DEVELOPMENT OF AN IMPROVED SCHEDULING ALGORITHM FOR MULTICAST SERVICES OVER WiMAX NETWORKS USING PARTICLE SWARM OPTIMIZATION TECHNIQUES

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DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

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ZARIA

NIGERIA

DECEMBER, 2015

DECLARATION

I, **Aliu Daniel,** herebydeclare that the work in this dissertation entitled "**Development of an Improved Scheduling Algorithm for Multicast Services over WiMAX Networks using Particle Swarm Optimization Technique"** has been carried out by mein the Department of Electrical and Computer Engineering. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for any degree or diploma at this or any other institution.

ALIU Daniel	______________________	______________________
	Signature	Date

CERTIFICATION

Thisdissertationentitled "**DEVELOPMENT OF AN IMPROVED SCHEDULING ALGORITHM FOR MULTICAST SERVICES OVER WiMAX NETWORKS USING PARTICLE SWARM OPTIMIZATION TECHNIQUE"** by DanielALIU meets the regulations governing the award of the degree of Master of Science (MSc) in Computer Engineering of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Chairman, Supervisory Committee ______________ ______________
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Head of Department ______________ ______________
(Dr. Y. Jibril) Signature Date

Dean, School of Post-graduate Studies ______________ ______________
(Prof. K. Bala) Signature Date

DEDICATION

This research work is dedicated to God Almighty for His guidance, kindness, grace and mercy, and to my Saviour Jesus Christand those who in one way or the other make a significant difference in an ordinary person's life.

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I thankGod almighty for His mercies, faithfulness, divine protection, my shepherd, light under my foot and love throughout my life and the period of this research work.

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ABSTRACT

The challenge of optimal resource allocation to subscribers ofmobile Worldwide Interoperability for Microwave Access (WiMAX) has not been fully overcome by researchers. This research work developed an optimal scheduling algorithm for WiMAX resource allocation based on an improved Particle Swarm Optimization (PSO) technique. In this work, an improved PSO based technique for allocating subcarriers and Orthogonal Frequency Division Multiplexing (OFDM) symbols to mobileWiMAX subscriberswasdeveloped using sub-group formation. The entire WiMAX network environment was sub-divided into 7 layers.Seven distinct modulation and coding schemes were used in transmitting packets to the subscribers located within the respective layers. The objective function was determined based on PSO for throughput maximization and channel data rate. An enhanced model for throughput maximization and channel data ratewas developed by implementing an improved PSO based WiMAX resource allocation algorithm. Simulation of different scenarios of WiMAX multicast service to mobile subscribers for the evaluation of Aggregate Data Rate (ADR) and Channel Data Rate (CDR) for each scenario were carried out.The results obtained for the various layers and uniform distribution of users over the entire layers based on the performance evaluation of the improved algorithm for ADR were 350Mbps, 525Mbps, 700Mbps, 1050Mbps, 1050Mbps, 1400Mbps, 1575Mbps and 1398Mbps. Similarly, for CDR the results obtained were 6.98Mbps, 10.48Mbps, 13.97Mbps, 20.95Mbps, 20.95Mbps, 27.94Mbps, 31.5Mbps and 28Mbps. Validation was done by comparing the results obtained using the improved algorithmwith those of Maximum Throughput Algorithm (MTA). The values of ADR obtained based on the published work of Araniti *et al.*, (2012) using the developed algorithm when users were randomly distributed and restricted to exist within each of the layers 1, 4 and 7 were 694Mbps, 175Mbps, 525Mbps and 788Mbps. Similarly, the results obtained for the CDRwere 13.9Mbps, 3.5Mbps, 10.5Mbps and 15.8Mbps. The corresponding values for the MTA were 400Mbps, 100Mbps, 400Mbps, 500Mbps and 12.5Mbps, 2.5Mbps, 12.5Mbps, 12.5Mbps, respectively. ADR of 694Mbps was achieved, which represented 88.88% of the maximum achievable ADR of the system as compared to 400Mbps, which represented 80% of the maximum achievable ADR obtained using MTA. This showed that the developed algorithm performed better than the MTA by 8.88%.

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LIST OF ABBREVIATIONS

IPTV	Internet Protocol Television	1
WiMAX	Worldwide Interoperability for Microwave Access	1
4G	4 Generation Network	1
DSLs	Digital subscriber Lines	1
QoS	Quality-of-Service	1
PMP	Point-to-Multipoint	2
OFDM	Orthogonal Frequency Division Multiplexing	3
OFDMA	Orthogonal Frequency Division Multiple Access	3
UGS	Unsolicited Grant Scheme	3
Rtps	Real-Time Polling Service	3
Nrtps	non-Time Polling Service	3
BE	Best Effort	3
Ertps	Extended Real-Time Polling Service	3
CBR	Constant Bit Rate	5
PSO	Particle Swarm Optimization	6
ADR	Aggregate Data Rate	6
CDR	Channel Data Rate	6
MTA	Maximum Throughput Algorithm	6
MSs	Mobile stations	7
TDD	Time Division Duplexing	14
FDD	Frequency Division Duplexing	15
UL	Uplink	15
DL	Downlink	15
MAC	Medium Access Control	15

TTD	Transmit/Received Transition Gap	15
RTG	Receive/Transmit Transition Gap	15
MAP	Media Access Protocol	16
PHY	Physical Layer Protocol	16
CQICH	Channel Quality Indicator	16
ACK	Acknowledgement	16
BS	BS	16
HARQ	Hybrid Automatic Repeat Request	16
FCH	Frame Control Header	16
FFT	Fourier Transform Size	17
NLOS	Non-Line-of-Sight	17
RSSI	Radio Signal Strength Intensity	17
QPSK	Quadrature Phase Shift Keying	44
QAM	Quadrature Amplitude Modulation	44

CHAPTER ONE

INTRODUCTION

1.1 Background

Rising demand for high speed multimedia services like Internet Protocol Television(IPTV) and mobile television has led to the introduction of broadband wireless access (Giacomini & Agarwal, 2013).One of such broadband wireless access is the Worldwide Interoperability for Microwave Access(WiMAX), which is also known as IEEE 802.16. The standard enables high-speed access to data, video and voice services (Chaari*et al*, 2012). Internet Protocol Television (IPTV) is expected to bring aboutgreat market value to the service providers in 4 generation (4G) wireless network (Hou*et al.*, 2009). It also serves as another possibility to cabled access networks, such as fiber optics, coaxial systems using cable modems and Digital Subscriber Lines (DSL) (Adebari& Bello, 2013). WiMAX has a wide coverage range per BS which can covers up to 30 miles in radius (Shu'aibu *et al.,* 2011). WiMAX requires changing and diverse Quality of Service (QoS) guarantee such as optimal system throughput, maximum latencyguarantees and minimal delay jitter (Genc *et al.,* 2008). Some of the QoS that need to be defined for the purpose of this research work are:

1. **Throughput:** This is the measure of numbers of packets sent successfully in a network and it is measured in terms of packets per second (Chauchan *et al.,* 2013).
2. **ChannelData Rate:** Accounts for the total number of user data transmitted by the BS (BS) over the air interface (Araniti *et al.,* 2012).

WiMAX is heterogeneous with unsystematic mix of real and non-real time traffic. The IEEE 802.16 standard provides two modes for sharing the wireless medium (Prasad & Kumar, 2013):

(i) Point-to-Multipoint (PMP)

(ii) Mesh (Optional)

Point-to-Multipoint(PMP)mode:Nodes are arranged in a cellular structure in such a way thatthe BS exchange information with a set of subscriberstations within the same antenna sector in a broadcast mode(Prasad & Kumar, 2013). Here all subscriberstations attain identical transmission from the BS. Where subscriberstations transmissions are targeted to the BSs and get synchronized.

Mesh mode: Nodes are arranged systematicallyin Ad-hoc mannerand scheduling is distributed among the subscriber stations without transmission fromthe BS(Prasad & Kumar, 2013). The uplink from subscriber stationto BS and downlink from BSto subscriberstationdata transmissions in the IEEE 802.16 standard are Frame- based (Wei *et al.*, 2005). In recent years, broadband wireless access networks have been rapidly evolving tosatisfy increasing user scalability and QoS. The salient features of IEEE 802.16eas described in (Nithyanandan&Susila, 2013) are:

(i) Higher data rate

(ii) Mobility

(iii) Scalability

(iv) QoS such as optimal system throughput

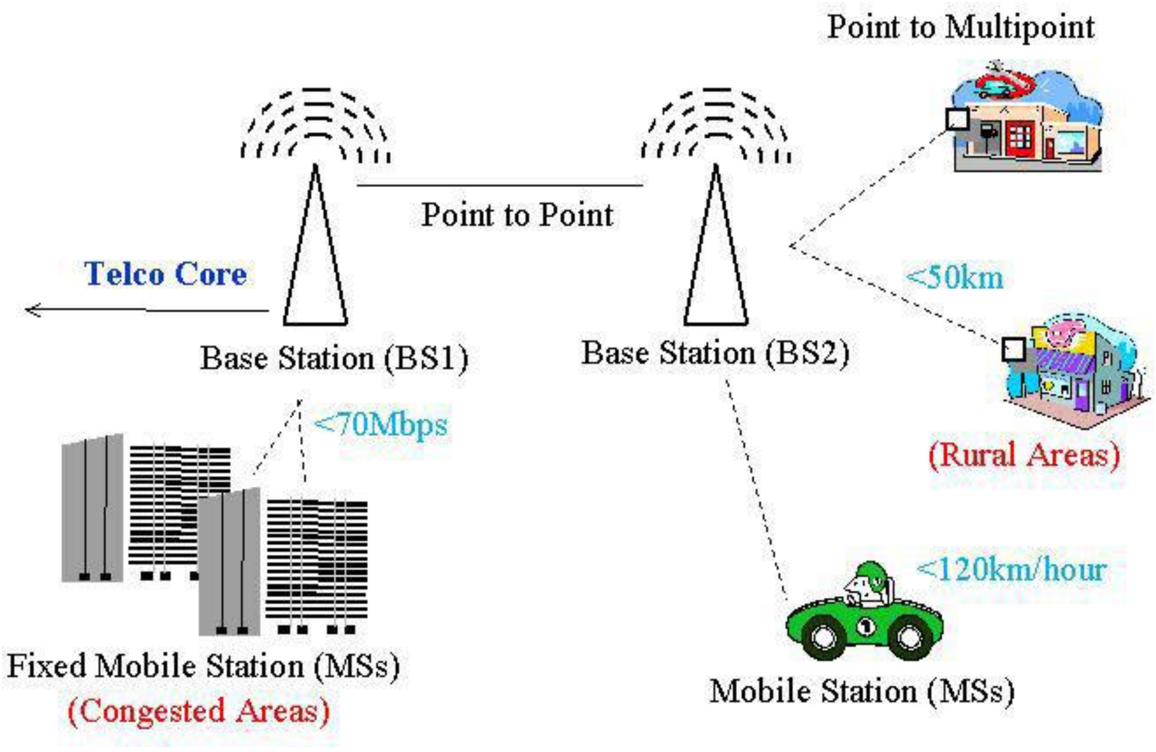


Figure 1.1 WiMAX Deployment Scenarios (So-In & Tamimi, 2009)

In order to support high data rate multicast and broadcast service in WiMAX, Orthogonal Frequency Division Multiplexing (OFDM) technology and its access technique are used. Video, voice and data are all Internet Protocol (IP) data services, but each has its own QoS requirements (Afolabi *et al.*, 2013). High availability, sufficient guaranteed bandwidth, low transmission delay and jitter are the QoS requirements for video services(Nithyanandan&Susila, 2013). In order to support QoS for various types of traffic, WiMAX medium access control protocol defines bandwidth request-allocation mechanism and five types of scheduling classes as follows (Shwetha *etal.*, 2011):

(i) Unsolicited Grant Scheme (UGS)

(ii) real-time Polling Service (rtPS)

(iii) nonreal-time Polling Service (nrtPS)

(iv) Best Effort (BE)

(v) extended real-time Polling Service (ertPS)

The pertinent characteristic of these five scheduling service classes are presented in(Oktay & Mantar, 2013) as follows:

(i) **UGS**: This scheduling service is designed for periodic fixed-size data packets. It supports constant bit rate real-time applications such as the Voice over Internet Protocol (VoIP) without silence suppression.

(ii) **ertPS**: This scheduling service class generates periodic variable-sized packets. It supports Variable Bit Rate (VBR) real-time applications such as the VoIP with silence suppression.

(iii) **rtPS**: This is designed for real-time applications that generate VBRs, such as audio/video (MPEG) streaming and Video on Demand (VoD).

(iv) **nrtPS**: This service class is designed for delay-tolerant nonreal-time applications such as the File Transfer Protocol (FTP) with guaranteed minimum throughput.

(v) **BE**: This service class is designed for applications that do not need QoSparameters. The HypertextTransfer Protocol (HTTP) and e-mail are the examples of this service application.

In addition to these scheduling services, mandatory QoSparameters have been designed in the standard WiMAX networks. The scheduling services and supported QoS parameters (IEEE 802.16e,Standard 2009) are shown in Table 1.1

Table 1.1:Mandatory QoS Parameters of the Scheduling Services (Oktay& Mantar,2013)

Services / QOS Parameters	UGS T1/E1 transport	ertps VOIP	rtps streaming audio/audio	nrtps FTP	BE HTTP, Data transfer
Tolerated jitter (TJ)	✓	✓	‘x’	‘x’	‘x’
Maximum latency (ML)	✓	✓	✓	‘x’	‘x’
Maximum sustained traffic rate (MSTR)	✓	✓	✓	✓	✓
Minimum reserved traffic rate (MRTR)	✓	✓	✓	✓	‘x’
Traffic priority (TP)	‘x’	✓	✓	✓	‘x’
Packet loss	✓	✓	✓	✓	✓
Throughput	✓	✓	✓	✓	✓
Packet delivery ratio	✓	✓	✓	✓	✓

Table 1.1 depicts the essential QoS parameters of the scheduling services. Here ‘✓’ symbol depicts that the service class has QoS defined for that particular parameter, while the ‘x’ symbol depicts that the service class has no QoS defined for that particular parameter.For real time application like IPTV and VoIP a guaranteed QoS level is very important because these are Constant Bit Rate(CBR)applications and are delay sensitive. However, the IEEE 802.16 standard 2005 that defines these five scheduling classes, does not provide any standard algorithms that should be used to provide QoS to the service flows (Shu’aibu*et al.*, 2011)

1.2 Statement of problem

The major problem in optimal resource allocation to subscribers of mobile WiMAX that belong to the same multicast group, distributed over different locations are throughput variation (fluctuations) and channel degradation because they experience different fading and path losses in time-varying wireless channels. This presents a challenge to providing satisfactory multicast service to all users within the network range (Tan*et al.*, 2011). In order to improve the system throughput, there is a need to partition the multicast group into smaller sub-groups to allow multiuser diversity to be exploited more efficiently, with a view to maximizing the system throughput and channel data rate. In this research work, a Particle Swarm Optimization Scheduling (PSO) algorithm for multicasting wireless traffic over mobile WiMAX network based on sub-groups formation technique is proposed to improve the system throughput and channel data rate while guaranteeing the QoS for each of the users in the network.

1.3 Aim and Objectives

The aim of this research work is to develop an improved scheduling algorithm for multicast services over WiMAX networks using PSO technique, with a view to maximizing Aggregate Date Rate (ADR) and Channel Data Rate (CDR).

The objectives of the research are as follows:

1. To develop a model for WiMAX network environment and throughput, CDR evaluation, as well as an optimal scheduling algorithm for WiMAX multicasting based on improved PSO technique.
2. To simulate various scenarios of WiMAX multicast service to mobile subscribers to maximize ADR and CDR;

3. To validate the performance of the developed model by comparing the results obtained with those of the Maximum Throughput Algorithm (MTA).

1.4 Methodology

The following are the list of the methodology adopted in carrying out this research work:

1) Development of a model for the WiMAX network environment based on seven concentric layers;
2) Development of a model for the WiMAX MobileStations (MSs), such that the sub stations are mobile and the network is configured to change after each frame interval.
3) Determination of an objective function for throughput maximization and CDR based on PSO technique;
4) Development of an improved algorithm for maximizing throughput and CDR, based on items (1) to (3)
5) Simulation of various scenarios of WiMAX multicast service to mobilesubscribers in order to evaluate the ADR and CDR of each scenario.
6) Validation of the developed model by using the parameters published in the work of Araniti *et al.,* (2012).

1.5 Significant Contribution

A lot of researchers have developed various scheduling algorithms on improving the WiMAX system capacity based on maximization of throughput while guaranteeing the desire QoS for each of the users in the network. Therefore, the significant contributions of this research work are itemized in terms of resources utilization as follows:

1. The developed objective function based on PSO technique achieved a maximum ADR and CDR of 88.88% when compared with MTA in terms of ADR and CDR of 80%

2. The developed scheduling algorithm maximizes ADR and CDR in the WiMAX network environment with 8.88% improvement as compared with MTA

1.6 Scope of the Dissertation

The scope of this research work is the development of an improved scheduling algorithm for multicast services over WiMAX network using PSO technique that is limited to maximizing the ADR and CDR of the WiMAX network.

1.7 Dissertation Organization

The general introduction is presented in chapter one, whilethe rest of the chapters are organized as follows: A detailed review of related literatures and relevant fundamental concepts of multicast service, WiMAX, channel propagation model, scheduling algorithms and heuristic techniques arecarried out in chapter two. Comprehensive approach and relevant mathematical models describing the developed objective function and the improved algorithm are presented in chapter three. The performance, analysis and discussions of the results are presented in chapter four. Conclusion and recommendation composes in chapter five. Quoted references and Appendices are also presented at the end of this dissertation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this section of this proposed research work, two important elements are discussed, which are:

(i) Discussion of fundamental concepts, algorithms, techniques and model equations relevant to this research.

(ii) Review of similar works in order to have an ideal knowledge of the extent of the research in resolving WiMAX throughput and CDR problem.

These two elements will give an understanding on how to approach the solution to the same problem in a different way to achieve better results.

2.2 Reviewof Fundamental Concepts

This sub- section presents a reviewof the concepts fundamental to the proposed research work. The review outlines the important principles and model equations relevant to achieving good results.

2.2.1Multicast

Multicast transmission is an efficient way of making the network throughput better by transmitting the same packets to numerous receivers simultaneously (Hou*et al*, 2009). It has been considered as a key technology for supporting emerging services in IEEE 802.16ebased Wireless Metropolitan Area Networks (WMANs), such as Internet Protocol Television (IPTV) and mobile TV.TheTraditional IP communication allows a host to send packets to a single host (unicast transmission) or to all hosts (broadcast transmission). IP multicast provides a third possibility that allows a host to send packets to a subset of all hosts as a group transmission.A multicast group is an arbitrary group of receivers thatexpresses an interest in receiving a particular data stream. This group has no physical or geographical boundary—the hosts can be located anywhere on the Internet or any private intranet. Hosts that are interested in receiving data flowing to a particular group must join the group using Internet Group Management Protocol(IGMP). Hosts must be members of the group to receive the data stream.

2.2.2 IP Multicast

IP multicast is a bandwidth-conserving technology that reduces traffic by simultaneously delivering only one stream of information to potentially thousands of corporate receivers and homes(Hou*et al*, 2009). Applications that take advantage of multicast include video conferencing, corporate communications, distance learning, and software distribution, stock quotes, and news. IP multicast delivers application source traffic to multiple receivers without burdening the source or the receivers while using a minimum of network bandwidth. Multicast packets are replicated in the network at the point where paths diverge by routers enabled with Protocol Independent Multicast (PIM) and other supporting multicast protocols; thus, resulting in the most efficient delivery of data to multiple receivers (Williamson, 2000). Figure 2.1shows how IP multicast is used to deliver data from one source to many interested recipients(Williamson, 2000). The receivers indicate their interest by sending an IGMP host report to the routers in the network. The routers are then responsible for delivering the data from the source to the receivers. The routers use Protocol Independent Multicast (PIM) to dynamically create a multicast distribution tree. The video data stream will then be delivered only to the network segments that are in the path between the source and thereceivers.

