TITLE PAGE

COMPARATIVE ANALYSIS OF DISTRIBUTED POWER CONTROL ALGORITHMS IN CELLULAR NETWORK

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF ELECTRONIC ENGINEERING (COMMUNICATION OPTION) IN THE DEPARTMENT OF ELECTRONIC ENGINEERING, UNIVERSITY OF NIGERIA, NSUKKA.

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Nwachukwu Nancy Nwakauru, a masterôs degree postgraduate student in the Department of Electronic Engineering with registration number PG/M.ENG/13/66697has satisfactorily completed the requirements for the award of Master of Engineering (M.ENG) in Electronic Engineering.

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DECLARATION

I, Nwachukwu Nancy Nwakauru, a postgraduate student of the Department of Electronic Engineering, University of Nigeria, Nsukka declare that the work embodied in this thesis is original and has not been submitted by me in part or in full for any other diploma or degree of this or any other University.

. . . .

Nwachukwu Nancy N   Date

DEDICATION

This research work is dedication to God Almighty who gave me all the inspiration and insight towards the completion of this project, and my father, late Mr. Nwachukwu Ewoh.

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Realization of this work has not been an easy task, and of course it would not have been possible without the help and support of several people to whom I want to express my heartfelt gratitude. I would like to start by appreciating my supervisor, Prof. C. I. Ani for his advice, contribution and guidance throughout the cause of this project. I also want to thank the entire staff of Electronic Engineering, University of Nigeria, Nsukka for contributing in one way or the other to my success in this program.

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ABSTRACT

Wireless Communication is one of the most active areas of technological development of our time. It covers a very wide array of applications that lead to an ever growing demand on the limited radio resources. Consequently, the need for efficient management of the limited radio resources has become imperatively a global issue. The complexity of the cellular system and the propagation channel resulted in the interference issues that degrade the system performance. Transmit power otherwise known as Power Control is an efficient radio resource management technique that mitigates both adjacent and co-channel interference under fading condition. It also suppresses the Near ï Far problems, enhances the battery life and the system capacity. In the light of this, different power control algorithms have been proposed by different authors but the choice of an appropriate power control algorithm is of great importance, as it should aim at improving the quality of service (QoS) to all the users and increasing the efficiency of the system. In this work, therefore, comparative analyses have been carried out on three popular distributed power control algorithms using performance metrics such as speed of convergence and total power consumption of the network. However, results have shown that Fully Distributed Power Control Algorithm (FDPCA) has a better efficiency in handling transmit power of the system more than New Distributed Power Control Algorithm (NDPCA) and Improved Distributed Power Control Algorithm (IDPCA) algorithms by 0.44% and 0.01% respectively, while IDPCA is more efficient in conserving power on the network than FDPCA and NDPCA by 0.04% and 2.38% respectively. Furthermore, analysis of variance (ANOVA) test carried out on the simulated data using means and standard deviation at 95% confidence level showed that the degree of variance of the algorithms is negligible.

LIST OF ACRONYMS

1G	1st Generation
2G	2nd Generations
3G	3rd Generations
3GPP	3rdGeneration Partnership Project
4G	4th Generations
AC	Admission Control
ATM	Asynchronous Transfer Mode
AuC	Authentication Centre
BCH	Broadcast Channel
BDPC	Balanced Distributed Power Control
BER	Bit Error Rate
BLER	Block Error Rate
BMC	Broadcast/Multicast Control
BS	Base Station
BTS	Base Transceiver Station
CC	Call Control
CCC	CPCH Control Command
CCCH	Common Control Channel
CDMA	Code Division Multiple Access
CGF	Charging Gateway Function
CIPC	Constant Improvement Power Control
CIR	Carrier to Interference Ratio
CLPC	Closed-Loop Power Control
CN	Core Network
CPCA	Centralized Power Control Algorithm
CS	Circuit Switched
CUG	Closed User Group
DCH	Dedicated Channel
DFSPC	Distributed Fixed Step Power Control
DL	Downlink
DPC	Distributed Power Control
DPCCH	Dedicated Physical Control Channel
DPCCH	Dedicated Physical Control Channel
DPDCH	Dedicated Physical Data Channel

DPDCH	Dedicated Physical Data Channel
DQPSK	Differential Quadrature Phase Shift Keying
DS-CDMA	Direct-Sequence Code Division Multiple Access
DTCH	Dedicated Traffic Channel
EDGE	Enhanced Data Rates for GSM Evolution
EIR	Equipment Identification Register
ETSI	European Telecommunications Standards Institute
FACH	Forward Access Channel
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FDPCA	Fully Distributed Power Control Algorithm
FER	Frame Error Rate
GERAN	GSM/EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GLR	Gateway Location Register
GMSC	Gateway Mobile services Switching Centre
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HLR	Home Location Register
IDPCA	Improved Distributed Power Control Algorithm
IMSI	International Mobile Subscriber Identity
IMT-2000	International Mobile Telecommunications 2000
IP	Internet Protocol
ITU	International Telecommunication Union
IWFs	Interworking functions
L1	Layer 1 (Physical layer)
L2	Layer 2 (the data link layer)
L3	Layer 3 (network layer)
LMSI	Local Mobile Station Identity
MAI	Multiple-Access Interference,
MAT	Multiple Access Technique
MIMO	Multiple Input Multiple Output
MM	Mobility Management
MMS	Multimedia Messaging Service

MRC	Maximal-Ratio Combined
MS	Mobile Station
MSC	Mobile Switching Centre
MSISDN	Mobile Station International ISDN Number
MSRN	Mobile Station Roaming Number
NAM	Network Access Mode
NDPCA	New Distributed Power Control Algorithm
NPDB	Number Portability Data Base
OFDM	Orthogonal Frequency Division Multiplexing
OLPC	Open-Loop Power Control
OVSF	Orthogonal Variable Spreading Factor
PC	Power Control
PCA	Power Control Algorithms
PCCH	Paging Control Channel
PCF	Point Coordination Function
PCH	Paging Channel
PCPCH	Physical Common Packet Channel
PDCH	Packet Data Channel
PDCP	Packet Data Convergence Protocol
PLMN	Public Land Mobile Network
PRACH	Physical Random Access Channel
PRACH	Physical Random Access Channel
PS	Packet switched
PSK	Phase Shift Keying
QoS	Quality of Service
RNC	Radio Network Controller
RRC	Radio Resource Control
RRM	Radio Resource Management
Rx	Receiver
SAP	Subscribers Access Point
SCH	Synchronization Channel
SGSN	Serving GPRS Support Node
SHCCH	Shared Channel Control Channel
SIR	Signal-to-Interference Ratio

SMS	Short Message Service
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TMSI	Temporary Mobile Station Identity;
TPC	Transmit Power Control
Tx	Transmitter
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication Services
UTRAN	UMTS Terrestrial Radio Access Network
VHE	Virtual Home Environment
VLR	Virtual Location Register
WCDMA	Wideband Code Division Multiple Access

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Wireless communication systems have experienced tremendous growth over the last decade, and this growth continues at a full strength worldwide [1]. Such development is mainly driven by strong market demand for personal communication systems and services, which provide ever-present and Seamless connectivity with other devices and fixed networks [2, 3].

The need to provide for user mobility in wireless system was designed to amend the errors of traditional wired and wireless communication networks which provide communication between the moving unit (User Equipment) and the stationary unit (Base Station) and vice versa [4]. These errors range from the inability of the traditional wireless communication networks to cope with travelling speed of fast mobile units, its low data rate and low capacity [5].

The concept of cellular communication came into place by dividing the coverage area into small regions called cells [6]. The cell size changes with time and is dependent on the traffic in the area to be covered. However, it is controlled by the transmitter power and the frequency of the cell operation, which also, could apply some cell techniques like; Frequency reuse, cell splitting etc to improve on the capacity of the system [7].

This rapid demand in the number of wireless communication users has led to tremendous technological advancement and evolution of the cellular systems. Hence, the need to develop a standard that will improve the performance of the system moved the evolution from the first generation (1G) which offered only voice service, and this led to the deployment of the 2nd generation (2G) systems which provided for both voice and data communications [4, 8]. But with the growing demand in the data service, there became a need to accommodate more services while enhancing the speed of the system [1, 9]. The limited capacity of 2G systems and the never-ending need for higher data rates are the main reasons for developing next generation mobile communication systems [10]. This is to provide multi-purpose functionality with higher data rates. Some improvements like General Packet Radio Services (GPRS) [11] and Enhanced Data Rates for Global Evolution (EDGE) were developed to repair the bottlenecks of the existing 2G systems [12]. These are often called as 2.5G techniques. GPRS enables the connectivity to the packet networks and the EDGE provides higher data rates for the GPRS. However, the current solutions to the problem are Universal Mobile Telecommunication Systems (UMTS) and Code Division Multiple Access 2000 (CDMA2000) [13], techniques for the 3G (third generation) mobile communication systems. Data transmission rates up to 384 kbps are provided at regular urban outdoor environments for the UMTS. The CDMA is used as a radio transmission technique to improve the network spectral efficiency.

The development of the third generation (3G) of mobile communication could support some multimedia services like voice, paging, messaging, Internet and broadband data [14]. The 3G technology ran two separate networks concurrently with help of the UMTS Terrestial Radio Access Network (UTRAN) as could be seen in the system architecture. UMTS represents the move into 3G of mobile networks. It is an umbrella term for the third generation radio technologies developed within the Third Generation Partnership Project (3GPP). It addresses the growing demand of mobile and Internet applications for new capacity in todayȇs overcrowded mobile communications [15].

However, radio resource management is very important when the number of users and the demand for bandwidth increase. Effective allocation and utilization of resources will improve the performance and increase the capacity of the wireless network. In such case, Power control as one of the Radio Resource Management (RRM) techniques is the most important and critical function technique.

In Wideband Code Division Multiple Access (WCDMA), the capacity of the system [16] is limited by the total interference, called Multiple-Access Interference (MAI), from all connected mobiles using the same frequency band on the uplink (mobile to base station link). Therefore, MAI is a dominant factor in system capacity and quality of communications, and must be suppressed or reduced if a high capacity cellular mobile system with a satisfactory performance is to be implemented [17]. Hence; efficient channel reuse is of paramount importance in the design of high capacity cellular radio systems. And it is especially important for uplink transmission.

In other words, WCDMA systems are self-interference systems. This is because every User Equipment (UE) transmitting on the system serves as a source of interference to other UEs on the system [18]. Also in uplink transmission, if user equipment is transmitting high power signals at a close location to node B, it can easily over shout the other user equipments which are farther than it or at cell edge. It can even block the whole cell. On the other hand, if a UE is transmitting at very low power, thenNode B will never hear that UE. This phenomenon is known as near-far problem [19]. In the downlink transmission, the radio system capacity is determined by the required power for each User Equipment. That is why this is essential to transmit the signal at minimum level with required signal quality at receiving end. This work is therefore, aimed at carrying out a comparative study on different distributed power control algorithms with a view to ascertaining the algorithm with efficient network performance and reduced interference.

1.2 Aims and objectives

The aim of this research is to carry out a comparative study on different distributed power control algorithms with a view to ascertaining the algorithm with efficient network performance and reduced interference.

The specific objectives of this thesis include the following:

- ✓ To carry out a critical review of the advances made in the area of power control schemes.
- ✓ To analyse some of the promising distributed power control algorithms proposed by some authors.
- ✓ To write a pseudo-code for the three selected distributed power control algorithms.
- ✓ To finally carry out a performance analysis on the three selected distributed power control algorithms on the basis of their speed of convergence and total power consumption of the network using Microsoft Excel.

1.3 Problem Statement

In WCDMA, many users transmit over the same radio channel using the same frequency band and time slots so that the signal of an individual user becomes interference for the other users. But the power control problem can be termed, ñNear-Far effectò. In a way, power control ensures that the mobiles in a network system transmit with equal power levels.

However, to accommodate greater number of these users, the available radio spectrum is divided among the users with some multiple access techniques and the same spectrum can be reused with different criteria. But, if the power levels of a user are not controlled, it may result in some interference to both co-channel and adjacent channel users.

To ensure an efficient cellular network, many researchers have looked into this area and came up with different power control algorithms which could be used to ensure that users transmit at the same power level, thereby mitigating the effect of all kind of interference. But not much significant works have been done on performance evaluation of some of the power control algorithms.

1.4 Scope of the Work

The scope of this work covers the Distributed Power Control (DPC) algorithms especially on the uplink aspect of cellular network. A comparative analysis of the three selected algorithms was carried on the bases of the selected performance metrics. No physical implementation of the algorithms was required for the analysis. Hence, only analytical and logical models were used for the comparative study of the algorithms using Microsoft Excel as a tool for the work.

1.5 Methodology

The following methodology was adopted to realizing the set objectives:

1. Review of the different power control algorithms in UMTS.
2. Review of distributed power control algorithms that could be employed in the uplink part of UMTS and choice of three popular algorithms.
3. Development of power control system model.
4. Model simulation result analysis based on standard performance metrics and algorithms comparisons.

1.6 Thesis Structure

This thesis is structured in the following way: Chapter one introduced the concept and the topic at hand. Chapter two handled the evolution and general background knowledge of 3G of Global System for Mobile Communications (GSM). It also reviewed the related works carried out under Power Control aspect of UMTS and cellular systems at large. Chapter three presented the physical model, the general system design employed, the flow chart of operation and the analytical analyses of the three algorithms in view. Chapter four discussed the programming of the three distributed power control algorithms and their result analysis. Finally, Chapter five deals with the conclusion and recommendation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Cellular System

Wireless network has made tremendous growth in the last fifteen years. This extraordinary growth in the wireless industry is visible, both in terms of mobile technology and its subscribers [1, 5]. The inherent problem in mobile communications is the efficient use of the scarce radio resource - the radio spectrum. Hence, the need for proper radio resource management is crucial. Radio Resource Management (RRM) is the system level management of co-channel interference, radio resources, and other radio transmission characteristics in wireless communication systems [20]. It has some functions which power control is a very important one as far as cellular network is concerned. On the other hand, Power control, broadly speaking, is the intelligent selection of transmitter power output in a communication system to achieve good performance within the system [21]. However, in this thesis, our work would focus more on power control and comparative analysis of power control algorithms in cellular networks but, before then let look into the evolution of the cellular systems. The mobile communications have evolved significantly from 1st generation (1G) to 5th generations (5G) [22]. There have been distinct generations of mobile networks. These generations of mobile networks are conventionally defined by their different technologies. The early cellular telephony system was based on the Frequency Division Multiple Access (FDMA), where the entire spectrum is divided among users and there are separate channels for uplink and downlink communications [23].

The First Generation systems in the early 1980s basically offered voice communications only. The introduction of data communications and the development in digital communications by the end of 1980s, have led to the deployment of the 2nd generation systems which provided for both voice and data communications [14]. The 2nd generation cellular systems are based on Time Division Multiple Access (TDMA) and also Code Division Multiple Access (CDMA). In TDMA, the user has the entire bandwidth for the allotted time-slot. This increased the system capacity tremendously. But with the greater demands on bandwidth and quality, 2.5G came on board [10]. The evolved 2.5-generation systems are based on higher level modulation techniques like 8PSK (Phase Shift Keying). In CDMA, all the users can avail the entire bandwidth for the entire time by using different spreading codes, which could further cater to the ever-increasing demands on bandwidth and quality [15, 24].

In 3rd generation systems, Wideband Code Division Multiple Access (WCDMA) as a standard has enhanced the capacity of the system much greater than FDMA and TDMA. It represents an evolution in terms of services and data speed from today's 2G mobile networks. Universal Mobile Telecommunication Systems (UMTS) represents the move into 3G of mobile networks [25]. It is an umbrella term for the third generation radio technologies developed within the Third Generation Partnership Project (3GPP) [26]. It addresses the growing demand of mobile and Internet applications for new capacity in todayôs overcrowded mobile communications. The UMTS increases transmission speed up to 2 Mbps per mobile user and establishes a global roaming standard. It allows many more applications to be introduced to a worldwide base of users and provides a vital link between currentmultiple GSM systems and the ultimate single worldwide standard systems for all mobiletelecommunications [27].

The 3G networks have been created to support the effective delivery of a range of multimedia services. They provide more efficient systems for the over-the-air transmission of existing services, such as voice, text and data that are available today [28]. Furthermore, 3G Systems are intended to provide a global mobility with wide range of services including telephony, paging, messaging, Internet and broadband data.

International Telecommunication Union (ITU) started the process of defining the standard for third generation systems, referred to as International Mobile Telecommunications 2000 (IMT-2000) [29]. In Europe, European Telecommunications Standards Institute (ETSI) was responsible for UMTS standardisation process. In 1998 Third Generation Partnership Project (3GPP) was formed to continue the technical specification work. The 3GPP has five main UMTS standardisation areas: Radio Access Network, Core Network, Terminals, Services and System Aspects and GERAN [30]

The specifications of UMTS are under development in 3GPP. To reach global acceptance, 3GPP is introducing UMTS in phases:

3GPP R99: Most of the specifications were frozen in March of 2000. It laid the foundations for high-speed traffic transfer in both circuit switched and packet switched modes by defining enhancements and transitions for existing GSM networks [26] and specifying the development of new radio access network.

- **3GPP R4:** Most of the core technical specifications were frozen in March 2001. It is a minor release with the evolutions including UTRAN access with QoS enhancement, CS domain evolution with introducing Mobile Switching Centre (MSC) server and MGWs based on IP protocols, enhancements in LCS, MMS etc.
- **3GPP R5:** It is a major release aiming to utilize IP networking as much as possible. IP and overlying protocols will be used in both networks control and user data flows, i.e. implement ñAll IPò network, but the IP-based network should still support circuit switched networks. In 3GPP R99, the basis for the UMTS radio access is WCDMA [31]. In 3GPP R4/R5, GSM/EDGE Radio Access Network (GERAN) is specified as an alternative for radio access to build a UMTS mobile network.

Table 2.1: Summary of Generations of cellular technologies (for the first three Generations) [1]

Generation	Year	Network	Technology	Data
1G	Early 1980s	Circuit switched	TACS, AMPS	Analog Voice
2G	Early 1990s	GSM, CDMA (IS-95)	GSM, DCS-1800 CDMA	Digital Voice
2.5G	1996	Circuit switched or Packet switched	GPRS	Digital Voice + Data
2.7G	1997	Circuit switched or Packet switched	EDGE, EVDO, EVDV	Digital Voice + Data
3G	2000	Non-IP Packet switched/ Circuit switched	WCDMA, CDMA2000	Digital Voice + High speed Data + video

The history of cellular communication is vast and the background of mobile networks thereby is also vast, however, in this chapter our focus is on network services, architecture and protocol of operation of 3G.

