CYCLIC MAP INFORMATION ELEMENT IN WiMAX NETWORKS

by

Hasan Canarslan
B.S., in Mathematics, Boğaziçi University, 2002

Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Computer Engineering
Boğaziçi University
2008

ACKNOWLEDGEMENTS

Firstly, I would like to thank my supervisor, Assoc. Prof. Fatih Alagöz for his continuous guidance and support this project. Without his help, success in this study would never have been possible. I also thank Assist. Prof. Tuna Tuğcu for his precious observations and advices. I am also grateful to Prof. Emin Anarım for his encouragement and support in my graduate education.

I would like to thank Mehmet Şükrü Kuran, H. Birkan Yılmaz and Evren Önem for their great help and friendship whenever I needed throughout this study. I would also thank all current and former fellow Satellite Laboratory (SATLAB).

I thank my previous and current coordinator of IT Department in Governorship of Istanbul. Namely Murat Çetiner and Ahmet Tolga Kuru. I would also thank my all workfellows of IT Department in Governorship of Istanbul.

Finally I thank my family for being the greatest support during my whole educational life.

This work is supported by The State Planning Organization under "The Next Generation Satellite Networks and Applications" project, No : DPT 2003-K120250

ABSTRACT

CYCLIC MAP INFORMATION ELEMENT IN WiMAX NETWORKS

Broadband Wireless Access (BWA) is an alternative to wired broadband like cable and xDSL. The IEEE 802.16 standard defines physical (PHY) and MAC layers of BWA systems. It has been called WiMAX (Worldwide Interoperability for Microwave Access) by industry.

The uplink transmission of Subscriber Stations (SS) is determined by Base Station (BS) with sending Uplink Map (UL-MAP) in point to multipoint networks. The UL-MAP is sent in the downlink subframe and its size affects downlink data capacity. In this thesis, we introduce a new scheme to minimize MAC overhead due to UL-MAP size by using UL-MAP Extended Information Element (IE) to send future periodic fixed size grants for the connection whose scheduling service type is Unsolicited Grant Service (UGS).

We evaluate our proposed scheme with simulations in OPNET 11.5 Modeler WiMAX module. Simulation results show that our proposed solution is superior to its conventional counterpart when there are high numbers of SSs with UGS connections in terms of cell throughput.

ÖZET

WiMAX AĞLARDA PERİYODİK HARİTA BİLGİ ÜYESİ

Geniş bant radyo yayını erişimi, kablo ve xDSL gibi tel çekilen geniş banda bir alternatiftir. IEEE 802.16 standardı, Fiziksel katman ile Ortak erişim kontrolü katmanını tanımlar. Endüstride WiMAX (Mikrodalga erişimi için dünya çapında enteroperabilite) olarak bilinir.

Tek noktadan çok noktaya şebekelerde kullanıcı istasyonun baz istasyonuna doğru veri aktarımı, kullanıcı istasyona uplink haritasını yollamak ile baz istasyonu tarafından belirlenir. Uplink haritası downlink bölümünde gönderilmekte ve büyüklüğü downlink bölümünde veri aktarımı kapasitesini etkilemektedir. Bu tezde, zamanlama servis tipi talep edilmeden tahsis hizmeti olan bağlantıların uzatılan bilgi üyesi yardımı ile gelecek periyodik sabit büyüklükteki bant genişliği tahsisleri gönderilerek uplink haritası nedeni ile oluşan ortak erişim kontrolü yükünü en aza indirmeyi sağlayan metodu geliştirdik.

Önermiş olduğumuz çözümü OPNET 11.5 simülatöründe WiMAX modülünü kullanarak değerlendirdik. Simülasyon sonuçlarmız bizim önermiş olduğumuz çözümün zamanlama servis tipi talep edilmeden tahsis hizmeti olan bağlantıların kullanıcı istasyonlar tarafında kullanıldığı zamanlarda, verimliliği artırdığını göstermiştir.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS/ABBREVIATIONS

C	Cycle
IE_{send}	The number of frames per second in which uplink bandwidth allocation is sent
IE_{notsend}	The number of frames per second in which uplink bandwidth allocation is not sent
F_{D}	Frame duration
T_{F}	Total frame in a second
ARQ	Automatic Repeat Request
ATM	Asynchronous Transfer Mode
BE	Best Effort
BS	Base Station
BWA	Broadband Wireless Access
CID	Connection Identifier
CPS	Common Part Sublayer
CRC	Cyclic Redundancy Check
CS	Convergence Sublayer
DCD	Downlink Channel Descriptor
DFPQ	Deficit Fair Priority Queue
DHCP	Dynamic Host Configuration Protocol
DIUC	Downlink Interval Usage Code
DL-MAP	Downlink Map
DOCSIS	Data Over Cable Service Interface Specification
DPAM	Data Packet Analysis Module
DRR	Deficit Round Robin
DSL	Digital Subscriber Line
EDD	Earliest Due Date
EDF	Earliest Deadline First
ertPS	Extended Real Time Polling Service