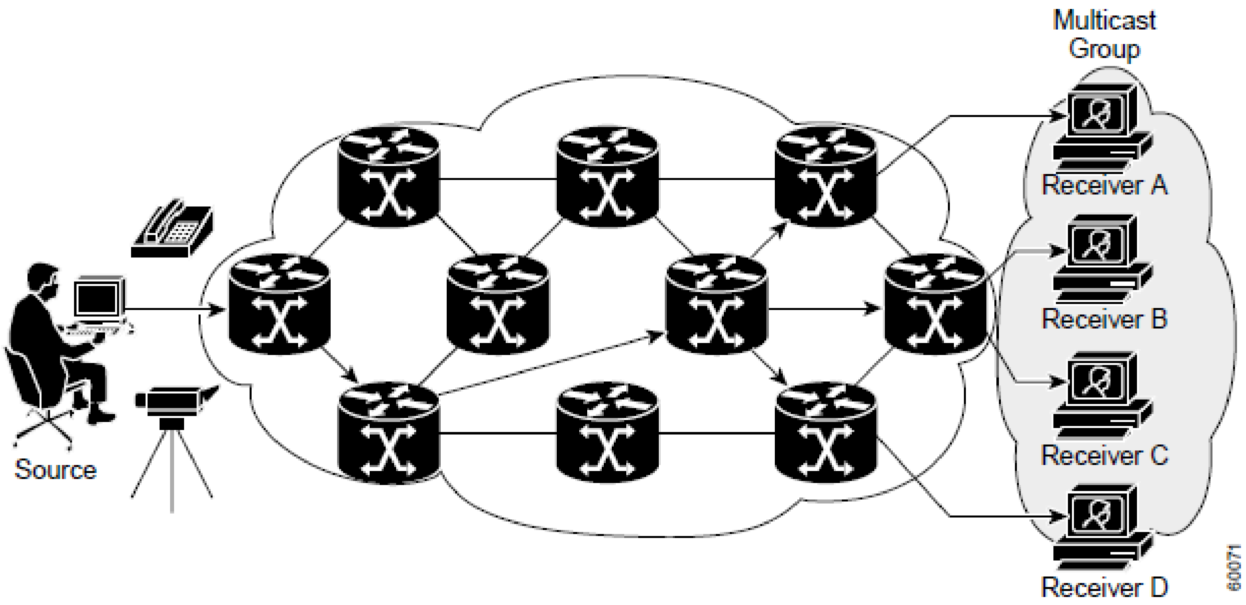


Figure 2.1: Multicast Transmission to Many Receivers (Williamson, 2000)

2.2.3WiMAX Internet ProtocolTelevision

Telecommunication industry is poised to offer a more interactivity and bring a heavy close of competition to the business of selling television among vendors. IPTV is a method of distributing television content over IP that enables a more customized and interactive user experience(Tariq *et al*., 2007). IPTV can allow people who are separated geographically to watch a movie or a TV program together, while also chatting and exchanging files simultaneously (Tariq *et al*., 2007). Broadband internet access and IP based television entertainment and programming is a wide streaming method that includes several applications all of which can be experimented on WiMAX.With WiMAX IPTV operators can offer facilities like voice, video and data totheir subscribers in a single platform (Tariq*et al*., 2007).

2.2.4Types of IPTV

IPTV comes in three different categories, which are itemized as follows:

(i) **Video on Demand** (VoD). This is a system that allows users to choose and watch video content of their choice on their televisionsor computers (Conduluci *et al*, 2o13).

VOD is one dynamic features offered by IPTV. VOD provides users with a menuof available videos from which to choose. The video data is transmitted via real-time streaming protocol.

(ii)**Time-shifted IPTV**, this is a way of watching ordinary, scheduled broadcasts at a time that is convenient for the user (Kazemi & Heydarian, 2013).

(iii)**Live IPTV** or IP simulcasting which involves broadcasting live TV programs across the Internet as they are being watched (Kazemi & Heydarian, 2013).

2.1.5 WiMAX IPTV principleofoperation

Key technical components of the IPTV service providers for the working principle of operation of IPTV are as follows:

(i) Storing Programs

(ii) Preparing Program

(iii) Streaming Program

(iv) IPTV Protocol Stack

(i). **StoringPrograms:**Live programs are streamed as they are produced, but prerecorded programs and movies need to be stored in such a way that they can be selected and streamed on demand. Some VOD services limit the number of programs the service provider make available not because they are short of storage space but because that is one way to limit the overall bandwidth of their service and its impact on the Internet(Condoluci *et al,* 2013).

(ii). **PreparingPrograms:**First, the television program (either prerecorded or captured live with a video camera) has to be converted into a digital format that can be delivered as packets using the Internet protocol. Sometimes the original program is in digital format already or sometimes it is in the form of a standard, analog TV picture (known as

STANDARD format) that needs an extra bit of processing (analog-to-digital conversion) to turn it into digital format(Mohamed *et al*, 2013). With current limitations on bandwidth, videos also need to be compressed (made into smaller files) so they can stream smoothly without buffering (periodic delays caused as the receiver builds up incoming packets). In practice, this means programs are encoded in either MPEG2 or MPEG4 format (MPEG4 is a newer form of video compression that gives higher quality for a similar bandwidth and requires only half as much bandwidth for carrying aSTANDARD picture as MPEG2) (Mohamed *et al*, 2013). Once that is done, the information has to be encrypted.

(iii). **Streaming Programs:**Whenbrowsinga website, a temporary link between two computers is made so one can effectively "suck" information off another. The computer (the client) pulls information off the other, typically much more powerful computer (the server) by linking directly to an IP address that corresponds to the website to be browsed. The client and server have a brief, intermittent conversation in which the client requests from the server all the files it needs to build the page the client will look at. Servers are generally so fast and powerful that many clients can download the requested programs simultaneously, with very little delay. This kind of ordinary downloading between one client and one server is known as IP unicasting (most web browsing falls into this category).

(iv). **IPTVProtocolsStack:**In IPTV protocol stack transmission audio/video content from the source is formatted and compressed, mostly, using MPEG-2 encoding compression standard and is enclosed as Real time Transport Protocol (RTP) (Mohamed*et al.,* 2013). The payload can either be Standard Definition Television (SDTV) or High Definition Television (HDTV).For real time streaming video services,user datagram protocol ports can be used and for VOD transmission control protocol ports can be used. Broadcast, multicast and unicast services are also supported. As a result, there can be multiple packets from various sources that must be delivered to targeted users with different QoS parameters, making it a challenging task. Worldwideinteroperability for microwave access BS media access control which addresses this issue through effective scheduling and implementation will be a key differentiator amongst competitor's products (Mohamed*et al.,* 2013).Protocol stack for IPTV transmission is depicted in Figure 2.2.

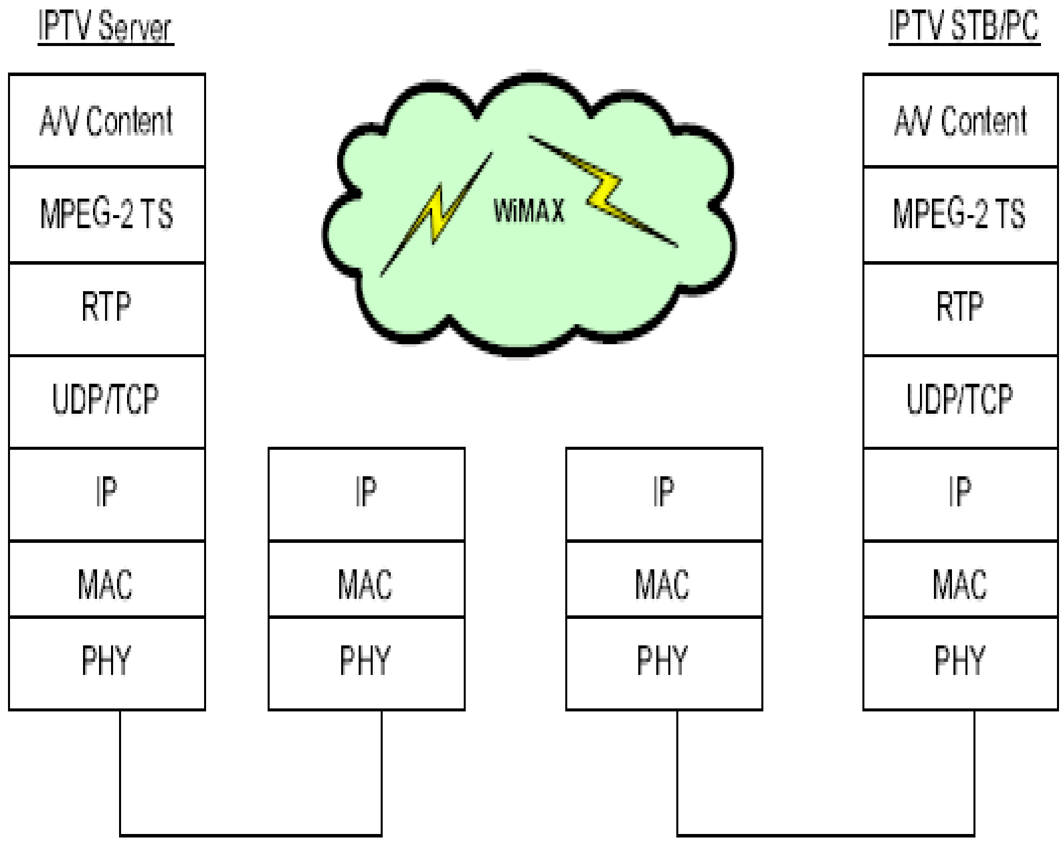


Figure 2.2: Protocol Stack for IPTV Transmission (Mohamed*et al.,* 2013)

2.2.5WiMAX Networks

The WiMAX technology has been specified in the IEEE 802.16 standard (So-In, 2010). The network is epicentrally supervised by the BS that offers connection-oriented services to subscriber stations (SSs) under its radio range. It supports data rates of 70Mbps over ranges of 50km with mobility support at vehicular speeds (Huang & Wu 2013).

The WiMAX networks operate in two duplexing modes (Hou*et al.,* 2009).Which are:

(i) Time Division Duplexing(TDD) mode

(ii) Frequency Division Duplexing(FDD) mode.

In FDD, the uplink and downlink sub-frames are transmitted simultaneously on different frequencies(Ahmadzadel*et al*, 2008).

In TDD, the uplink and downlink sub-frames are transmitted on the same carrier frequencies atdifferent time (Ahmadzadel*et al*, 2008)

The following are the advantages of TDD over FDD:

(i) In TDD the Downlink (DL) sub-frame and the Uplink (UL) sub-frame are transmitted in the same channel consecutively which is useful when working with limited bandwidth resources.

(ii) TDD's dynamically adjust DL/UL ratio which allows it to be used with both symmetric and asymmetric traffic.

(iii) TDD assures channel reciprocity for better support of link adaptation

(iv) Transceiver designs for TDD implementations are less complex and therefore, less expensive.

In TDD, the UL and DL sub-frames are transmitted on the same carrier frequencies at different time (Forum WiMAX, 2006). In FDD, the UL and DL sub-frames are transmitted simultaneously on different carrier frequencies (Ahmadzad *et al*, 2008). In TDD, the time domain isdivided into Medium Access Control (MAC) frames withequal duration, each of which is composed of a DL sub-frame and UL sub-frame, aTransmit/Receive Transition gap(TTG), and a Receive/TransmitTransition Gap

(RTG),respectively to prevent DL and UL transmission collision (Hou*et al.*, 2009).Figure 2.2 depicts WiMAX OFDMA TDD frame structure.

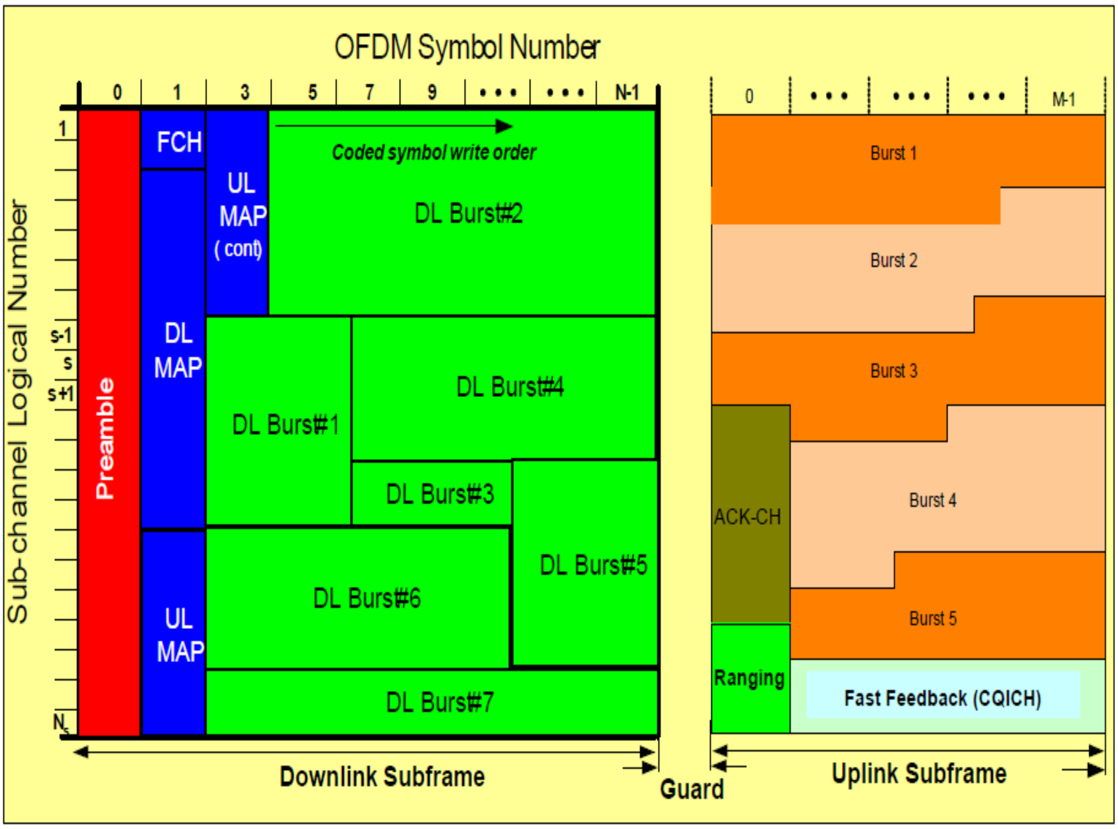


Figure 2.3:WiMAX OFDMA TDD Frame Structure (WiMAX, 2006)

In a frame, the following control information is used to ensure optimal system operation (WiMAX, 2006):

(i) **Preamble**: This is used for synchronization, and it is the first OFDM symbol of the frame.

(ii) **Frame Control Header** (FCH): This follows the preamble. It provides the frame configuration information such as Media Access Protocol (MAP) message length and coding scheme and usable sub-channels.

(iii) **DL-MAP and UL-MAP:** The DL-MAP and UL-MAP provide sub-channel allocation and other control for the DL and UL sub-frame respectively.

(iv) **UL Ranging:** The UL ranging sub-channel is allocated for Mobile Stations (MSs) to perform close-loop time, frequency and power adjustment, as well as bandwidth requests.

(v) **UL CQICH:** The UL Channel Quality Indicator (CQICH) channel is allocated for the MS to feedback channel state information.

(vi) **UL ACK:** The UL Acknowledgement (ACK) is allocated for the MS to provide feedback to DL Hybrid Automatic Repeat Request (HARQ)acknowledges.

.The mobileWiMAX based on Orthogonal Frequency Division Multiple Access (OFDMA) Physical (PHY) is used to access multiple users simultaneously. It allows sub-channelization in both ULand DL, where sub-channels form the minimum frequency Resource-unit allocated by the BS called slot which is equal to 48 data tones(IEEE 802.16e,Standard2009). The slot allocation depends on the link direction, that is, DL or UL and the sub-channelization mode (Chandrasekaran &Nagarajan, 2014). There two types of sub-carrier permutation for sub-channelization (WiMAX-part M, 2006):

(i) Diversity permutation

(ii) Contiguous Permutation

(i). **Diversity Permutation:** Draws sub-carriers pseudo-randomly to form sub-channel. It provides frequency diversity and inter-cell interference averaging. The diversity permutations include DL fully used sub-carrier (FUSC), DL partially used sub-carrier (PUSC) and UL PUSC (WiMAX-part M, 2006). In PUSC mode, a slot consists of one sub-channel over two OFDM symbol periods to DL and one sub-channel over three OFDM symbol periods for UL (Chandrasekaran & Nagarajan, 2014).

(ii). **Contiguous Permutation:** It groups block of contiguous sub-carriers to form a sub-channel (WiMAX-part M, 2006). The contiguous permutations include DL adaptive modulation and coding scheme (AMC) and UL AMC and have the same structure.

Therefore, different sub-channels may be allocated to different users as a multiple-access mechanism. This type of multi-access scheme is called OFDMA, which is used to access multiple users simultaneously (Prasad & Velez, 2010).OFDM is a technology that divides the bandwidth into multiple subcarriers at any given time. OFDMA symbol will be used alongside TDDin this proposed scheduling algorithmin order to effectivelymaximize the resource utilization.

Advantages of OFDMA over OFDM in mobile WiMAX network are as follows:

(i) It has variable bandwidth such as 5MHz, 10MHz, 8.75MHz and 20HMz which is needed for higher capacity

(ii) It has variable Fast Fourier Transform (FFT) size 512, 1024 and 2048 and longer FFT provides better Non-Line-of-Sight (NLOS), better multi-path and channel fading handling

(iii) It supports HARQ

(iv) It provides a better platform for frequency reuse schemes and support multicast and broadcast service.

For a given perfect channel quality, the best modulation and coding scheme can dynamically be assigned to it based on the exploitation of adaptive modulation and coding scheme. The system performance can be improved invariably by adaptive modulation and coding scheme and this is worthwhile in providing group-oriented services (Araniti *et al.,* 2012). With the ability of WiMAX networks to supportmulticast content, the standard includes options to send data on multicast connections that are identified by a MulticastConnection Identifier(MCID) (Araniti *et al.,* 2012).

Subgrouping is a technique that enhances the utilization of radio channel in multicast surrounding. Subgrouping is a scheme that divides a multicast group into smaller subgroups and places the sub-groups with the same degree of link quality in similar sub-group in order to maximize the system throughput.

Sub-grouping is a scheme that has the capability to improve both the system capacity and session quality, since there is reduction in the negative effects produced by edge-cell user in the network. The scheduling algorithm is based on sub-grouping for multicast wireless services support in mobile WiMAX networks to account for the system throughput maximization.

2.2.6Subgroup- based Resource Distribution in WiMAX Networks

Subgrouping in multicast traffic delivery performance in mobile WiMAX was first proposed by (Tan*et al,* 2011).Itemployed adaptive multicast scheme for OFDMA- based multicast wireless systemsby taking the system throughputoptimizationinto account to demonstrate the effectiveness of subgrouping in improving the multicast traffic delivery.The Generic Modulation and Coding Scheme (MCS_n)where: n represents a variablethat varies from 1 to a maximum level N. Ndenotes aconstant which depends on the channel bandwidth in the WiMAX network(Araniti*et al.,* 2012).The attainable data rate for a given MCS_ncan be defined as the function of the number of assigned OFDM symbols (Araniti*et al.,* 2012). Such a rate can be defined as:

$$d_n = rb_n \quad (2.1)$$

where:

$b_n$depictsthe data rate achieved when 1 OFDM symbol is transmitted with $MCS_{n,}$ r the number of OFDMsymbols assigned by the base station to the subscriber station.

The r values can vary from 1 to R, where R depends on the system bandwidth (Cho*et al.,* 2005). The radio resource allocation policy to be implemented at the BScomprises of three main stagesas follows:

(i) Channel Monitoring

(ii) Subgroup Creation

(iii) Radio Identification Resource Distribution

2.2.6.1ChannelMonitoring

In order to make the sub-grouping and resource allocation algorithm work effectively, channel awareness is considered compulsory (Araniti*et al.*, 2012). The BS perceives the quality of links toward each subscriberstation under its radio range with the aid of a channel state monitoring function. The assumption is that all subscriberstations will perform Radio SignalStrength Intensity (RSSI) and Carrier to Interference and NoiseRatio (CINR) measurements.The textitBandwidthRequestand CINR report messages are the Signaling messages used to Update the estimates of RSSI'sand CINR's mean and standard deviation values, and reportthem back to the BS for slot allocations(IEEE 802.16e,Standard 2009). The assumptionthat holds in this proposed scheduling algorithm is thataperfectlink quality remain invariableon a per-frame basis,the reports of the channel measurement received at each frame beginning is valid for the entire frame; which is equivalent to modeling a block-fading channel (Araniti*et al.*, 2012). The determination of modulation and coding scheme appropriatefor each BSto subscriberstationtransmission is compare with the allowed values of Signal-to- Noise Ratio (SNR) and minimum input level sensitivity (S_{RX}).The values of $S_{RX}$are calculated according to the specifications in (Ahmadzadel, 2008), and is expressed as:

$$S_{RX} = -114 + SNR_{RX} - 10\log d_k + 10\log\left[\frac{F_s N_{used}}{N_{FFT}}\right] + \mathrm{ImpLoss} + NF \qquad (2.2)$$

where:

SNR_{RX} is the receiver Signal-to-Noise Ratio

F_S is the sampling frequency [MHz]

$N_{used}$is the number of used subcarriers

N_{FFT} is the number of point of FFT or total number of subcarriers;

d_k is the maximum allowable data rate per channel data rate

ImpLoss is the implementation Loss

NF is the receiver noise figure referenced to the antenna port.

$$d_k = \frac{b_{m.k} . c_{r_{m.k}}}{T_s} \tag{2.3}$$

$b_{m.k}$is the bits per modulation scheme in the kth layer

$c_{r_{m.k}}$is the coding rate of each symbol in the kth layer

$T_s$is the symbol duration

F_S =Floor (n・BW/8000)・8000 (2.4)

Where:

n is a sampling factor

BW is the nominal channel bandwidth.

When the receiver sensitivityfor a given profile is higher than the received signal level and target Bit Error Rate(BER), a more robust transportmode is chosen, if available. A channel can be usedfor transmission as long as there is a burst profile which isable to cope with its present status. Else, if the signallevel is below the receiver sensitivity even for the most robustburst profile (binary phase shift keying “BPSK” modulation with 1/2 coding rate), then thechannel is considered too poor for sending packets (Araniti*et al*, 2012).In the channel monitoring phase the BS collects the channelquality information from each subscriber station belonging to the multicastgroup. Multicast group (MG) can be expressed through the multicast userset*k*, where K = |*k*| represents the MG size, that is, the numberof multicast users in the group. The Modulation and Coding Scheme supported by the generic subscriberstationdenotes MCS^k, where*k* = 1, 2, . . . ,K. A vector U = $\{u_1, u_2, \ldots, u_n\}^T$is built,where the base station saves the channel state information collected by allthe multicast members in order to determine the member to allocates resource based on the request received. The number of subscriber stationssupporting a Modulation and Coding Scheme (MSC) level equal to generic Modulation and Coding Scheme(MCS_n) is represented by a generic item u_n(Araniti*et al.*, 2012). As a result

$$\sum_{n=1}^{N} \mathcal{U}_n = K. \qquad (2.5)$$

where:

nrepresents a variablethat varies from 1 to a maximum level N
Ndenotes aconstant which depends on the channel bandwidth of the system configuration
$\mathcal{U}_n$represent the number of subscriber stations supporting a MCS level equal to MCS_n

K is the total number of multicast users in the group

Vector U is the input parameter for thesubgroups creation phase (Araniti*et al.*, 2012).