2.2 UMTS SERVICES

UMTS offers three services. According to ITU-T these services can be divided into three types. Telecommunication services (like speech or SMS), supplimentary and bearer services, which provide the capability for information transfer between access points [32]. It is possible to negotiate and renegotiate the characteristics of a bearer service at session or connection establishment and during ongoing session or connection. Both connections oriented and connectionless services are offered for Point-to-Point and Point-to-Multipoint communication. Bearer services have different quality of services (QoS) parameters for maximum transfer delay, delay variation and bit error rate [25]. Offered data rate targets for UMTS are:

- 144 kbits/s satellite and rural outdoor
- 384 kbits/s urban outdoor
- 2048 kbits/s indoor and low range outdoor

2.2.1 UMTS network services have different QoS classes for four types of traffic [12, 28]:

1. Conversational class (voice, video telephony, video gaming)
2. Streaming class (multimedia, video on demand, webcast)
3. Interactive class (web browsing, network gaming, database access)
4. Background class (email, SMS, downloading)

UMTS also has a Virtual Home Environment (VHE), which is a concept for personal service environment portability across network boundaries and between terminals [33]. Personal service environment means that users are consistently presented with the same personalised features, User Interface customisation and services in whatever network or terminal, wherever the user may be located. UMTS also has improved network security and location-based services.

2.2.2 Universal Mobile Telecommunication Systems (UMTS) Architecture

A UMTS network consist of three interacting domains; Core Network (CN), UMTS Terrestrial Radio Access Network (UTRAN) and User Equipment (UE)[26]. The main function of the core network is to provide switching, routing and transit for user traffic. Core network also contains the databases and network management functions. The basic Core Network architecture for UMTS is based on GSM network with GPRS. All equipment has to be modified for UMTS operation and services. The UTRAN provides the air interface access method for User Equipment. Base Station is referred as Node-B and control equipment for Node-Bôs is called Radio Network Controller (RNC). It is necessary for a network to know the approximate location in order to be able to page user equipment. Here is the list of system areas from largest to smallest [33].

I. UMTS systems
II. Public Land Mobile Network (PLMN)
III. MSC/VLR or SGSN
IV. Location Area
V. Routing Area (PS domain)
VI. UTRAN Registration Area (PS domain)
VII. Cell and Sub cell

2.2.3 UMTS Physical Architecture

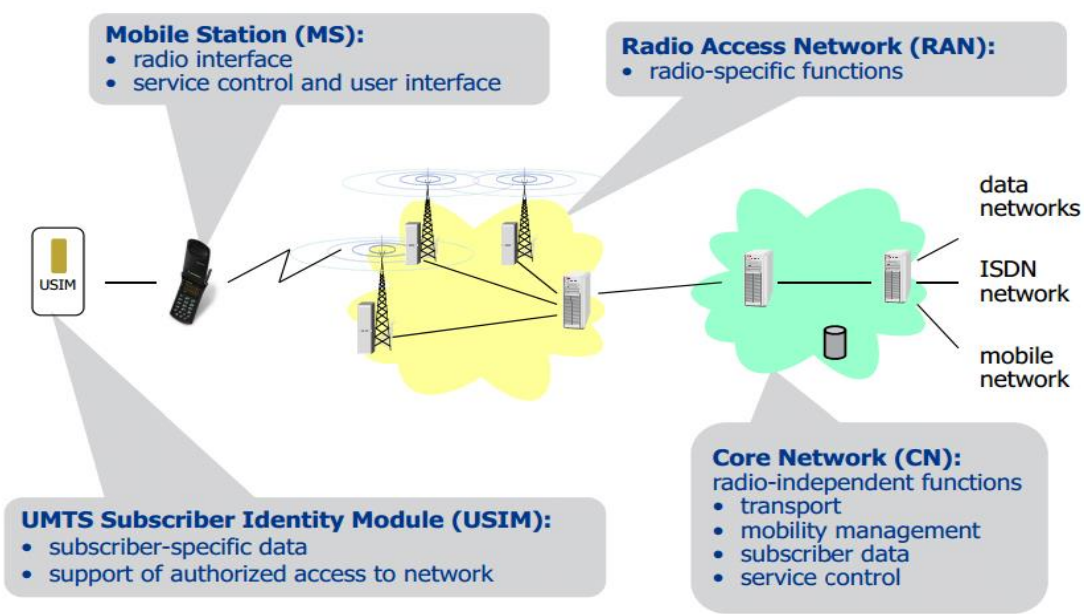

Figure 2.1: UMTS Physical Architecture [34]

This diagram above could be further simplified with the diagram below - Umts System Architecture

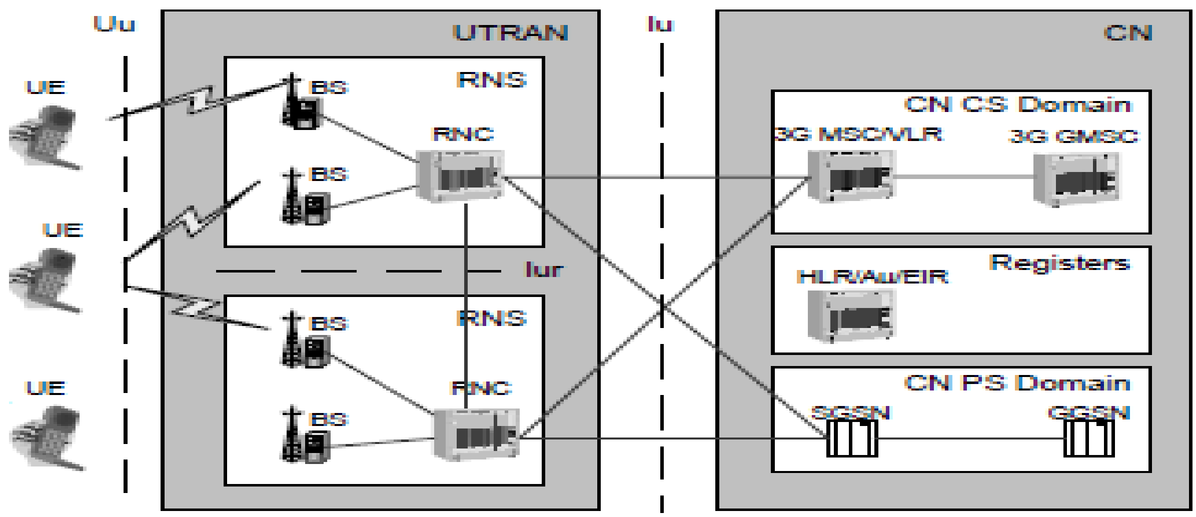

Figure 2.2: UMTS System Architecture [35]

2.3 Core Network

The Core Network is divided into circuit switched and packet switched domains [26]. Some of the circuit switched elements are Mobile services Switching Centre (MSC), Visitor Location Register (VLR) and Gateway Mobile services Switching Centre (GMSC). Packet switched elements are Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). Some network elements, like Equipment Identification Register (EIR), Home Location Register (HLR), Visitors Location Register (VLR) and Authentication Centre (AUC) are shared by both domains [34]. The Asynchronous Transfer Mode (ATM) is defined for UMTS core transmission. ATM Adaptation Layer type 2 (AAL2) handles circuit switched connection and packet connection protocol ATM Adaptation Layer type 5 (AAL5) is designed for data delivery [19]. The architecture of the Core Network may change when new services and features are introduced. Number Portability Data Base (NPDB) will be used to enable user to change the network while keeping their old phone number. Gateway Location Register (GLR) may be used to optimise the subscriber handling between network boundaries. MSC, VLR and SGSN can merge to become a UMTS MSC.

Furthermore, it should be noted that UMTS has different releases which is an upgrade of the previous release. An example is release 5 which is an upgrade of release 99. In release 99, the core network is logically divided into circuit switched and packet switched. The circuit switched network is built around MSC and the packet switched is equally built around SGSN [26]. However, let us look at the various elements that make up the core network of UMTS.

2.3.1 Mobile Switching Centre

The mobile switching centre (MSC) is the centre-piece of the circuit switched core network. The same MSC can be used to serve both the GSM-BSS and the UTRAN connections. A GSM-MSC must be upgraded to meet the 3G requirements, but the same MSC can be used to serve both access networks. In addition to the radio access networks [35], it has interfaces to the fixed PSTN network, other MSCs, the packet-switched network (SGSN), and various core network registers (HLR, EIR, AuC). Physically, the VLR is implemented in connection with the MSC, so the interface between them (the B interface) exists only logically. Several BSSs can be connected to an MSC [34]. The number and the size of MSCs also vary; a small operator may only have one small MSC, but once the number of subscriber increases, several large MSCs may be needed.

The functions of an MSC include the following as discussed in [26]

- Paging;
- Coordination of call setup from all MSs in the MSCȏs jurisdiction;
- Dynamic allocation of resources;
- Location registration;

- Interworking functions (IWFs) with other type of networks;
- Handover management (especially the complex inter-MSC handovers);
- Billing of subscribers (not the actual billing, but collecting the data for the billing centre);
- Encryption parameter management;
- Signalling exchange between different interfaces;
- Frequency allocation management in the whole MSC area;
- Echo canceller operation and control.

2.3.2 Visitor Location Register

The Visitor Location Register (VLR) contains information about the mobile stations roaming in this MSC area. It is also possible that one VLR handles the visitor register of several MSC areas [30]. Note that a VLR contains information from all active subscribers in its area, even from those to whom this network is their home network, so the name VLR is misleading as most entries in that register are not visitors, but users in their own home network. The VLR contains as much information as the Home Location Register (HLR), the difference being that the information in the VLR is there temporarily, whereas the HLR is a site for permanent information storage [26].

When a user makes a subscription, the subscriberos data is added to his HLR, from there it is copied to the VLR the user is currently registered with. When a user registers with another network, the subscriber data is removed from the old VLR and copied to the new VLR. However, there are some network optimization schemes, which may change this principle in the future. The VLR contains such data [25] that the normal call setup procedures can be handled without consulting the HLR. This is important especially if the user is roaming abroad, but the signalling connection to the home network is expensive.

A VLR subscriber data entry includes the following information:

i. International Mobile Subscriber Identity (IMSI);

ii. Mobile Station International ISDN Number (MSISDN);

iii. Mobile Station Roaming Number (MSRN);

iv. Temporary Mobile Station Identity (TMSI), if applicable;

v. Local Mobile Station Identity (LMSI), if used;

vi. Location area where the mobile station has been registered;

vii. Identity of the SGSN where the MS has been registered, if applicable;

viii. Last known location and the initial location of the MS.

2.3.3 Home Location Register

This information is entered when the user subscribes to the network. Each subscriber information profile is stored in only one HLR. The HLR can be implemented in the same equipment as the MSC/VLR, but the usual arrangement is to have the MSC/VLR [30] as one unit, and the HLR/AuC/EIR combination as another unit. One PLMN can have several HLRs. The subscriber information is entered into the HLR when the user makes a subscription. There are two kinds of information in an HLR register entry: permanent and temporary. The permanent data never change, unless the subscription parameters are changed [12]. An example of this is the user who adds some supplementary services to his/her subscription. The temporary data contain things like the current (VLR) address and ciphering information, which can change quite often, even from call to call. Temporary data are, sometimes, conditional; that is, it is not always there. A subscriber data entry can be accessed by either IMSI or MSISDN.

The permanent data in the HLR include among others [25]:

- MSISDN [the directory number of the MS]
- MS category information;
- Possible roaming restrictions;
- Closed User Group (CUG) membership data;
- Supplementary services parameters;
- Authentication key

- Network Access Mode (NAM), which determines whether the user can access the GPRS networks, non-GPRS networks or both.

2.3.4 Authentication Centre (AuC)

This component physically exists with an HLR. The AuC component stores, for each subscriber [37], an authentication key K as well as the corresponding IMSI, which are permanent data entered at subscription time. AuC plays a crucial role in the networkôs security architecture since it is responsible for the generation of important data used in the authentication and encryption procedures [35].

2.3.5 Serving GPRS Support Node (SGSN)

This component is responsible for the mobility management and IP packet session management. It routes user packet traffic from the radio access network to the appropriate Gateway GPRS Support Node [35], which in turn provides access to external packet data networks. In addition, it generates records to be used by other modules for charging purposes. SGSN helps to control access to network resources, preventing unauthorized access to the network or specific services and applications. The Iu PS interface links the SGSN, the main component of the PS domain, with the RNC in the UTRAN [37]

2.3.6 Gateway GPRS Support Node (GGSN):

This module is the gateway between the cellular network and external packet data networks such as the Internet and corporate intranets [35]. As its partner the SGSN, and other components, the GGSN also collects charging information, which is forwarded to the Charging Gateway Function (CGF).

2.4 UMTS Terrestrial Radio Access Network (UTRAN)

The UTRAN is the new radio access network designed especially for UMTS. Its boundaries are the Iu interface to the core network and the Uu interface (radio interface) to user equipment (UE).The UTRAN is just one realization of the GRAN concept [27].

It offers the tools necessary to manage and control the WCDMA radio resources. It further includes the functionality needed to handle handover. The main task of UTRAN is to create and maintain RAB for communications between UE and the CN [38], and fulfils end-to-end QoS services. The UTRAN consists of radio network controllers (RNCs) and Node Bs (base stations). Together, these entities form a radio network subsystem (RNS).

The internal interfaces of the UTRAN include the Iub and Iur. The Iub connects a Node B to the RNC and the Iur is a link between two RNCs [25]. The Iub is intended to be an open interface, but it is situated in so delicate a position in the network infrastructure that it is also possible that it will, in practice, become a manufacturer proprietary interface. The corresponding interface in GSM (A-bis) is like that; one has to use compatible equipment from the same manufacturer on both sides of the A-bis interface.

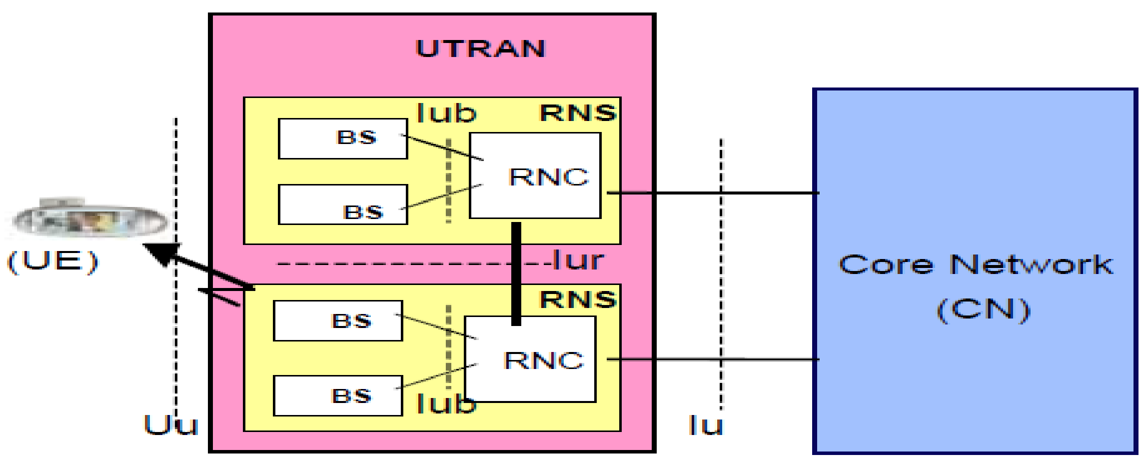

Figure 2.3: UTRAN Architecture [26]

2.4.1 Node B (Base Station)

This is the base transceiver station of the UTRAN that serves one or more cells (sectors). Some of its functions include: error detection on transport channels and indication to higher layers, modulation/demodulation of physical channels, radio measurements and notification to higher layers and power weighting [37]. Some vendors offer base stations that support both UMTS and CDMA2000 standards through the use of field-replaceable modules and a high percent of compatible hardware and software. The interface between UE and Node B is actually the WCDMA-based UTRA radio interface [31].

The functions of Node-B are:

- Air interface Transmission/Reception
- Modulation/Demodulation
- CDMA Physical Channel coding
- Micro Diversity
- Error Handing
- Closed loop power control

2.4.2 Radio Network Controller (RNC)

Manages the radio resources of each of the Node Bs that are connect to it. Figure 2.3 shows that the RNC is connected to the core networkœs CS domain [25] through the IuCS interface, and to the PS domain through the IuPS interface. Not only does the RNC manage the user equipmentœs radio resources, but it is part of the path to/from the core network for the services being used by the user equipment [27]. Some other tasks performed by RNC include: processing of voice and data traffic, hand off between cells and calls setup and termination.

The functions of Radio Network Control (RNC) are:

- Radio Resource Control

- Admission Control
- Channel Allocation
- Power Control Settings
- Handover Control
- Macro Diversity
- Ciphering
- Segmentation/Reassembly
- Broadcast Signalling
- Open Loop Power Control

2.4.3 User Equipment

The UMTS standard does not restrict the functionality of the User Equipment in any way. Terminals work as an air interface counterpart for Node-B and have many different types of identities [39].

UMTS mobile station can operate in one of three modes of operation [35]:

- **PS/CS mode of operation:** The MS is attached to both the PS domain and CS domain, and the MS is capable of simultaneously operating PS services and CS services.
- **PS mode of operation:** The MS is attached to the PS domain only and may only operate services of the PS domain. However, this does not prevent CS-like services to be offered over the PS domain (like VoIP).
- **CS mode of operation:** The MS is attached to the CS domain only and may only operate services of the CS domain.

The UMTS Integrated Circuit card has same physical characteristics as GSM SIM card [40, 41]. It has several functions:

1. Support of one User Service Identity Module (USIM) application.
2. Support of one or more user profile on the USIM.
3. Update USIM specific information over the air.
4. Security functions.
5. User authentication.
6. Optional inclusion of payment methods.

2.4.4 UMTS Interfaces

The interfaces in the UMTS system follow the GSM/GPRS naming convention, where applicable. The UTRAN contains some new interfaces and, thus, some new names.

UMTS defines four new open interfaces [42]:

- Uu: User Equipment to Node B (UTRA, the UMTS Wï CDMA air interface)
- Iu: Radio Network Control to GSM Phase 2+ Core Network interface (MSC/VLR or SGSN)
    1. Iu-CS for circuit-switched data
    2. Iu-PS for packet-switched data
- Iub: RNC to Node B interface
- Iur: RNC to RNC interface, not comparable to any interface in GSM

The Iu, Iub, and Iur interfaces are based on ATM transmission principles [43].

The RNC enables autonomous Radio Resource Management (RRM) by UTRAN. It performs the same functions as the GSM BSC, providing central control for the RNS elements (RNC and Node Bs).

The RNC handles protocol exchanges between Iu, Iur, and Iub interfaces and is responsible for centralized operation [35] and maintenance (O&M) of the entire RNS with access to the OSS. Because the interfaces are ATMï based, the RNC switches ATM cells between them. The userôs circuit-switched and packet-switched data coming from Iuï CS and Iuï PS interfaces are multiplexed together for multimedia transmission via Iur, Iub, and Uu interfaces to and from the UE [39].

The RNC uses the Iur interface, which has no equivalent in GSM BSS, to autonomously handle 100 percent of the RRM, eliminating the burden from the CN. Serving control functions such as admission, RRC connection to the UE, congestion and handover/macro diversity are managed entirely by a single serving RNC (SRNC) [32].

