is 0.01. This value was used because as seen from the plot, it gives the least value of update parameter such that for even a large iteration (beyond 10) it acts on the update parameter in such a way that consecutive increments or decrements still keeps then user within the active region without oscillating. By analyzing simulation results more closely, it was noticed that for higher values of the update speed controller, the value of the update parameter increases or decrease in higher magnitude which will most likely cause the update parameter to reach its limit quickly. To avoid low transmit power due to small step size, a trade off was to use a speed controller value that is not high or too low thus 0.01 was used.

4.4 Performance Evaluation of the Modified Adaptive Power Control

4.4.1 Outage Probability

System availability is the main performance metric considered in this work. This is a very important parameter that is fundamental in system analysis. The outage probability is one of the performance measures adopted for this work and it indicates the number of dropped calls which is described as the probability that the signal-to-noise ratio (SNR) at the output is below a given threshold value (-14dB was used in this work)-outage threshold value. The outage threshold is a limit value for the SNR that measures the quality of service (QoS). This QoS parameter was simulated and analyzed as outage performance metric since it can be applied for different QoS requirements.

As discussed in chapter three the Modified Adaptive power control (MAPC) algorithm which clearly has some interesting properties compared to the fixed step size method is a simple variant of the adaptive step size power control algorithm that is able to significantly decrease the oscillations inherent in the adaptive step power control algorithm. Fig 4.4 shows how the MAPC clearly reduced the outage probability as well as the oscillations over the number of iteration as compared with that of ASPC as shown in Fig 4.5.