ETE	End to End
FCH	Frame Control Header
FDD	Frequency Division Multiplexing
FEC	Forward Error Correction
FIFO	First In First Out
FTP	File Transfer Protocol
GMH	Generic MAC Header
GPC	Grant per Connection
GPSS	Grant per Subscriber Station
HTTP	Hypertext Transfer Protocol
IE	Information Element
IEEE	Institute of Electrical and Electronics Engineers
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
LAN	Local Area Network
LOS	Line of Sight
MAN	Metropolitan Area Network
MDRR	Modifed Deficit Round Robin
MPEG	Moving Pictures Experts Group
NLOS	Non LOS
nrtPS	non-Real Time Polling Service
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PDU	Protocol Data Unit
PF	Proportional Fair
PHS	Payload Header Suppression
PMP	Point to Multipoint
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RR	Round Robin

RTG	Receive/transmit Transition Gap
rtPS	Real Time Polling service
SC	Single Carrier
SDU	Service Data Unit
SS	Subsriber Station
TDD	Time Division Duplexing
TTG	Transmit/receive Transition Gap
UCD	Uplink Channel Descriptor
UGS	Unsolicited Grant Service
UIUC	Uplink Interval Usage Code
UL-MAP-IE	UL-MAP Information Element
WFQ	Weight Fair Queue
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Networks
WRR	Weighted Round Robin

1. INTRODUCTION

1.1. Problem and Motivation

IEEE 802.16, also known as WiMAX (Worldwide Interoperability for Microwave Access) provides broadband wireless access in metropolitan areas. It is demonstrated that the IEEE 802.16 system is a viable alternative to cable modem and xDSL technologies. The IEEE 802.16 system has many advantages such as variable and high data rate, last mile wireless access, point to multipoint communication, large frequency range, Quality of Service (QoS) for various types of application.

Although the IEEE 802.16 system has many advantages, it suffers MAC overhead for managing MAC protocols. Uplink Map (UL-MAP) MAC management message which contains usage of uplink subframe is sent in the downlink subframe by the Base Station (BS). UL-MAP has to be reliable by using quite robust modulation and coding type so that each Subscriber Station (SS) can decode it. BS assigns consequently great amount of capacity for sending UL-MAP. Thus its size affects downlink data capacity inversely. Unsolicited Grant Service (UGS) connections require periodic fixed size grants negotiated at connection setup time, motivating us to propose cyclic UL-MAP Information Element (IE) scheme that can alleviate MAC overhead due to reduction in size of UL-MAP.

1.2. Thesis Contributions

The contributions from this thesis are:

- A new scheme to minimize MAC overhead.
- Implementation of our proposed scheme in Opnet Modeler 11.5 WiMAX Module.
- End to End (ETE) delay for voice packets and cell throughput analysis of our proposed scheme for different sets of application when there are high numbers of SS with UGS connections.

1.3. Thesis Organization

Chapter 2 introduces the background of IEEE 802.16 Physical (PHY) and Medium Access Control (MAC) layers. In Chapter 3, we will present previous works in packet scheduling and MAC overhead. In Chapter 4, we will describe our proposed scheme. In Chapter 5, we will present numerical analysis and evaluation of our proposed scheme with simulations in OPNET Modeler 11.5 Wimax Module. We will also present simulation details with our assumptions. Finally in Chapter 6, we will present our conclusions and future directions.

2. IEEE 802.16 OVERVIEW

2.1. History of IEEE 802.16

The IEEE 802.16 task group which was established in 1999 is a unit of the IEEE 802 LAN/MAN standards committee and develops the air interface technology for the Wireless Metropolitan Area Networks (WMAN). The IEEE 802.16 standard defines Physical (PHY) and Medium Access Control (MAC) layers. It has been called Worldwide Interoperability for Microwave Access (WiMAX) by industry. WiMAX forum which creates the name of WiMAX, promotes and certifies the compatibility and interoperability of products using IEEE 802.16 specification. In analogy, Wifi promotes IEEE 802.11 for Wireless Local Area Network (WLAN), WiMAX promotes IEEE 802.16 for WMAN.

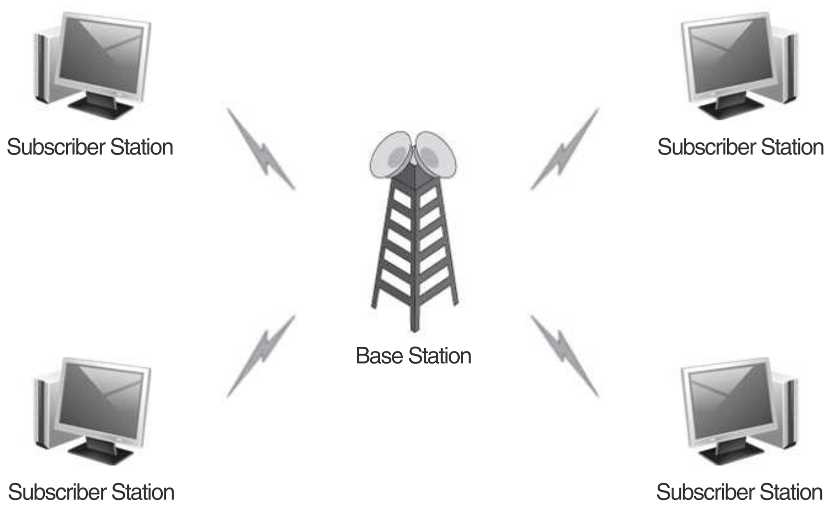

Figure 2.1. PMP mode

The first IEEE 802.16 standard provides broadband wireless access in Point to Multipoint (PMP) topology (Figure 2.1) with only Line of Sight (LOS) capability. It uses a Single Carrier (SC) PHY specification. The PHY layer works at the 10-66