2.2.6.2Subgroup Creation

In this length of time,BS applies its radio resource distributionpolicy by starting from the knowledge of the U vector for the subgroup creation (Araniti*et al.,* 2012). Theresource distribution procedure arranges the multicast receiving subscriberstations into subgroups by taking into account the received CINR reports and, then, chooses the suitable number of OFDM symbols and transmission parameters for each enabledsubgroup. The assumption is that all the subscriberstationsexperiencing the similar degree of channel quality arelocated inthe same subgroup, while a subgroup with dissimilar channel quality could serve subscriberstations withdifferent associated MCS. Under this assumption, the possiblenumber of different subgroups, that is, *S*, varies from 1 to N.$Ks \subseteq K$denotesthe set of users belonging to the s-th subgroup (withs = 1, 2, . . . , *S*) and $Ks = |Ks|$represents the number of subscriber stations served by such a subgroup(Tan*et al*, 2011).The *s*-th subgroup is presented according to the minimum MCSamong those supported by users belonging to the subgroup,that is, according to $Min_{k2Ks}MCS^k$(Araniti*et al.,* 2012). This condition guaranteesthat each subscriberstation within the subgroup can successfully support the traffic delivery. The output of this phase, that is, the subgroupconfiguration, is chosen by the radio resource allocation in order to optimizea given cost function. Such a configuration is denoted bythe subgroup vectorR = $\{r_1, r_2, \ldots, r_n\}$, where $0 \leq r_n \leq R$and

$$\sum_{n=1}^{N} r_n = R \tag{2.6}$$

The subgroup with an MCS equal to MCS_n is enabledif $rc \neq 0$

where:

$r_n$is the amount of OFDM symbolsassigned to the subgroup.

The number S of enabled subgroupsis given by the number of items in R >0.

2.2.6.3RadioIdentification ResourceDistribution

Radio identification depends on the possibility of exchanging automatically information about identity of a user by means of radio transmission of short packet (Reggiani *et al.*, 2013). The multicast service istruly provided, after the creation of subgroups. Depending on R, a data rate is served to generic subscriber station supporting a modulation and coding scheme equal to MCS_n (Araniti*et al.*, 2012). The data rate served can be defined as follows:

$$d_n^R = \{max(r_i b_i)\ i = 1, 2, \ldots \ldots n\} \tag{2.7}$$

Indicating that the subscriberstation is served with the MCS nearest to thoseallowed by the perceived channel condition. According to equation (2.5), the BSgenerates the data rate vectorD^R that stores the datarate per MCS level.

2.2.6.4Radio-DetectionSubgrouping Techniques

Different policies for subgroup formation tailored to WiMAX existed in this phase. The two subgrouping algorithms used in this phase are Maximum Throughput (MT) and Proportional Fair(PF).These algorithms are distinguished indefinition base on cost function (Aranitiet *al.,* 2012): the maximum throughput aims at maximizing the network throughput.Proportional fairness tries to evenly share the available resources among the multicast receivers. The conventional multicast scheme like unicast transmission and cooperative multicast transmissionare used to transmit to single receiver and multiple receivers (Tan*et al,* 2011).

2.2.6.5Maximum Throughput

The implementation ofMTA can overcome the throughput demean generated by the conventional multicast scheme approachresource allocation for subgroup generation(Tan *et al.,* 2011). The maximization of ADR is the main objective of MTA(Tan*et al,* 2011).Maximum throughput can be defined as the addition of the receiving data rate of all the multicast subscriberstations. The optimization of the cost function MTtailored for a maximum throughput approach in WiMAXnetworks is defined in (Araniti*et al.*, 2012)as follows:

$$\mathrm{MT} = \underset{\mathrm{R} \in \mathcal{R}}{\arg\max} \left\{ \sum_{n=1}^{N} d_n^R \, \mathcal{U}_n \right\} = \underset{\mathrm{R} \in \mathcal{R}}{\arg\max} \left\{ \mathrm{D}^{\mathrm{R}} . \mathrm{U}^{\mathrm{R}} \right\} \quad (2.8)$$

$$\mathrm{S.t} = \left\{ \sum_{n=1}^{N} r_n = R \right\} \quad (2.9)$$

where:

$\underset{\mathrm{R} \in \mathcal{R}}{\arg\max}$ means that f(R) is the set of elements in $\mathcal{R}$ that achieve the global maximum

MT is the maximum throughput

N denotes a constant that is channel bandwidth dependent

n is the variable that varies between 1 to N

d_n^R indicating the subscriber station that is served with MCS closest to those allowed by the perceived channel condition

$\mathcal{U}_n$represent the number of subscriber stations supporting a MCS level equal to MCS_n

D^R is the data rate vector

$U^R$is the size of the user vector

$r_n$is the amount of OFDM symbolsassigned to the subgroup

R is the maximum number of OFDM symbols assigned for the multicast service

R is the subgroup vector

Equation (2.8) maximizes the aggregate data rate which represents the system throughput. Equation (2.9) is a constraint that guarantees that the whole set of OFDM symbols is assigned by the BS

WhereR depicts the search space for theRadio Resource Management(RRM) optimization problem,the MTA approach cannot guarantee full network coverage. Indeed, data rate maximization can be achieved by avoidingtransmitting data to the subset of subscriber stations (SSs) which excessively bound the data rate of the group (cell-edge SSs). These SSs are considered in "outage" condition and so they are not scheduled by the BS (BS) (Araniti*et al.*, 2012).

A further constraint defined as(Araniti*et al.*, 2012):

$$d_n^R > 0 \qquad \forall_n | \mathcal{U}_n > 0 \tag{2.10}$$

Equation (2.10) is the constraint that is introduced in order to guarantee effective network coverage.This constraint guaranties, in case of layer-encoded video for example, that the base layer is carried to all group members, whileenhancement layers are supplied only to a subset of users that can dynamicallyvary frame by frame (Araniti*et al*., 2012). This policy is referred as maximum throughput with Effective Network Coverage(MTENC).

2.2.6.6Proportional Fairness

The maximum achievable throughput for a given configurationU is guaranteed by maximum throughput scheduling algorithm. For practical systems implementationparametersfairness needs to be evaluated (Araniti*et al*., 2012). Proportional Fairness (PF)scheduling represents a suitable answer for subgroup generation aiming at improving fairness among the users altogether with increasing the system throughput. Firstly, the proportional fairness was defined in (Kelly *et al.*, 1998) as an optimization problem for maximizing the sum of logarithmic data rates, and is depicted as a proportional fairness allocation problem.The cost function based on the PF approach tailored to WiMAX networks is defined in (Araniti*et al*., 2012)as follows:

$$\mathrm{PF} = \underset{\mathrm{R} \in \mathcal{R}}{\arg\max} \left\{ \sum_{n=1}^{N} \log(\, d_n^R) \mathcal{U}_n \right\} \tag{2.11}$$

Equation (2.11) guarantees a fair sharing of the available resources among the multicast receivers and is subjectedto constraints in equations (2.9) and (2.10).Themaximization of system capacity isalso guaranteed bythe PF principle. Indeed, in a given subgroup configuration where one or more subscriberstations are not scheduled (then their data rate is equal to zero) the cost function will approach $-\infty$. In this way, such a configuration will neverbe selected by the radio resource allocation, since subgroup creation is aimed at maximizing the sum of logarithmic rates (Araniti*et al*., 2012). Importantly, the proportional fairness algorithm will choose a subgroup configuration R where each subscriberstation receives a data rate greater than zero which is guaranteed on all occasions.

2.2.6.7Conventional MulticastScheme (CMS)

In a case of subgrouping that applies a conservative approach for dependable multicast traffic delivery (Rhee&Cioffi, 2000). A single group is activated (S = 1) and all the available R OFDM symbols are transmitted with the minimum modulation and coding scheme among those supported by all the subscriberstations, that is, according to $\min_{k2K} MCS^k$. As all subscriberstations are served, the network coverage is maximized (Aranoti*et al*., 2012).

2.2.7 Channel Modelling

Wireless access networksare becoming relevant tools for some models in keeping communications, especially at home and workplaces (Singh, 2012). Comprehending the way wireless medium behave is absolutely necessary to appreciate the reasoning behind specific designs for wireless communications protocols (Martinez, 2006). In particular, physical-layer andMAP designs are influenced greatly by the behavior of the channel which changes substantially in different locations. The effective design, assessment and installation of a radio network require accurate characterization of the channel (Abu-alhiga, 2010). Some of the channel propagation models that are commonly used on the basis of path loss and signal strength in WiMAX network are: Adaptive White Gaussian noise (AWGN), Stanford University Interim (SUI) model, Egli model, Erceg model and COST-231 Hata model. However, the COST-231 Hata model is the propagation model adopted in this research. This model is explainedas follows:

2.2.7.1 COST-231 Hata Model

The model is an extension to Hata-Okumura model developed by Hata in 1981 from original Okumura path loss model in 1981 (Priya, 2010), COST stands for Cooperative for Scientific and Technical and is used for the prediction of path loss for mobile wireless systems in urban environments (Priya, 2010). However, due to its simplicity and extensive usage, the model can be used in 2360 – 2390MHz band and can also be used in 3500MHz (Singh, 2012).

COST-231 Hata model Path Loss (PL) can be calculated as follows (Priya, 2010):

$$PL = 46.3 + 33.9\log_{10}\ f_c\ - 13.82\log_{10}\ h_t\ - a\ h_r\ +\ 44.9 - 6.55\log_{10}\ h_t\ \ \log_{10}\ d\ +\ C_m\ + X_\sigma \quad (2.12)$$

where:

C_m is 0dB for medium sized cities and suburban and 3dB for metropolitan areas.

$f_c$depicts the carrier frequency

dis the distance between transmitter and receiver antennae in km

h_t is the transmitter antenna height above the ground level in meters

$X_\sigma$is normally distributed variable that captures the shadowing loss component, with its standard deviation being 8dB for both urban and suburban environments.

ah_r is theCorrection parameter that can be defined for urban areas as follows:

$$ah_r = 3.20\ \log_{10}\ 11.75h_a\ ^2 - 4.97\ for\ f \triangleright 400HMz \quad (2.13)$$

where:

$h_a$is the receiver antenna height.

h_r depicts mobile station antenna height

For suburban or rural areas (flats) as follows:

$$ah_r =\ 1.1 \times \log_{10}\ f - 0.7\ \ h_a -\ 1.5\log_{10}\ f - 0.8 \quad (2.14)$$

COST 231 Hata model predicts the path loss exponent as follows:

$$n\ =\ {(44.9\ - 6.55\log(h_b))}/{10} \quad (2.15)$$

where:

n is the parameter of simpler path loss.

$h_b$is the receiver antenna height in path loss exponent

Equation obtained using least square regression analysis is as follows:

$$L_p[dB]\ = L(d_o)\ + 10n\log_{10}(d/d_o) \quad (2.16)$$

where:

n is parameter of simpler path loss

dis the distance between transmitter and receiver antennae in km

d_o is the reference distance to the BS antenna height

$L(d_o)$ is the path loss at the reference distance

Table2.1: Restricted Range of Parameters for COST-231 Hata Model (Singh, 2012)

Parameter	Value
Carrier Frequency	1.5GHz
base antenna Height	30m to 300m
Mobile antenna Height	1m to 10m
Distance d	1km to 20km

COST-231 is chosen to be the propagation model in this dissertation because it is the best model to estimate the path loss exponents, as compared to the Stanford University Interim (SUI) model and Egli model (Priya, 2010).

2.2.8 Radio Channel Characteristics

One fundamental aspect of radio channels is that the transmitted signal strength is reduced between a transmit and a receive antennas. That is, the signal strength is afunction of the propagation distance from transmitter. Therefore, free space path loss is simply a distance-dependent attenuation.

(i) Path loss: This is the reduction of the strength of the signal power caused by the distance between the transmitter and the receiver. The path loss is usually modeled as follows (Martinez,2010):

$$P_r = P_t \left({d_o}/{d} \right)^{\mu} \tag{2.17}$$

where:

$P_r$is the received signal
P_t is the transmitted signal
d is the distance between the transmitter and the receiver
$d_o$denotes a reference distance
μ is the path loss exponent
Usually, fading can be attributed and widely categorized into two main classes as:

(i) Shadowing or long term fading or slow fading
(ii) Short term fading

(i)**Shadowing or long-term fading or slow fading:** This class of fading is caused by diffractions, scattering and multiple reflections resulting from terrain contours such as maintains, hills, and building. This kind of fading is slow time-varying and can be modeled with log-normal distribution (Martinez, 2006).

The path loss along with the shadowing effect can be mathematically expressed in decibels as follows (Abu-alhiga, 2010):

$$g = A + 10\mu \log_{10}\left(\frac{d}{d_o}\right) + \xi \quad (2.18)$$

where:
A is the antenna-dependent constants
$\xi$is a zero mean Gaussian distributed random variable with standard deviation σ_S in dB

(ii)**Short-term fading:** this is also known as small-scale fading which is due to the different multipath signals being added up with random phases, constructively or destructively, at the receiver (Kazemi & Heydarian, 2013). These cause rapid fluctuations in the received signal level.

2.2.9 Radio Channel Diversity

Multipath fading can be tackled by combing two or more versions of the received signal to enhance the reception (Abu-alhiga, 2010). The fundamental logic is that while some of the received copies of the transmitted signal may suffer fading, others may not. The fundamental idea is known as diversity which results from the spreading of the signal in various dimension, time, frequency and space (Li, 2007). Diversity gain is the improvement of the system performance by implementing diversity techniques.

Generally, multipath propagation and movement of the Mobile Station (MS) create dispersion in the channel across a number of domains. Such channel dispersion is a result of the received signal energy being spread in frequency, time and space (Martinez, 2006). These three kinds of diversity are briefly described as follows (Martinez, 2006):

(i) Frequency Diversity (Delay Spread)

(ii) Time Diversity (Doppler Spread)

(i) Frequency Diversity (Delay Spread): Multipath propagation results in delay differences among the received versions of the transmitted symbol over different paths. The span of these differences in delay is known as delay spread, which causes Inter-Symbol Interference (ISI) (Rami, 2010).

(ii) Time Diversity (Doppler Spread): The change of location ofMS or surrounding scatterers give riseto Doppler spread, which shifts the frequency of the received signal from the transmitted frequency due to its relative motion (Rami, 2010). Multipath propagation of the signal causes the relative speed of the MS with respect to different copies of the received signal to differ, in different Doppler shifts. The width of this shift is referred as the maximumdoppler spread, which is inversely proportional to the coherence time of the channel as follows (Abu-alhiga, 2010):

$$T_c \approx \frac{1}{f_d} \quad (2.19)$$

where:

f_d is the maximum doppler spread and coherence time

T_c represents the time interval over which the channel does not change significantly

2.2.10 Time-Varying Channel

In mobile radio applications, the channel is time-varying when the motion between the transmitter and the receiver results in propagation path change (Tariq *et ai*, 2006). It can be noted that since the channel characteristics are dependent on the relative position of the transmitter and receiver, time variance is equivalent to space variance (Tariq *et ai*, 2006).

2.2.11 Multiuser Diversity

Traditionally, diversity can be achieved over fading channels either over space (multiple antennas in reception or transmission), over time (interleaving) or in frequency (Condoluci *et al.*, 2013). In multiple access wireless networks, multiuser diversity is another source of diversity that can be obtained exploiting the time-varying characteristic of the users' channels. In order to maximize the total system capacity, the optimal strategy is to schedule at any one time, the user with the best channel quality to transmit a request to the BS. Overall system throughput is maximized by allocating at any time the common channel resource to the user that can best exploit it (Martinez, 2006).

2.2.12 Adaptive Modulation and Dynamic Resource Allocation

WiMAX coding and modulation ensure a balance signal strength over distance by decreasing throughput over distance to deliver the best QoS (Parihar *et al.*, 2010). In wireless network like WiMAX, dynamic allocation of radio resource is highly complicated and non-linear (Shu'aibu *et al.*, 2011). It is even more complicated for a wireless network that is design for heterogeneous traffics with distinct QoS requirement (Shu'aibu *et al.*, 2011). Adaptive modulation is one of the mechanisms that a WiMAX system uses to ensure better QoS. The BS monitors the network and allocates more resources for affected connections.Unlike WiFi and many cellular technologies which used fixed width channels, WiMAX allows almost any available spectrum width to be used (So-In *et al.,* 2010). Allow channel bandwidths vary from 1.25MHz to 20MHz. the channel is divided into many equally spaced subcarriers (IEEE 802.16 Standard 2009). For examples, a 10MHz channel is divided into 1024 subcarriers some of which are used for data transmission while others are reserved for monitoring the quality of the channel (Pilot subcarriers), for providing safety zone (guard subcarriers) between the channels, or for use as a reference frequency (DC subcarriers) (IEEE 802.16 Standard 2009). The data and pilot subcarriers are modulated using one of the respective available MCS. Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM) are examples of modulation schemes that are employed in WiMAX (So-In *et al.,* 2010). The MCSs, as stipulated by WiMAX convention are briefly described as follows:

1. **Layer 1 (QPSK):** In this layer users receive signal through QPSK modulation. In this kind of modulation, each OFDM symbol has 2 bits. This layer has a coding rate of 1/2.
2. **Layer 2 (QPSK):** In this layer, each OFDM symbol has the same number of bits as that of layer 1 but the layer has a coding rate of 3/4.
3. **Layer 3 (16-QAM):** The QAM scheme is employed in this layer. In this layer each OFDM symbol has 4bits and is coded at a rate of 1/2.
4. **Layer 4 (16-QAM):** This layer has the same MCS as layer 3 but has a coding rate of 3/4.
5. **Layer 5 (64-QAM):** This layer has the same data rate as that of layer 4 but has 6 bits per modulation symbol and a coding rate of 1/2.
6. **Layer 6 (64-QAM):** This layer differs from layer 5 in that it has a coding rate of 2/3.

7. **Layer 7 (64-QAM 3/4):** In this layer, a coding rate of 3/4as in layer 2 and 4 use for data transmission.

2.2.13 ReviewofSchedulingAlgorithms

This sub-section describes some of the scheduling algorithms used for the maximization of throughput. Scheduling algorithms are mainly responsible for effective use of resource that are available in the network and share them among users in order to ensure the desire quality of service (Nie*et al.*, 2011). However, serving all the users and meet their demand in fair proportion is a real challenge in scheduling. The main-goal of any scheduling algorithm is to maximize the network utilization and achieve fairness among all users (Prasad, 2013). The traditional techniques aim at solving some problems such as providing QoS and distributing the resource among all users fairly. Many of these algorithms were proposed purposely for wired networks. However, they are used in WiMAX networks to satisfy the requirements of scheduling service (Chauhan*et al.*, 2013). Some of the scheduling algorithms are discuss as follows:

i.First InFirst Out (FIFO): This scheduling algorithm is based on a queuing system in which the received packet is served based on the order of arrival. However, it does not take priority or QoS into consideration when packets are queued or dequeued (Dhrona*et al.*, 2008).

ii.Round Robin (RR): RR is the plainest scheduling algorithm designed specifically for time distributing systems (Khoei*et al.*, 2014). It works in a cyclical manner between the existing queues in a time sharing system to avoid starvation on queues with lower priority. It equally designates allocation to all connections one by one. Stations with larger packets experience an uneven advantage with packet- based allocation. However, RR might not work conserving, the allocation made for connections that may have nothing to transfer; as such RR cannot guarantee QoS for different service classes (Mardini&Alfool, 2011).

iii.Earliest deadline first (EDF): The scheduler is developed to serve users of high priority classes in wide area networks. The scheduler allocates bandwidth to all subscriber stations and assigns deadlines to each packet based on maximum delay requirements. The setback of this scheduler is that potentials starvation can occur to subscriber stations with lower class of service since they do not have delay requirements (Nie*et al.*, 2011).

iv.Weighted fair queuing (WFQ): This technique is commonly used in uplink traffic in WiMAX networks. WFQ sorts the packets in an increasing order according to its finish time which is computed depending on the size and weight assigned to the packets of the subscriber stations. The main drawback of WFQ is that the start time of the packets is not taken into account (Mardini&Alfool, 2011).

v.Max Rate: Max rate scheduler communicates always to the user having the highest signal to noise ratio, so users that are likely to be scheduled all the time are the users that have the highest fading, while others that experience deep fades are not scheduled at all (Martinez, 2006). Max Rate scheduler yields, higher throughput than anyother possible scheduling policy, however, it totally ignores fairness (Prasad &Kumar, 2013). In wireless environments invariable user's channel can be very different, due to different locations from the BS, although both channel fluctuate due to multipath fading (Khamayseh, 2012). So, always selecting the strongest user would be highly unfair.