If another RNC is involved in the active connection through an interï RNC soft handover, it is declared a drift RNC (DRNC). The DRNC is only responsible for the allocation of code resources. A reallocation of the SRNC functionality to the former DRNC is possible (serving radio network subsystem [SRNS] relocation). The term controlling RNC (CRNC) is used to define the RNC that controls the logical resources of its UTRAN access points [25].

2.5 UMTS PROTOCOL

Since protocol specification work was divided between various groups in the Third Generation Partnership Project (3GPP) technical organisation, it was quite natural that each of the groups developed its own protocol reference architecture for those protocols for which it was given the mandate to carry out the specification work. This resulted in three major areas [43].

2.5.1 The Radio Interface Protocol Reference Model

The UMTS Terrestrial Access Network (UTRAN) radio interface is based on Wideband Code Division Multiple Access (WCDMA) radio technology, which has some fundamental differences from all 2G radio access technologies [40]. There are two major protocol design aspects in UMTS, one is the separation of generic transport aspect from UMTS specific mobile networking aspect by horizontal layers, the other is the separation of network control aspect from the user data transfer aspect by vertical planes [31]. The UMTS protocol model is divided into three layers: transport network layer, radio network layer and system network layer, all in horizontal decomposition and two planes (control plane and user plane) in vertical separation.

The horizontal layers depict the protocol interworking across multiple interfaces and protocol terminations. The transport network layer provides transport services for all UMTS network elements thus making them able to communicate across different interfaces [30]. The radio network layer is responsible for the interworking between UE and CN on all radio bearer related aspects.

The system network layer protocols extend from UE to the transit network edge of the UMTS CN and take care of the interworking of UMTS communication service related aspects.

The vertical planes illustrate the system control and user data flow in the UMTS [39]. The control plane protocols in different UMTS interfaces interwork with each other to make system-wide control of communication resources and services. The user plane protocols interwork each other across the different interface to ensure the end-to-end flow of user data.

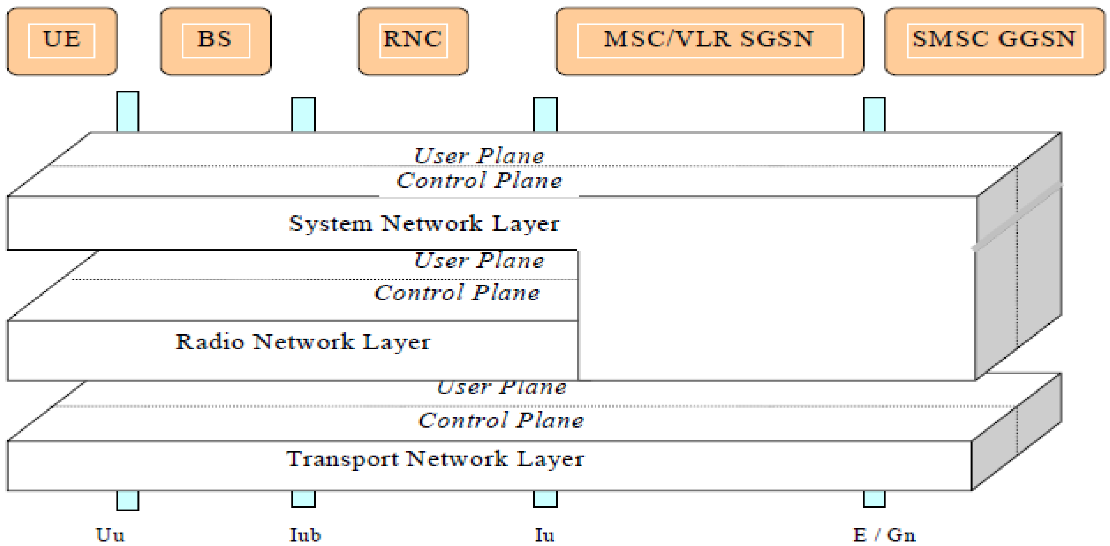

Figure 2.4: UMTS protocol interworking architecture [39]

2.5.2 (UTRAN) Protocol Reference Model

In the radio access network, UTRAN has the overall responsibility of WCDMA radio resources. UTRAN carries out radio resource management, controls among its own network elements and creates the radio access bearers that allow communication between UEs and the Core Network (CN) across the whole UTRAN infrastructure [31]. This communication is structured according to the generic UTRAN protocol reference model illustrated in Figure 2.5. The model is generic in the sense that the architectural elements - though not the specific protocols are the same for all the UTRAN interfaces: Iu, Iub and Iur.

The main elements of the UTRAN protocol architecture are layers and planes. The general layering principle applied in the UTRAN design is primarily, to distinguish between the two major parts of the protocol stack [38]. Therefore, all the lower layer protocols together comprise what is called the óótransport network layerôô of UTRAN. The other set of protocols on top of the transport [43] network layer is - consistently with the radio interface protocol model which is called the óóradio network layerôô. These protocols have been carefully designed for the UMTS and the usual task for them is to control the management and use of radio access bearers across the various UTRAN interfaces.

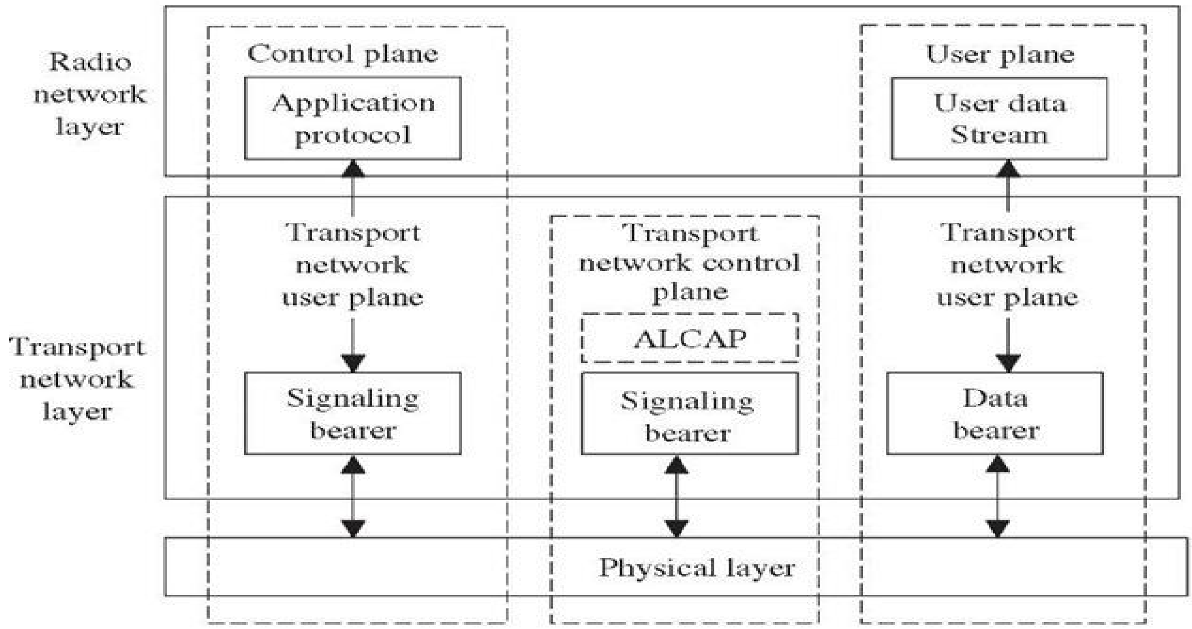

Figure 2.5: UTRAN protocol reference model [39]

The figure above shows that it has two main layers: the radio network layer and the transport network layer. The UTRAN related requirements and the standard transport technology are handled in Radio Network Layer [39]. The User plane and the control plane are in the vertical direction. These planes are used to transmit user data from higher layer and to control the link or connection respectively. The control plane consists of signalling bearers and application protocols and the user plane includes data streams and data bearers. The transport network control plane (TNCP) does not contain the radio network information. It contains (ALCAPs) protocol [44].

2.5.3 Uu Interface Protocol

The key task of the radio interface is multiplexing different kinds of traffic flows from different origins. To have effective control of multiplexing, a three-layer model is applied to it as illustrated in Figure 2.5. In this model, the radio interface is divided into three protocol layers as in [26]:

Layer 1(L1) - Physical layer

Layer 2(L2) - the data link layer

Layer 3(L3) - network layer

L1 provides its services as a set of WCDMA transport channels. It takes care of the first level multiplexing function to map the traffic flows between transport channels and physical channels and vice versa [39].

L2 is split into different sub-layers, MAC, RLC, PDCP and BMC. It is another multiplexing layer and contributes to dynamic sharing of the capacity of the WCDMA radio interface. MAC controls the use of transport block capacity [43]. RLC adds regular link layer function onto the logical channels provided by the Subscribers Access Point (SAP) between RLC and MAC. The PDCP makes the UMTS interface applicable to carry IP data packets. The BMC is specified for message broadcast and multicast domain.

L3 and RLC are divided into Control and User planes. PDCP and BMC exist in the User plane only. L3 control plane is the RRC protocol [39] taking care of radio resource management. An RRC entity locating on both UE and UTRAN sides has control interfaces with all other protocol entities.

The MM and SS/CC/SM protocols are located on top of L3. The MM is responsible for mobility management, SM controls the establishment and release of packet transfer sessions or PDP contexts in the CN PS domain, CC takes care of the establishment and release of circuit switched calls in the CN CS domain, SS controls the activation and deactivation of various call related or non-call related supplementary services [45].

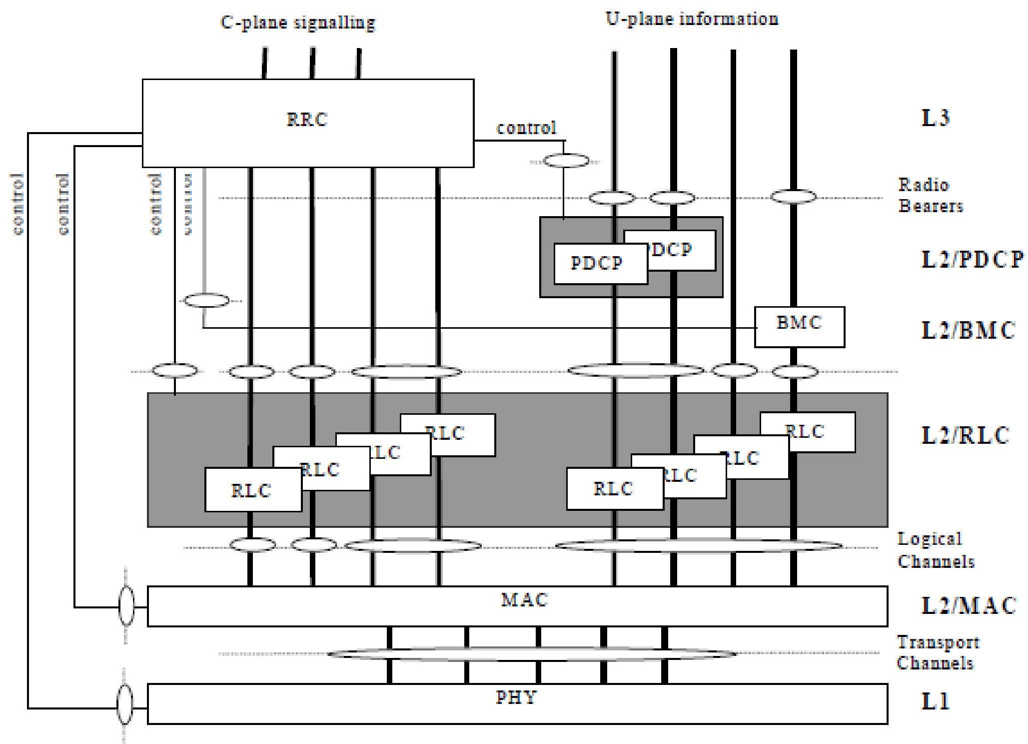

Figure 2.6: Radio Interface Protocol architecture [45]

2.6 Radio or Wireless Channel

Radio communication channel is the propagation medium for electromagnetic waves between the transmitter and receiver [1]. Designing a perfect radio channel in mobile communications would be practically an impossible task since the channel is stochastic in nature as the mobile terminals keep moving almost all the time with different speeds and the channel fading are unpredictable [23].

The signals in a radio channel undergo different propagation effects like reflection, refraction, scattering and shadowing. A smooth surface reflects the signals. But,when the signals encounter sharp edges of buildings, they are refracted, while arough surface scatters them [46]. When these signals are obstructed by big buildings,they pass through them causing the shadowing effect. All these effects cause thechannel to be lognormal, Rayleigh and Rician distributed. So, the receiver receives multiple copies of the same signal with variation in time and phase. These signals are either added constructively or destructively depending on the phase of the signals.

2.6.1 Channel Organisation in WCDMA

The channel organisation used by WCDMA technologies comprises of three channels [31]:

1. Physical Channel,
2. Transport Channel
3. Logical channel**.**

Logical channels describe the types of information to be transmitted, transport channels describe how the logical channels are to be transferred. And physical channels are the óótransmission mediaôô providing the radio platform through which the information is actually transferred [45].

The Transport Channels are interface between MAC and Layer 1, while Logical Channels are interface between MAC and RLC. The logical and transport channels define what data are transported, while the physical channels define how and with what physical characteristic the data are transport.

2.6.2 Physical Channel

The WCDMA defines two dedicated physical channels [31] in both directions.

- Dedicated Physical Data Channel (DPDCH) to carry dedicated data generated at layer 2 and above.
- Dedicated Physical Control Channel (DPCCH) to carry layer one control information.

Each connection is allocated one DPCCH and zero, one or more DPDCHs. In addition, there are common physical channels defined as

- ❖ Primary and secondary common control physical channels (CCPCH) to carry downlink common channels.
- ❖ Synchronization Channel (SCH) for cell search.
- ❖ Physical Random Access Channel (PRACH) FOR THE CALL setup from user equipment to the base station.

2.6.3 Transport Channels

We have Two types of transport channels: common and dedicated. The difference among them is that the first is used for distributed resource between a user group in a cell (they use explicit addressing) whereas the dedicated ones are used for dedicated resources, identified by a code and a certain frequency (inherent addressing to the UE) [25].

2.6.3.1 Dedicated Transport Channel

A dedicated transport channel denominated DCH (Dedicated Channel) for the Release 99 only exists. It is used to transport all the information related with the higher layers (data and signalling of the higher layers) in circuit switch (for packet switching several can be used) [25, 35]. It is characterized by:

- Bidirectional Channel (UL and DL)
- Can be transmitted over all or part of a cell using adaptive antennas
- It admits fast Power Control in closed loop (1500 Hz of maximum frequency of Power Control, resultant to send a command by interval)
- Soft-Handover supports
- Possibility of using synchronization in the uplink
- Possibility of changing the bit rate of fast form of one frame to other (each 10 ms)

2.6.3.2 Commons Transport Channels

There are currently six different common transport channel types defined for UTRA: BCH, FACH, PCH, RACH, CPCH and DSCH. They do not have soft handover, although some of them can have fast power control [26].

[I] Broadcast Channel (BCH)

It is a downlink transport channel that is used to spread information of the UTRA system and the concrete cell [25]. As the terminals cannot be registered in the network if they cannot decode this channel must be transmitted with an elevated power in the entire cell to reach all the zone of cover. The bit rate of this channel is limited by the capacity of terminals of low speed of decode, it what is in a channel of low and fixes rate. It has a simple transport format [47].

[II]Forward Access Channel (FACH)

It is a downlink transport channel that is used to transport information of control to the terminals located in a determinate cell (it transmits small amounts of data and it is used to respond for example to a random access, to give relative information and traffic information to a service) [35]. It is transmitted in the entire cell, or in part of its using adaptive antennas. Its bit rate is low so that it can be decoded by all the terminals in the cell. A slow power control in this channel can be used although it is not possible to use the fast. The transmitted messages in this channel must use identification to allow their correct reception.

[III] Paging Channel (PCH)

It is a downlink transport channel that is used to transmit all the information related with the procedure of paging (when the network wishes to contact with the terminal). The terminals must receive the information of paging in the entire cell [26]. The design of the paging channel affects to the consumption of power of the terminal in the standby mode (if the terminal listens this channel little, its battery will last much).

[IV] Random Access Channel (RACH)

It is an uplink transport channel that is used to transport control information from the terminal (to ask the establishment of a connection). It can be used to send small amounts of data packages from the terminal to the network [25]. This channel must be listened by the base station from any point of the cover area, reason why the data rate must be low. The field data is limited and it is characterized to support power control in open loop and to be submitted to collisions.

[V] Common Packet Channel (CPCH)

It is an uplink transport channel that is used to transport traffic bursts. This channel is associated to a dedicated channel in downlink that provides the power control and the commands of control for this channel. It is characterized by an initial collision and it can be transmitted with the fast power control in the message. It is transmitted in the entire cell or in part of it using adaptive antennas. It offers the possibility of changing the bit rate from a frame to another one.

[VI] Downlink Shared Channel (DSCH)

It is a downlink transport channel that is used to transport dedicated data of user and information of control that can be shared by several users. This channel is associated to one or several DCHs in the FDD mode (in TDD is possible to associate it to the FACH). It supports fast and slow power control when is associate to a dedicated channel [25, 31]. It is possible to be transmitted on the entire cell or part of it using adaptive antennas. It offers the possibility of varying its bit rate from a frame to another one.

2.6.4 Logical Channels

The 3G logical channels include [35]:

- ***Broadcast Control Channel (BCCH)*** (downlink). This channel broadcasts information to UEs relevant to the cell, such as radio channels of neighbouring cells, etc.
- ***Paging Control Channel (PCCH)*** (downlink). This channel is associated with the PICH and is used for paging messages and notification information.
- ***Dedicated Control Channel (DCCH)*** (up and downlinks) this channel is used to carry dedicated control information in both directions.
- ***Common Control Channel (CCCH)*** (up and downlinks). This bi-directional channel is used to transfer control information.
- ***Shared Channel Control Channel (SHCCH)*** (bi-directional). This channel is bi-directional and only found in the TDD form of WCDMA/UMTS, where it is used to transport shared channel control information.
- ***Dedicated Traffic Channel (DTCH)*** (up and downlinks). This is a bi-directional channel used to carry user data or traffic.
- ***Common Traffic Channel (CTCH)*** (downlink) a unidirectional channel used to transfer dedicated user information to a group of UEs.

2.7 Characteristic of Wireless Channels

The wireless radio channel puts fundamental limitations to the performance of wireless communications systems. It, in contrast to wired channels, behaves in an unpredictable manner [1]. The state of such a channel may vary considerably within a short time, therefore, communication over wireless channels are not straight forward as over wired ones. Wireless channels are often classified depending on their propagation environment: urban, suburban, indoor environment etc, with each of them having their own characteristics [48]. These channel environments have an attenuating effect on signals transmitted over them. The three major effects that results in the overall attenuation of the transmitted signal are path loss, shadowing, and fading.