GHz frequency band. IEEE 802.16a was an amendment to the standard and introduced in 2003. The PHY layer works lower frequency in 2-11 GHz, including licensed and licensed exempt frequencies. It also required non Line of Sight (NLOS) capability by using an Orthogonal Frequency Division Multiplexing (OFDM)-based physical layer. Support for Orthogonal Frequency Division Multiple Access (OFDMA), were also included. In addition to new PHY layer, IEEE 802.16a also supports Mesh mode topology. After IEEE 802.16d amendment, IEEE 802.16-2004 was introduced in 2004 [1]. The IEEE 802.16-2004 standard revised and consolidated IEEE Standards 802.16, 802.16a, and 802.16c.[1] An amendment to IEEE 802.16-2004, IEEE 802.16e-2005 approved in 2005 [2]. It implemented many enhancements to IEEE 802.16-2004 including better support for Quality of Service (QoS) and the use of scalable OFDMA. It also added mobility support to the family of the standard. It is often referred to as Mobile WiMAX. New and upcoming amendments to the IEEE 802.16 standards are given in Table 2.1 [3].

Table 2.1. New and upcoming IEEE 802.16 standards [3]

New Active Amendments	
802.16f - 2005	Management Information Base
802.16g - 2007	Management Plane and Procedure
802.16k - 2007	Bridging of 802.16
Amendments under development	
802.16h	Improved Coexistence Mechanisms for License-Exempt Operation
802.16i	Mobile Management Information Base
802.16j	Multihop Relay Specification
802.16Rev2	Consolidate IEEE 802.16 2004/e/f/g
Amendments at pre-draft stage	
802.16m	Advanced Air Interface

[1]We will refer to IEEE 802.16-2004 as IEEE 802.16 as generally done in the literature.

2.2. PHY Technology in IEEE 802.16

The IEEE 802.16 is a universal standard and comprehending different kinds of link and communication [4]. The physical layer of IEEE 802.16 standard operates in 10-66 GHz or 2-11 GHz band. In the 10-66 GHz band, single carrier modulation is used and LOS is required between BS and SS in initial IEEE 802.16 standard. WirelessMAN-SC is the air interface specification for IEEE 802.16 operating in this frequency band. For 2-11 GHz frequency band, three additional PHY specifications were developed for supporting NLOS communication. WirelessMAN-SCa, WirelessMAN-Orthogonal Frequency Division Multiplexing (OFDM) and WirelessMAN-Orthogonal Frequency Multiple Access (OFDMA) are the air interface specifications for IEEE 802.16 operating in these frequency bands. Table 2.2 summarizes the nomenclature for the various air interface specifications in the standard [1]. Raw data rate is 36-135 Mbps in

Table 2.2. Air interface nomenclature [1]

Designation	Applicability	Duplexing Alternative
WirelessMAN-SC	10-66 GHz	TDD,FDD
WirelessMAN-SCa	Below 11GHz	TDD,FDD
WirelessMAN-OFDM	Below 11GHz	TDD,FDD
WirelessMAN-OFDMA	Below 11GHz	TDD,FDD
WirelessHUMAN	Below 11GHz	TDD

LOS communication depending on channel bandwidth, modulation and coding scheme [1, 5]. However, raw data rate in NLOS communication, IEEE 802.16 provides at most 75 Mbps [1, 6, 7, 8]. Channel bandwidth can be 20, 25, and 28 MHz for WirelessMAN-SC (see Table 2.3).

Table 2.3. IEEE 802.16 WirelessMAN-Sc Data Rates (Mbps) [1]

Channel Bandwidth (in Mhz)	QPSK	16QAM	64QAM
20	32	64	96
25	40	80	120
28	44.8	89.6	134.4

To provide interoperability, WiMAX Forum defined profiles, one for Fixed WiMAX and one for Mobile WiMAX. The Fixed WiMAX profile uses OFDM PHY layer with 256 carriers. Two different spectrum bands are used in this profile: 3.5 GHz and 5.8 GHz. Channel width is defined in these spectrum bands as 3.5 or 7.5 MHz in 3.5 GHz and 10 MHz in 5.8 GHz. While TDD or FDD duplexing mechanisms can be used in 3.5 GHz, TDD duplexing mechanisms can be used in 5.8 GHz because TDD offers better cost performance than FDD in this spectrum band [9].