2.2.14 ReviewofOptimizationTechniques

This sub-section describes some of the optimization techniques for enhancing a system performance. Some of these techniques are:

(i) Genetic Algorithm (GA)

(ii) Ant Colony Optimization (ACO)

(iii)Tabu Research

(iv)Particle Swarm Optimization

2.2.14.1 Genetic Algorithm (GA)

GAwhich was first developed by John H. Holland in 1975 (Castillo-Villar, 2014), is an adaptive meta-heuristic that mimics the process of natural evolution. GA is a search technique that is used in computation to find genuine or approximate solutions to optimization and search problems (Jha*et al.,* 2012). GA are a particular form of evolutionary algorithms that use techniques inspired by evolutionary biology such as inheritance, mutation, selection and crossover which is also known as recombination (Malhotra*et al,* 2011). The evolution usually starts from a population of randomly created individuals and occurs in generations. In each generation, the fitness of every individual in the population is evaluated, where multiple individuals are selected from the current population (based on their fitness), and modified to form a new population (Jha*et al.*, 2012). The new population is used in the next iteration of the algorithm. The algorithm ends when either a maximum number of generations have been produced, that is, a satisfactory fitness level has been reached for the population. The theorem that has stood for a long period as a pivotal result of genetic theory is Schema theorem (McCall, 2005). The theorem made some assumptions by making H to denote a schema, the number of chromosomes belonging to H present in population i of an evolving GA to represent mH(i) . Then the expectation of the number of chromosomes belonging to H in population i + 1, denoted bym_H(i + 1), is given by the equation as follows (McCall,2005):

$$m_H(i+1) = F_H(i)m_H(i)\left[1 - PC\frac{L_H}{L-1}\right][(1 - p_m)^{OH}] \quad (2.20)$$

where: $F_H(i)$ is the relative fitness of H, defined to be the average fitness of all those chromosomes in the population belonging to H divided by the average fitness of all chromosomes in the population; PC is the crossover probability; Pm is the mutation probability.

Advantages of GA(Malhotra et al., 2011):

(i) It can solve every optimization problem which can be described with the chromosome encoding

(ii) It solves problems with multiple solutions

(iii)The execution technique of GA does not depend on the error surface, so it can solve multi-dimensional, non-continuous and non-parametrical problems

(iv)GA algorithms are easily transferred to existing simulation and models

Disadvantages of GA(Malhotra et al., 2011):

(i) GA cannot solve an optimization problems that is variants in nature

(ii) There is no absolute assurance that GA will find a global optimum

(iii) GA cannot assure a constant optimization response times

2.2.14.2 Ant Colony Optimization (ACO)

ACOwhich was first introduced in 1992 by Dorigo (Castillo-Villar, 2014), is a meta-heuristic inspired by the searching behavior of ants for tracking between their nest and source of food to seek an optimal path (Gudos, 2014). In this subclass of evolutionary algorithms, ants will first seek regions close to the nest aimlessly, and then, they spread out farther to discover food. While they seek for food, they deposit a chemical called a pheromone, which can be discovered by other members of their nest. After finding food and evaluating its quality and quantity, the ants will leave enough of pheromone to aid the rest of the colony to track the food source (Castillo-Villar, 2014). This aspect of real ant, colonies is exploited in ant colony algorithms in order to solve combinatorial optimization problems considered to be non-deterministic polynomial.

Advantages of ACO (Selvi & Umarani, 2010):

(i) Inherent parallelism

(ii) It has a positive feedback accounts for rapid discovery of good solution

(iii) Efficient for solving travelling salesman problem

(iv) ACO can be used for dynamic application, that is, adapts to changes such as new distances.

Disadvantages of ACO(Selvi & Umarani, 2010):

(i) Theoretical analysis is difficult in ACO

(ii) Sequences of random decision not independent in a ACO

(iii) Probability distribution changes by iteration

(iv) Time of convergence is umcertain

2.2.14.3 Tabu Search (TS)

TSis a heuristic approach that was first introduced to address combinatorial optimization problems in 1986 by Glover (Castillo-Villar,2014). TSis the technique that keeps track of the regions of the solution space that have already been searched in order to avoid repeating the search near these regions (Said *et al.*, 2014). TS is an extension of classical search methods. However, it can be interpreted as the combination of local search with short-term memories. The definition of its search space and its neighborhood structure had two basic elements of TS (Castillo-Villar, 2014). The search space is defined as the space of all possible solutions that can be visited during the search. Regarding the neighborhood structure, at single iteration of the algorithm, the local transformation that can be applied to the current solution, define a set of neighboring solutions in the search space, that is, the neighborhood of current solution. Indeed, the neighborhood of the current solution is a subset of the search space of the solutions obtained by employing a single local transformation to the present solution (Said *et al.,* 2014). Tabus are used to prevent cycling doing non-improving moves when moving away from local optima. Tabus are implemented to prevent the search from back-tracking its steps. Therefore, tabus mean forbidden moves that reverse the effect of recent moves.

Advantage of TS(Kevin, 2014):

(i) TS method is easy to implement with other methods

Disadvantages of TS(Kevin, 2014):

(i) TS approach is to climb hill in steepest direction and stop at top and then climb downwards to search for another hill to climb. The drawback is that a lot of iterations are spent climbing each hill rather than searching for tallest hill.

2.2.14.4 Particle Swarm Optimization (PSO)

PSO is a population based stochastic optimization technique that was first developed by Eberhart and Kennedy (Annauth&Rughooputh, 2012). The technique is an evolutionary based algorithm that imitates the swarm behavior of bird flocking and fish schooling (Goudos, 2014). The most common PSO algorithms include the classical inertia weight PSO and construction factor PSO (Clerc, 1999). PSO is an algorithm that is easy to implement with computational efficiency (Chakravarthy & Reddy, 2010).PSO algorithm is inherently used only for real-valued problems. The clamped velocity is a constraint that is used to control the particles from the likelihood of particles leaving the search space(Sarkar& Purkayastha, 2013). The role of PSO is to solve the problem of throughput fluctuation by tuning the following parameters mentioned (Goudos, 2014):

(i) Particle: Candidate solution to a problem

(ii) Fitnesss: Best solution obtained

(iii) Velocity: Rate of position change

(iv) P_{best}: Best value achieved in previous particle

(v) g_{best}: Global best value secured so far by any particle in the population

With a view to obtaining the best optima system throughput and CDRaccording to the objective function that describesthe maximization of throughput. The swarm is initialized randomly with numbers of particles and it then searches for two optimum values to update each particle in every iteration, the first of the two optimum values is the best solution achieved so far known as P_{best} and the other is the global best value secured by any particle in the generation of the population known as g_{best} (Goudos, 2014). With respect to the two best values obtained, a particle updates its velocity and position with the aid of the following equation(Goudos, 2014):

$$U_{G+1,ni} = WU_{G,ni} + C_1 rand_{1\ 0,1} \ \ P_{best_{G+1,ni}} - X_{G,ni} \ \ + C_2 rand_{2\ 0,1} \ \ g_{bset_{G+1,ni}} - X_{G,ni} \qquad (2.21)$$

where $U_{G+1,ni}$is the ith particle velocity in the nth dimension, $G+1$ denotes the current iteration and G the previous, $X_{G,ni}$is the particle position in the nth dimension, $rand_{1(0,1)}$,$rand_{2(0,1)}$are uniformly distributed random numbers in (0,1), $W$is a parameter known as the inertia weight, and C_1 and C_2 are the learning factors.

The reasons for usingPSO are as follows (Hisashi*etal*., 2011)

(i) It does not have any complicated evolutionary operators such as crossover and mutation as in GA, ACO and TS which makes it easy to solve real-time application in respect to packet transmission in WiMAX network.

(ii) Particle Swarm Optimization tends to converge quickly and efficiently.

(iii) Particle Swarm Optimization delivers packets at a reasonable speed.

(iv) It has less parameter to adjust.

Disadvantages of PSO(Selvi & Umarani, 2010):

(i) PSO easily suffers from the partial optimization, which causes less exact at the regulation of its speed and then direction

(ii) PSO cannot work out the problems of scattering and optimization

(iii) PSO cannot work out the problems of non-coordinate system, such as the solution to the energy field and moving rules of the particles in energy field.

2.3 ReviewofSimilar Works

This section provides an overview of previous research works. Optimizing WiMAX networks has led to much research and design projects by way of improving the system performance by maximizing the throughput. In the aspect of optimizing the performance of these models, the following presents a critical review of similar research works:

Xergias*et al.*,(2005) examined and evaluated a frame registry tree scheduler which aimed at preparing in advance the creation of time frame and avoid complex processing at the beginning of each frame.The authors used flexible tree structure to map the scheduler's decision to minimize packet loss and throughput fluctuation of different types of traffic. The problem with their work is that the comparison between time and space evaluationwas not considered.

Khisti*et al.*,(2006) designed a framework to analyzeuser cooperation protocols limit of large network size (number of nodes), which they illustrated in the case of a multipath-rich Rayleigh fading environment to achieve a rate close to the network capacity. However, their work could not account for a better model beyond the Rayleigh fading model within the framework and could not keep the system performance constant when the sum power constraint was replaced with individual power constraints.

Zafer& Modiano,(2006)studied the blocking probability behavior of connection oriented traffic model for multihop wireless line and grid topologies. The study focused on two areas which were: (i) the effect of transmission radius of nodes and (ii) dynamic channel assignment algorithm. They were able to show that in line topology, a large transmission radius substantially reduces blocking probability and a smaller transmission radius is suitable for a grid network with a denser node topology.Theyalso developed a non-rearranging channel assignment algorithm that reduced blocking probability by spatially re-using the channel in an efficient manner which improved the network performance. However, the study could not establish the relationship between blocking probability and general rate of increase of interfering nodes with the transmission radius.

Hou*et al.*,(2009) developed a cooperative transmission model for efficiently supporting multimedia applications in WiMAX. It composed of two phases: First, the BS multicasts data at a high rate and users in good channel conditions decode the data and secondly, the users in good conditions decoded the data then assisted in relaying the received data to the remaining users with poor channel conditions. The problem with their work is that the impact of mobility differentiation was not considered.

Jin & Li,(2009)examined a multicast scheduling with multihop, multipath transmission over multiple OFDMA channels to fully exploit the effectiveness of cooperative communication and random network coding. Their work showed that cooperative communication and random network coding favoured users with good channel conditions by enjoying high multicast flow rates from the source and cooperatively helped others with poor channel conditions simultaneously with little overhead. They considered channel and power allocation on relays as their performance metrics. The study was able to achieve significant throughput improvement due to its effective use of wireless spectrum. However, the limitation of the study is that the mobilestations did not make any contributions to the networks for multicasting.

Shwetha*etal.*,(2011) carried out a performance analysis of Automatic Repeat Request (ARQ) mechanism for the effect of implementation of ARQ for WIMAX network by considering performance metrics like throughput, delay andjitter. The mechanism used a feedback channel for the confirmation of error-free packet delivery or packet retransmission. They found that the method increased the network throughput even when the radio channel conditions were getting worse. The limitation of this study is that the network delay increased because of the time spent in the retransmission of packet.

Siltamen*etal.*,(2011) made practical measurements of the WiMAX system's QoS performance behavior of the UGS and RTPSby comparing the results obtained in WiMAX laboratory environment in conjunction with laboratory exercise tests, as well as theoretical results from mathematical modeling with the results obtained in authentic urban environment. Based on these, they used a technology thatutilized a license-free frequency to replace Asymmetric Digital subscriber Line(ADSL) connections over copper cables in the rural areas, but their devices were best suited for point-to-point connections. However, the set back of this study is that point-to-multipoint and a way of optimizing the problem of cost effective coverage area extension by using relay and algorithm for "multi-hop" WiMAX networks was not considered.

Araniti*et al.*,(2012) developed a subgroup- based resource management scheme, whereby they cluster SSs with similar channel quality in the same multicast subgroup of a WiMAX cell. Different cost functions for subgroup formation to trade off fairness and throughput requirement were used to improve the system performance. The work did not give any technique for reducing the computational cost of the subgroup creation.

Chandra &SaravanesSelvi.,(2012)developeda mathematical formulation of problem to analyzethe selectionof optimal sub-streams from scalable video streams under bandwidth constraints to maximize the quality for mobile receivers. Their work gave a better throughput when comparedto weighted round robin and similar homogeneous schedulers like round robin and first in first out. However, they did not consider channel conditions in their work such as fading and multi user diversity.

Mehta & Gupta,(2012) used Ad hoc on demand distance vector routing (AODV) to analyze various essential WiMAX quality of service parameters to determine the performance of a WiMAX network. They were able to obtain optimum value of QoS parameters as the mobile users kept on increasing in the network. The major setback of this work is that it could not handle the issue of power consumption because the power consumption increased with an increase in the number of group members.

Kazemi&Heydarian,(2013) discussed the performance and efficiency of WiMAX MAC layer that adapted with the physical layer (PHY) for point-to-multipoint topology for designing 4G networks that ensured required bandwidth, minimum latencies for different services through quality of service.The network was resilient to multipath fading channels because of the physical layer. However, the limitations of multi-input multi-output and advanced antenna systems were discarded in this work

Huang &Wu,(2013)examined adaptive real-time service based distributed scheduling scheme that comprises of three components: Priority Assignment, Resource Allocation and Preserved Bandwidth Adjustment which guaranteedQoS of real-time service connections and provided fairness to every connection. They concluded that real-time distributed scheduling dynamically allocated bandwidth to different types of connections to meet each QoS requirement. This work suffered a setback by not taking uplink scheduling and fairness to non-real time into consideration.

Dartmann*et al.*,(2013)developed an uplink-downlink duality framework, that is, they derived by Lagrangian duality theory for multicast max-min beamforming problem with multiple power constraints.They demonstrated that the research achieved a higher signal-to-interference-plus-noise ratio for the weakest users in the network. The limitation associated with this work is that it could not tackle the slow convergence of the network.

Nithyanandan&Susila,(2013) developed a cooperative multicast scheduling scheme for wireless IPTV over mobileWiMAX based onresource assignment algorithm for QoS optimization. The developed model increased the network throughput as the network coverage was increased. However, this work still relied on the cooperative multicast transmission developed by (Hou*et al.*, 2009), which did not consider mobility differentiation.

Oktay& Mantar,(2013)created a channel delay aware scheduler for real-time applications which comprised of two modules, the wireless and the network delay monitoring tools. The wireless module included the compensation module, whichwas responsible for considering the throughput loss of the SS due to channel condition which improved fairness between all the SSs that were included in the same service class. The channel state monitoring module was responsible for monitoring and reporting the SSs channel state conditions to the scheduler. Also, the network delay monitoring tool calculated the estimated network delay of the paths and used this estimated delay to calculate the packet deadline for meeting the delay requirement. Theirwork was able to meet the delay requirements of real-time applications by taking the channel conditions and network delay into account. In addition, the work fairly distributed the network resources among the SSs and increased the network throughput. The limitation of the work is that it was not able to satisfy the short-term fairness due to the channel conditions.

Prasad& Kumar, (2013) designed a joint routine scheduling and admission control protocol for WiMAX network, in which packets were transmitted per allotted slots from different priority of traffic classes adaptively depending on the channel condition. In the adaptive scheduling, the best route was found by means of combination of the bandwidth estimation technique with route discovery and setup. The admission control technique was based on the estimation of bandwidth utilization of each traffic class. The work was able to achieve a better throughput and channel utilization while reducing the blocking probability and delay. However, the study did not consider the interference between call admission control and scheduling algorithm working on different criteria in the same network.

SaraVanaSelui&Latha, (2013) carried out survey on several bandwidth allocations and call admission control in which a scheduling algorithmwaschosen based on maximum throughput and maximum delay that were based on service flow types. The various scheduling types used and their traffic class analyzed were round robin, weighted round robin, earliest deadline first, weighted fair queue, priority queue and reinforcement learning algorithm. They found out that the mean delay was increased for Best Effort (BE) and non-Real Time Pulling Service(nRTPS) when compared with Unsolicited Grant Service(UGS) and Real Time Pulling service(RTPS) flows when the system was overloaded.They discovered that priority and delay tolerant traffic were the main parameters for providing bandwidth for UGS and RTPS flows. However, the work did not take into account channel error and loss rate because channel condition was not considered due to the channel unaware scheduling that were evaluated.

Chandrasekaran &Nagarajan, (2014)developed a novel scheduling algorithm for downlink services that totally exploit the physical layer properties of the WiMAX network, which maximized the throughput of the network at the same time guaranteed improved QoS of various services by the network. The performance of the algorithm was improved further by employing fuzzy logic design. However, they did not evaluate the performance of the algorithm on non-real time traffic scenarios.

Wee*etal.*,(2014)designed a proportional bandwidth granting schemes consisted of proportional byte based that kept the individual bandwidth request in the byte format, which was the original value extracted from the bandwidth request message. The second mechanism was the proportional physical slot before any bandwidth allocation calculationwas done, which gave a better average throughput and jitter when compared to common bandwidth granting mechanism approach. However, their designed mechanism appeared inefficient with increase in user distribution factor and the number of subcarriers to be shared. The approaches in most of the literatures reviewed so far were not suitable for implementation on computer as tools for WiMAX analysis.In view of the aforementioned imperfections associated with the reviewed works, and the need to overcome the inefficiencies of the conventional scheduling multicast schemes in addressing the throughput fluctuations and channel degradation due to time varying wireless channels, an improved scheduling algorithm is hereby proposed. The proposed algorithm will maximize ADR and CDRwhile guaranteeing the QoS for each of the users in the network. The proposed algorithm would be based on Particle Swarm Optimization (PSO) using sub-group formation technique in order to improve the system performance.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter describes the detailed procedure of the methods and materials used to model the WiMAX environment and the steps used in developing the algorithm used to maximize ADR and CDR.

3.2. Proposed WiMAX Network Environment

In the developed algorithm, the network environment was modeled as a circular area covered by 7 concentric layers. These layers depict a set of MCS as stipulated by the WiMAX convention.

In the proposed WiMAX network environment model, a $MCS_k$is presented, where k represents the index of the layer of reference. Table 3.1 shows the burst profile for the various MCSs for wireless MAN-OFDMA PHY layer channel bandwidth of 10MHz

Table 3.1: WiMAX Burst Profile for WirelessMAN-OFDMA PHY Layer (IEEE 802.16 Standard, 2009)

Layer (k)	Modulation Type	Coding Rate ($Cr_{m.k}$)	SNR [dB]	S_{RX} [dBm]

1	QPSK	1/2.	5	-89.2
2	QPSK	3/4.	8	-86.29
3	16-QAM	1/2.	10.5	-83.79
4	16-QAM	3/4.	14	-80.29
5	64-QAM	1/2.	16	-78.29
6	64-QAM	2/3.	18	-76.29
7	64-QAM	3/4.	20	-74.29

In Table 3.1., each of the modulation schemes hasspecifiesSignal-to-Noise Ratio (SNR) and corresponding Receiver Input Sensitivity (S_{RX})in order to determine the layer to allocate resource with respect to distance from the BS. These two parameters are used to dynamically select the desired MCS for eachof the layers with respect to the WiMAX BS. The assumed environment for this research is the urban and open terrain for COST-231 Hata path loss model. As can be seen from Table 3.1, the SNR and S_{RX} increase from MCS_1 to MCS_7 which corresponds to QPSK 1/2 to 64 QAM 3/4. The values of S_{RX} (dBm) in Table 3.1 are obtained using equation (2.2). Therefore, the WiMAX network environment is such that layer 7 is the closest to the BS while layers 6 to 1 follow respectively. Figure 3.1 illustrates the WiMAX environment based on 7 layers architecture. A coverage area of 1257km^2 was chosen based on the COST-231 Hata model which specifies a coverage radius of 20km.

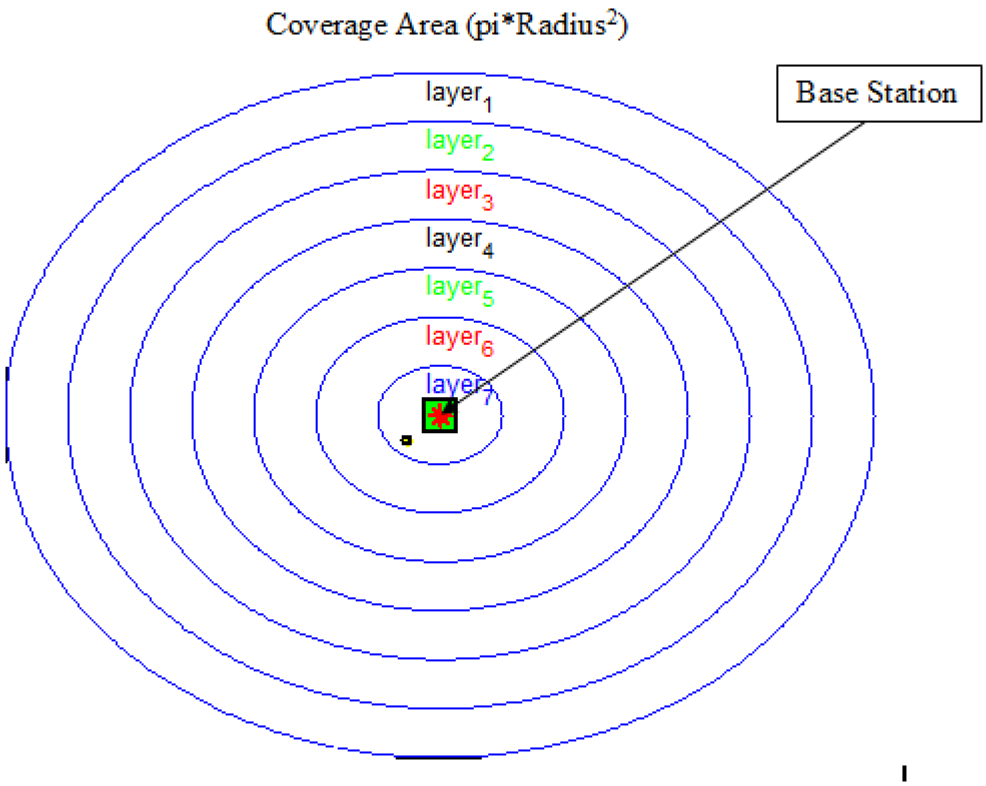


Figure 3.1: ProposedWiMAX Layered Architecture

3.2.1 Layer Data Rate

In the proposed WiMAX network environment, each of the layers is characterized based on its maximum allowable data rate per subcarrier per OFDM symbol. Equation (3.1) is used to estimate the allowable CDRfor each of the layers.The symbol duration (T_s) is determined from the following equations (Ahmadzadeh, 2008):

$$d_k = \frac{b_{m.k} . c_{r_{m.k}}}{T_s} \tag{3.1}$$

$$T_S = [G + 1]T_b \tag{3.2}$$

$$G = {}^{T_g}/_{T_b} \tag{3.3}$$

$$T_b = {}^{1}/_{\Delta f} \tag{3.4}$$

$$\Delta f = \frac{F_s}{N_{FFT}} \tag{3.5}$$

$F_s = floor({}^{nBW}/_{8000})8000$ (3.6)

where:

d_k is the maximum allowable data rate per channel data rate of the kth layer.