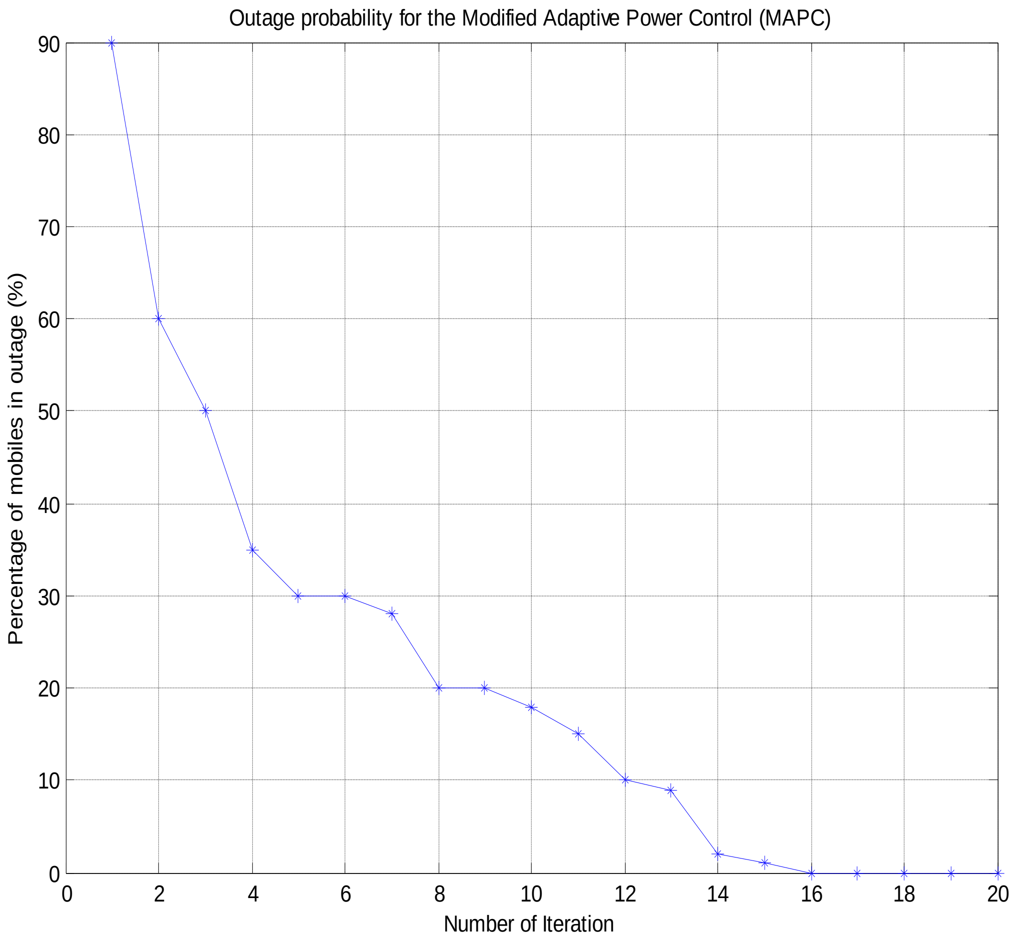

Figure 4.4: Outage probability for the MAPC algorithm

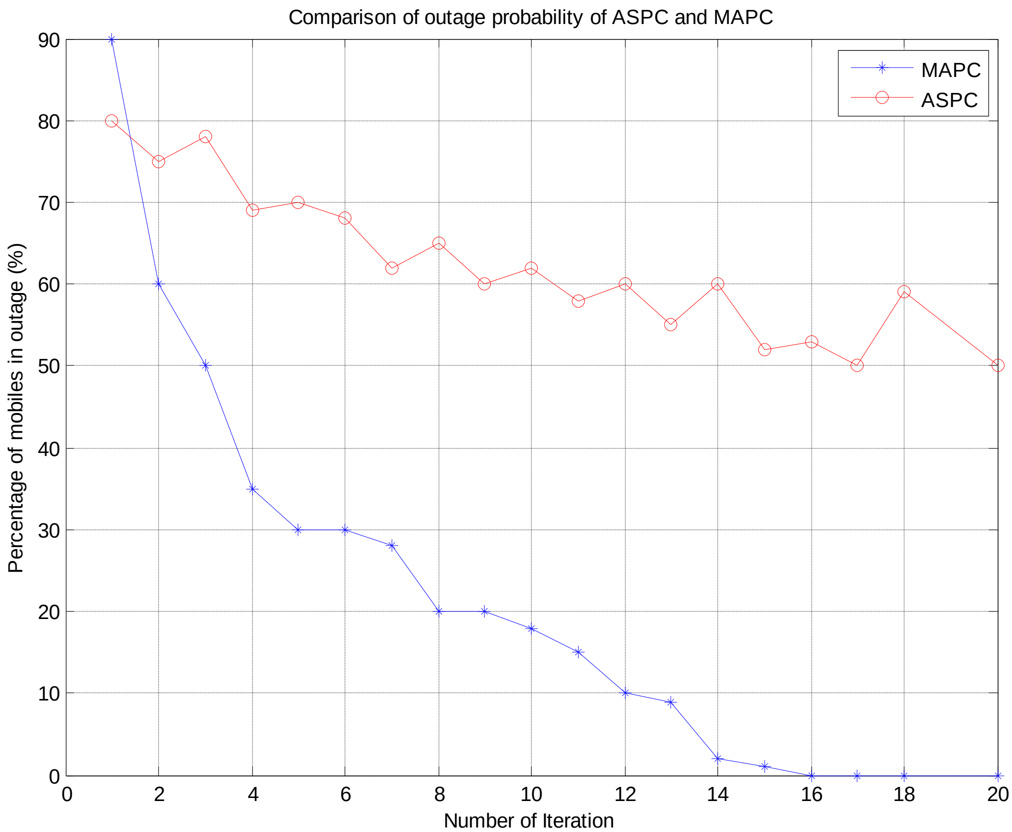

Figure 4.5: Comparison of the outage probability of the ASPC and MAPC Algorithms

Fig. 4.5 shows that there is a reduction in the percentage of outages as the number of iteration increases. However, oscillations are observed in the case of the adaptive step power control (ASPC) algorithm due to the single threshold separating the outage and non–outage regions. This work introduced a buffer zone based on hysteresis in the MAPC algorithm which eliminated the oscillations completely while maintaining a comparable rate of reduction of outage percentage, as seen in Fig. 4.5.