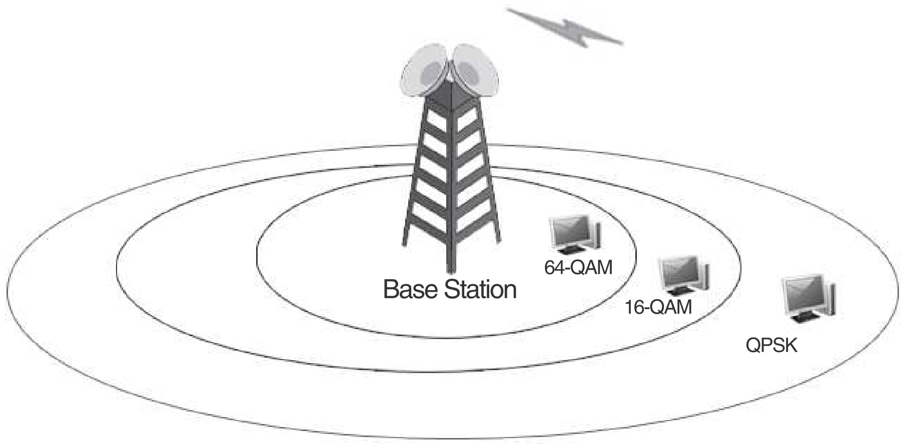

Figure 2.2. Adaptive modulation and coding

The IEEE 802.16 standard includes several modulation schemes and Forward Error Correction (FEC) mechanisms to cope with radio channel instability. The modulation techniques defined in IEEE 802.16 standard in uplink and downlink are Quadrature Phase Shift Keying (QPSK) and, 16-state QAM and 64-state QAM [10]. The IEEE 802.16 standard supports adaptive modulation and coding on the user data part of the frame (Figure 2.2). Available modulation schemes and coding rates in the network are described with Uplink Interval Usage Code (UIUC) for uplink and Downlink Interval Usage Code (DIUC) for downlink. Uplink Channel Descriptor (UCD) and Downlink

Channel Descriptor (DCD) which are broadcasted by the BS at periodic intervals, define particular UIUC and DIUC respectively. When link condition degrades possible due to environmental factors, system uses more robust modulation scheme and coding rate. Otherwise, if link condition improves, system may use less robust modulation scheme and coding rate to maximize system capacity.

2.3. MAC Layer in IEEE 802.16

The MAC layer of the IEEE 802.16 transmits higher layer packets using PHY resources in an efficient manner. The IEEE 802.16 MAC is designed to support PMP and optional Mesh network topology. In PMP network topology, there is one BS and one or more SS. Transmission from BS to SSs is downlink transmission which BS is

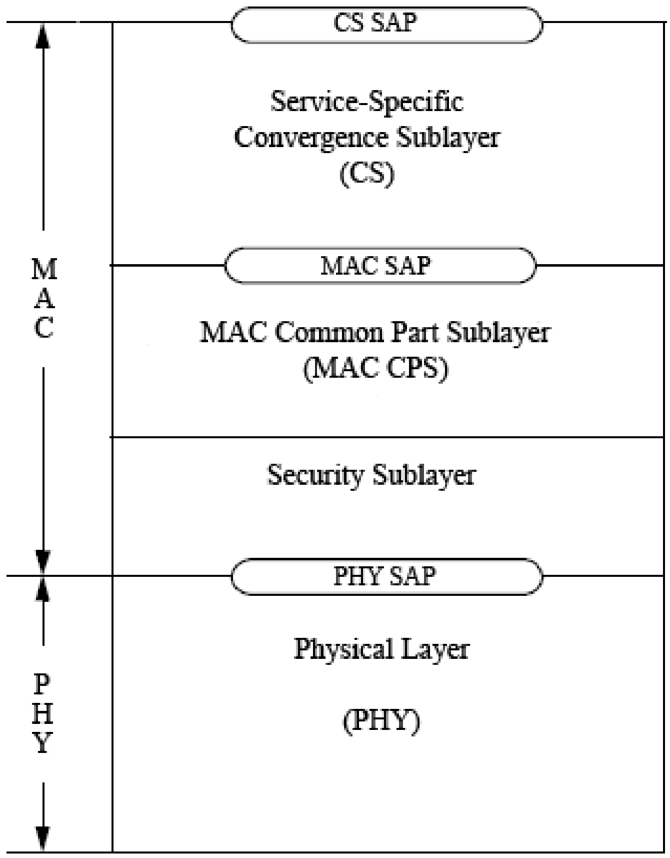

Figure 2.3. Layers in IEEE 802.16 [1]

the only one entity to transmit all data on this direction. Transmission from SS to BS is uplink transmission which the usage of this direction is determined by the BS.

SSs share uplink transmission to BS on a demand basis. SSs are not permitted to communicate each other directly and SSs transfer all their data on the BS.

In IEEE 802.16, MAC layer is divided by three sublayers: the Service-Specific Convergence Sublayer (CS), MAC Common Part Sublayer (CPS), Security Sublayer (Figure 2.3).

The CS classifies data packets received from higher layer. These higher layer data packets are also known as MAC Service Data Units (SDU). This sublayer utilizes mechanisms like Payload Header Suppression (PHS) in order to save radio resources by suppressing common header information. Currently, two types of service specific CS are provided: the Asynchronous Transfer Mode (ATM) CS for ATM networks and the packet CS for all packet based protocols, such as IPv4, IPv6, Ethernet.

The second sublayer, the CPS is independent of the higher layer protocols and performs core MAC functionalities such as network entry, bandwidth allocation, connection management, QoS scheduling etc. The SDUs receiving from CS sublayer are assembled to create MAC Protocol Data Units (PDU) (Figure 2.4).