$b_{m.k}$ is the bits per modulation scheme in the kth layer

$Cr_{m.k}$ is the coding rate of each symbol in the kth layer

T_s is the symbol duration

T_b is the useful symbol time

T_g is the guard time

G is the cyclic prefix

Δf is the subcarrier spacing

N_{FFT} is the number of points for FFT or total number of subcarriers

F_S is the sampling frequency

n is the sampling factor

BW is the normal channel bandwidth

In the developed algorithm, the value of the product ($b_{m.k}$x $Cr_{m.k}$) for each layer is given in Table 3.2. The values of $Cr_{m.k}$ are obtained from Table 3.1 while values of $b_{m.k}$are shown in Table 3.2

Table 3.2:Data Rate Multiplier for the Various Layers

Layer index	$b_{m.k}$x	$b_{m.k}$x $Cr_{m.k}$
1	2	1
2	2	1.5
3	4	2
4	4	3
5	6	3
6	6	4

7	6	4.5

Based on Table 3.2, it could be observed that the higher the index of the layer, the higher the allowable data rate. This is so because the higher the layer index, the closer the layer is to the BS, users closer to the BShave the possibility of higher data rates based on the MCS applied. Equation (3.7) can be used to obtain the maximum data rate of each of the layers when the entire subcarriers are allocated to it.

$$D_k = d_k \times N_{used} \tag{3.7}$$

where:

D_k is the maximum data rate a layer can have

N_{used} is the number of used subcarriers (usually specified for a given bandwidth)

3.2.2 WiMAX SubscriberSubstations

In the developed algorithm, the WiMAX network users are referred to as subscribers and their location is referred to as station. The characteristic of the developed algorithm is such that the substations are mobile. Therefore, it is possible for the network configuration to change after each frame interval. This property makes the network dynamic and aids in maximizing the aggregate data rate of the system (system throughput). Since a circular cell is considered, users can be defined based on two parameters, namely:

(i) Radius (R)

(ii) Direction (θ)

The following Matlab command can be used to generate users randomly within the WiMAX network coverage area.

```
SS_distance = radius * rand (1,no_SS)
SS_direction = 2 * pi * rand (1,no_SS)
```

Therefore, the possibility of any user within the network environment can be completely defined using the cartecian coordinate system [x_i, y_i], where x_i is the x- coordinate of the ith user and y_i is the y-coordinate of the ith user. The followingequations can be used to define the positions of the entire users in a given WiMAX network environment (Kobayashi & Tsuchiya, 2015):

$$X = 2\pi R[rand(1,N)].\times\ [\cos(rand(1,N))] \tag{3.8}$$

$$Y = 2\pi R\ [rand(1,N)]\ .\times\ [\sin(rand(1,N))] \tag{3.9}$$

where:
X is the x – coordinate matrix of the set of N users.
Y is the y – coordinate matrix of the set of N users
R is the range/radius of WiMAX coverage
.x signifies elementwise multiplication of matrixes
Rand (1, N) is a Matlab command that generates a row of N numbers ranging between 1 and 0 (forming a one by N matrix)

3.2.2.1 User Distribution Parameters

In the developed algorithm, the users can be restricted from occupying various portions of the coverage area, that is, a user can be bound within a set of layer. In order to define these boundaries a set of user distribution parameters are used. These parameters are α and β. Thus equations (3.8) and (3.9) are modified to yield X and Y (Kobayashi & Tsuchiya, 2015):

$$X = 2\pi R\left(\left(\frac{7-\alpha}{7(\beta+1)}\right)[rand(1,N)] + \frac{\beta}{\beta+1}\right) .X\ [\cos(rand(1,N))] \tag{3.10}$$

$$Y = 2\pi R\left(\left(\frac{7-\alpha}{7(\beta+1)}\right)[rand(1,N)] + \frac{\beta}{\beta+1}\right) .X\ \left[\sin\left(rand(1,N)\right)\right] \tag{3.11}$$

It could be observed that, equations(3.10) and (3.11) will eventually become equations(3.8) and (3.9) respectively if α = β = 0. This criterion is referred to as uniform distribution of users. In general, if α is zerothen β determines the position of the users from the BS, While if β is zero, then α determines the position of the user from the BS. In the developed algorithm, α and β are designed to vary from 0 to 6.α is a user distribution parameter that is used in shifting the user towards the BS while β is used in shifting the user away from the BS.

3.2.3 PSO baseObjective Function

The conventional PSO algorithm was designed to solve maximization or minimization problems. Consequently, it can only support an objective function to be minimized or maximized (Sarkar & Purkayastha, 2013). In this dissertation, PSO was proposed to solve a maximization problem. Therefore, the minimization problem in PSO has to be converted into maximization as shown (Sarkar & Purkayastha, 2013):

$$\max\left[F_{obj}\right] = \min_{k}\left[{}^{1}/_{F_{obj}}\right] \tag{3.12}$$

where:

k is the particle population
F_{obj} is the throughput of the system
$\max\left[F_{obj}\right]$ is the maximum throughput

If $\max\left[F_{obj}\right]$ is replaced by MT, Then, equation (3.12) can easily be rewritten as:

$$\mathrm{MT} = \min_{k}\left[{}^{1}/_{F_{obj}}\right] \tag{3.13}$$

where:

F_{obj} is the objective function and is defined as the aggregate data rate of the entire WiMAX network.

In order to develop an objective function for throughput maximization, there is need to consider some of the PSO model parameters. Such as:

(i) Population size of the particles, (popsize)/number of individuals

(ii) Number of parameters in each population/individual.

Therefore, a generation of particles has p particles each with np parameters such that it can be represented by a matrix with p rows and np columns. In the developed algorithm, np is chosen to be twice the number of layers in the network, that is,for the 7 layers network. np = 14. The value of p is defined at the beginning of the optimization process. Since matlab is proposed for simulation, the populationis generated randomly using:

$$G_i \ = rand(p, np)$$

where:

G_i is the ith generation matrix and it contains only values ranging from 0 to 1.
p is the number of particles in the swarm
np is the number of parameters in each particle (*np* = 14)

The maximum value of *i* is referred to as the number of generationsI_{max}

3.2.3.1 Throughput (Fobj)

In the developed algorithm, all the users in the WiMAX network environment are grouped into 7 based on the number of layers. The users' matrix can be defined using equation (3.14) as (Kobayashi & Tsuchiya, 2015):

$$u \ = \ [u_1, \ \ u_2, \dots \dots .. u_7] \tag{3.14}$$

where:

u is the user matrix of size 1 by 7

$u_1$to u_7 represents the number of users in layer 1 to 7, respectively.

The user matrix u is generated using a defined matlab function '`s_sub station`'. The maximum bit rate of each of the layers is also evaluated using the matlab function. 'ubitrates' and stored in a matrix $u_b$of size 1 by 7. Therefore, the maximum aggregate data rate of each layer per OFDM symbol per subcarrier can be stored in a matrix of data rates shown in:

$$ADR_i = \left[d_{a_1}, \ \ d_{a_2}, \dots \dots \dots .. d_{a_7}\right] \tag{3.15}$$

where:

$$d_{a_i} = u_i \times u_{b_i}[i = 1, 2, \ldots \ldots 7] \tag{3.16}$$

And

$$u_b = \left[u_{b_1}, u_{b_2}, u_{b_3} \ldots \ldots \ldots \ldots . u_{b_7}\right] \tag{3.17}$$

The generation matrix is used in allocating subcarriers and OFDM symbols to user of each of the layers.

Let N_{sc} be the total number of subcarriers to be allocated, let N_{os} be the total number of OFDM to be allocated. In order to improve quality of service, there is need to show that at least one subcarrier and one OFDM symbol is allocated to every layer containing at least one user, to achieve this, seven OFDMs and seven subcarriers are initially shared, one for each layer. Therefore, the allocation problem becomes that of (Nsc – 7) by (Nos – 7) subcarrier and OFDM symbol respectively. The objective function can, therefore, be formulated using equation in (Kobayashi & Tsuchiya, 2015) given as:

$$F_{obj} = round\left[\frac{\sum_{L=1}^{7}(N_{sc} - 7)g_L \cdot d_{a_L}}{\sum_{j=1}^{7} g_i}\right] \times round\left[\frac{\sum_{L=8}^{14}(N_{os} - 7)g_L \, . \, d_{a_L}}{\sum_{L=8}^{14} g_i}\right] \tag{3.18}$$

where:

$$G_i = [g_1, g_2, g_3, \ldots \ldots \ldots \ldots . . g_{14}] \tag{3.19}$$

g_1 *to* g_{14} are the parameters of a candidate particle in the ith generation. In general, the objective function of the ith generation F_{obj} is defined as in:

$$F_{obj} = \begin{bmatrix} F_{obj.1} \\ F_{obj.2} \\ F_{obj.3} \\ \vdots \\ F_{obj\,.p} \end{bmatrix} \tag{3.20}$$

$$F_{obj.t} = \sum_{k=1}^{7} u_{b.kt} \otimes u_{kt} \otimes L_{s.kt} \otimes L_{0.kt} \tag{3.21}$$

where:

$F_{obj}$is the objective function of the ith generation

$F_{obj.t}$is the objective function of the tth particle in the ith generation

$u_{b.kt}$is the maximum bit rate of the kth layer for the tth particle in the ith generation

$u_{kt}$is the number of users in the kth layer for the tth population in the ith generation

$L_{s.kt}$is the number of subcarriers allocated to layer k for the tth particle in the ith generation

$L_{o.kt}$is the number of OFDM symbols allocated to layer k for the tth particlein the ith generation

$\otimes$ represents elementwise multiplication

The objective function is used to evaluate the fitness of each of the particles while performing the PSO of the WiMAX network throughput. Figure 3.2 is a flow chart for evaluating the fitness of particles (Throughput) for each generation.

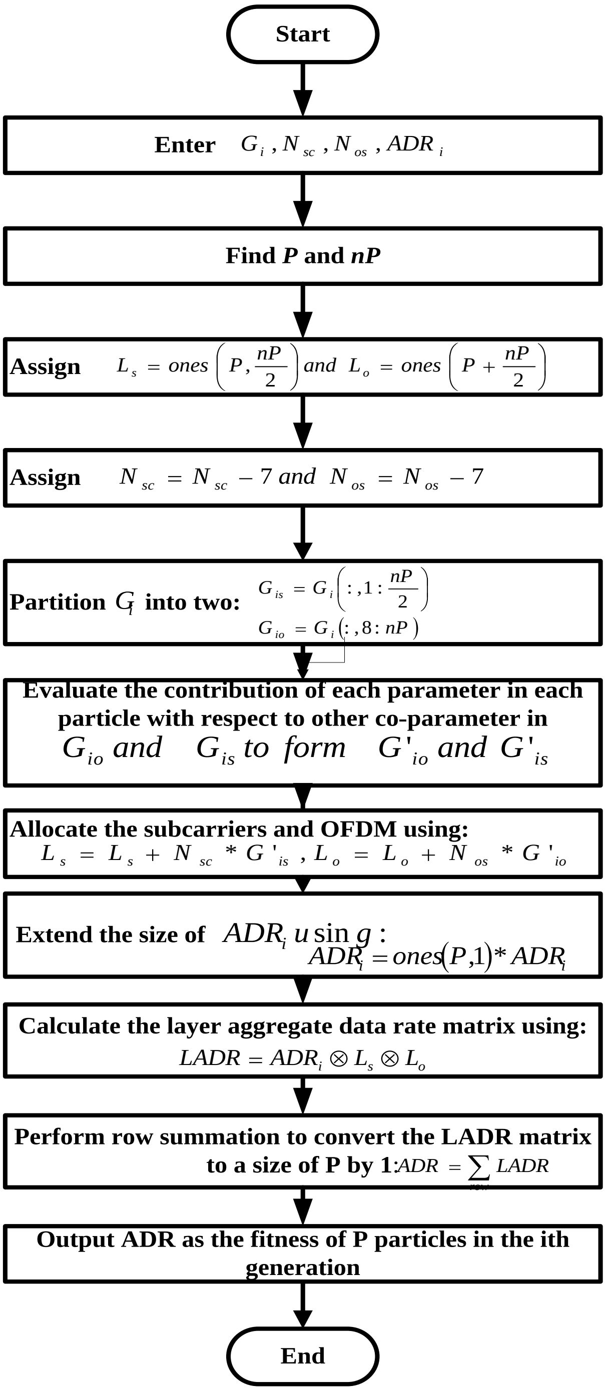


Figure 3.2: Flow Chart for the Objective Function

3.2.4 Proposed PSO Algorithm for Throughput Maximization

In the proposed research work, the conventional PSO is modified to suit application in WiMAX network for throughput maximization. The dimension of the optimization problem is greatly increased if the number of frames to be transmitted is estimated at the beginning of the optimization using (WiMAX-part M, 2006):

$$N_f = \frac{T_{sm}}{T_f} \tag{3.22}$$

where:

N_f is the number of frames to be transmitted
T_{sm} is the communication duration
T_f is the frame duration

In a typical WiMAX network, frame duration is a multiple of 5ms,that is, each frame last for 5ms, 10ms, 15ms, etc. Therefore, the number of OFDM symbols per frame can be estimated using(Ahmadzadeh, 2008):

$$N_{os} = \frac{T_f}{T_s} \tag{3.23}$$

where:

N_{OS} is the number of OFDM symbol per frame
T_S is the symbol duration determined using equation (3.2)

In the developed algorithm, frames are transmitted one after the other and the total network throughput is maximized. The following pseudo code can be used to transmit frames while performing throughput maximization.

```
i.      Start
ii.     Get the Tsm and Tf
iii.    Determine the number of frames
iv.     Transmit a frame
v.      Is there frame left
vi.     If yes
vii.    Nf = Nf – 1
viii.   Else
ix.     Stop
x.      End
xi.     Run PSO and optimize throughput
xii.    Is there any order better throughput
xiii.   If yes
xiv.    Throughput = better throughput
xv.     Else
xvi.    Continue
xvii.   End
xviii.  Go to line 5
xix.    Stop
```

3.2.5 Development of Improved PSO

The PSOwas initialized by obtaining a cognitive parameter C_1, which ranges between 0 and 3; a social parameter C_2 is computed using (Napoles *et al.,* 2012):

$$C_2 = 4 - C_1 \tag{3.24}$$

where a constriction parameter C, can take any value between 1 and 4, the number of particles p and the dimension of each particle np. 2-dimensional space of x and y is considered. The search space is from -3 to 3 in both dimensions.

The generation matrix G_i is then generated using equation $G_i = rand$ (p, np). The velocity of each particle is also generated using (Goudos, 2014):

$$V = rand\ (p, np)$$

The fitness of G_i can then be evaluated using the flow chart shown in Figure 3.3.

In order to determine the best particle,that is,the maximum throughput at the current generation, the fitnesses are inverted as in equation (3.13) to suit manipulation using the PSO algorithm. Therefore, the following are used to estimate the cost function, maximum throughput and the average throughput for the current generation (Giacomini, 2013).

$$Cost(i) = \frac{1}{\left(cost(i)\right)} \tag{3.25}$$

$$Minc(i) = Min\left(cost(i)\right) \tag{3.26}$$

$$Meanc(i) = Mean\left[\frac{1}{cost(i)}\right] \tag{3.27}$$

This process is repeated while storing the maximum throughput and average throughput at each of the generations for the entire particles in the Swarm. The following terms hold.

1. **Local Maximum Throughput:** A throughput is said to be local if and only if it is highest of all the throughputs estimated for every particle in a particular generation (swarm).

2. **Average Throughput:** The average throughput is defined for each generation as the sum of the throughputs of the entire particles in a particular generation divided by the total number of particles in that generation.
3. **Global Maximum Throughput:** This simply signifies the highest throughput obtained so far in the simulation or the highest of the entire throughput that have been computed.

The outputs of the proposed PSO algorithm are three matrixes each of size p by I_{max} where; p is the number of particles in each swarm and Imax is the total number of generation carried out. The three matrixes represent the following:

(1) Local Maximum throughput (MT_{lm})

(2) Global Maximum throughput (MT_{gm})

(3) Average throughput (MT_a)

The conventional PSO has the following pseudo code:

Start

Define necessary parameters and generate users

While iter < itermax

$$\boldsymbol{W = \frac{itermax - iter}{itermax}}$$

$$\boldsymbol{r_1 = rand(p, np)}$$

$$\boldsymbol{r_2 = rand(p, np)}$$

Update velocity using r_1, r_2, C_1, C_2, C, W

Update population using the velocity

Replace individual that are not fit

End while

Stop

In the proposed research work, the conventional PSO was improved to aid application in WiMAX for throughput maximization. The conventional PSO is characterized by fair allocation of speed to parameters and therefore, the individuals differ uniformly due to the fact that they are usually created using normal distribution probability in matlab.

In throughput maximization, fair distribution of parameters (closely related individuals) will result in fair allocation of subcarriers and OFDM symbols. The possibility of getting the maximum throughput can be increased by ensuring that the parameters of individuals vary widely so that large number of subcarriers and OFDM symbols can be allocated to the layer with the highest data rate having the highest number of users.

Therefore, the following modification was made to the conventional PSO to aid its speed of convergence, that is, with respect to equation $G_i = rand\ (p, np)$, G_i is modified using the following pseudocode:

```
Start
     Get the value of the generation matrix Gi
     Sort the element of Gi in ascending order
     Evaluate the ADRi of the ith generation
     for each particle
Arrange the parameters in increasing order of the
layer dai
     End for
Stop
```

This pseudocode ensures that the parameters of each particle are arranged in accordance with the aggregate data rate of the layers per subcarrier per OFDM symbol which in turn results in an increased convergence speed.