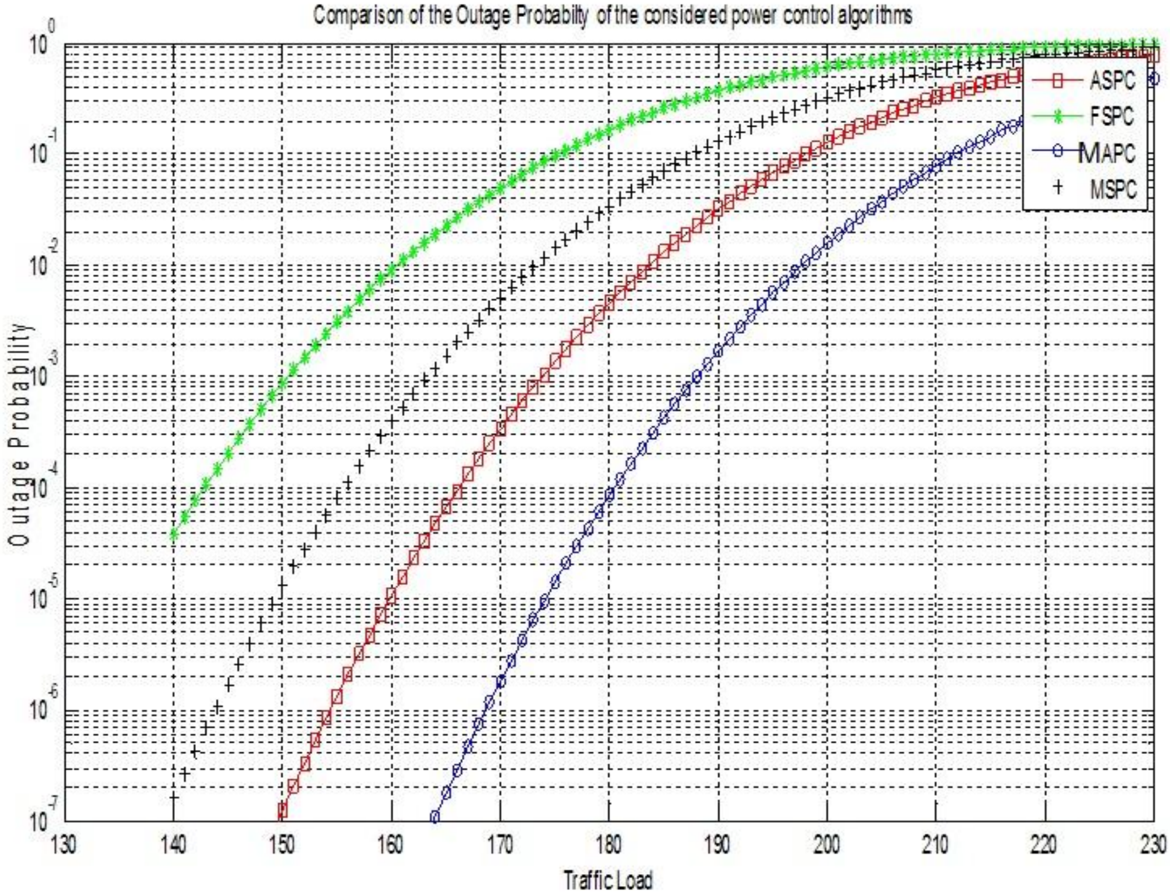

Figure 4.6: Outage Probability of Various power control algorithms

Fig.4.6, shows the outage probability of the various power control techniques considered in this work, and it shows the extent to which the various techniques applied succeeded in reducing the outage probability in a WCDMA network. In Fig 4.6, when all the four techniques are compared, at outage probability equal to 10^{-3}, it can be observed that for the fixed step power control (FSPC) the number of active users was about 155. This number increases to about 168 for multiple step power control (MSPC), then to about 175 for adaptive step power control (ASPC) and to 190 for the Modified adaptive power control (MAPC). This allows the system to accommodate more users which means that larger cells can be allowed, thus achieving coverage extension, which is an improvement in the QoS of the network.