[I] Path Loss

Path loss is a deterministic phenomenon that reduces the power of any transmitted electromagnetic wave. It is caused by dissipation of the power radiated by the transmitter as well as the effects of the propagation channel. This loss of power depends only on the frequency and the distance which the wave travelled to reach its destination. However, path loss can be defined as the ratio between the received and transmitted powers [49].

[II] Shadowing

Under fixed distance, frequency and transmission power conditions, there are still variations in the received power to be observed. These variations are caused by objects in and around the signal propagation path and do have stochastic properties [50]. Shadowing gives account of the deviation, in terms of received power, from the theoretical mean value given by the path loss formulas. The deviations are mainly caused by reflections, diffraction, refraction, scattering and absorption that typically affect the propagation of an electromagnetic wave [51].

The objects responsible for shadowing are of such dimensions that a receiver moving along a line at constant distance from the transmitter may need several hundreds of milliseconds to reach an area with different characteristics, which is the reason why shadowing is also referred to as slow - fading [52]

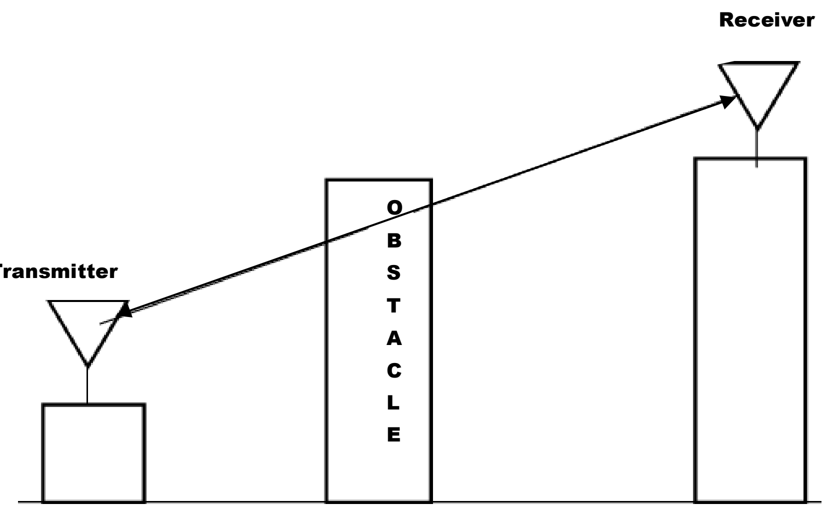

Figure 2.7: Receiver under the influence of an obstacle of huge dimension [50]

[III] Fading

In wireless communications, fading is considered to be a random fluctuation about the mean power level determined by the shadowing and path loss models. It is caused by multipath effect, i.e. when multiple reflected waves of a transmitted signal reach their destination having travelled different paths [53]. Object surrounding both the transmitter and the receiver, known as scatterers, are responsible for this multipath propagation. The concept of fading basically represents the interference of signal generated at the receiver, which results in a variation of the overall signal strength. It is responsible for the fastest and strongest changes of the signal amplitude and its phase. This phenomenon can be classified as small time scale effect, since the signal variations are experienced on small fractions of second [54].

Here, to understand fading, it is essential to understand multipath. Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. It is caused by ionospheric reflection and refraction, atmospheric duct, reflection from terrestrial objects such as mountains and building. Multipath causes constructive and destructive interference, and shifting of the signals.

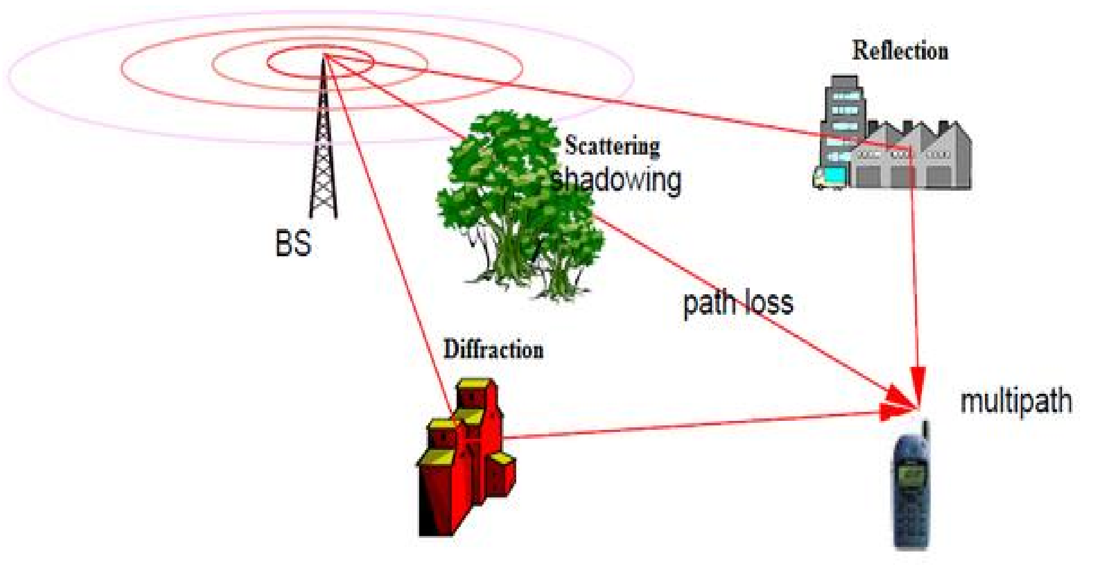

Figure 2.8: Multipath in wireless environment [53]

2.8Functions of Radio Resource Management

There are three main functions of radio resource management [54].

1) Power Control

2) Handoff control

3) Call Admission control

4) Load control

5) Packet scheduling control.

However, the above function could be re-grouped into two parts:

1. Connection oriented function such as

i. Power control

ii. Handoff control

2. Network Oriented Function such as

i. Load control

ii. Power control

iii. Packet scheduling control

Location of Radio Resource Function

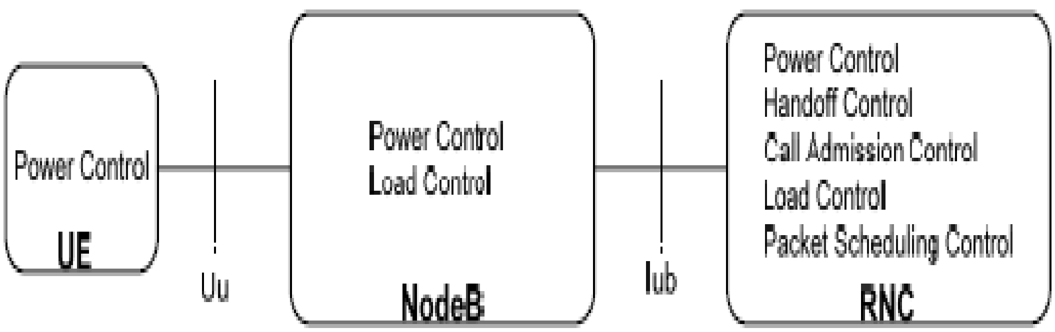

Figure 2.9: Radio Resource Management Functions and Areas ofAapplication on a Wireless Network [55].

[I] Handoff Control

This mechanism transfers an active call from one cell to one of its neighbouring cell with subscriberǿs movement. Handoffs are very important in cellular architecture. Handoff provides freedom of mobility within the boundaries of the cellular system [2, 55]. But this mobility can cause some problems related to link quality and interference level during communication.

[II] Load Control Principles

The basic principle of load control is the same as admission control. While admission control is carried out as a single event, load control is a continuous process where the interference is monitored [18]. Load control measures the load factor, and, if the predefined load factor is exceeded, the network either reduces the bit rates of those users whose service contract allows it to be done, delays the transmission of those users without delay requirements, or drops low priority calls.

[III] Call Admission Control

Call Admission Control (CAC) has the function to regulate and provide resources for new call request or already going call [7]. CAC also ensure the quality of service for the calls in terms of required radio resources. The main objective of admission control is to ensure the free radio resources for a new or handoff call with required Signal to Interference Ratio (SIR) and bit rate [56]

[IV] Packet Scheduling Control

A packet scheduling scheme is essential to schedule packet transmission and control interference in order to meet various QoS requirements such as delay bound, throughput [16].

It handles all non real time traffic, (packet data users) [54]. It decides when a packet transmission is initiated and the bit rate to be used.

[V] Power Control

One of the important resource management issues in WCDMA is power control since the entire users transmit on the same carrier frequency; increase in the number of users creates more interference. In this case, effective resource management is really important to maintain the system performance [57]. If the transmitted signals of all the mobile stations are at the same level, a strong signal from a near-in-mobile will mask the weak signal from a far-end mobile station. The stronger signals cause unnecessary interference on the reverse links (uplink) of other mobile station unless they are controlled [16].

2.9 Importance of Power Control in UMTS.

1. Provides sufficient power for each user equipment

It is a known fact that power control is important in any system, particularly in an age of global warming in which everyone is trying to achieve a lean carbon footprint [19]. When it comes to mobile phones, the idea is to extend battery life by using the minimum possible power while maintaining reliable communications.

2. Control Interference

In Wideband Code Division Multiple Access (WCDMA) technology, interference is a critical factor because communications occur on the same frequencyband and time slot such as in the UMTS FDD mode. Interference is directly linked to coverage andcapacity of such a network [17]. This interference is produced by different factors such as thermal noise, intra cell traffic, traffic in adjacent cells and external traffic. In addition, the increase in number of users in a cell consequently increases the total interference in the network. Hence, the interference must be controlled to improve the throughput of the network

3. Overcoming the near-far effect

Power control is needed in WCDMA systems to mitigate the so-called ñnear-far effectò, which is caused by the large variations of signal strength due to the Rayleigh fading radio propagation channel [55]. Here, a User Equipment close to the Node-B transmitting at the same power as another at the cell edge will potentially block out the latter [58].

However, Power Control mechanism aims to equalise the received signal power from all users. This is not an easy task because the signal transmitted through a radio channels subjects to many attenuations such as path-loss due to distance, shadowing due to shielding phenomenon and multipath fading [59]. UMTS power control must be designed with a capability to cope with the above attenuations. This means that propagation path loss between the User Equipment and the Node-B should be taken into account. In an ideal environment, this alone is sufficient [60]. But real environments are rarely ideal. This is illustrated with the figure below.

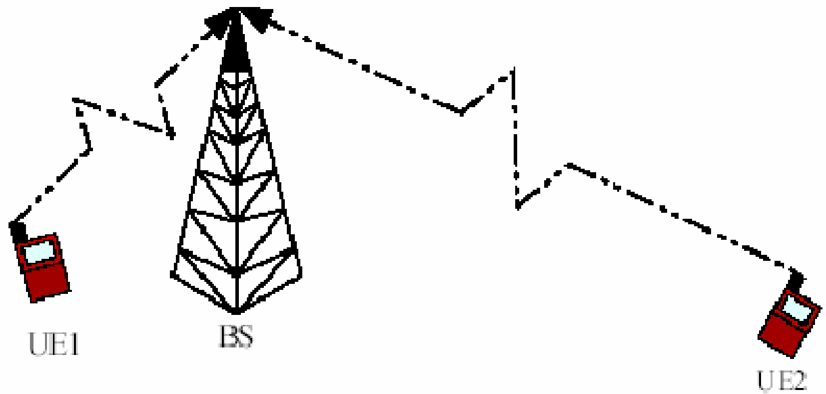

Figure 2.10: Near-Far-Effect [19]

4. Maximize the battery life of the user equipment
5. Another purpose of power control is to ensure the QoS with minimum power in the CDMA system

2.10 Power Control Mechanism

In order to properly manage the power control in CDMA, the system uses one of the two well known power control mechanisms [61]

- Open-Loop Power Control (OLPC)
- Closed-Loop Power Control (CLPC)

2.10.1 Open-Loop Power Control (OLPC)

The OLPC adjusts the transmitted power according to its estimation of the channel. It does not attempt to obtain feedback information. It is used in WCDMA. The major benefit of OLPC is to provide a very rapid response over a period of just a few microseconds [19]. This is desirable for cases of sudden change in channel conditions. It adjusts the mobile transmit level and thus prevents the mobile transmitter power from exceeding some threshold with respect to the downlink received power level. The power of received pilot signal reduces as distance between

UE and Node B increases, and increases as distance between UE and Node B decreases [62].

However, if this initial power is not sufficient to be taken care of, it will increase at constant intervals in dB; until it receives confirmation of the base station that its signal has been received. If from a first moment the power had been excessive, it would directly have entered to execute the algorithms of power control [60].

2.10.2 Closed-Loop Power Control (CLPC)

This is a more effective long-term PC method. It is used to ensure that each of the users transmit just an adequate power to fulfil the service requirement for a particular dedicated link. In [63], the BS provides a continuous feedback to each mobile so that the mobile varies its power accordingly. Each BS measures the received signal power or SIR from each mobile. The measured power or SIR is compared to the desired power level or SIR for that mobile. The solution to power Control in WCDMA is fast closed-loop power control. It is further divided into

- Inner Loop Power Control
- Outer Loop Power Control

Inner closed loop power control is also known as fast closed loop power control. In inner loop power control, transmitter of user equipment adjust transmitted power in accordance with the transmit power control commands transmitted by Node B to achieve the better signal to interference ratio (SIR) nearest to given target SIR. Transmitter changes its power with step size 1, 2 and 3 dB steps after receiving the transmit power control command [16].

WCDMA air interface is organized in frames. Each frameøs duration is 10ms and each frame contains 15 time slots. There is one transmit power control command in each time slot and transmitted power has a fixed value during a time slot. So the power control update rate is 1500 bps [62].

Inner loop power control is responsible to neutralize the fading of radio channel and keep close the signal to interference ratio (SIR) of uplink transmission to SIR target set by outer loop power control.

In inner loop power control, Node B measures the received signal quality, i.e, SIR of uplink transmission and compares it with the target SIR. If the calculated SIR is less than the target SIR, then it will send the transmit power control command ñ1ò requesting a transmit power increase for uplink transmission. Otherwise it will send the transmit power control command ñ0ò requesting a transmit power decrease for uplink transmission [64]. Now transmitter for uplink transmission takes necessary action on these commands. This is better illustrated with the figure below.

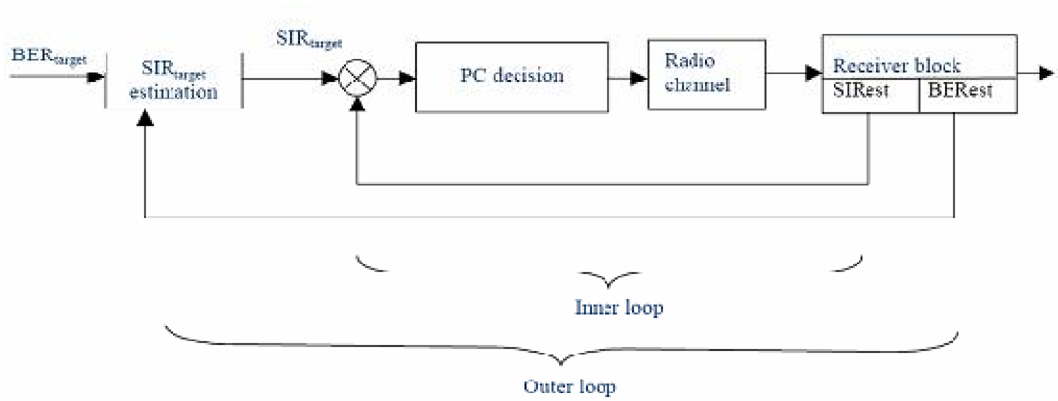

Figure 2.11: Inner and Outer Closed Loop Power Control at Node B [64]

However, the principle of Inner Loop Power Control could be summarised as follows

1. The receivers calculate the SIR by estimating the power strength and the current interference. Then, compare this one to SIRtarget
   - If $\mathbf{SIR_{measured}} < \mathbf{SIR_{target}}$, send **TPC = 1**to inform receivers increase its transmission power

- If $\mathbf{SIR_{measured}} > \mathbf{SIR_{target}}$, send **TPC = 0**to inform receivers decrease transmission power

2. The receiver that receives the TPC will adjust the transmission power by used algorithms. The inner loop power control can converge the estimated SIR to SIR target [63]

Outer loop power control is responsible for the calculation of target SIR to maintain the quality of communication with lowest possible transmission power. Outer loop power control is the part of Radio Resource Control Layer. This relates to long term variations of the channel. A target SIR is usually specified [16]. If the received SIR is less than this target, transmit power needs to be increased. Otherwise, it needs to be decreased. In practice, downlink target quality is in terms of transport channel block error ratio (BLER). The BLER can be related to a target SIR. If the received SIR is less than the target, BLER is likely not to be met [64]. Alternatively, if the BLER is more than the target, transmit power has to be increased, i.e. the outer closed loop power control sets the target signal to interference ratio (SIRtar) in accordance to the received block error rate (BLER) or bit error rate(BER), in order to match the required BLER. This control is in the UE and the RNC. This is also known as **slow closed loop power control.** It happens at the rate of 10-100 Hz

2.11 Further Classifications of Power Control Algorithms or Techniques based on **type of controller** is as follows [63]:

- Centralized power control
- Distributed power control

2.11.1 Centralized Power Control is a mechanism with a central controller having the information of all the link gains of the system. These link gains are utilized to find the optimal solution to the power control in all the links simultaneously [23]. This type of power control is practically unrealizable, since it involves added infrastructure and introduces a feedback delay in power control process, which degrade the system performance. Also, bandwidth is wasted due to the extreme signaling between base stations.

2.11.2 Distributed power control is based on the local link gain measurements. Each base station measures its local parameters like link gain and Change-to Interference Ratio (CIR) to control the power in that link [64]. This type of power control is practically realizable since it does not involve complex signalling and is easier to implement.

2.12 Power Control Algorithms

With the technological attainment in cellular system, several power control algorithms have been proposed to control the power especially for CDMA systems. Most of the existing algorithms utilize either SIR or transmit power as a reference point in the PC decision-making process. PC algorithms can be classified in many different ways. One of such classifications is the following [65]:

- Power Control for uplink (Reverse link)
- Power Control for downlink (forward link)

2.12.1 Uplink Power Control

Uplink power control is important to combat fading, the near- far problem and to adjust the transmit power of the User Equipment, so that the signals received at the Radio Base Station (RBS) from all UEs have equal Signal-to-Interference Ratio (SIR) at the same bit rate (this is to counteract the near-far problem), and to reduce the co-channel interference caused by simultaneous users [66].