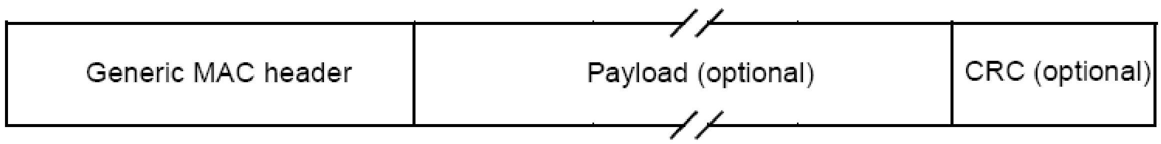

Figure 2.4. MAC PDU format [1]

Each MAC PDU consists of fixed length generic MAC header followed by payload and Cyclic Redundancy Check (CRC). There are two types of MAC header: generic MAC header and bandwidth request header (Figure 2.5). These two header formats are distinguished by the HT field. Payload may consists of zero or more subheaders such as fragmentation, packing etc. and zero or more MAC SDUs from CS. Bandwidth request MAC PDUs do not contain payload. The CPS can pack multiple SDUs into single MAC PDU. In the case of large SDU, CPS can fragment the MAC SDU into multiple MAC PDUs. The MAC also contains a separate security sublayer providing

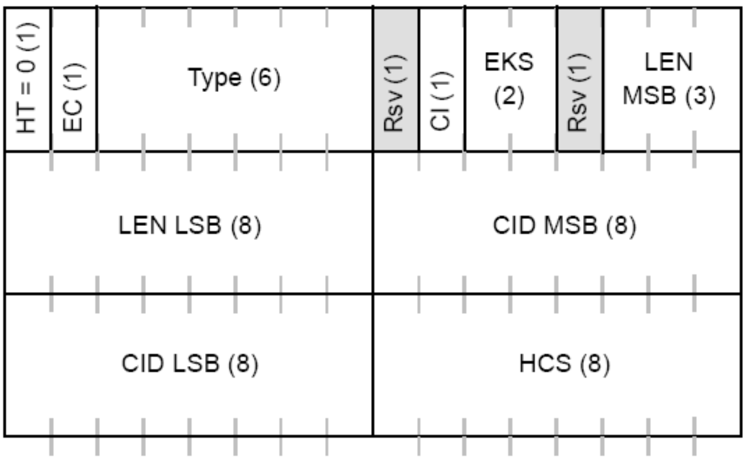

Figure 2.5. Generic MAC header [1]

authentication, secure key exchange, and encryption.

The IEEE 802.16 standard also defines an optional use for Automatic Repeat Request (ARQ) that can be applied only to NLOS PHY interfaces.

One of the major attributes of PMP MAC is connection oriented. All data communications are in the context of a connection. Connectionless services are also mapped to connections. When a subscriber station accesses the network, three types of management connections are established between the SS and the BS (before transport connections can be established):

- Basic management connection for exchange of short, delay-critical MAC management messages.
- Primary management connection for exchange of longer, more delay tolerant MAC management messages.
- Secondary management connection for exchange of delay tolerant IP-based messages, such as used during DHCP transaction.

Each connection has a unique 16-bit connection identifier (CID) in downlink as well as in uplink direction. To setup a connection, each SS has to perform ranging, capability negotiation, authentication, registration process in-sequence.

The IEEE 802.16 MAC supports a request-grant mechanism for data transmission in uplink direction. There are two modes of transmitting the bandwidth request:

- Contention Mode: SS sends bandwidth request during the contention period. Contention is resolved using back-off resolution.
- Contention Free Mode: BS polls each SS and SSs reply by sending bandwidth request.

All bandwidth requests are in terms of bytes needed to carry the MAC header and payload, but not PHY overhead. Bandwidth requests are incremental or aggregate. When the BS receives an incremental bandwidth request, it will add the quantity of bandwidth requested to its current perception of the bandwidth needs of the connection. When the BS receives an aggregate bandwidth request, it will replace its perception of the bandwidth needs of the connection with the quantity of bandwidth requested. Bandwidth request may come as an optional piggyback request. Piggybacked bandwidth requests are always incremental. An SS requests uplink bandwidth on a per connection basis. The IEEE 802.16 defines the following two ways for allocation of bandwidth grants:

- Grant per Connection (GPC): Bandwidth is allocated to a connection and SS uses this grant only for this connection
- Grant per Subscriber Station (GPSS): SS granted bandwidth aggregated into a single grant. SS distributes this grant into various flows, running at this SS.

2.3.1. MAC support of PHY and Frame Structure

The MAC of IEEE 802.16 supports Frequency Division Multiplexing (FDD) and Time Division Multiplexing (TDD). In the case of FDD, the uplink and downlink channel are located on separate frequencies, which allows the SSs to transmit and receive simultaneously. Fixed frame duration is used for uplink and downlink transmission. Bandwidth allocation algorithms are simplified by using fixed frame durations. In the case of TDD, the uplink and downlink transmission occur at different times and usually share the same frequency. Bandwidth allocated to uplink and downlink can be adaptive and it is controlled higher layers. A TDD frame has a fixed duration which varies for different PHY layers and contains one downlink and one uplink subframe. Table 2.4 shows possible frame duration in OFDMA PHY specification. Figure 2.6

Table 2.4. OFDMA frame duration [1]

Frame duration (ms)	Frames per second
2	500
2.5	400
4	250
5	200
8	125
10	100
20	50

shows a typical TDD/OFDMA frame structure. Each small interval on the horizontal and vertical axis represents a symbol and a subchannel, respectively.