4.4.2 Speed of Convergence

As the radio channel is highly stochastic, the channel characteristics vary veryquickly. So, the power update by any power control algorithm should be fastenough to converge and stabilize the system quickly. So, the speed of convergenceis an important performance comparison parameter that gives the responsivenessof the power control algorithm.

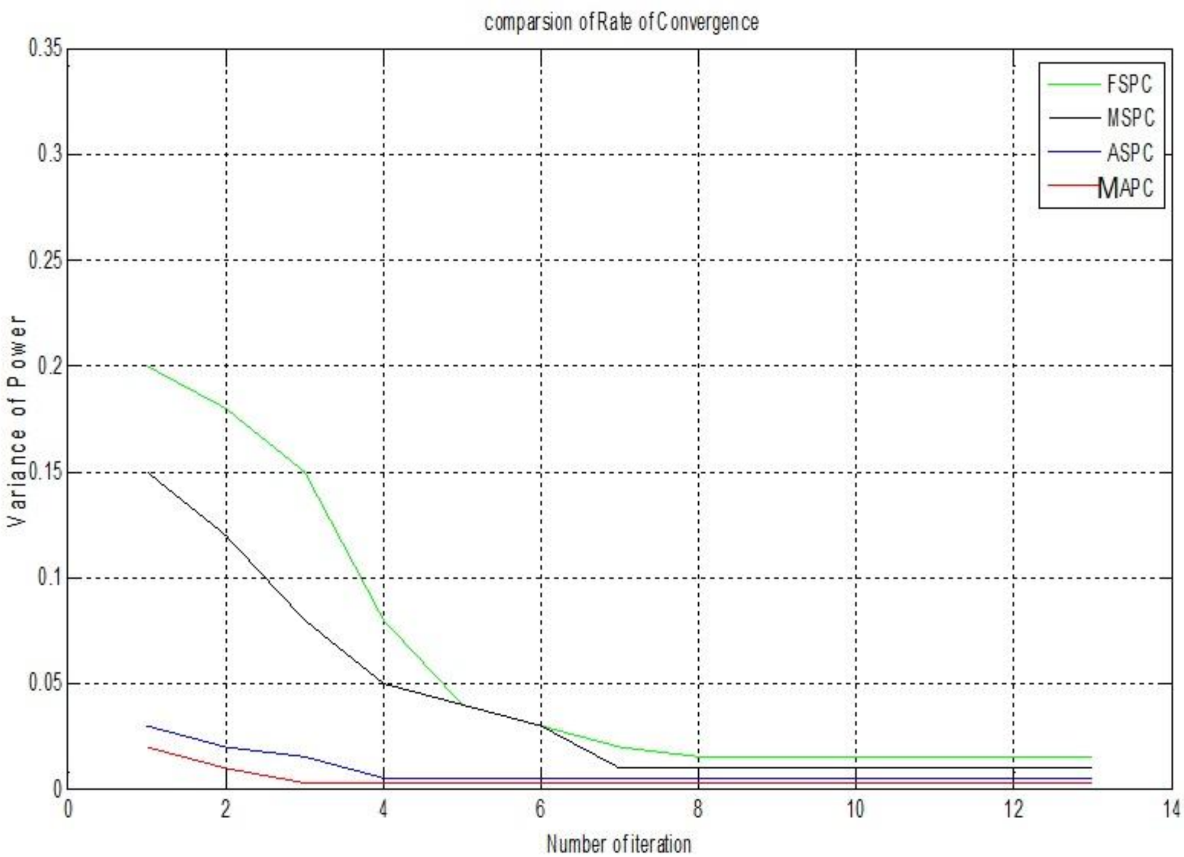

Figure 4.7: Comparison of Rate of Convergence

Fig.4.7 depicts the variance of power levels in all consecutive iterations for the four algorithms. From the plot it is clear that ASPC converges quicker than MSPC and the FSPC, but the MAPC almost converges instantly. The relatively high values of outage probabilities are due to the 'admit-all' policy. A convenient admission policy, which could be associated with power control, would lead to better performances. Yet, Fig 4.7 shows the amelioration due to the use of the ASPC algorithm. The faster convergence of the MAPC algorithm leads to a smaller outage probability, as noticed in Fig. 4.6. For the same outage probability, the MAPC leads to a greater average number of MS per cell (increase cell load) and thus increases the network capacity.