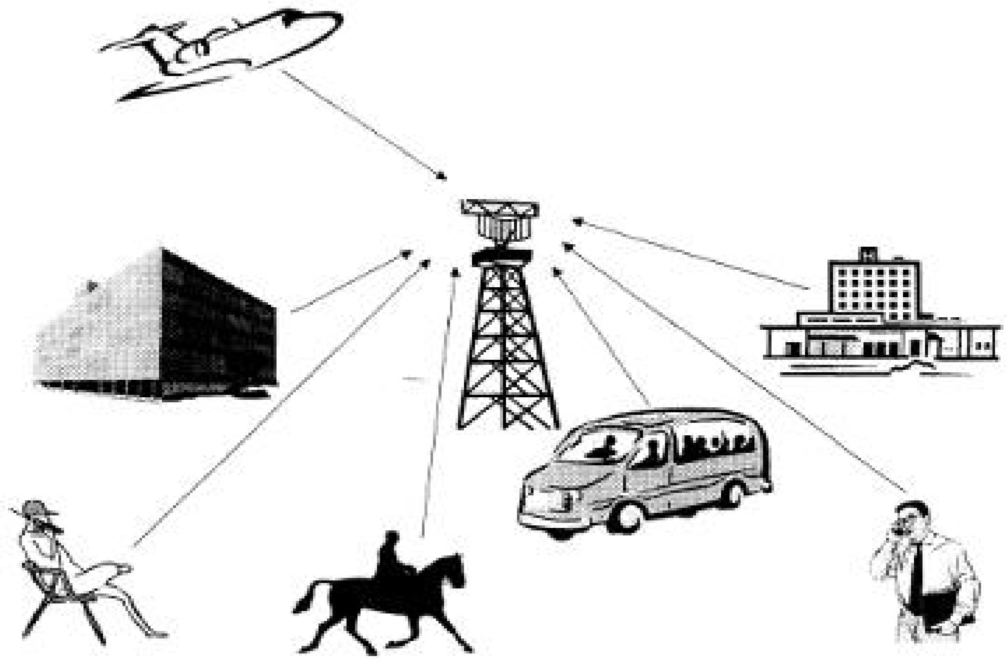

Figure 2.12: A Model of Uplink Power Control [66]

The figure above is a simple diagram of a reverse link of a (cellular-like) wireless system, which consists of a base station receiver, and the different users' transmitters, at different locations.

In the closed loop uplink power control, the base station needs to set SIR to a given SIR_{tar} to maintain a certain QoS for all mobile stations [63]. After comparing the received SIR from the mobile station with the reference value, the base station sends either a power up or down command

2.12.2 Downlink Power Control

The downlink power control adjusts the power transmitted by the base station to the station to the mobile station. Thus, the mobile transmit the power control command to the station. This is to provide more power to the user at the cell edge as compared to other user [17]. It is used to minimize the transmitted power of the Radio Baseband Station and to compensate for channel fading in the downlink. Its objective is to maximize capacity by minimizing power and interference.

2.13 A Closed Loop Power Control Model for FDD-CDMA System

In a FDD-CDMA system, a physical channel is definedby its code and its frequency. The methods applied in this paper could be applied to downlink and TDDsystems after some slight adaptations. Power control isonly applied at Layer 1 (inner closed-loop PC). Circuit switchedsystems(e.g., voiceService) and Closed Loop Power Control (CLPC) model are considered [62].

The Figure below shows the relevant CLPC functions in the context of UTRA-FDD Mode. The user data and control information present on channels DPDCH and DPCCH respectively are spread to the chip rate using channelization codes [16, 67]. There is $N_d$data symbols on DPDCH and $N_p$pilot symbols on DPCCH. The spread signal is then scrambled using a complex scrambling code of length 1 radio frame [68]. The reverse operations are performed at the receiver to distinguish the desired user and the channels. Perfect delay estimation and perfect phase estimation of the multi-path components has been assumed. CHEST is performed on each resolved path that is used for RAKE combining [69]. RAKE receiver, used specially in CDMA cellular systems, can combine multipath components, which are time-delayed versions of the original signal transmission. This combination is done in order to improve the signal to noise ratio (SNR) at the receiver. RAKE receiver attempts to collect the time shifted versions of the original signal by providing aseparate correlation receiver for each of the multipath signals. This can be done due to multipath components are practically uncorrelated from another when their relative propagation delay exceeds a chip period [70].

The paths are maximal-ratio combined (MRC) and the RAKE output data is used for SIR estimation. The estimated SIR is then compared with a target ***SIR*** that varies with the service and the user environment. These functions come under the PC command generation block as could be seen in the figure below. The received PC commands at the MS are interpreted as a óstep-upô or óstep-downô in power on both DPDCH and DPCCH, by a fixed amount.

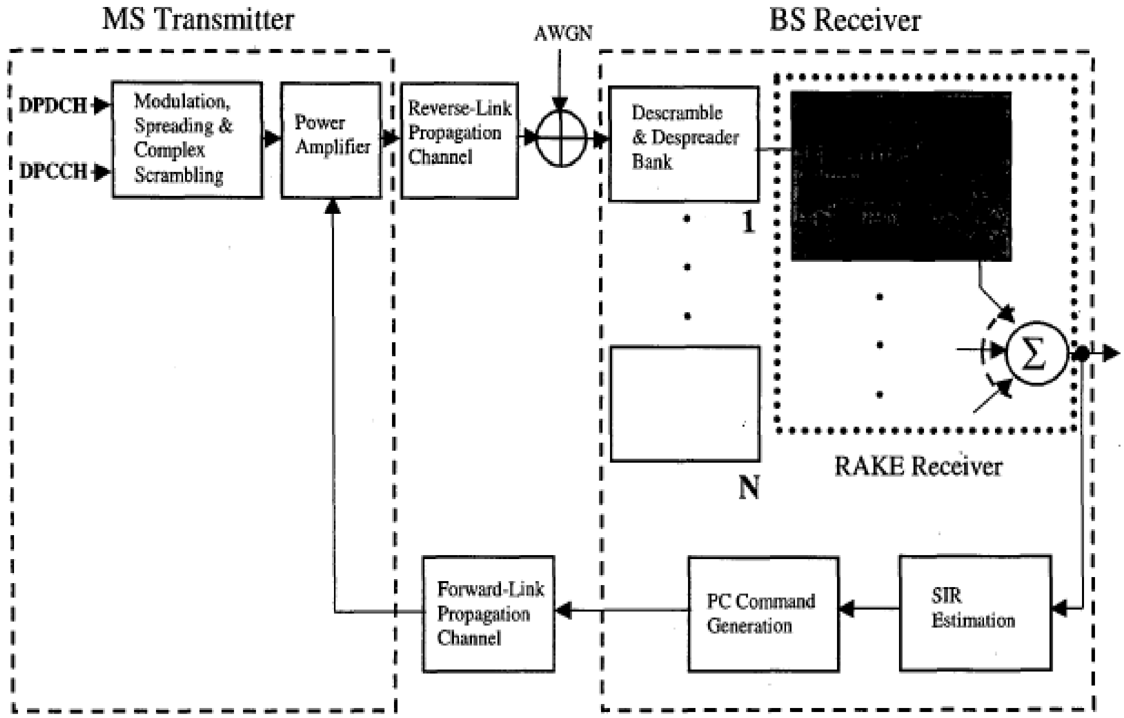

Figure 2.13:UE and BS Function for Uplink Closed Loop Power Control (CLPC) [69]

2.14 Related Works on Power Control Algorithms

A lot of research works have been carried out on Radio Resource Management and power control (in particular) since the inception of Multiple Access Techniques, which advocate for new power control algorithms. Much power control algorithms were proposed for satellite communication systems and later were applied to the cellular systems.

Many algorithms with different configuration were proposed for global system for mobile communication (GSM), CDMA and WCDMA systems.

Power control algorithms could be categorised as Centralized or Distributed power control algorithm. At the beginning, centralized power control algorithm based on balancing of the received power levels was proposed in [71] but the centralized Power control algorithms were not practically realizable. Recent researches concentrated more on the distributed schemes than on the centralised ones because centralized power control requires large- scale data management and induces network vulnerability [72, 73]. However, these shortfalls encountered in centralized power control have made many researchers to venture in to distributed power control, which has a better and realistic effect on improving the capacity of the system. Hence works on efficient and distributed power control algorithm for cellular systems commonly referred to as the Foschini-Miljanic algorithm was proposed [74]. A new transmit power control scheme for SINR-based fast power control algorithms using frequency multiplexed pilot symbols on the uplink of a WCDMA was proposed [75]. Other ones considered the power control problem in fading wireless channel; a new method of power control for interference-limited wireless network with Rayleigh fading of both the desired and interfering signal was proposed [76, 77]. The problem of power control in very fast Rayleigh fading wireless system concerning the effect of interference and noise was studied in other to minimize the total transmit power with constraint on the users outage probabilities [78]. Also a new distributed power control algorithms for mobile communication, tracking of fast fading was achieved by assuming that both path gain and interference to be time varying function as shown [78]. Different types of power control schemes for cellular systems have been presented [79]. Moreover, constrained power control has been studied [80, 81] since the maximum transmit power of a mobile user is limited. However, the influence of power constraints needs further exploration for different scenarios, such as the impact of a peak power constraint on the convergence of power control algorithms, and the performance evaluation in networks with random node locations, etc instead of the small-scale fading time scale. Stochastic power control for cellular systems has been studied [82], and a similar stochastic approximation has been proposed [83, 84] to obtain the optimal power allocation for ad hoc wireless networks in random channel environments.

Again, power control in UMTS specification with a fixed stepsize algorithm in which transmission power will either increase or decrease based on a fixed step was developed [85]. Also a power control that is very simple to implement in practice and has very low complexity came up but was not capable of tracking rapid changes in radio channel when UE is moving fast [86]. In light of this, adaptive power control algorithms were proposed [87, 88]. Yang et al in their research shows one of the ways to alleviate the possible effects of positive feedback in PC-based on SIR measurement [89]. In order to meet the demanding quality of service requirement, many more distributed power control algorithms were proposed with different criteria like call blocking and cell removal [90]. Finally, a distributed power control algorithm which does not need the normalization procedure and can achieve carrier to interference ratio balancing with probability one was developed [73].

However, due to the inherent problems associated with the centralized power control which involves added infrastructure and induced network vulnerability, this work is centred on the distributed power control which has a better and realistic effect on improving the capacity of the network. In WCDMA technology, distributed power control is linked to interference. This is because all the user equipments transmit signals at the same frequency band and time slot, thereby inducing interference in the network. This interference increases with increase in UE in the cells and has the effect of degrading the capacity of the network.

Furthermore, many distributed power control algorithms were proposed based on the signal to interference ratio (SIR) and power step size with different cellular setup in order to handle this issue of interference. Although, every researcher promised his or her own algorithm outperformed the other but, there have not been enough research works on the performance of distributed power control algorithms on the bases of speed of convergence, total power consumption of the network, outage probability and bit error rate [23, 57, 69 and 71]

In conclusion, this thesis looked at three promising distributed power control algorithms that could be efficient in handling interference in uplink part of the cellular network by carrying out comparative analyses on them on the bases of their speed of convergence and total power consumption on the network.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Model Design

In this thesis, ñComparative Analysis of Distributed Power Control Algorithm in Cellular Networkò, three main types of models were considered. They are the physical model which is a simplified realization of the system, logical model which uses logical relations or mathematical equations to represent a system, and the computer simulation model which was where the thesis focused more. The computer simulation model was done using Microsoft Excel and the result was later analysed graphically

3.1.1 Physical Model

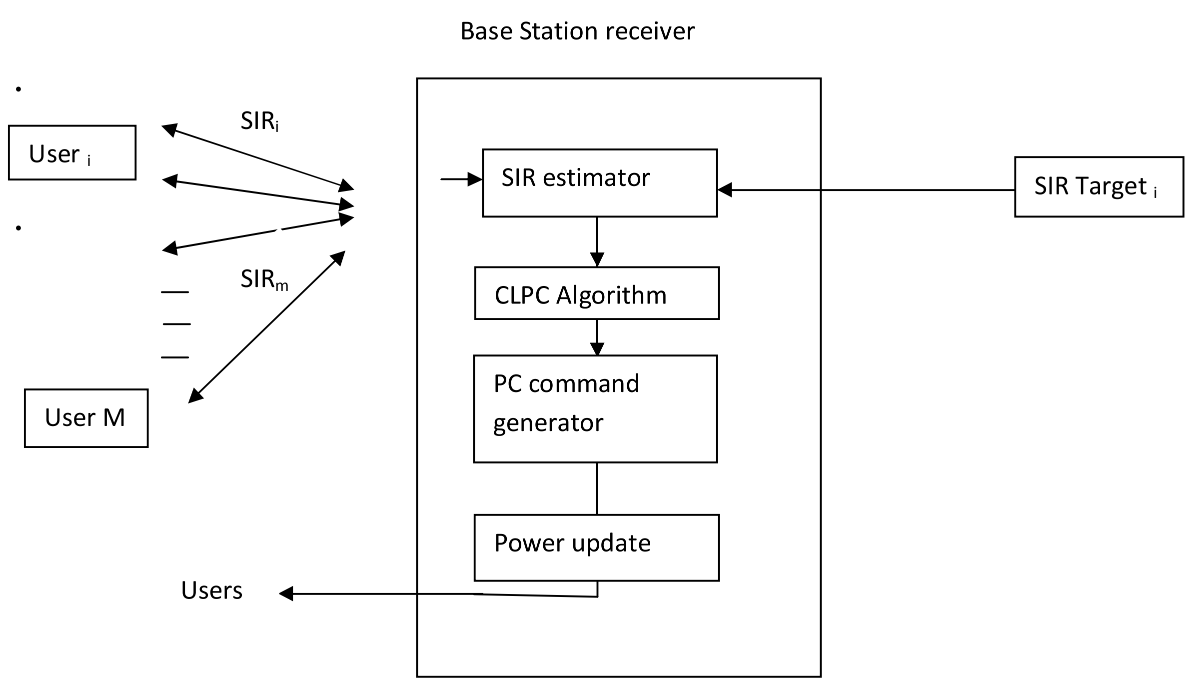

Figure 3.1: Physical model of Uplink Power Control

In uplink transmission of a cellular system, the major aim is to control the power level with which a user equipment can access the base station as to reduce the effect of interference on the network. This could be realised using the transmit power or Signal-to-Interference ratio of the individual users by ensuring that each mobile transmitter power level is controlled so that its signal arrives at the cell site with the minimum required signal-to-interference ratio[91]. Now from the figure, when a signal from the user equipment gets to the base station, the base station compares the userôs SIR at that moment with the target SIR of that user. It then, sends the result to the CLPC algorithm block which enhances it based on the algorithm in consideration. Afterwards, the output of the CLPC algorithm block will be sent to power control command generator which works on it and generates a power update for the user. I.e., it either increases or decreases the power. Consequent on this, the base station could conserve power that could be used by other users thereby increasing the capacity of the system and reducing the effect of interference at the base station.

3.1.2 System Model

A simple simulation system model was used. This allows comparisons between the PC algorithms. In this research work, Signal-to-interference ratio (SIR) was used inter-changeably with carrier-to-interference ratio (CIR) [92]. When there are **N** number of base stations and **M** number of mobile stations in a system, then the powers transmitted by the mobiles will be p=[P_1, P_2, P_3, ...P_M] and the respective CIRs at the mobiles will be ɔ = [$ɔ_1$, $ɔ_2$, $ɔ_3$, ... $ɔ_M$] while $ɔ_{tar}$ be the target CIR. The goal of power controlis to adjust the transmit powers such that the Signal-to-interference ratio (SIR) or Carrier-to-Interference (CIR) of each receiver meets a given thresholdrequired for acceptable performance. The CIR at thei-th BS ($ɔ_i$), could be expressed in equation (3.1) [93]

$$CIR_i = ɔ_i = \frac{[illegible]}{[illegible]} \quad (3.1)$$

Where $$ɔ_{[illegible]} = \frac{[illegible]}{\sum [illegible]}$$

And where

□□ = base station power

□□ = Background noise level.

G_{ij} = link gain between the mobile and the transmitter

P_i = power received by the mobile

For a successful base-to-user transmission in the cell, the following constraint should be satisýed as expressed in the expression (3.2)

□□ ≥ □□□□ (3.2)

Where □□□□ = CIR target.

3.1.3 Modeling of the Channel

A cellular channel refers to the channel between a fixed Base Station and a User Equipment (vice versa) in current cellular networks. Cellular mobile communications system uses a large number of low-power wireless transmitters to create cells - the basic geographic service area of a wireless communications system. Variable power levels allow cells to be sized according to the subscriber density and demand within a particular region [4, 5].

This radio channel places fundamental limitations on wireless communication systems. Unlike wired channels that arestationary and predictable, radio channels involve manyuncertain factors such as path loss, the shadowing, and Rayleighfading, so they are extremely random and do not offer easyanalysis. These channel uncertainties can attenuate the power of the signal at the receiver and thus cause variations in the receivedSIR and therefore degrading the performance of any DPCscheme [94].

In the light of this, a tremendous amount of researches have been conducted on cellular channels in the past decades resulting in several modelling and simulation approaches for cellular channels. Also, the basis for the cellular system concept is introduced in [4, 10 and 95]. The cellular system model considered is the one in which frequency reuse is implemented. Frequency reuse refers to the use of radio channels on the same carrier frequency to cover different areas which are separated from one another by sufficient distances so that co-channel interference is not intolerable.

This cellular mobile system investigated in this paper consists of a finite number of cells. Cells using the same channel are placed symmetrically in a hexagonal grid. The base stations use Omni directional antennas and are located at the centre of the cells. Mobiles are assumed to be uniformly distributed over the cell area. Each cell has N independent channel pairs, each consisting of independent uplink and downlink channels [96]. The power control algorithms can be used for both uplink and downlink channels. However, we assume the algorithms are used for uplink channels. The interference caused by adjacent channels is assumed to be much smaller than co-channel interference and, thus, is neglected. Similarly, thermal noise is not considered. The set of cells using a certain channel at some given instant is called the co-channel set and the size of the co-channel set is denoted by *N.* All co-channels are assumed to be in use [23]. For simplicity, the total interference power is modelled as the sum of the powers of all active interferers and the transmission quality is assumed to depend only on CIR. Furthermore, the cells of a co-channel set are numbered from 1 to **N**and the base station or mobile in cell **i**is referred to as base station **i**or mobile **i**, respectively [95, 96]. Under these assumptions, the CIR at mobile **i**, denoted by CIR_i. In this thesis, a cellular system model with cluster size of 7 which are spaced with a reuse distance D, was considered on the assumption that each cell is a hexagon. The reuse distance is obtained from the formula.

$$D = R\sqrt{3N} \qquad (3.3)$$

Where

R = the radius of the cell taken as R = 1Km

N = the frequency reuse factor.

That is, 7 cells per cluster as shown in figure 2.21. It is also assumed that the system is fully loaded with all the co-channel cells in use. All the assumptions considered for uplink case can also be applied for downlink case.