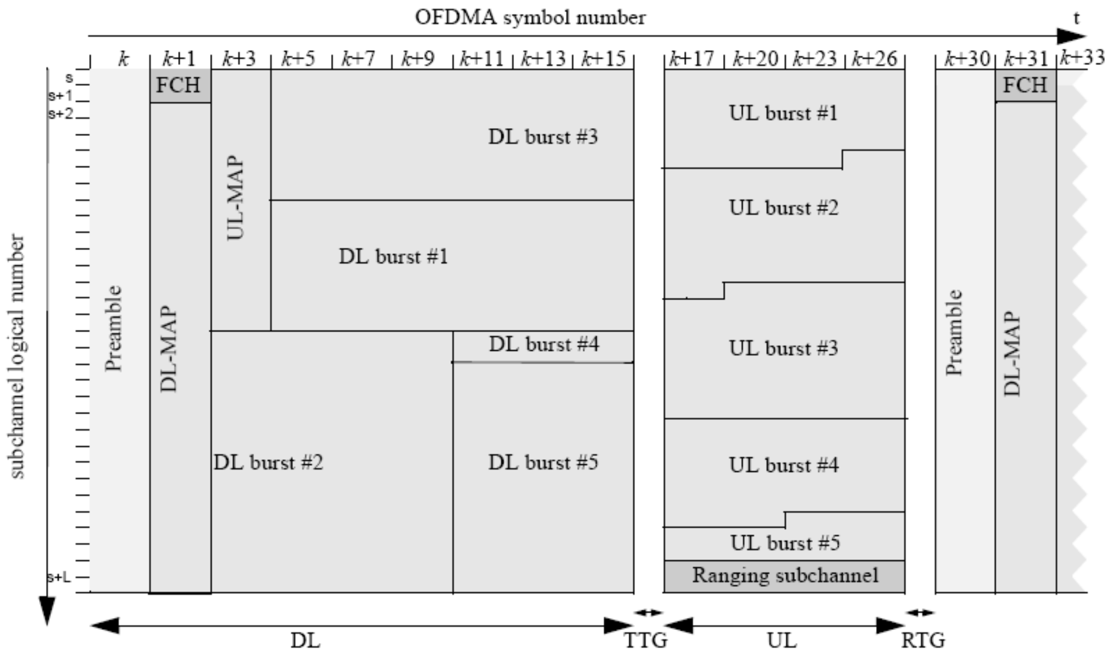

Figure 2.6. TDD/OFDMA frame structure [1]

Each frame in the downlink transmission begins with preamble followed by a downlink transmission period and uplink transmission period. In each frame, there are the Receive/transmit Transition Gap (RTG) and Transmit/receive Transition Gap (TTG) to allow the BS to turn around. RTG represents an interval between consequent frames and TTG represents an interval between downlink and uplink subframe. Frame Control Header (FCH) follows preamble and specifies the length of downlink map (DL-MAP) and the repetition coding used for the DL-MAP message. Downlink subframe also contains DL-MAP and Uplink Map (UL-MAP) MAC management messages. While DL-MAP contains usage of the downlink subframe, UL-MAP contains the usage of uplink subframe. They contain modulation and coding type information, start and duration symbols of each allocation. DL-MAP and UL-MAP are generated and broadcasted by the BS. Each SS decodes these control messages and sends or receives a packet with specified size and position in MAP control messages. If SS cannot decode UL-MAP, then SS cannot send a packet to BS. Therefore UL-MAP has to be reliable by using robust modulation and coding type e.g. QPSK modulation techniques with 1/2 coding rate. As a consequence, MAP overhead is increasing and depends on many factors including numbers of SS scheduled in a frame. Map overhead increases linearly as the numbers of scheduled SS increase.

2.3.2. Scheduling Services

Scheduling services have represented the data handling mechanisms supported by the MAC scheduler for data transport on a connection. Each connection has a unique service flow type. Service flow type defines QoS parameters for the PDUs that are exchanged on the connection [3]. The IEEE 802.16 standard defines four scheduling services. One new scheduling service is added with IEEE 802.16e standard. The Scheduling services are:

1. Unsolicited Grant Service (UGS): It supports real-time services that generate fixed size data packets on a periodic basis. Typical applications for this service are T1/E1, Voice over IP without silence suppression. BS generates fixed size grants on a periodic basis regardless of the scheduler in the BS. Size of the grant

is negotiated at connection setup. This eliminates the overhead and latency of the SS bandwidth request. The mandatory QoS service flow parameters for this scheduling service are maximum sustained traffic rate, maximum latency, tolerated jitter, and request/transmission policy. If present, minimum reserved traffic rate will be maximum sustained traffic rate. The poll me bit in the grant subheader of UGS connections is used to request unicast poll for bandwidth needs of non-UGS connections. Piggyback request and bandwidth stealing are not allowed for this scheduling service.