The flow chart for the improved PSO algorithm is shown in Figure 3.3

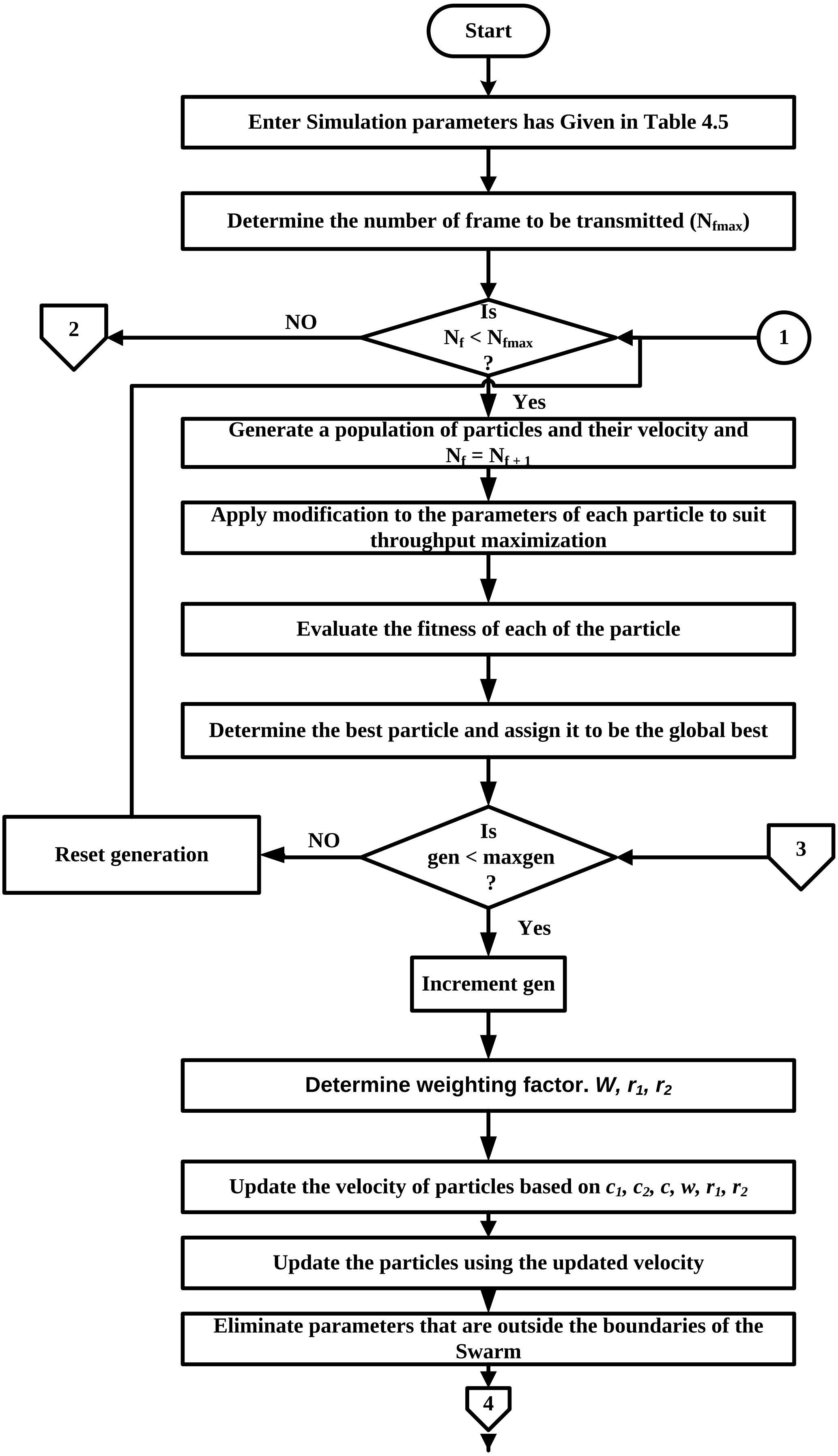


Figure 3.3: Flow Chart for the Improved PSO Algorithm

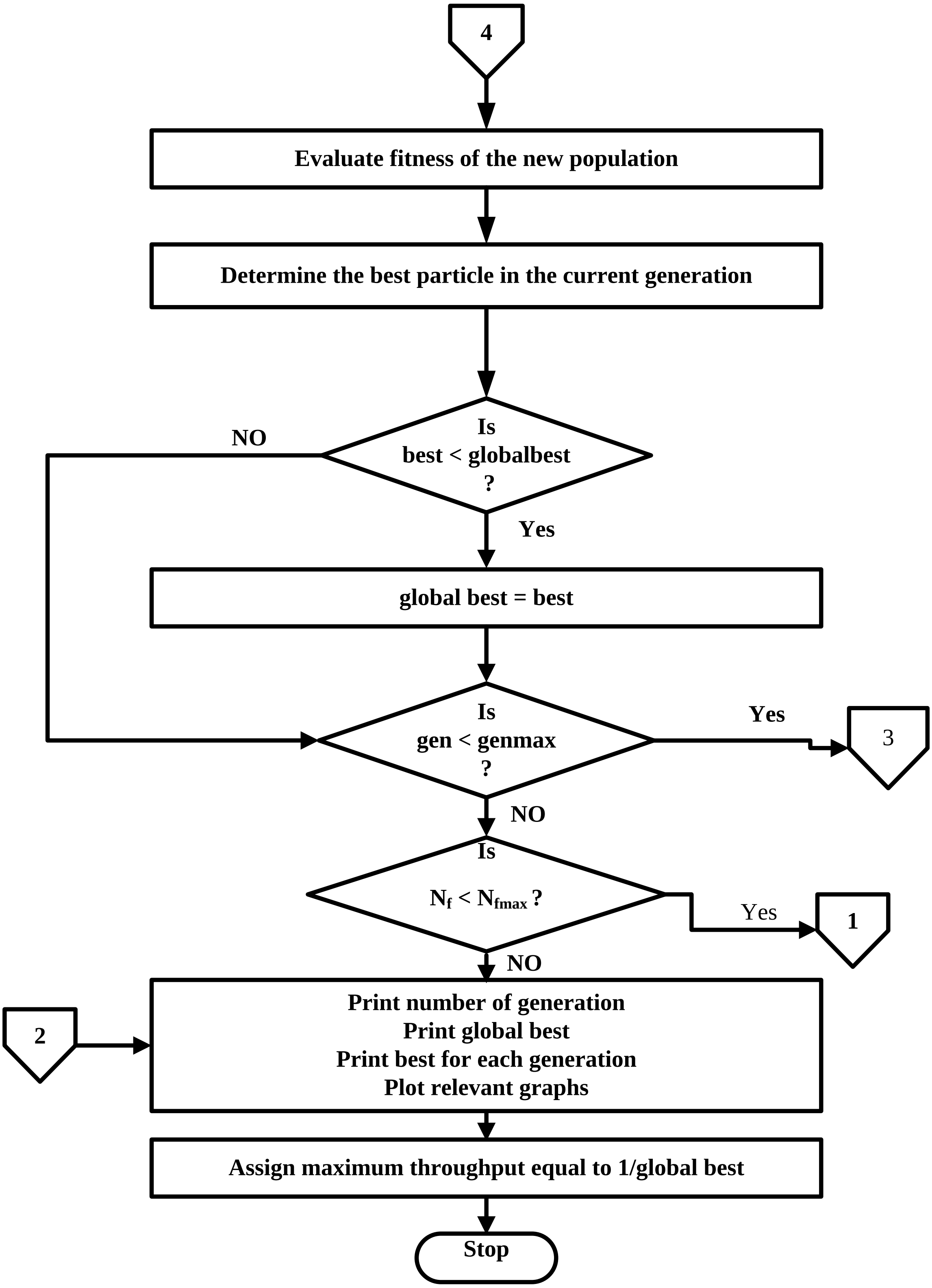


Figure 3.3: Flow Chart for the Improved PSO Algorithm

The following Matlab function files (m.files) form the structure of the proposed PSO based throughput maximization algorithm:

1. **Circles:** Construct concentric circular layers around the WiMAX base station;
2. **Mtobjectivefunc:** The PSO based maximum throughput objective function;
3. **S_sub station:** Constructs the user cardinality matrix U that stores the number of users in each layer;
4. **Ubitrate:** Computes the maximum allowable bit rates of each layer per subcarrier per OFDM symbol;
5. **Wimax:** Invokes the WiMAX analysis window (editor);
6. **Wimax_environment:** Creates the WiMAX circular cell and place a base station at its center (WiMAX environment);
7. **Wimaxanalysis:** Generate a WiMAX simulation user interface;
8. **Wimaxpso:** The PSO algorithm for WiMAX throughput maximization;

The m.files listed in items 1 to 8 are presented in Appendix A to G.

The m.files work together to maximize ADRand CDRof a WiMAX network in which the parameters are defined at the beginning of the simulation process.

CHAPTERFOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, the developed throughput maximization algorithm was used in carrying out simulation of WiMAX multicast service using the developed WiMAX network environment on MATLAB R2013b. A number of scenarios were simulated and the results were presented. The plots generated by the developed PSO algorithm were presented to enhance the understanding of the results obtained. The performance of the proposed algorithm was compared with the performance of maximum throughput algorithm for validation.

4.2 Aggregate Data Rate

In the proposed model of WiMAX network environment, the radius of coverage of the WiMAX network was chosen to range from 20/7 km to 20km, which formed a maximum coverage area of 1257km^2 and gave rise to 7 layers architecture. The seven layers were arranged in a concentric manner and in descending order of layer index (7, 6, 5…1) as shown in Figure 3.1. MCS is assigned to each of the layers as shown in Table 3.1. Fifty subscriber sub stations (50) where considered for each of the scenarios for RTPS.

Figure 4.1 is bar chart showing the throughput obtained in various scenarios of the distribution of subscriber sub stations over the WiMAX coverage area. The first bar (0) represented the maximum throughput obtained when the users were randomly distributed over the entire WiMAX coverage area. The plots generated by the developed PSO algorithm for this case (bar 0) are also shown in Figures 4.2, 4.3 and 4.4, respectively. The rest of the bar (1, 2, 3...7) represent the ADR obtained by restricting the users to exist only within a single layer. It could be observed that the highest achievable ADR corresponds to that obtained when all the users are within layer seven. This is so because layer 7 uses a MCS that offers the highest bit rate per subcarrier per OFDM symbol (64-QAM-3/4). It could also be observed that the height of the bar gradually decreases as the layer index decreases (from layer 7 to 1) which correspond to the aggregate data rate obtained as the distance from the WiMAX base station increases. Layers 4 and 5 were found to have the same aggregate data rate which corresponds to bar 4 and 5, respectively. This is so because they have equal data rate per subcarrier per OFDM symbol due to their respective MCS (16-QAM-3/4 and 64-QAM-1/2).

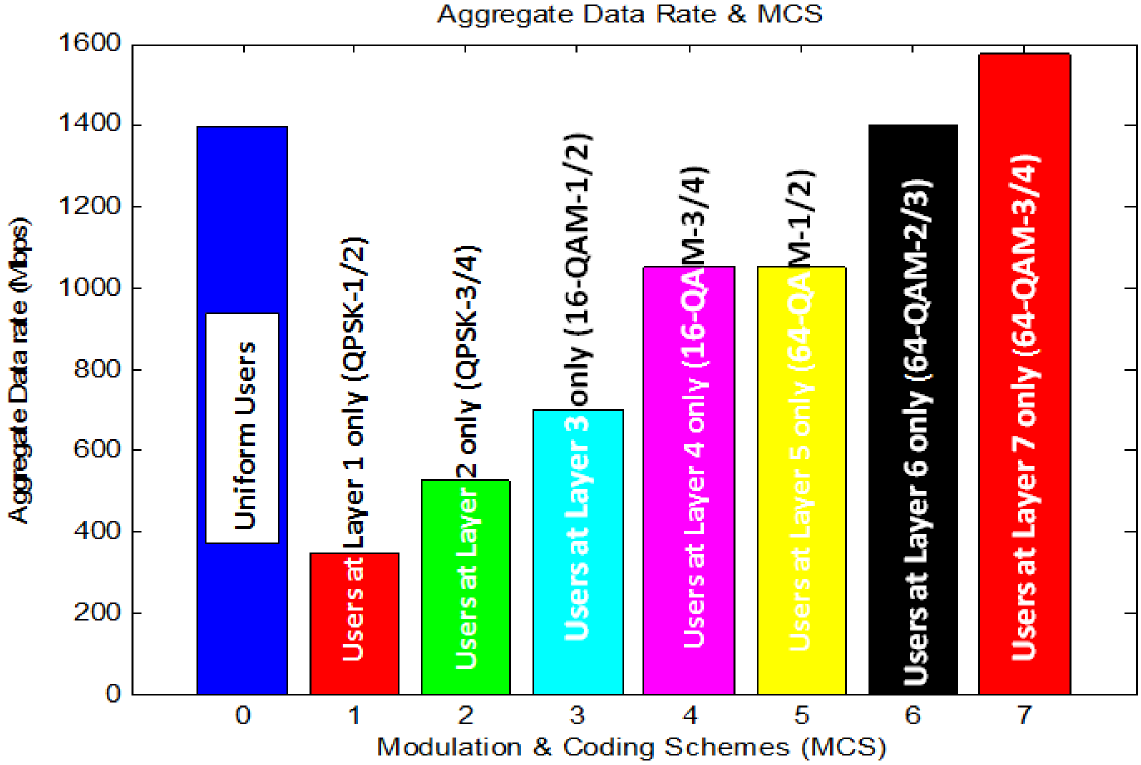


Figure 4.1: Maximum Throughput (Aggregate Data Rate) versus User Distribution

In order to demonstrate the effectiveness of the developed PSO algorithm in maximizing the aggregate data rate of WiMAX network, a scenario of 50 users uniformly distributed over a coverage area of 1257 km-square was simulated.

With reference to Figure 4.2, the improved PSO algorithm was found to converge to the maximum throughput at the fourth generation. It could be observed that the blue and green dotted lines which correspond to the local maximum and average throughput have their peaks at the 4th and 10th generation, and falls far low at any other generation. This shows that, the entire populations of particles in the entire generations are closely alike and has very low fitness value compared to the global best particle. This is as a result of large number of particle in each swarm at each of the generations.

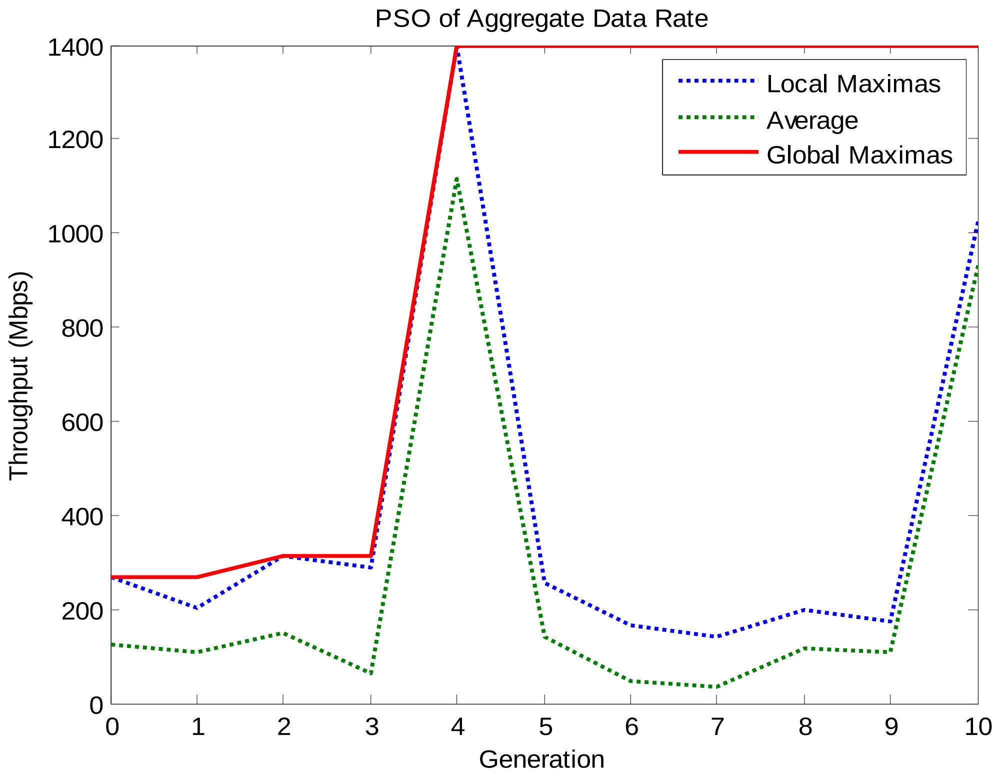


Figure 4.2: Rate of Convergence of Improved Algorithm for ADR

The developed PSO algorithm was also designed to generate a plot of the CDR maximization. Figure 4.3 was generated by the developed improved PSO algorithm. In Figure 4.3, the CDR can be observed to vary in the same pattern as the ADR. ADR represents the maximum data rate (bit rate) a usercan have over the WiMAX channel. The improved algorithm converges at the fourth generation which correspond to the optimal result obtained for CDR in the scheduling processing

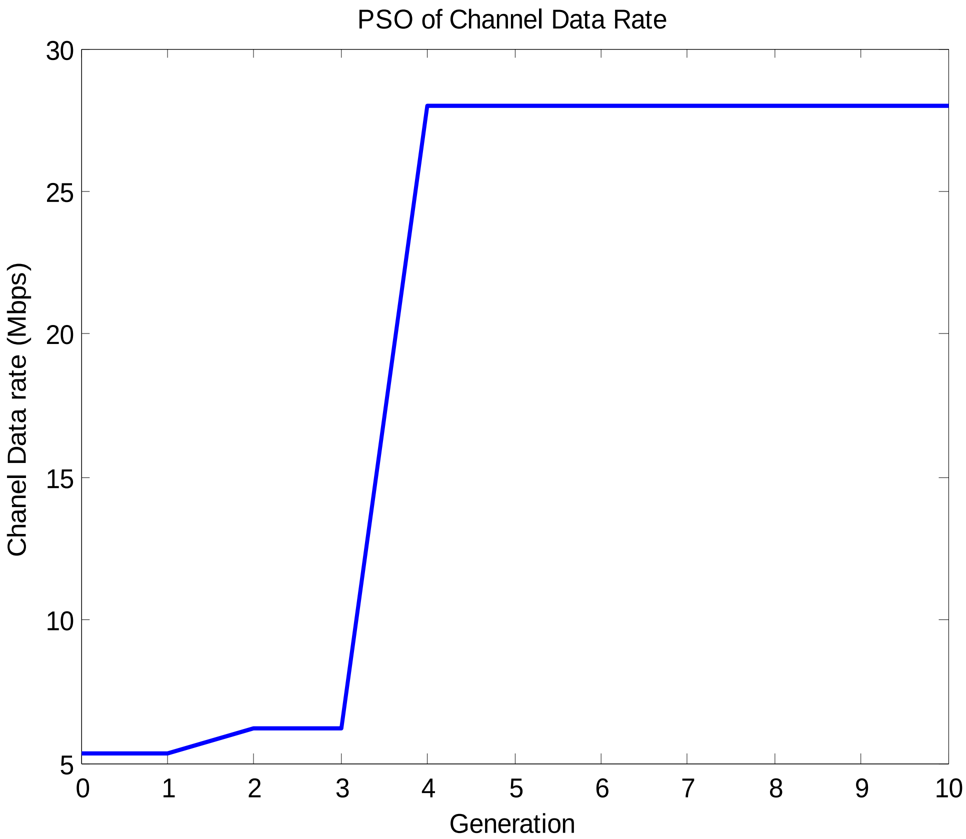


Figure 4.3: Rate of Convergence of Improved algorithm for CDR

Figure 4.4: shows the WiMAX coverage at the end of the simulation process. It could be observed that the users are randomly distributed over the WiMAX coverage area. This users move randomly after each frame is transmitted forming a mobile WiMAX.

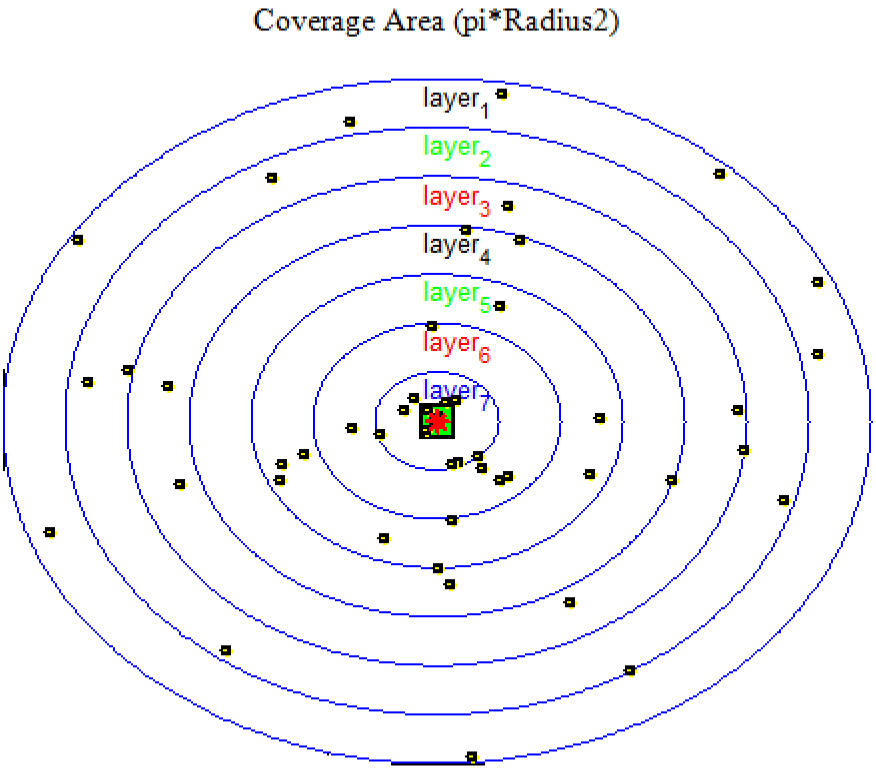
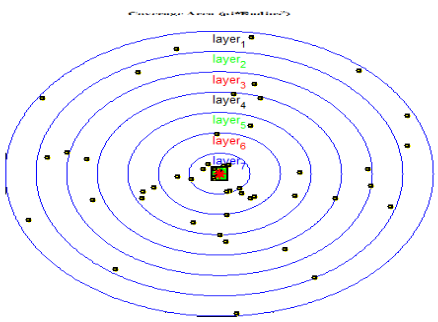
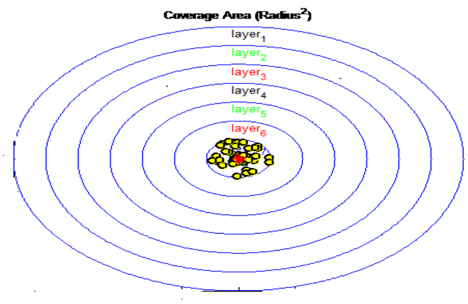


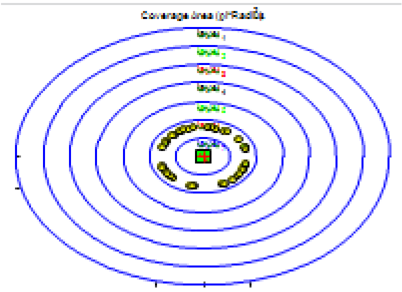
Figure 4.4: WiMAX Network Topology at Convergenceof Improved Algorithm for Uniform Users at the end of Simulation Process

It could be observed that, equations (3.10) and (3.11) eventually become equations (3.8) and (3.9) when $\alpha = \beta = 0$. This criterion is referred to as uniform distribution of users. Figures 4.5(a) to 4.5(h) are the plots of 50 users/MSs in the proposed WiMAX environment for different values of α and β that differentiate the distance of the mobile users within each layer from the base station, in order to maximize the system throughput and channel data rate.