3.1.4 PROPAGATION AND PATH LOSS MODEL

Path loss refers to the attenuation in the transmitted signal while propagating from the transmitter (Tx) to the receiver (Rx). Path loss is caused by dissipation of the radiated power as well as effects of the propagation channel such as absorption due to moisture, structures etc [10, 91]. Here the channel is assumed to be noise free and interference limited. For instance, consider a mobile ñ**i**ò under a base station ő**i**ô and mobile ñ**j**ò under a base station ñ**j**ò. The distance between $\mathbf{j}_{th}$ base station and $\mathbf{i}_{th}$ mobile is considered as $\mathbf{d}_{ij}$. The channel link gain between $\mathbf{j}_{th}$ base station and $\mathbf{i}_{th}$ mobile station is given by $\mathbf{g}_{ij}$, and is calculated using the equation (3.5) [23, 49].

$$g_{ij} = \frac{S_{ij}}{d_{ij}^{\alpha}} \qquad (3.5)$$

Where S_{ij} = shadowing effect on the power level

Ŭ= is the path loss exponent,

Which is an important simulation parameter varying from 2 to 5. In these simulations, the value of ñŬò is taken as 4 and the shadowing effect $\mathbf{s}_{ij}$ is a log normally distributed random variable with 0 dB mean and a variance of 6 dB. All the link gains of the system are calculated and together considered as a Gain Matrix.

3.2 FLOW CHART OF OPERATION

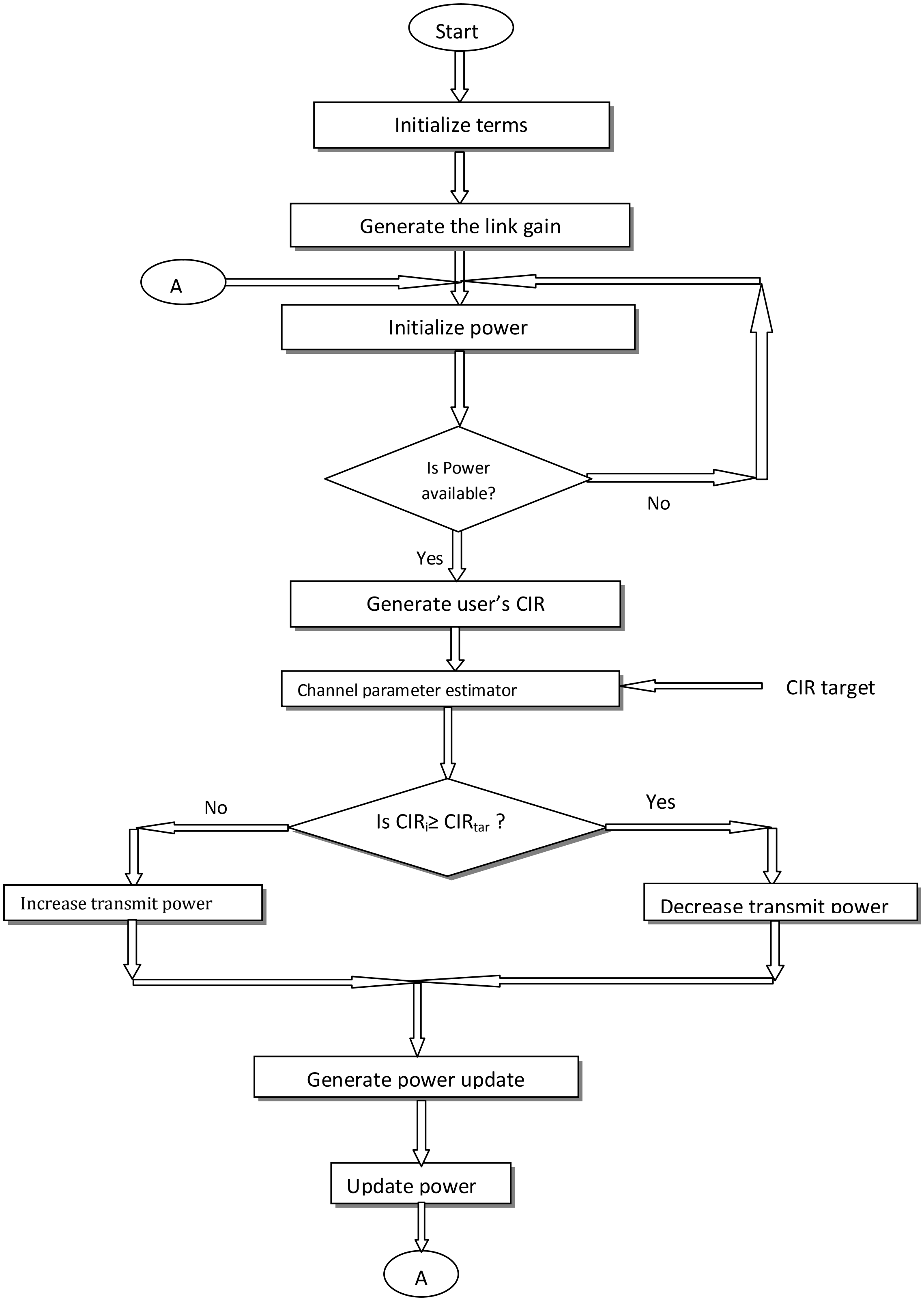

Figure 3.3: Flow Chart of Operation Diagram

3.3 THREE DISTRIBUTED POWER CONTROL ALGORITHM CHOSEN

At this point, we looked in to the three selected algorithms, the performance metrics chosen. But prior to the consideration of the mathematics involved in the power control, some of the parameters and terminologies used may be looked into. When there are **N** number of base stations and **M** number of mobile stations in a system, then the powers transmitted by the mobiles will be p=[P_1, P_2, P_3, ...P_M] and the respective CIRs at the mobiles will be ɔ = [ɔ$_1$, ɔ$_2$, ɔ$_3$, ... ɔ$_M$] be the target CIR. The link gain between the base station ǽiǿ communicating with the mobile station ǽjǿ is given by $\boldsymbol{g}_{ij}$[93]. G is the gain matrix, where all the link gains from each and every mobile station to each and every base station are present. Some of the choice power control algorithms are:

3.3.1 FIRST ALGORITHM: Fully Distributed Power Control Algorithm (FDPCA)

The FDPCA is one of the best-distributed power control algorithms, which achieves very good performance in cellular systems. As the name implies, it is self-explanatory and it is fully distributed because the algorithm uses only the local link information and does not depend on the global information for controlling the power. The power control algorithm proposed [70] could be used for both uplink and downlink channels.

The interference caused by adjacent channels is assumed to be much smaller than co-channel interference and thus is neglected. Similarly, thermal noise is not considered as could be seen in the material. All co-channels are assumed to be in use. And for simplicity, the total interference power is modelled as the sum of the powers of all active interferers and the transmission quality is assumed to depend only on CIR. Under some assumptions, the cells of a co-channel set are numbered from 1 to N. And the CIR at mobile ǽiǿ is given by

$$\mathrm{CIR}_{\text{[illegible]}} = \frac{\text{[illegible]}}{\text{[illegible]}} \quad (3.6)$$

$$\text{CIR}_{□} = □_{□} = \frac{□_{□}}{\sum_{□□□}^{□} □_{□}□□_{□}} \qquad (3.7)$$

$$= \frac{□_{□□}□_{□□}}{\sum_{□□□}^{□} □_{□}□_{□□}□□_{□}□_{□□}} \qquad (3.8)$$

$$= \frac{□_{□}}{\sum_{□□□}^{□} □_{□}□_{□□□}□_{□}} \qquad (3.9)$$

Where R_j =the power received from the *j*th base station

T_j = the transmitting power used by base station *j*

L_{ij} = the link gain between mobile *i* and base station *j*

Z_{ij} = the normalized link gain

But $□_{□□□} \frac{□_{□□}}{□_{□□}}$ (3.10)

And $□_{□□} = \frac{□_{□□}}{□_{□□}}$ (3.11)

Where A_{ij}= the attenuation factor

d_{ij} = the distance between mobile *i* and base station $_j$

Z_{ii} = 1 for all i, 1 ≤ □≤ □and we assume that $A_{ij,}$ 1 ≤ □,□≤ □

Here just a brief explanation of the power-updating step is given.

FDPC Algorrithm

$$P^{o} = 1 \qquad (3.12)$$

And $$□_{□}^{(□□□)} = □_{□}^{□} * □_{□}^{□} \qquad (3.13)$$

Where $$□_{□}^{□} = \frac{□\ □□\ (□□□_{□}^{□}, □)}{□□□_{□}^{□}}, \qquad 0 < □ < \infty \qquad (3.14)$$

PSEUDO-CODE FDPC ALGORITHM

1. Initialize number of iterations
2. Initialize number of mobiles
3. Initialize number of Base Stations
4. Initialize $□_{□□□}$, $P_{j,}$
5. For K=1 to number of iterations
    - Generate uniformly distributed vector of mobile-to-base station distance
    - Generate a vector of link gains of mobiles from their own base station
    - Initialize power $P_{(1)}$
    - Initialize Charge-to-Interference ratio CIR_i
    - For i=1 to number of mobiles
    - CIR_i = [Received power by mobile /∑ received from the base station -Received power by mobile]
    - Initialize power $□_i$ parameter
    - $□_i = \min(CIR_{i,}\ □_{□□□})/CIR_i$
    - Initialize Power update $P_{(k+1)}$
    - $P_{(k+1)} = □_i * P_1$
    - Generate variance of power
    - End
    - Calculate the total power consumption of the network
    - End
6. Plot the power update against the number of iteration.
7. Plot the total power consumption against the number of iterations.

3.3.2 SECOND ALGORITHM: (Neto *et al* algorithm) - New Distributed Power Control Algorithm (NDPCA)

This algorithm is distributed in nature in that the power level of each connection is decided upon independently of the decision made towards other radio links. It is a modification of the popularly known distributed power control algorithm proposed by Foschini and Miljanic as could be seen in [72]. A new DPC algorithm which outperforms the distributed power control algorithm proposed by Foschini and Miljanic by believing that in principle, the path gain and interference are assumed to be time varying functions because co-channel interference depends on path gains was presented [78]. Additionally, if all links use power control, it is expected that the perceived interference levels should vary with time.

The power of each transmitter is limited by resource usage of the link and the perceived quality is related to the signal-to-interference ratio.

$$\gamma_i(t) = \frac{P_i(t) \cdot G_i(t)}{I_i(t)} \qquad (3.15)$$

Where $P_i(t)$ Transmitter power

$G_i(t)$ Channel power gain

$I_i(t)$ Interference power from other connection

$\gamma_i(t) =$ Signal-to-interference ratio of ith user

Now, from the time-continuous differential equation

[illegible] (3.16)

Where $\gamma_i(t)$ = SIR of the ith user

[illegible] = Constant between 0 and 1

□□□□ = The target SIR

Hence the new Distributed Power Control algorithm is

□□□□ □□□ □□□□ □□ 1 − □□ + □ $\frac{□□□□}{□□□□}$ □ (3.17)

PSEUDO-CODE for NDPC algorithm.

1. Initialize number of iterations
2. Initialize number of mobiles
3. Initialize number of Base Stations
4. Initialize □, □□□□, P_j
5. For k = 1 to number of iterations
   - Generate uniformly distributed vector of mobile-to-base station distance
   - Generate a vector of link gains of mobiles from their own base station gain
   - Initialize power $P_{(1)}$
   - For i = 1 to number of mobiles
   - CIR_i = [Received power by mobile /∑ received from the base station -Received power by mobile]
   - Initialize power update
   - $P_{(k+1)} = P_1$*(1+□) + P_1 *□* □□□□/CIR_i
   - Generate variance of power
   - end
   - Calculate the total power consumption of the network
   - End
6. Plot the power update against the number of iteration
7. Plot the power consumption against the number of iterations

3.3.3 THIRD ALGORITHM: An Improved Distributed Power Control Algorithm (IDPCA)

A new DPCA that achieves CIR balancing with unit probability was proposed [90]. This new algorithm works excellently with instability detention rule to achieving a better performance in terms of outage probability and convergence speed. In this scheme, for a successful base-to-mobile transmission to take place, the following condition should be met.

$$\gamma_i \geq \gamma_{min},\ i = 1,2,3,\ldots,N$$

Where γ_{min} is called the system protection ratio or the user's minimum required (target) CIR. And a corresponding effective power vector for a simultaneous satisfactory transmission quality can be defined by equation (3.18)

$$P = (P_1, P_2, \ldots, P_N)^T \tag{3.18}$$

However, when a system meets equation (3.18), **P** would be the effective power vector and the system is said to be stable at that state. Otherwise, the cell removal process will be invoked so that all the users maintain a minimum CIR of γ_{min}. This algorithm is complex in nature due to the cell removal procedure which depends on the instability detention rule. The power updating step for the algorithm is given as the equation (3.19)

$$P_i^{k+1} = c\left(\alpha P_i^k + \beta \frac{\gamma_{min}}{\gamma_i^k}\right) \tag{3.19}$$

Where

α and β = power balancing parameters

c is used to rescale the power vector.

Theorem:

If ɔtaris achievable, then by choosing ɕ = 1/(1 +) and >0, the proposed algorithm willdeýnitely achieve the effective power vector irrespective of the value of the initial power vector, P^0. Also, with Ŭ = 1 in Equation. (3.19), the constraint improvement power-control (CIPC) algorithm in [95] would be a special case of the proposed algorithm.

PSEUDO-CODE for IDPC Algorithm

1. Initialize number of iterations
2. Initialize number of mobiles
3. Initialize number of Base Stations
4. Initialize , , ,
5. Initialize DPC rescaling parameter
6. For k= 1 to number of iterations
   - Generate uniformly distributed vector of mobile-to-base station distance
   - Generate a vector of link gains of mobiles from their own base station gain
   - Initialize power
   - = reciprocal of (1 +)
   - For i = 1 to number of mobiles
   - CIR_i = [Received power by mobile /∑ received from the base station -Received power by mobile]
   - Initialize power update $P_{(k+1)}\, p_1^{k}$
   - $P_{(k+1)}$ = ∗ ∗ P + ∗ ∗ P ∗ γ/CIR
   - Generate variance of power
   - End
   - Calculate the power consumption of the network

- End

7. Plot the power update against the number of iterations
8. Plot the total power consumption against the number of iterations.

CHAPTER FOUR

SIMULATION RESULTS ANALYSIS

4.1 Result and Analysis

In this section, the graphical results of the three selected algorithms using Microsoft Excel were discussed. Finally, the comparative analyses of the results of the algorithms were carried out on the basis of their convergence speed and total consumption power of the network as their performance metrics.

Speed of Convergence of power control algorithms is an important characteristic by which one can determine the practical applicability of a given power control algorithm and measures its degree of responsiveness [23]. It gives us the speed with which an algorithm can converge to the desired power level; this desired power level is achievable at minimum level with required signal quality at receiving end.

The total power consumption of the network gives us the total power consumed by the mobiles in a network [97]. It is calculated as the sum of all the powers of mobiles in the network. However, a good power control algorithm should quickly converge to the state where the system supports as many users as possible

In the simulation, the same initial power, normalized gain, CIR values were used for all the algorithms.

Fully Distributed Power Control Algorithm (FDPCA)

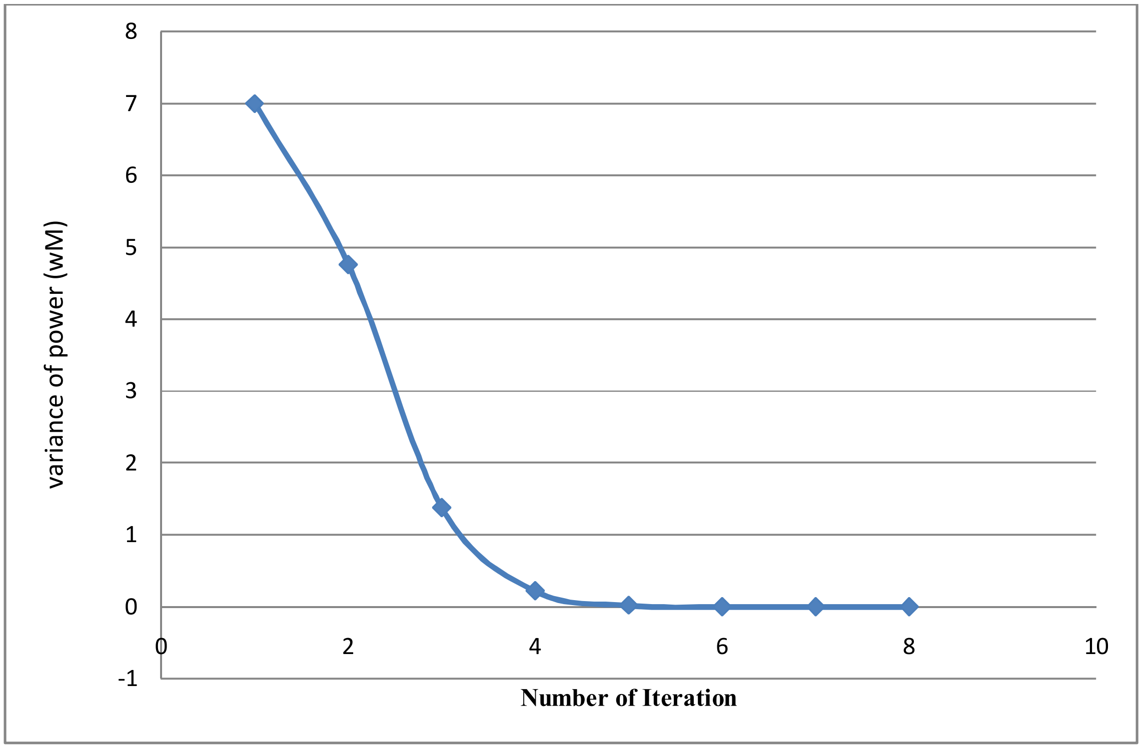

Figure 4.1: Graph of variance of power against the number of iteration.

The above graph shows the speed of convergence of the variance of power in a single GSM cell area against the number of iterations. The graph of FDPCA algorithm has a good convergence property and has shown good variance of power in the simulations. In cellular systems, it is a fact that the power of a wireless signal attenuates with distance, hence the variance of power of this algorithm converges to the optimal power. Here, the maximum power level chosen for the simulation was 7mW but later converged after fourth iterative point in which more admission of calls into the cell might not have much effect on the power level.The main drawback with this algorithm is that as number of iteration increases, the power levels of all the mobilestend to zero, which is highly undesired for any power control algorithm.