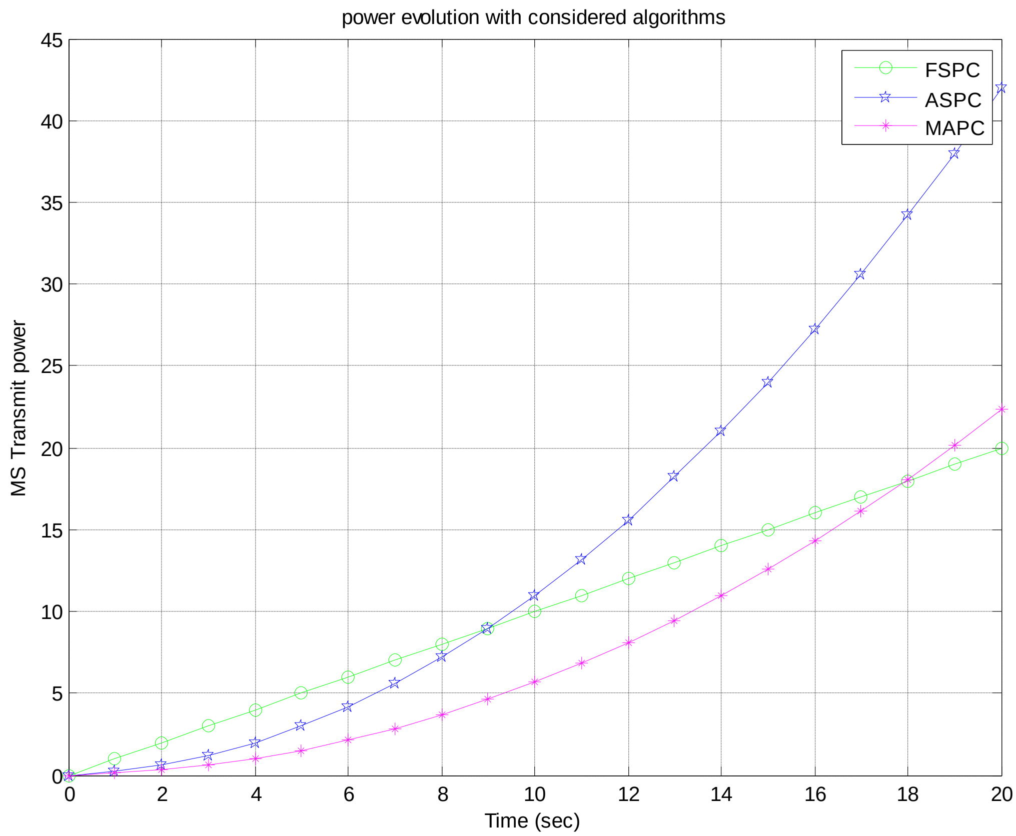

Figure 4.8: Power Evolution of considered power control

Fig. 4.8 shows the power evolution graphically with the parameters that were selected using simulation experiments to give reasonable performance. From the graph, it can be seen that the rate of change in the transmission power with the MAPC algorithm is much better than the other power control algorithms because the mean power consumption is reduced per given time and hence more users can be accommodated. For instance, as at 10 seconds, ASPC algorithm consumes more two times the power consumed by the developed algorithm. This shows that the power allocated to each mobile per time is reduced and hence more users are accommodated, thus increasing the channel capacity.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Several research works is on-going with the aim of improving QoS as well as allowing more users in UMTS communication. Most of the research efforts were channelled into software based solution to the mirage of problems confronting UMTS networks. The focus on software based solution is not far-fetched, considering the cost of erecting a communication mast in already developed areas like Onitsha. One may say it is almost impossible to buy a parcel of land with the sole purpose of erecting a communication mast; apart from the cost, the growing awareness of the health hazards inherent in one staying close to electromagnetic radiations from the Mast for a long period of time. In a bid to solve some of the challenges the mobile service providers have resorted to using the BS for GSM and multiplexing and de-multiplexing it to serve both WCDMA,HSPA and LTE.The service providers have gone further into alliance amongthemselves by using the same BS to serve their customersby co-location.