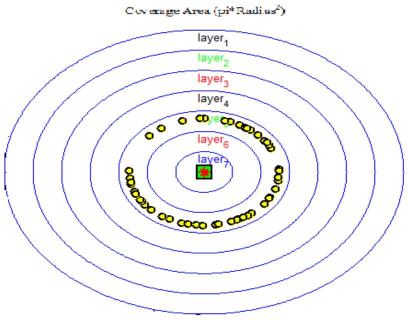




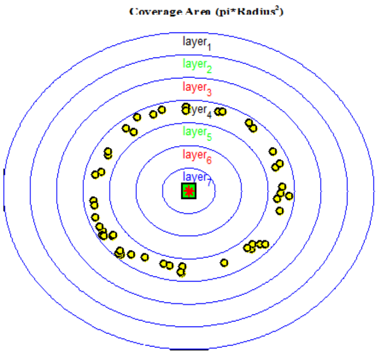
(a): Uniform Users across all layers(b): Users at Layer 7



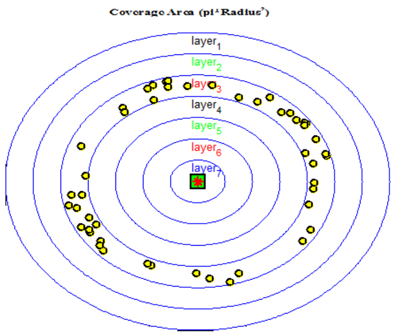
(c): Users at Layer 6



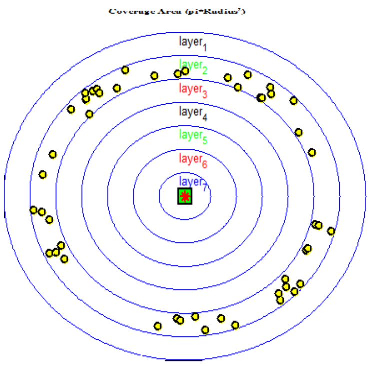
(d): Users at Layer 5



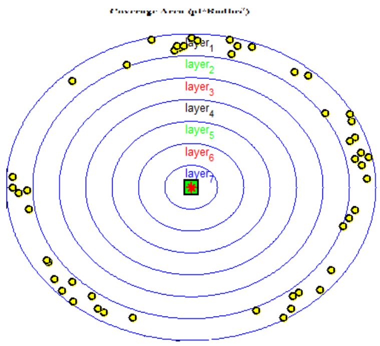
(e): Users at Layer 4



(f): Users at Layer 3



(g): Users at Layer 2



(h): Users at Layer 1

Figure 4.5: Users Representation of Different Layers

Table 4.1:Values of α and β for Figure 4.5(a) to 4.5(h)

Table 4.1:User Distribution Parameters

Figure 4.5	**α**	**β**
a	0	0
b	0	6
c	4	3
d	6	1.5
e	6	0.9
f	6	0.5
g	6	0.2
h	6	0

4.3 Summary of Results Obtained fromImproved PSO Algorithm

Table 4.2 is a summary of the results obtained for the various individual layers and the uniform distribution of users over the entire layers.

Table 4.2: Summary of ResultsObtained of Improved PSO Algorithm

Users of Layer (k)	**ADR (Mbps)**	**CDR (Mbps)**
Uniform distribution	1398	28
1	350	6.98
2	525	10.48
3	700	13.97
4	1050	20.95
5	1050	20.95
6	1400	27.94
7	1575	31.5

4.4 Performance Evaluation of Improved Algorithmand Maximum Throughput Algorithm

This subsection describe the performance of the developed algorithm evaluated by comparing the results obtained with that of maximum throughput algorithm using the simulation parameters as published by Araniti *et al.,* (2012).

The plots generated by the developed PSO algorithm represents the maximum throughput obtained when the users are uniformly distributed are shown in Figures 4.6 and 4.7, respectively. In order to demonstrate the performance of the developed PSO algorithm in maximizing the aggregate date rate of WiMAX network, a scenario of 50 users uniformly distributed over a coverage area of 1257km^2 was also simulated.

With reference to Figure 4.6, the improved PSO algorithm was found to converge to the maximum throughput at the fourth generation. It could be observed that the blue and green dotted lines which correspond to the local maximum and average throughput have their peaks at the 2nd and 4th generation, and falls far low at any other generation. Thisshows that, the entire populations of particles in the entire generations are closely alike and has very low fitness value compared to the global best particle.

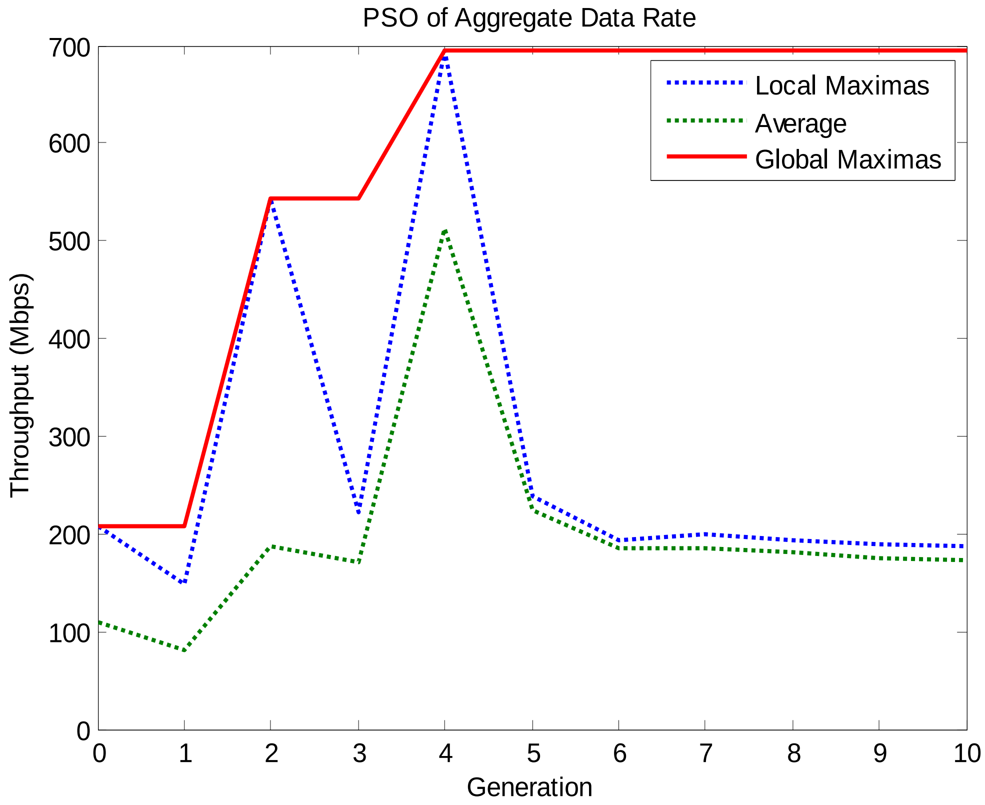


Figure 4.6: Performance Evaluation of Rate of Convergence of Improved Algorithm For ADR based on Simulation Parameters Published in Araniti *et al.*, (2012)

The developed PSO algorithm was also designed to generate a plot of the CDR maximization. Figure 4.7 was generated by the developed improved PSO algorithm. In Figure 4.7, CDR can be observed to vary in the same pattern as the ADR. ADR represents the maximum data rate (bit rate) a user can have over the WiMAX channel. Its description is synonymous to that of Figure 4.6described earlier.

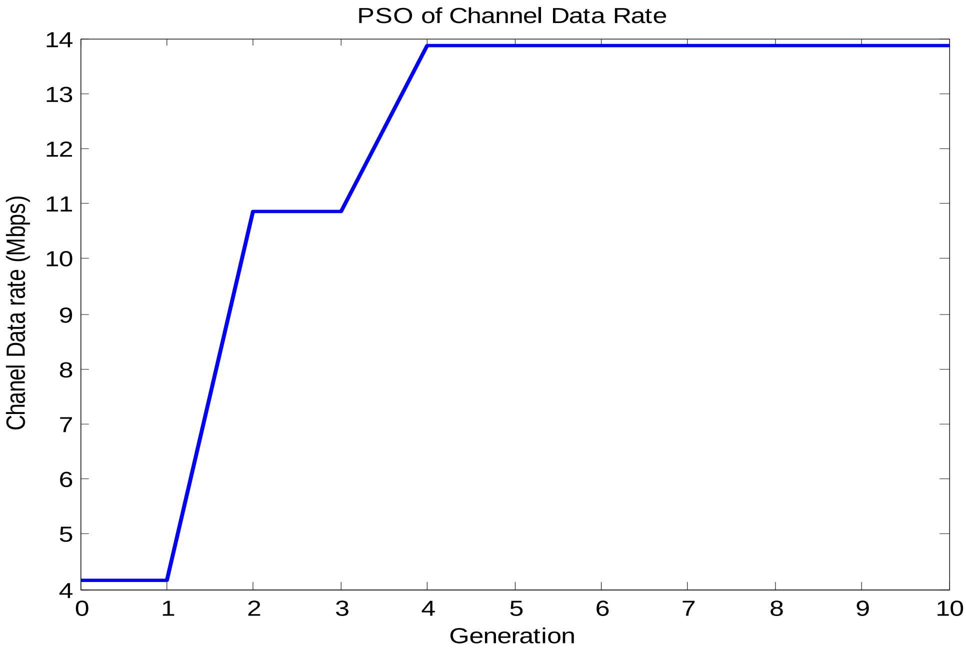


Figure 4.7: Performance Evaluation of Rate of Convergence of Improved algorithm For CDR based on Simulation Parameters Published in Araniti *et al.*, (2012)

4.5 Summary of Results Obtained basedon the Parameters Published in Work ofAraniti *et al.*, (2012) using the Improved Algorithm

Table 4.3 is a summary of the results obtained for the various layers and the uniform distribution of users over the entire layers using the published work of Araniti *et al.*, (2012).

Table 4.3: Summary of Results Obtained based on the Parameters Published in the Work of (Araniti *et al.*, 2012) using the Improved Algorithm

USERS of LAYER (k)	**ADR (Mbps)**	**CDR (Mbps)**
Uniform distribution	694	13.90
1	175	3.50
2	263	5.25
3	350	7.00
4	525	10.50
5	525	10.50
6	700	14.00
7	788	15.80

4.6 Comparison of Results

The results obtained using the maximum throughput algorithm that was developed by Araniti *et al.,* (2012) were compared with those of the developed algorithm. The deliverables used for comparison were the throughput and channel data rate. The comparison showed that the developed algorithm performed better than the maximum throughput algorithm. A maximum throughput/ADR of 694Mbps was achieved, which represents 88.88% of the maximum achievable aggregate data rate of the system as against that of maximum throughput algorithm of 400Mbps of 80%of the maximum achievable ADR of the system. The developed algorithm achieved 8.88% performanceimprovement of the entire system of IEEE802.16e.

Figure 4.8 shows the comparison between the developed algorithm and maximum throughput algorithm in terms of ADR. The blue line depicts the proposedmodel and the red line denotes the maximum throughput algorithm. The developed algorithm and maximum throughput algorithm achieved aggregate data rate of 694Mbps and 400Mbps, respectively when the users are uniformly distributed which is indicated in the origin of Figure 4.8. The respective values of the improved model and maximum throughput algorithm when the users were restricted to exist within layer 1, 4 and 7 were 175Mbps, 525Mbps, 788Mbps and 100Mbps, 400Mbps, 500Mbps, respectively.

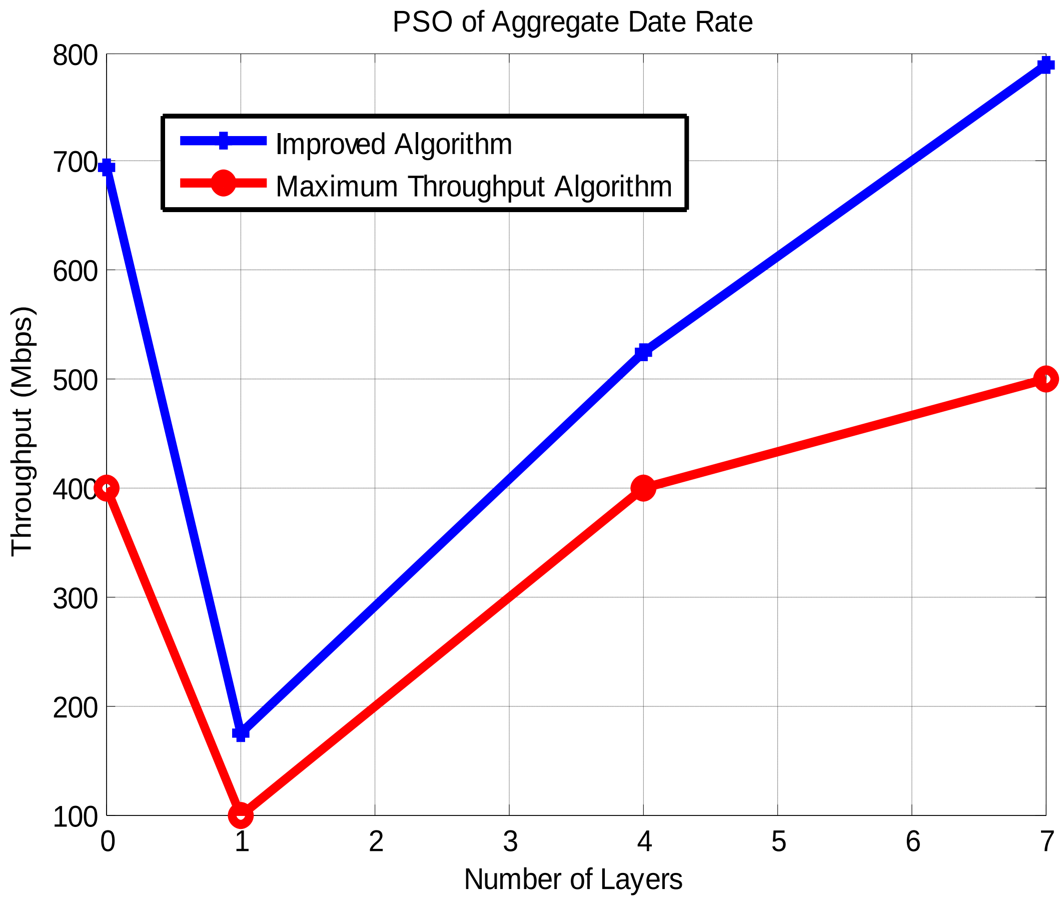


Figure 4.8: Comparison of the Rate of Convergence of Improve Algorithm with Maximum Throughput Algorithm for ADR

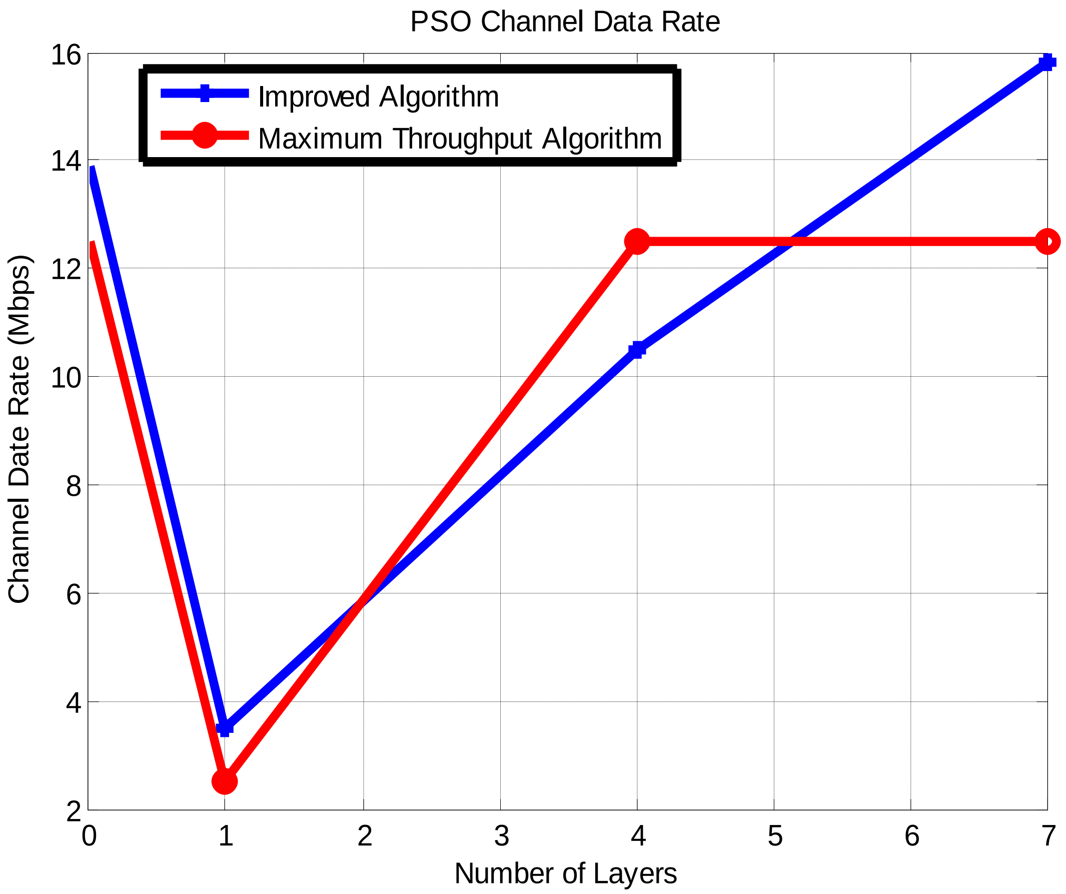


Figure 4.9: Comparison of the Rate of Convergence of Improved algorithm with Maximum Throughput Algorithm for CDR

Figure 4.9 shows the comparison between the improvedalgorithm and maximum throughput algorithm in terms of CDR. The blue line depicts the improvedalgorithm and the red line denotes the maximum throughput algorithm. The improved algorithm and maximumthroughput algorithm achieved a CDR of 13.9Mbps and 12.5Mbps, respectively when the users were uniformly distributed which is indicated in the origin of Figure 4.9. The respective values of the developed algorithm and maximum throughput algorithm when the users were restricted to exist within layer 1, 4 and 7 were 3.5Mbps, 10.5Mbps, 15.8Mbps and 2.5Mbps, 12.5Mbps, 12.5Mbps,respectively. This is an indication that the developed algorithm performed better than the maximum throughput algorithm by 8.88%. The comparison of results obtained using the two algorithms are summarizedin Table 4.4. The dash lines depict layers that were not simulated in maximum throughput algorithm because MCSs responsible for these layers were not selected for packet transmission.

Table 4.4: Comparison of Resultsof Improved Algorithm and Maximum Throughput Algorithm

USERSof LAYER (k)	**DEVELOPED ALGORITHM**		**MAXIMUM THROUGHPUT ALGORITHM**	
	ADR (Mbps)	**CDR (Mbps)**	**ADR (Mbps)**	**CDR (Mbps)**
Uniform distribution	694	13.9	400	12.5
1	175	3.5	100	2.5
2	263	5.25	-	-
3	350	7	-	-
4	525	10.5	400	12.5
5	525	10.5	-	-
6	700	14	-	-
7	788	15.8	500	12.5

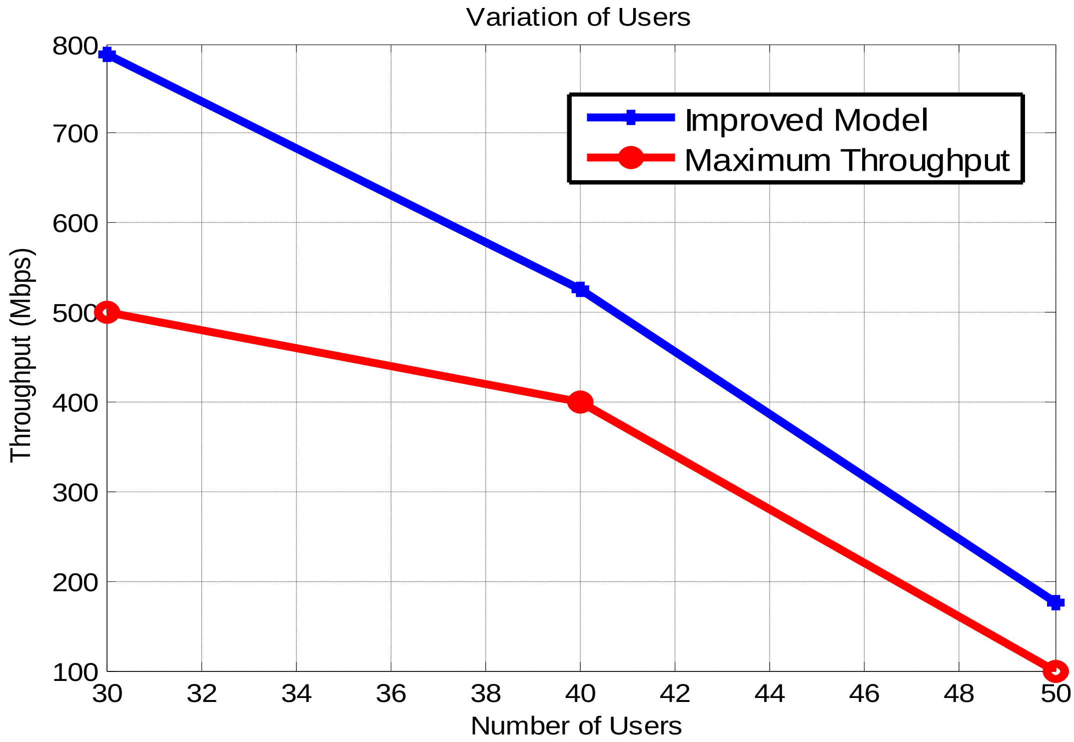


Figure 4.10: Comparison of Rate of Convergence of Improved Algorithm and Maximum Throughput Algorithm in term of users' variation(ADR)

Figure 4.10 shows comparison of the aggregate data rate of the system with respect to users' variation. It could be observed that the developed algorithm performed better than maximum throughput algorithm as the number of users increase.

4.7 Validation

Validation was done by comparing the results obtained using the developed algorithm with those published in the work of Araniti *et al*., (2012). The comparison was done based on two important metrics, which are throughput and channel data rate as shown in Figures 4.7 and 4.8, respectively.

Details of the simulation parameters are shown in Table 4.5.