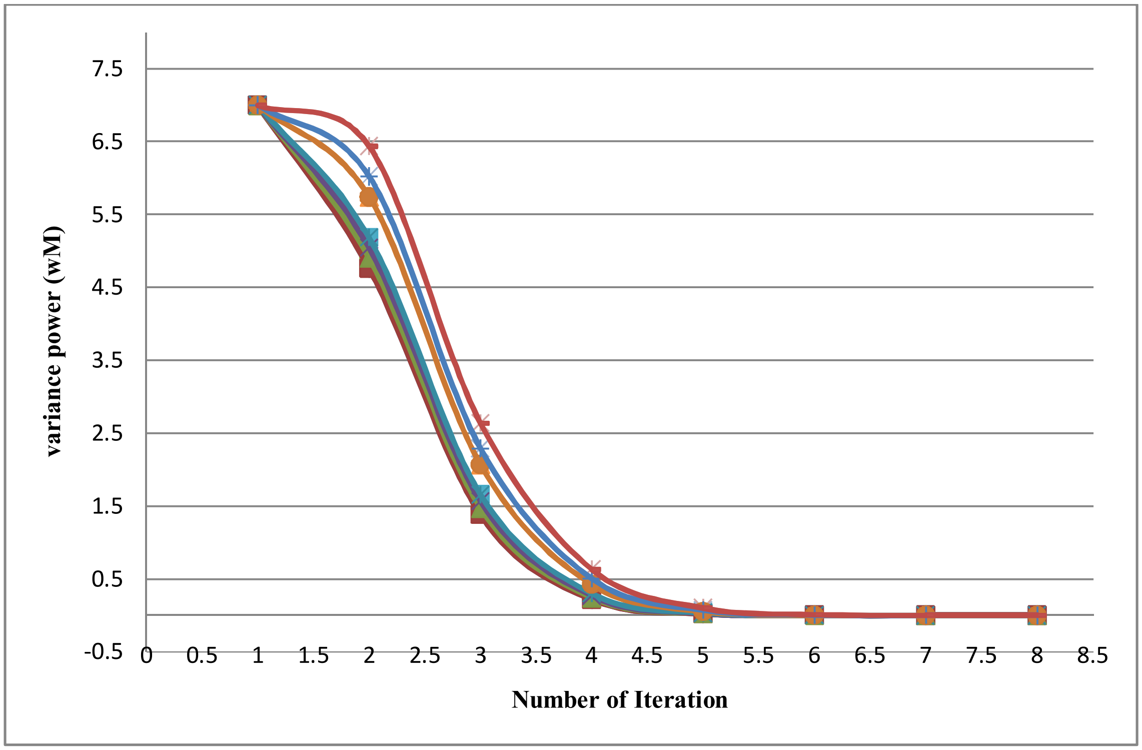

Figure 4.2: Graph of variance of power against the number of iteration.

The figure above is the graph of variance of power against number of iterations in a given Cellular network with 7 cells. Each of the graphs above represents the variance of power with the number of iteration in a cell of the cellular network. Here, it could be seen that the algorithm has a good convergence property. As the number of iteration is increasing, the power levels kept on decreasing until at a point that further increase in the number of iteration could make the power levels of all the mobilesto tend to zero. This is highly undesirable in cellular network.

Again, at every iterative point, the power level increased from first cell to subsequent ones. From the third iterative point as an instance, the power level of the 2nd cell was increased by 6.09% from the 1st cell, and the third cell was increased by 11.65% from the 1st cell.

Furthermore, analysis of variance (ANOVA) test carried out on the simulated data showed that the variation in the power update of the cells is not significant as was shown on tables 4.1 and 4.4. This slight increase in power level is however, attributed to interferences from the adjacent cells.

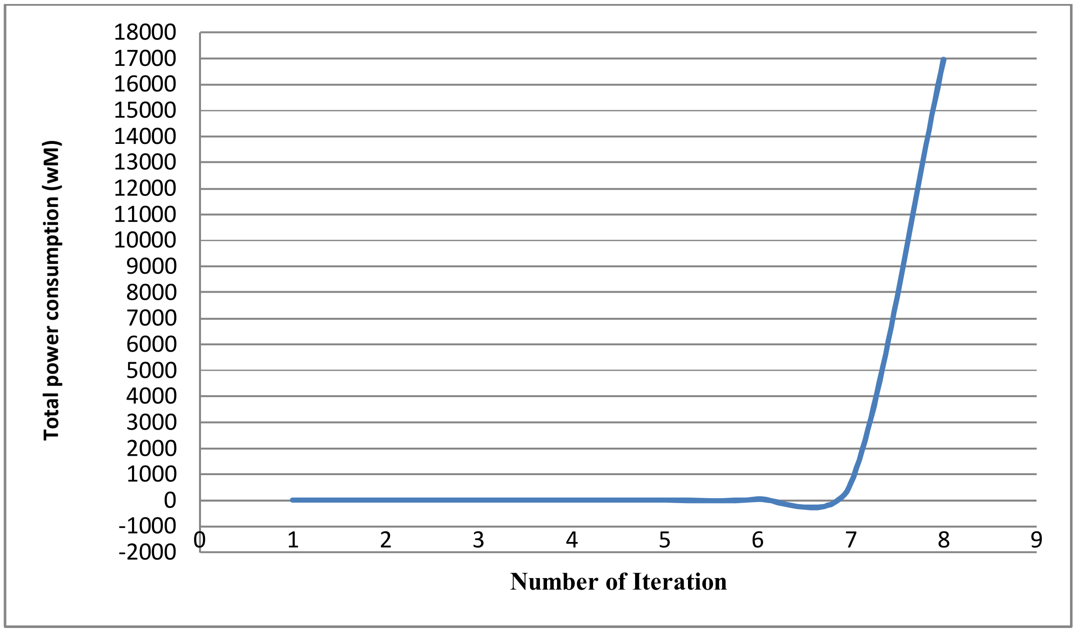

Figure 4.3: Graph of total power consumption against number of iteration.

The graph above is the graph of total power consumption of the network against the number of iteration.Total power consumption of the network gives us the total power consumed by all the mobiles in the network. A good power control algorithm should be such that would not take up much power from the network, as this would affect both the quality of service and the capacity of the system.

However, from the graph, the initial total power consumption of the network was 0.0204mW at the first iterative point, later increased to 0.0227 mW at the second iterative point and this continued gradually until at a point where the total power consumption was sky rocketed-627.7625Mw. Hence, this algorithm would not conserve power efficiently on the network.

New Distributed Power Control Algorithm (NDPCA)

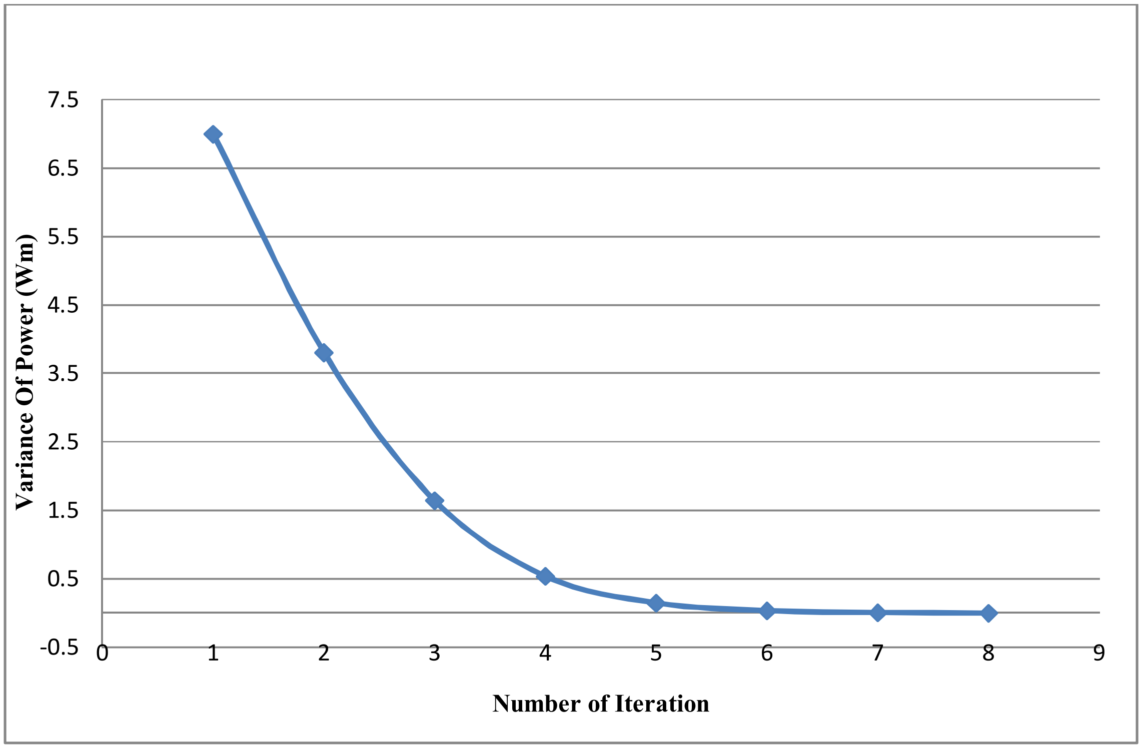

Figure 4.4: The graph of variance of power against the number of iteration.

The above graph is the graph of variance of power in a single GSM cell area against the number of iteration for New Distributed Power Control Algorithm. This algorithm has a better convergence property and has shown good variance of power in the simulations. This is attributed to its ability in track fast fading and interference in the network.

Again in the graph, the variance of power decreased gradually at every iterative point but never tends to zero unlike FDPC. That is, the initial power level for the mobiles in the cell was 7wM but later converged at the sixth iteration. Hence, one could say that the algorithm has a slow convergence speed.

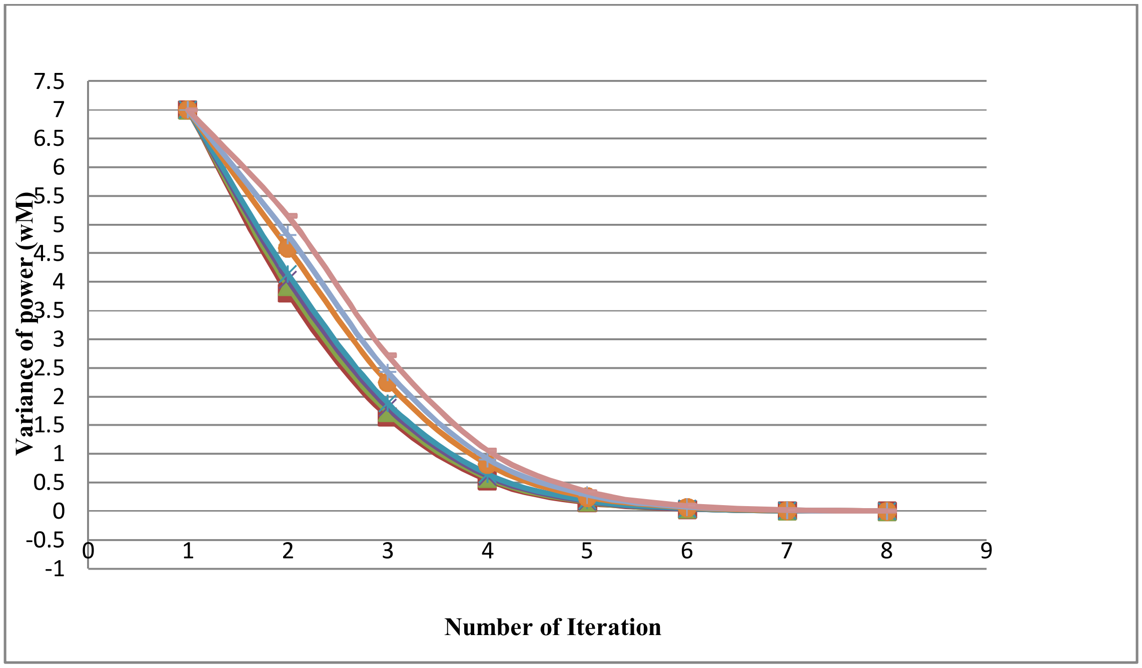

Figure 4.5: The graph of variance of power against the number of iteration.

The figure above is the graph of variance of power against number of iterations in a given network. Each of the graphs above represents the variance of power with the number of iteration on the cellular network. The graphical result showed that as the number of iterations increased, the power levels also decreased as the users move randomly from the first cell to the subsequent cells at each iterative point. But the change was a gradual one. And at every iterative point, the power level increased from one cell to the subsequent one.

At the third iterative point, the power level of the second cell was increased by 4.62% from the 1st cell, and the third cell was increased by 8.93% from the 1st cell.

Furthermore, analysis of variance (ANOVA) test carried out on the simulated data showed that the variation in the power update of the cells is not significant as was shown on tables 4.2 and 4.4. This slight increase in power level is however, attributed to interferences from the adjacent cells but, this algorithm had a better performance on the network in handling interference.

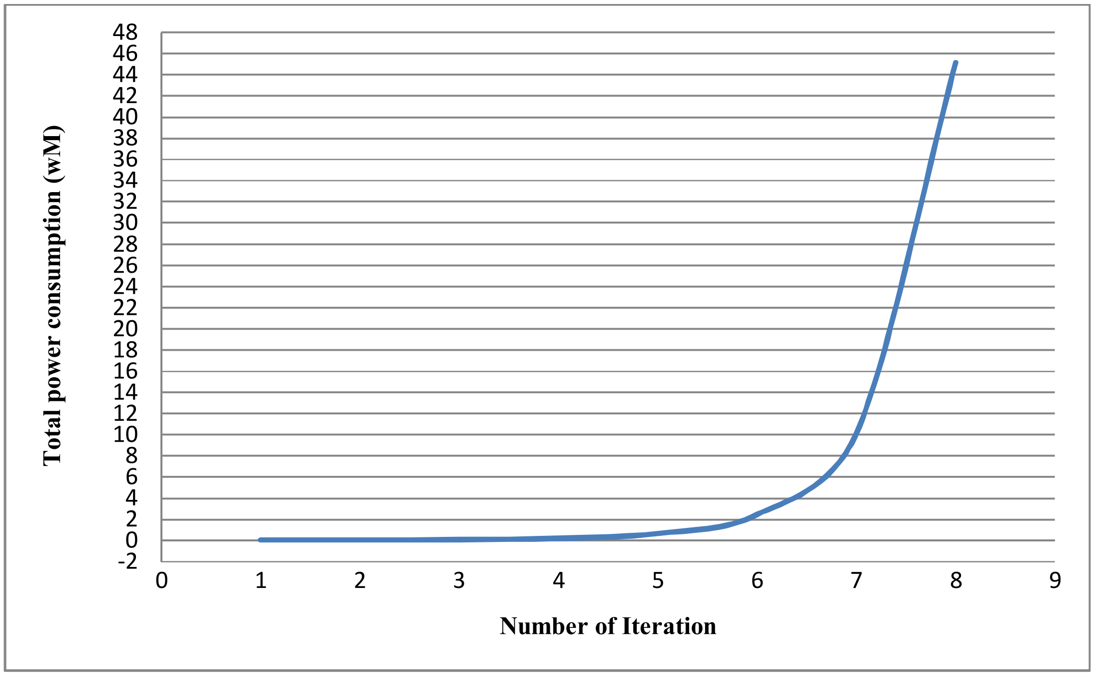

Figure 4.6: Graph of total consumption power against number of iteration.

The graph above is the graph of total power consumption of the network against the number of iteration for the second algorithm.

The initial total power consumption of the network as observed from the graph was 0.0204mW at the first iterative point, later increased to 0.0328mW at the second iterative point and this continued gradually until at a point where the total power consumption of NDPCA became sky-rocketed but not like that of FDPCA - 45.16mW.

However, this decrease in the total power consumption of NDPCA is as a result of algorithm to tackle both fading and interference on the network.

Improved Distributed Power Control Algorithm (IDPCA)

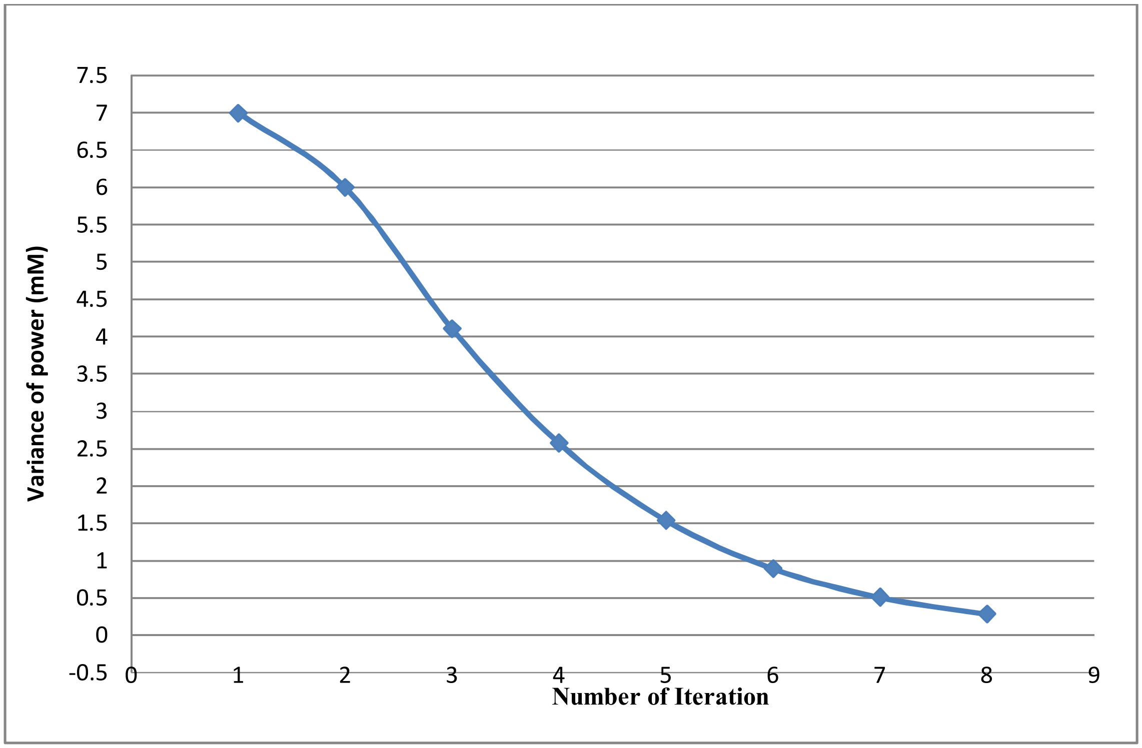

Figure 4.7: The graph of variance of power against number of iteration.

The above graph is the graph of variance of power in a single GSM cell area against the number of iteration for the IDPCA. This algorithm had a very poor convergence property as could be seen on the graph. This is because it required more iterative points for it to achieve convergence of power levels. This challenge was what led to the introduction of instability detection rule into the algorithm as was proposed by the author. But, the main drawback with this algorithm is that cell removal procedure is complex in nature and highly undesirable in cellular mobile systems.

Hence, the cell removal procedure can be avoided by increasing the number of iterations but that makes the convergence speed become slower.