2. Real Time Polling Service (rtPS): It supports real-time services that generate variable sized data packet that are issued at periodic intervals, such as Moving Pictures Experts Group (MPEG) video. BS provides periodic unicast bandwidth request opportunities in the uplink subframe for the rtPS connection so that the SS can specifies the size of the desired grant which meets the flows real-time needs. Thus rtPS connections never contend for bandwidth request. Due to request/grant mechanisms, this scheduling service requires more overhead and latency than UGS. The mandatory QoS service flow parameters for this scheduling service are minimum reserved traffic rate, maximum sustained traffic Rate, maximum latency, and request/transmission policy. Piggyback request and bandwidth stealing are allowed for this scheduling service.
3. non-Real Time Polling Service (nrtPS): It is designed to support delay-tolerant data streams, such as File Transfer Protocol (FTP), that require variable sized data packets for which a minimum data rate is required. BS provides periodic unicast bandwidth opportunities in the uplink subframe for the nrtPS connection, but the polling periods of nrtPS connections are longer than the polling periods of rtPS connections. Unlike rtPS, nrtPS connections are allowed to enter contention for the bandwidth request. The mandatory QoS service flow parameters for this scheduling service are minimum reserved traffic rate, maximum sustained traffic rate, traffic priority, and request/transmission policy. Piggyback request and bandwidth stealing are allowed for this scheduling service.
4. Best Effort (BE): This service type is designed to support data streams, such as web browsing and email etc., which no minimum service level is required. BE connections can send bandwidth allocation requests only using contention. The

mandatory QoS service flow parameters for this scheduling service are maximum sustained traffic Rate, traffic priority, and request/transmission policy.

5. Extended Real Time Polling Service (ertPS): Addressing [11], IEEE 802.16e standard introduces ertPS scheduling service. It is designed to support real time services, such as voice over IP with silence suppression, that generate variable sized data packets. It combines UGS and rtPS scheduling services. It does not have any bandwidth request mechanisms similar to UGS, but bandwidth allocated to ertPS can change in time similar to rtPS. ertPS scheduling service have the same QoS parameters with the rtPS scheduling service.

Although IEEE 802.16 standard defines bandwidth allocation and QoS mechanisms, QoS scheduler in both BS and SS is not defined. Thus efficient QoS scheduler is left to the vendors to differentiate their equipments [4].

3. RELATED WORKS

Nowadays, the IEEE 802.16 standard is drawing a great deal of interest from the engineering and research communities. Many papers are available in QoS scheduling domain and MAC overhead domain. We will present many works about QoS scheduling domain and MAC overhead domain.

In [12], authors propose a hierarchical scheduling structure of the bandwidth allocation to support all types of service flows for TDD mode. Their scheduling uses a combination of Deficit Fair Priority Queue (DFPQ) for multiple service flow, Round Robin (RR) for BE, Earliest Deadline First (EDF) for rtPS and Weight Fair Queue (WFQ) for nrtPS. Six queues are defined according to their direction (uplink and downlink) and service classes. Authors use minimum reserved traffic rate for admission control and maximum sustained traffic rate for scheduling.

In [13], authors proposed signaling mechanisms and scheduling. The hierarchical structure of the bandwidth allocation in BS is proposed. In this architecture, two-layer scheduling is deployed. Six queues are defined according to their direction (uplink or downlink) and service classes (rtPS, nrtPS and BE). Since service of UGS will be allocated fixed bandwidth (or fixed time duration) in transmission, authors will cut these bandwidths directly before each scheduling. The algorithm of the first layer scheduling is called DFPQ, which is basically based on priority queue. 2 policies of initial priority are defined as following:

- Service class based priority: $rtPS > nrtPS > BE$
- Transmission direction based priority: $Downlink > Uplink$

In the second layer scheduling, three different algorithms are assigned to three classes of service to match its requirements. Authors apply Earliest Deadline First (EDF) for rtPS , which means packets with earliest deadline will be scheduled first. Weight Fair Queue (WFQ) is deployed for nrtPS services. Authors schedule this type of packets based on the weight (ratio between a connection's nrtPS Minimum Reserved Traffic Rate and the total sum of the Minimum Reserved Traffic Rate of all nrtPS connections). The remaining bandwidth is allocated to each BE connection by Round Robin (RR).

In [14], authors propose uplink bandwidth allocation scheduling part and admission control part at the BS and traffic management module at SS. SS scheduler transmits UGS packets to append virtual packet arrival time of rtPS. Data packet analysis module is defined. Data Packet Analysis Module (DPAM) of BS received uplink data from SS obtains virtual packet arrival time of rtPS at UGS packet of each SS. DPAM can find the rtPS deadline information. Based on this deadline information, the uplink bandwidth allocation scheduling of BS will know exactly when to schedule packets such that packet delay requirement are met.

In [15], authors' proposed uplink scheduling algorithm is Weighted Round Robin (WRR) with GPSS mode. The schedule process is divided into two steps. The first step is performed in the BS. According to the information of the request from SS, the BS's upstream scheduler schedules grants to the SS. Then the SS's upstream scheduler is responsible for the selection of appropriate packets from perspective UGS-AD, rtPS, nrtPs, BE queues and sends them through the upstream data slots granted by the BS upstream scheduler. The authors choose five priority queues with dynamic priority. The author use WFQ scheduling for higher priority service, WRR scheduling for middle priority service and FIFO scheduling for lower priority service. When SS using more than allocated bandwidth, authors employ some traffic policing and traffic shaping methods to stop.

In [16] authors select Deficit Round Robin (DRR) as the downlink scheduler and Weighted Round Robin (WRR) as uplink scheduler. In implementation of authors, SSs only use piggybacking for busy connections, and uplink subframe capacity that is not scheduled as uplink grants to SSs is made available as broadcast polls. The authors presents extensive performance analysis of the IEEE 802.16 operated with the WirelessMAN-OFDM air interface in FDD mode.