Table 4.5: Simulation Parameters of WiMAX

Parameters	Value
Channel bandwidth	10MHz
Frequency band	3.5MHz
DL/UL ratio	35/12
Population size	500
Maximum number of generation	10
Cognitive parameter	1
Constriction factor	1
Number of used subcarriers	720
Number of OFDM symbols	35
Radius of coverage	20km
Number subscriber stations	50
Number of bits per modulation symbol for 7 layers	See Table 3.1
Sampling factor (n)	28/25
Cyclic prefix (G)	1/8
Number of frames	500
FFT size	1024
Duplexing mode	TDD
Link orientation	DL
Traffic	RTPS
Sub-channelization	PUSC

The reasons for chosen the various simulation parameters of WiMAX are obtained in (IEEE 802.16 standard, 2005, Ahmadzadeh, 2008 and Napoles *et al.*, 2012)

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter presents the summary of the whole dissertation. Conclusion, limitations encountered during the course of this research and recommendations for further work are also presented.

5.2 Summary of Findings

This research has proposed the development of an improved scheduling algorithm using PSO, which was aimed at maximizing throughput and CDR while guaranteeing the desire QoS in a WiMAX network. The performance of the algorithm was validated by comparing the results obtained with those of maximum throughput algorithm. It was found that the proposed algorithm outperforms the maximum throughput algorithm with 8.88% of the maximum achievable ADR of the system.

5.3 Conclusion

WiMAX environment was modeled on seven concentric layers based on modulation and coding schemes which were proposed for packet transmission to subscriber substations within the WiMAX coverage area. The research work developed an improved scheduling algorithm using PSO based on sub-group formation by incorporating adaptive modulation and coding scheme for link adaptation, with a view to maximizing throughput and CDR while guaranteeing the desire QoS of the system. The algorithm was developed and implemented in Matlab R2013b. The performance of the algorithm was evaluated by comparing the results obtained with those of maximum throughput algorithm. The results obtained showed that the improved algorithm had better maximization ability as compared to those of maximum throughput algorithm. A maximum throughput/ADR of

694Mbps was achieved, which represented 88.8% of the maximum achievable aggregate data rateof the system as compared with maximum throughput algorithm of 400Mbps, which represented 80% of the maximum achievable aggregate data rate of the system. This result signifies 8.88% improvement in maximization of throughput in WiMAX network environment. This is an indication of the validity of the ImprovedAlgorithm.

5.4 Limitations

The limitations of this research work are itemized as follows:

i. This research work did not consider fairness in the distribution of the network resources in order to avoid tradeoff between throughput and fairness

ii. This research work did not evaluate delay in the scheduling process because the time of packet transmission was not considered.

5.5 Recommendations for Further Work

The following possible areas of further work are recommended for consideration.

(i) A hybrid algorithm can be developed based on heuristic techniques for fair distribution of network resources.

(ii) Development of an improvealgorithm based on reducing the network delay can be considered.

(iii) The developed algorithm can be applied to network design and analysis with a view to determining the traffic class to be deployed in the network.

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APPENDIX A

m. file ‘circles’

```
function circle(x,y,r)
%x and y are the coordinates of the center of the circle
%r is the radius of the circle
%0.01 is the angle step, bigger values will draw the circle faster but
%you might notice imperfections (not very smooth)
ang=0:0.01:2*pi;
xp=r*cos(ang);
yp=r*sin(ang);
plot(x+xp,y+yp);
```

APPENDIX B

m. file 'mtobjectivefunc'

```
function
MaxT=mtobjectivefunc(par,Nused,Nofdm,radius,no_ss,layers,alpha,beta,B,b
pms,cod_rate,n,Nfft,G)
[lentpar,bretpar]=size(par);
Uc=s_sub station(radius,no_ss,layers,alpha,beta);
Layer_Rate_max=B*ubitrates(B,bpms,cod_rate,n,Nfft,Nused,G)/(10e6*Nused*
Nofdm/(sum(Uc~=0))^1.05);
maxi=Layer_Rate_max.*Uc;
for y=1:length(Layer_Rate_max)
if maxi(y)==max(maxi)
        found=y;
end
end
Ones=ones(lentpar,1);
subcarrier_alloctn=par(1:lentpar,1:bretpar/2);
ofdmsymb_alloctn=par(1:lentpar,((bretpar/2)+1):end);
subcarrier_alloctn(:,found)=Ones;
ofdmsymb_alloctn(:,found)=Ones;
subcarrier_alloctn=subcarrier_alloctn./(sum(subcarrier_alloctn,2)*ones(
1,bretpar/2));
ofdmsymb_alloctn=ofdmsymb_alloctn./(sum(ofdmsymb_alloctn,2)*ones(1,bret
par/2));
opt_subc_alloc=ones(lentpar,bretpar/2);
opt_ofdms_alloc=ones(lentpar,bretpar/2);
avail_nused=Nused-bretpar/2;
avail_nofdm=Nofdm-bretpar/2;
nused_distribution=floor(avail_nused*subcarrier_alloctn);
nofdm_distribution=floor(avail_nofdm*ofdmsymb_alloctn);
nused_distribution(:,1)=nused_distribution(:,1)+(avail_nused-
sum(nused_distribution,2));
nofdm_distribution(:,1)=nofdm_distribution(:,1)+(avail_nofdm-
sum(nofdm_distribution,2));
opt_subc_alloc=fliplr(nused_distribution+opt_subc_alloc);
opt_ofdms_alloc=fliplr(nofdm_distribution+opt_ofdms_alloc);
carrier_ofdms=(opt_subc_alloc.*opt_ofdms_alloc);
if sum(Uc==0)==0
MaxT=sum(carrier_ofdms.*(ones(lentpar,1)*Layer_Rate_max).*(ones(lentpar
,1)*Uc),2);
end
if sum(Uc==0)~=0
    opt_subc_alloc=fliplr(opt_subc_alloc);
    opt_ofdms_alloc=fliplr(opt_ofdms_alloc);
t=0;
 U_zero=[];
for k=1:length(Uc)
if Uc(k)==0
    t=t+1;
    U_zero(t)=k;
end
end
if ~isempty(U_zero)
    unused=0;
    unofdm=0;
for g=1:length(U_zero)
        unused=unused+opt_subc_alloc(:,U_zero(g));
        unofdm=unofdm+opt_ofdms_alloc(:,U_zero(g));
        opt_subc_alloc(:,U_zero(g))=zeros(lentpar,1);
```

```
        opt_ofdms_alloc(:,U_zero(g))=zeros(lentpar,1);
end
end
opt_subc_allocn=opt_subc_alloc;
opt_ofdms_allocn=opt_ofdms_alloc;
ofdmsymb_alloctn=par(1:lentpar,1:(layers-length(U_zero)));
subcarrier_alloctn=par(1:lentpar,1:(layers-length(U_zero)));
ofdmsymb_alloctn=ofdmsymb_alloctn./(sum(ofdmsymb_alloctn,2)*ones(1,(lay
ers-length(U_zero))));
subcarrier_alloctn=subcarrier_alloctn./(sum(subcarrier_alloctn,2)*ones(
1,(layers-length(U_zero))));
opt_subc_alloc=ones(lentpar,(layers-length(U_zero)));
opt_ofdms_alloc=ones(lentpar,(layers-length(U_zero)));
avail_nused=unused-(layers-length(U_zero));
avail_nofdm=unofdm-(layers-length(U_zero));
nused_distribution=floor((avail_nused*ones(1,(layers-
length(U_zero)))).*subcarrier_alloctn);
nofdm_distribution=floor((avail_nofdm*ones(1,(layers-
length(U_zero)))).*ofdmsymb_alloctn);
nused_distribution(:,1)=nused_distribution(:,1)+(avail_nused-
sum(nused_distribution,2));
nofdm_distribution(:,1)=nofdm_distribution(:,1)+(avail_nused-
sum(nused_distribution,2));
opt_subc_alloc=fliplr(nused_distribution+opt_subc_alloc);
opt_ofdms_alloc=fliplr(nofdm_distribution+opt_ofdms_alloc);
l=0;
for f=1:length(Uc)
if Uc(f)~=0
        l=l+1;
        opt_subc_allocn(:,f)=opt_subc_allocn(:,f)+opt_subc_alloc(:,l);

opt_ofdms_allocn(:,f)=opt_ofdms_allocn(:,f)+opt_ofdms_alloc(:,l);
end
end
carrier_ofdms=(opt_subc_allocn.*opt_ofdms_allocn);
MaxT=sum(carrier_ofdms.*(ones(lentpar,1)*Layer_Rate_max).*(ones(lentpar
,1)*Uc),2);
end
```

APPENDIX C

m. file ‘s_sub station’

```
function Uc=s_sub station(radius,no_ss,layers,alpha,beta)
[SS_possition]=wimax_environment(radius,no_ss,layers,alpha,beta);
close('WiMAX COVERAGE')
layer1=[];
layer2=[];
layer3=[];
layer4=[];
layer5=[];
layer6=[];
layer7=[];
for user=1:length(SS_possition)
if 0<=SS_possition(user)
if SS_possition(user)<radius/7
        layer1=[layer1,SS_possition(user)];
else
if radius/7<=SS_possition(user)
if SS_possition(user)<2*radius/7
            layer2=[layer2,SS_possition(user)];
else
if 2*radius/7<=SS_possition(user)
if SS_possition(user)<3*radius/7
                layer3=[layer3,SS_possition(user)];
else
if 3*radius/7<=SS_possition(user)
if SS_possition(user)<4*radius/7
                    layer4=[layer4,SS_possition(user)];
else
if 4*radius/7<=SS_possition(user)
if SS_possition(user)<5*radius/7
                        layer5=[layer5,SS_possition(user)];
else
if 5*radius/7<=SS_possition(user)
if SS_possition(user)<6*radius/7
                            layer6=[layer6,SS_possition(user)];
else
                            layer7=[layer7,SS_possition(user)];
end
end
end
end
end
end
end
end
end
end
end
end
end
Uc=fliplr([length(layer1),length(layer2),length(layer3),length(layer4),
length(layer5),length(layer6),length(layer7)]);
```

APPENDIX D

m. file 'ubitrates'

```
function Layer_Rate_max=ubitrates(B,bpms,cod_rate,n,Nfft,Nused,G)
%Layer_Rate_max=ubitrates(B,radius,no_ss,layers,bpms,cod_rate,n,Nfft,Nu
sed,
%G) is used to estimate the maximum attainable bitrate of a layer with
MCS
%defined using the matrix bpms and cod_rate
%B=system bandwidth
%bpms=number of bits per modulation symbol of each of the layers
%bpms is matrix of size 1 by 7
%cod_rate=coding rate of each of the modulation and coding scheme it
has the
%same size as bpms
% n=sampling factor
% Nfft is the total number of subcarriers in the system
%Nused is the number of used subcarriers
% G cyclic prefix of each frame. it also defined as Tg/Tb
Fs=floor(n*B/800)*800;
delta_f=Fs/Nfft;
Tb=1/delta_f;
Ts=(G+1)*Tb;
Rate_max=Nused*bpms.*cod_rate/Ts;
Layer_Rate_max=Rate_max;
```

APPENDIX E

m. file ‘wimax_environment’

```
function [SS_possition]=wimax_environment(radius,no_ss,layers,alpha,beta)
for draw=1:1     %Creating the WiMAX coverage area with users
%situated at various layers
figure('name','WiMAX COVERAGE')
hold on
for k=0:layers-1
    circle(0,0,radius*(layers-k)/layers)
if k==0
    text(-radius/35,radius*(layers-k)/layers-radius/(2*layers) , 'layer_1',
'Color', 'k')
end
if k==1
    text(-radius/35,radius*(layers-k)/layers-radius/(2*layers) , 'layer_2',
'Color', 'g')
end
if k==2
    text(-radius/35,radius*(layers-k)/layers-radius/(2*layers) , 'layer_3',
'Color', 'r')
end
if k==3
    text(-radius/35,radius*(layers-k)/layers-radius/(2*layers) , 'layer_4',
'Color', 'k')
end
if k==4
    text(-radius/35,radius*(layers-k)/layers-radius/(2*layers) , 'layer_5',
'Color', 'g')
end
if k==5
    text(-radius/35,radius*(layers-k)/layers-radius/(2*layers) , 'layer_6',
'Color', 'r')
end
if k==6
    text(-radius/35,radius*(layers-k)/layers-radius/(2*layers), 'layer_7',
'Color', 'b')
end
    hold on
end
plot(0,0,'--rs','LineWidth',2,...
'MarkerEdgeColor','k',...
'MarkerFaceColor','g',...
'MarkerSize',15)
xlabel('Distance (km)')
hold on
ylabel('Distance (km)')
hold on
title('Coverage Area (Radius^2)')
hold on
SS_possition=(1/(beta+1))*((layers-alpha)/layers)*radius*rand(1,no_ss)+(1-
(1/(beta+1)))*radius;
directn=2*pi*(rand(1,no_ss));
for h=1:no_ss
    plot(SS_possition(h)*sin(directn(h)),SS_possition(h)*cos(directn(h)),'--
go','LineWidth',2,...
'MarkerEdgeColor','k',...
'MarkerFaceColor','y',...
'MarkerSize',4)
   hold on
end
plot(0,0,'--r*','LineWidth',2,...
'MarkerEdgeColor','r',...
'MarkerFaceColor','g',...
'MarkerSize',10)
end
```

APPENDIX F

m. file 'WiMAXanalysis'

```
function WiMAXanalysis
%_________________________WiMAX ANALYSI &
SIMULATION_________________________
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%
% Matlab File for  WiMAX analysis: By:::::::: amkabudee@www.zee.......
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%
%-----------------------------------------------------------------------
----
%............''''''''''''................''''''''''''
%...............
% WORning!!!!!!!!!!!!!!!
% MAKE SURE THAT THE ENTIRE SUB-PROGRAMS ARE SAVED IN A DIFFERENT.....
%.......... LOCATION IN CASE OF ANY MODIFICATION THAT..........
%......................RESULTS IN PROGRAM..................
%.........................MALFUNCTIONING.................
%............. THE SAVED FILES WILL SERVE AS BACKUP.................
% .......
%
% SIMPLY ENTER THE APPROPRIATE VALUE FOR EACH OF THE FOLLOWING
PARAMETWERS
% AND CLICK THE <RUN> BUTTON SIMULATE WiMAX THROUGHPUT MAXIMIZATION
% A BRIEF DESCRIPTION OF THE RESPECTIVE VALUES ARE PRESENTED
ACCORDINGLY
%
%....!!!!!!! ----------YOU CAN MODIFY ANY OF THE FOLLOWING VALUES------
-
%______________________________________________________________________
popsize =10; %  population of particles in swamp varies from 1 to
750000
%                 the more the population the higher the computation
time
%______________________________________________________________________
maxit =10;     %  Maximum number of generation/iteration in pso
%                 the more the generations the higher the computation
time
%______________________________________________________________________
cogntpar =1;   %  Cognitive parameter of the swamp
%                 its value affects the velocity of the swamp
%______________________________________________________________________
Constfact =1; %  Constriction factor of the swamp
%                 its value affects the velocity of the swamp
%______________________________________________________________________
Nused =720;    %  The number of used subcarriers
%                 usually specified for a given operating Bandwidth
%______________________________________________________________________
Nofdm =35;     %  The number of OFDM symbols
(Nofdm=frame_duration/symbol_duration)
%                 usually specified for a given operating Bandwidth and
T_frame
%______________________________________________________________________
radius =20;    %  (km) Range of coverage usually equal to the radius if
a circular
%                 cell is assumed
%______________________________________________________________________
no_ss =50;     %  Number of  subscriber sub stations/users
```

```
%                 the more the users the higher the computation time
%______________________________________________________________________
layers =7;     %  The possible modulation schemes which are available
for data
%                 transmission (MCS)
%______________________________________________________________________
alpha =6;      %  User distribution parameter, takes a value of 0 to 6
%                 used in shifting the user towards the  base  station
%______________________________________________________________________
beta =0;       %  User distribution parameter, takes a value of 0 to 6
%                 used in shifting the user away from the  base  station
%______________________________________________________________________
B =10000000;   %  Network Bandwidth
%______________________________________________________________________
bpms =[2,2,4,4,6,6,6]; % The number bits per modulation symbol for the
7 layers
%    [QPSK_1/2, QPSK_3/4, 16QAM_1/2, 16QAM_3/4, 64QAM_1/2, 64QAM_2/3,
64QAM_3/4]
%______________________________________________________________________
cod_rate =[1/2,3/4,1/2,3/4,1/2,2/3,3/4]; % The coding rates for the 7
layers
%                 usually specified for a given modulation type
%______________________________________________________________________
n=28/25;       %  The sampling factor
%                 usually specified for a given operating Bandwidth
%______________________________________________________________________
Nfft=1024;     %  The number of requred Fast Fourier Transform
%                 usually specified for a given Nused
%______________________________________________________________________
G=1/8;         %  Cyclic prefix ratio (Tb/Tg)
%                 usually specified for a given operating Bandwidth
%______________________________________________________________________
no_frames=5; %  Number of rames that can be tansmitted over the
simulation time
%                 usually specified for a given simulation time and
frame duration
%______________________________________________________________________
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
%-------STOP............
%______________________STOP___________________
%...................................STOP...............
%....!!!!!!! ----------YOU CANNOT MODIFY ANY OF THE FOLLOWING VALUES---
----
%______________________________________________________________________
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%
Maximum_Throughput=WiMAXpso(popsize,maxit,cogntpar,Constfact,Nused,Nofd
m,radius,no_ss,layers,alpha,beta,B,bpms,cod_rate,n,Nfft,G,no_frames)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%
%----------------------------------------------------------------------
----
```

APPENDIX G

m. file 'WiMAXpso'

```
function
MT=WiMAXpso(popsize,maxit,cogntpar,Constfact,Nused,Nofdm,radius,no_ss,l
ayers,alpha,beta,B,bpms,cod_rate,n,Nfft,G,no_frames)
% Particle Swarm Optimization - PSO
% Haupt & Haupt
% 2003
clc
Mt=[];
Minc=[];
Meanc=[];
Globalmin=[];
for frame=1:no_frames
ff = 'mtobjectivefunc'; % Objective Function
% Initializing variables
%popsize = 10; % Size of the swarm
%npar = 2; % Dimension of the problem
%maxit = 100; % Maximum number of iterations
%c1 = 1; % cognitive parameter
%c2 = 4-c1; % social parameter
%C=1; % constriction factor
% Initializing swarm and velocities
c1=cogntpar;
c2=4-c1;
C=Constfact;
npar=2*layers;
par=rand(popsize,npar); % random population of
% continuous values
vel = rand(popsize,npar); % random velocities
% Evaluate initial population
cost=feval(ff,par,Nused,Nofdm,radius,no_ss,layers,alpha,beta,B,bpms,cod
_rate,n,Nfft,G); % calculates population cost using
% ff
cost=cost.^-1;
minc(1)=min(cost); % min cost
meanc(1)=mean(cost.^-1); % mean cost
globalmin=minc(1); % initialize global minimum
% Initialize local minimum for each particle
localpar = par; % location of local minima
localcost = cost; % cost of local minima
% Finding best particle in initial population
[globalcost,indx] = min(cost);
globalpar=par(indx,:);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Start iterations
iter = 0; % counter
while iter < maxit
iter = iter + 1;
% update velocity = vel
w=(maxit-iter)/maxit; %inertia weiindxht
r1 = rand(popsize,npar); % random numbers
r2 = rand(popsize,npar); % random numbers
vel = C*(w*vel + c1 *r1.*(localpar-par) +...
c2*r2.*(ones(popsize,1)*globalpar-par));
% update particle positions
par = par + vel; % updates particle position
overlimit=par<=1;
underlimit=par>=0;
```

```
par=par.*overlimit+not(overlimit);
par=par.*underlimit;
% Evaluate the new swarm
cost =
feval(ff,par,Nused,Nofdm,radius,no_ss,layers,alpha,beta,B,bpms,cod_rate
,n,Nfft,G); % evaluates cost of swarm
% Updating the best local position for each particle
cost=cost.^-1;
bettercost = cost < localcost;
localcost = localcost.*not(bettercost) +...
                             cost.*bettercost;
localpar(bettercost,:) =par(bettercost,:);
% Updating index g
[temp, t] = min(localcost);
if temp<globalcost
indx=t;
globalpar=par(indx,:);
globalcost=temp;
end
%disp([iter globalpar globalcost]); % print output each
% iteration
minc(iter+1)=min(cost); % min for this
% iteration
globalmin(iter+1)=globalcost; % best min so far
meanc(iter+1)=mean(cost.^-1); % avg. cost for
% this iteration
end% while
iters=0:length(minc)-1;
Minc=[Minc;minc];
Meanc=[Meanc;meanc];
Globalmin=[Globalmin;globalmin];
M=max(globalmin.^-1);
Mt=[Mt,M];
end
MT=max(Mt);
for searchi=1:length(Mt)
if Mt(searchi)==MT
        s=searchi;
end
end
figure('name','PSO / ADR')
plot(iters,(Minc(s,:).^-
1)/(1e6),':',iters,Meanc(s,:)/(1e6),':',iters,(Globalmin(s,:).^-
1)/(1e6),'-','linewidth',2);
xlabel('Generation');ylabel('Throughput (Mbps)');
legend('Local Maximas','Average','Global Maximas')
title('PSO of Aggregate Data Rate')
[~]=wimax_environment(radius,no_ss,layers,alpha,beta);
figure('name','PSO / Channel_rate')
plot(iters,(Globalmin(s,:).^-1)/(no_ss*1e6),'-','linewidth',2);
xlabel('Generation');ylabel('Chanel Data rate (Mbps)');
title('PSO of Channel Data Rate')
MT=[MT,MT/no_ss];
```