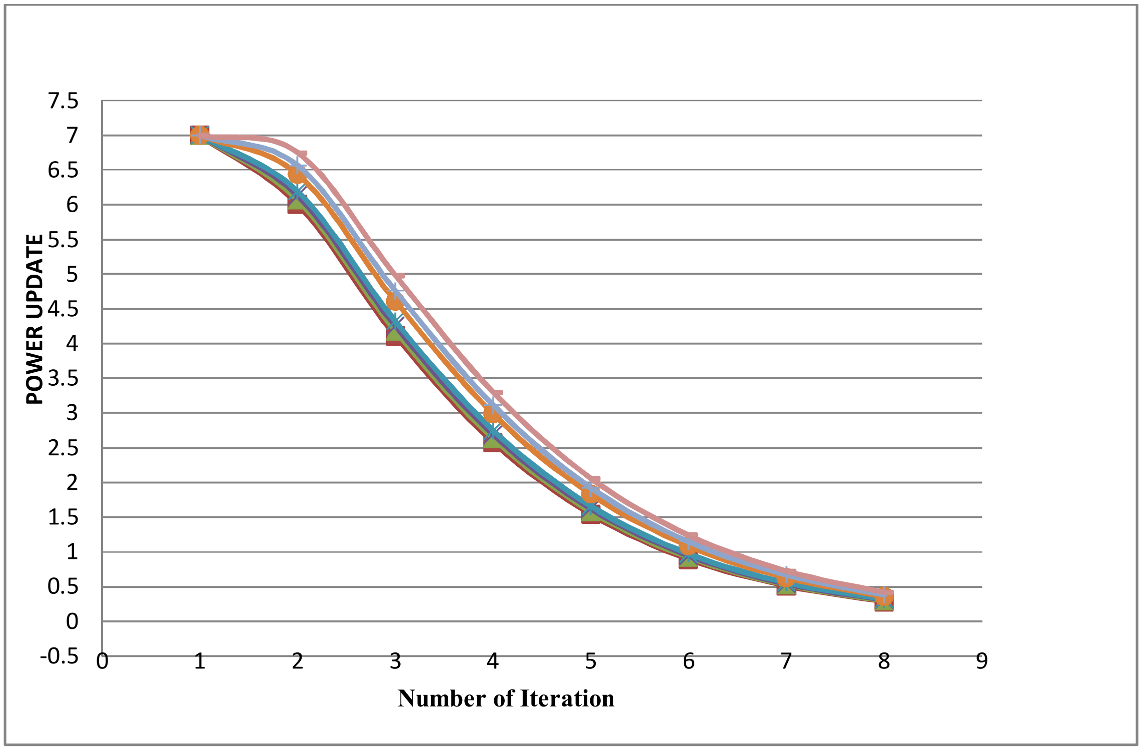

Figure 4.8: The graph of variance of power against number of iteration.

The figure above is the graph of variance of power against number of iterations in a given Cellular network with 7 cells. The Improved Power Control Algorithm had a very poor convergence property on the network. This is because the algorithm required more number of iterations for it to converge to the desired power level in the network.

Also, as the number of iterations increased, the power levels also decreased as the users move randomly from the first cell to the subsequent cells at each iterative point. From the third iterative point as an instance, the power level of the 2nd cell was increased by 1.66% from the 1st cell, and the third cell was increased by 3.29% from the 1st cell.

Furthermore, analysis of variance (ANOVA) test carried out on the simulated data showed that the variation in the power update of the cells is not significant as was shown on tables 4.3 and 4.4. This slight increase in power level is however, attributed to interferences from the adjacent cells but, this algorithm had a better performance on the network in handling interference.

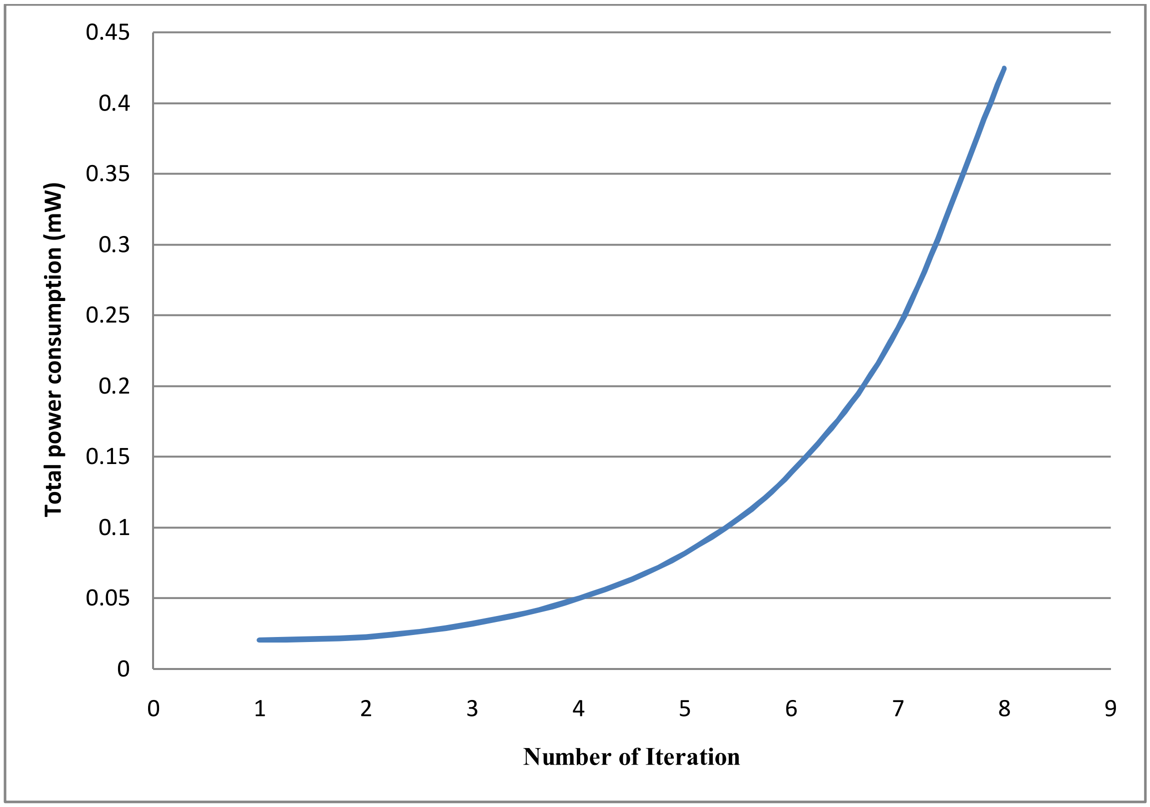

Figure 4.9: Graph of total power against number of iteration.

The graph above is the graph of total power consumption of the network against the number of iteration.The initial total power consumption of the network was 0.0204mW at the first iterative point as was observed from the graph, but later increased to 0.0227mW at the second iterative point and this continued gradually without the total power consumption being sky rocketed- the last total power consumption of the algorithm on the network was 0.424mW

However, IDPC Algorithm has the ability to conserve more power on the network as was shown above. It is good in handling interference and has low outage probability on a network since the total power consumption of the network did not sky rocket with the increase in number of iteration.

4.3 COMPARISON OF THE THREE ALGORITHMS

4.2.1 Speed of convergence

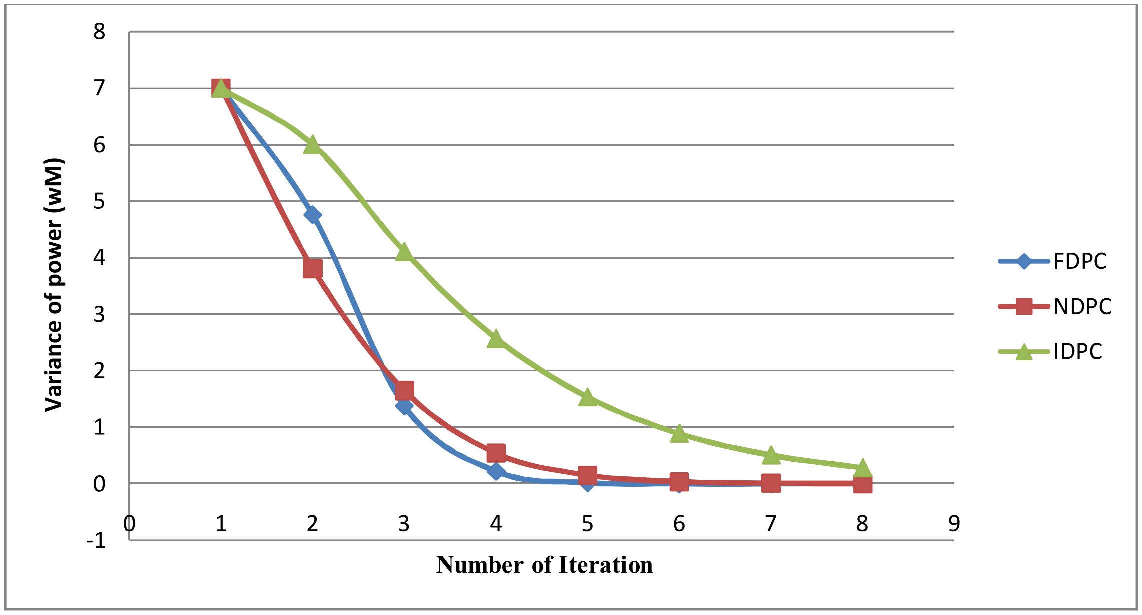

Figure 4.10: The graph of variance of power against number of iteration.

Speed of convergence of an algorithm is an important performance metric that gives the degree of applicability and responsiveness of the power control algorithm in on the network., It is obvious from the graph that NDPCA performed better than FDPCA and IDPCA at the second iterative point and this was attributed to its ability in tracking of fading and interference. However, the FDPCA had a better converging property on the network more than NDPCA and IDPCA. This was later analyzed using statistical method which proved that the speed of convergence of FDPCA outperformed NDPCA by 0.44% and IDPCA by 0.01% at the seventh iterative point.

Furthermore, the simulated data were subjected to ANOVA test, analysed using means and standard deviation at 95% confidence level as shown on table 4.5 and 4.7. The tables showed that the degree of variance between the three algorithms is negligible with NDPCA having the least variance of 6.397. Although, FDPCA had the best speed of convergence property and can stabilize the system quickly but, the algorithm with lowest variance is said to be more efficient on the network because it has low standard error and is potent in handling interference on the network.

4.2.2 Total Power Consumption on the Network

Figure 4.11: Graph of total power consumption against number of iteration.

The total power consumption of the network gives us the total power consumed by the mobiles in a network. It is calculated as the sum of all the powers of mobiles in the network. However, a good power control algorithm should be such that could conserve the power of the network as much as possible. The total power consumption of IDPCA on the network was observed to be smaller than FDPCA and NDPCA at every iterative point as shown on the graph above. It was analyzed using statistical method which proved that the total power consumption on the network of IDPCA outperformed FDPCA by 0.04% and NDPCA by 2.38% at the seventh iterative point.

Furthermore, the simulated data were subjected to ANOVA test, analysed using means and standard deviation at 95% confidence level as shown on table 4.6 and 4.7. The tables showed that the degree of variance between the three algorithms is slightly high with IDPCA having the least variance of 0.020. Hence, IDPCA is said to conserve power more on the network than NDPCA and FDPCA.

4.3 Computation of the statistical analysis of the result in percentage

Equation in percentage = $\frac{[illegible]}{[illegible]} \times 100$

1. **FDPCA on network in page 84**

For the 2nd cell in percentage = $\frac{[illegible]}{[illegible]} \times 100$ = 6.09%

For the third cell in percentage = $\frac{[illegible]}{[illegible]} \times 100$= 11.6%

2. **NDPCA on network in page 87**

For the 2nd cell in percentage = $\frac{[illegible]}{[illegible]} \times 100$ = 4.62%

For the third cell in percentage = $\frac{[illegible]}{[illegible]} \times 100$= 8.93%

3. **IDPCA on network in page 90**

For the 2nd cell in percentage = $\frac{[illegible]}{[illegible]} \times 100$ = 1.66%

For the third cell in percentage = $\frac{[illegible]}{[illegible]} \times 100$ = 3.29%

4. **Speed of Convergence in page 92**

In percentage = $\frac{[illegible]}{[illegible]} \times 100$

For NDPCA = $\frac{[illegible]}{[illegible]} \times 100$ = 99.56%

=100 - 99.56 = 0.44%

For IDPCA = $\frac{[illegible]}{[illegible]} \times 100$ = 99.99%

= 100 - 99.99 = 0.01%

5. Total power consumption of the network in page 93

For FDPCA = $\frac{[illegible]}{[illegible]} \times 100$ = 99.96%

= 100 ï 99.96 = 0.04%

For NDPCA = $\frac{[illegible]}{[illegible]} \times 100$ = 97.62%

= 100 ï 97.62 = 2.38%

4.4 Analysis of Variance (ANOVA) table and its descriptive statistics

Table 4.1: Power Uplink for FDPC Algorithm

Descriptive Statistics

	N	Mean		Std. Deviation	Variance
	Statistic	Statistic	Std. Error	Statistic	Statistic
cell 1	8	1.672932091	.9563949465	2.7050934086	7.318
cell 2	8	1.705127463	.9633632502	2.7248027479	7.425
cell 3	8	1.737942430	.9705787657	2.7452113075	7.536
cell 4	8	1.771388916	.9780409889	2.7663176621	7.653
cell 5	8	1.911736658	1.0103499514	2.8577012081	8.166
cell 6	8	1.986026950	1.0279780658	2.9075610451	8.454
cell 7	8	2.102910226	1.0562634954	2.9875643212	8.926

Table 4.2: Power Update (Variance of power) for NDPC algorithm

Descriptive Statistics

	N	Mean		Std. Deviation	Variance
	Statistic	Statistic	Std. Error	Statistic	Statistic
cell 1	8	1.648486084	.8942449332	2.5293066251	6.397
cell 2	8	1.678950077	.8978992438	2.5396425764	6.450
cell 3	8	1.709950961	.9017328742	2.5504857206	6.505
cell 4	8	1.741498034	.9057459958	2.5618365426	6.563
cell 5	8	1.873339665	.9235967113	2.6123259905	6.824
cell 6	8	1.942791059	.9336032875	2.6406288621	6.973
cell 7	8	2.051613540	.9499683809	2.6869163361	7.220

Table 4.3: Power Update (variance of Power) for IDPC algorithm

Descriptive Statistics

	N	Mean		Std. Deviation	Variance
	Statistic	Statistic	Std. Error	Statistic	Statistic
cell 1	8	2.864509974	.9106595045	2.5757340440	6.634
cell 2	8	2.899285374	.9126822305	2.5814551770	6.664
cell 3	8	2.934464435	.9147316453	2.5872517973	6.694
cell 4	8	2.970051458	.9168075556	2.5931233586	6.724
cell 5	8	3.116566598	.9253724901	2.6173486514	6.851
cell 6	8	3.192386727	.9298093476	2.6298979796	6.916
cell 7	8	3.309422600	.9366541937	2.6492581281	7.019

Table 4.4: ANOVA test for the three algorithms

		Sum of Squares	df	Mean Square	F	Sig.
Power Update (Variance of power) for FDPC algorithm	Between Groups	1.254	6	.209	.026	1.000
	Within Groups	388.337	49	7.925		
	Total	389.591	55			
Power Update (Variance of power) for NDPC algorithm	Between Groups	1.103	6	.184	.027	1.000
	Within Groups	328.523	49	6.705		
	Total	329.626	55			
Power Update (Variance of power) for IDPC algorithm	Between Groups	1.346	6	.224	.033	1.000
	Within Groups	332.513	49	6.786		
	Total	333.860	55			

Table 4.5: comparison of speed of convergence

Descriptive Statistics

	N	Mean		Std. Deviation	Variance
	Statistic	Statistic	Std. Error	Statistic	Statistic
FDPC	8	1.672932091	.9563949465	2.7050934086	7.318
NDPC	8	1.648486084	.8942449332	2.5293066251	6.397
IDPC	8	2.864509974	.9106595045	2.5757340440	6.634

Table 4.6: Comparison of total power consumption of the network

Descriptive Statistics

	N	Mean		Std. Deviation	Variance
	Statistic	Statistic	Std. Error	Statistic	Statistic
FDPC	8	2202.601824175	2108.7310745267	5964.3921699865	35573973.957
NDPC	8	7.335367129	5.5384466951	15.6650928613	245.395
IDPC	8	.126374788	.0501310053	.1417918951	.020

Table 4.7: ANOVA test for the two performance metrics

		Sum of Squares	df	Mean Square	F	Sig.
Comparison of speed of convergence	Between Groups	7.731	2	3.866	.570	.574
	Within Groups	142.445	21	6.783		
	Total	150.176	23			
Comparison of total power consumption of the network	Between Groups	25787053.046	2	12893526.523	1.087	.355
	Within Groups	249019535.608	21	11858073.124		
	Total	274806588.654	23			

4.5 Conclusion

The literature review revealed different researchers with strong arguments that their power control algorithms out-performed the others. On the contrary, the comparative analysis of some of these algorithms has placed them on a limelight where their potentials and deficiencies were obvious.

However, from the result analysis, FDPCA under speed of convergence as a performance metric has a better practical applicability more than the other two algorithms, but it is not efficient in handling interference on the cellular network. Also, IDPCA is very efficient in conserving energy of the network than FDPCA and NDPCA. This is attributed to the principle of Instability Detention Rule applied in the algorithm, but this makes the network complex and practically unaccepted.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Wireless Communication is one of the most active areas of technological development of our time. It leads to an ever growing demand on the limited radio resources with the influx of mobile phone users. Consequent on this, this thesis looked into the concept of power control in cellular systems as an essential radio resource management technique in handling Multiple Access Interference (MAI) in CDMA. Though, Power control in cellular communications is a challenging task since the system is complex and mobiles move randomly all the time. Thus the channel is time varying and the various channel parameters affect the system performance considerably.

In this work, the performance of different basic distributed power control algorithm was evaluated and compared on the basis of their simulation in Microsoft Excel. In the simulation, some assumptions were made and taken to be same in the simulation for the three selected algorithms.

The theoretical study and simulation result presented in Chapter 3 and 4 (respectively) illustrate that each algorithm has different speed of convergence and total power consumption. However, from the results, it could be concluded that their speed of convergence and total power consumption evaluate the efficiency of the algorithms.

However, from the results, it could be concluded that speed of convergence and total power consumption of the network actually evaluated potency of the algorithms. It could be concluded that FDPCA had a better efficiency in handling transmit power of the network than NDPCA and IDPCA by 0.44% and 0.01% respectively, while IDPCA is more efficient in conserving power on the network than FDPCA and NDPCA by 0.04% and 2.38% respectively.

5.2 Recommendation

During the course of review of the work, some issues were encountered which are recommended for future work in this area. First on the list is Comparison of different power control algorithms using Bit Error Rate (BER), Frame Error Rate (FER) and outage probability as their performance metrics. Furthermore, thesystem model could be extended to accommodate more number ofusers randomly moving in and out of the cell area. Also, combined power control with its performance comparison is an interestingarea of research. Power control in MIMO and adaptive antennasystems in WCDMA can be further explored in the lightof this thesis.

5.3 Contribution to Knowledge

Based on the findings in this study, one could make bold to say that the work could be of help in the selection of Power Control algorithms with quality potential for cellular networks, control the effect of interference thereby, improving on the capacity of the system. This work will also act as first line information to the researchers who are exploring the possibilities of controlling the effect of interference on cellular network.

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