Power control in 3G WCDMA System was studied in this work. The performance of different basic distributed power control algorithms was evaluated and compared on the basis of the simulations in Matlab. Motivation for the dissertation, problems in today's wireless communications, the advantages of Radio Resource Management (RRM) techniques mainly power control for enhancing the performance, background of power control, how and why power control was done, have been discussed in detail. This work presented an evolution of the power control algorithm of the third-generation WCDMA system. The algorithm was based on an adaptive modification of the transmitted power update step size. It was observed that the Adaptive-Step Power Control Algorithm, which was easily implemented, was an interesting variant of the one-bit command Power Control of WCDMA System. An enhancement to the ASPC algorithm was obtained using the concept of hysteresis, by introducing a buffer region instead of a single SIR threshold. This resulted in a better performance in terms of mitigating the oscillations of the MS in outage at lower values of outage percentage.

This improvement allows the WCDMA system to accommodate more users which by extension means that larger cells can be allowed, thus achieving coverage extension, which is an improvement in the QoS of the network and also increased network capacity.

Outage probability was reduced compared with ASPC, MAPC converge rapidly at 16^{th} iteration, while the ASPC is still in outage even after 20 iterations. MAPC at an outage probability of 10^{-3} has about 83.61% active users, compared to FSPC, MSPC and ASPC with 67.39%, 73.04%, and 76.09% active users respectively. Oscillations at low outage percentages have been mitigated using this enhanced Algorithm. Also MAPC has 40% improved power conservation compared to ASPC and 60% compared to FSPC for MT

5.2 Contribution to Knowledge

This work has made contribution to existing knowledge in Power control in UMTS communication networks in the following ways:

- Empirical Path loss model for Onitsha was developed as $P_L(dB) = 111.89 + 37.9Log\left(\frac{d}{d_0}\right)$. This will help in wireless service design for Onitsha.
- The development of an Algorithm that could reduce the outage probability in WCDMA communication system, invariably increasing the capacity of the WCDMA channels. This was achieved by allocating power to mobile users that is just sufficient to maintain an acceptable link quality and thereby reducing both intra cell and inter cell interference level.
- This work has also provided a solution to the reoccurring challenge of irregular oscillation in the presently used step size power control system by introducing a Buffer zone in the developed algorithm thereby making the network more stable.
- This work has also provided a fast converging power control Algorithm, this has improved the response time to any desired power level obtainable in the step size power control system.
- This work also brought to lime light impact of shadowing with maximum shadowing factor of 9.22dB for Onitsha and the impact of various seasons of the year in communication environment, this will help mobile users understand the reasons for reduced QoS during the various seasons of the year, as well as buildings blocking LOS.
- This work also provided information as to the path loss exponent for WCDMA network operating in the 2112MHz band for Onitsha urban; which was found to be η =3.79

The challenge of energy loss by MT could be addressed by this work, MTs can now transmit only energy needed to maintain acceptable communication quality.

5.3 Recommendations

The outcome of this work strongly suggests that proper network planning for Onitsha urban city be carried out, with the develop path loss model and exponent.

Pre-installation planning should also be carried out before introducing new improved technology on already installed mask, such as multiplexing 3G services into 2G base stations or 4G into 3G BS, as well as in co-location to mobile service providers in the same base station which was originally designed to serve only one mobile service provider. Theserecommendations are necessary in order to improve QoS and have a better power control system in maintaining good communication link quality.

5.4 Future Research Work

More research effort could be carried out in the following aspects of power control in wireless communication:

- Soft handover in WCDMA should be investigated, Mobile terminal connecting to at least three base station while evaluating signals from them to know which of them has a stronger link quality creates some challenges in effective power control in WCDMA.
- Also a research could be carried out with the aim of enhancing the WCDMA system by combing the MAPC Algorithm and an adaptivecoding technique.
- A study could be carried out to investigate the impact a variable-step power control in the next generation of system such as LTE to achieve better performance required in next generation systems to achieve better performance.

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