In [17], authors propose such a scheduler, referred to as the “Frame Registry Tree Scheduler”, that aims at providing differentiated treatment to data connections, based on their QoS characteristics. The basic idea is to schedule transmission of each piece of data in the last frame before its deadline. The tree consists of six levels; root, time frame, modulation, subscriber, QoS service and connection level. The scheduler resides on the BS.

In [18], authors propose uplink packet scheduling uses a combination of strict priority service discipline, Earliest Deadline First (EDF) and Weight Fair Queue (WFQ). In uplink scheduling principle bandwidth allocation per flow follows strict priority, from highest to lowest: UGS, rtPS, nrtPS and BE. UGS services allocates fixed bandwidth, Earliest Deadline First (EDF) is applied for rtPS, WFQ is applied for nrtPS, and remaining capacity is equally allocated for BE services. Authors’ proposed scheduler consists of three modules: Information Module; Scheduling Database and Service Assignment Module.

In [11], authors developed an ON-OFF model in OPNET to model voice traffic. BS allocates uplink slots to SS based on voice state information of SS which is conveyed to BS using reserved Grant Me bit of generic 802.16 MAC header. BS simply allocates maximum grant size which is sufficient to send voice data packets when GM bit sets ‘1’ and exponential decrease slot size when GM bit sets ‘0’.

In [19], authors propose a scheduling algorithm which manages the resource allocation and grants an appropriate QoS per connection. At the BS, a scheduling algorithm is a strict semi preemptive priority between the four traffic classes, assigning the highest to UGS and the lowest to BEs. Every connection identifier is grouped inside a flow type and, after strict priority evaluation, each traffic group is scheduled separately : the UGS one is scheduled by Packet Based Round Robin(PBRR); rtPS is managed with Earliest Deadline First (EDD) algorithm; nrtPS and BE are scheduled with WFQ.

In [20], authors suggest an uplink scheduling architecture for IEEE 802.16 and DOCSIS with Grant per Connection mode. The authors define three types of queue. Type 1 queues (FIFO) are for UGS flows and unicast request for rtPS and nrtPS. Type 2 (FIFO) queues are flows with minimum reserved bandwidth and type 3 queues for flow with no bandwidth reservation. The scheduling algorithm does desired slot allocation of type 1 queues then Prioritized WFQ scheduling is applied for type 2, 3 queues. Authors also provide an algorithm to calculate the number of contention slots for each frame and buffer management of various queues.

In [21], authors propose hybrid algorithms (EDD along with Weighted Fair Queuing). In simulation, data classifier puts the packets into appropriate service queue. M/D/1 queuing model is considered for each service class. The packets arriving into each service queues are buffered. Each packet is treated with respective priorities according to the EDD or WFQ scheduling algorithm. Authors present simulation results to show their algorithm effectiveness on end to end delay for real time services. Authors also make comparative study of scheduling algorithms in GPC and GPSS mode.

In [22], the proposal of authors is an extension of Proportional Fair (PF) scheduling for non-real-time polling service. It uses channel quality information. They modify PFS to provide QoS control for minimum reserved traffic rate (Rmin) and maximum sustained traffic rate (Rmax). The polling frequencies can be controlled based on desired rates specified by two parameters [Rmin , Rmax]. If an average data rate is lower than Rmin , it tries to poll the corresponding user more often and if the data rate is higher than Rmax, it polls the user less frequently. Although they get success results for non-real-time-polling service, it is not suitable for real time polling services.

In [23], authors propose a novel adaptive scheduling algorithm for WiMAX wherein a SS sends request for extra bandwidth beforehand to BS by speculating real time polling service traffic pattern. A SS will request time slot not only for present data in the queue but also on the data which arrive in the queue in between the time request was made and the corresponding time at which rtPS queue will be served. The method adopted in this work is “Differential Time Grant” method. They are estimating average rate of incoming data and duration of above time interval to estimate amount of the data that has arrived in this interval.

In [24], authors proposed a scheduler that takes as input information about connections queues status, bandwidth requests and current burst profiles of each user. It combines a strict priority policy among the different service categories with suitable queuing management disciplines for each class. rtPS and nrtPS connections are handled through WRR scheme, where connection' weights are determined according to their guaranteed bandwidth, while BE connections are handled through RR scheme. The innovative solution consists in handling WRR and RR in the presence of variable size data packets, supporting fragmentation, packing and PHS functionalities. WRR and RR schemes are performed among connections with different burst profiles in the following way

1. Preliminary WRR/RR allocation of the leftover available bandwidth among all connections which are assumed to use most robust active downlink burst profile.
2. Evaluation of the actual bandwidth allocated to each connection at step 1 on the basis of its current burst profile.
3. Updating of the available bandwidth and of the connections allocation.
4. Reiteration of the above steps from step 1 if there is leftover available bandwidth and any active connection.

In [25], authors propose cross-layer scheduling algorithms at the MAC layer for multiple connections with diverse QoS requirements. Each connection admitted in the system is assigned a priority, which is updated dynamically depending on its channel quality, QoS satisfaction, service priority; thus, the connection with the highest priority is scheduled first.

In MAC overhead domain, [26] presented analysis of impact of different parameters, such as MAC frame size, MAC PDU size, and the number of connections on MAC performance of IEEE 802.16e in OFDMA PHY. Authors also mentioned of reducing MAC overhead by giving two solutions based on reducing or combining the number of Information Elements (IE) related with each connections. One solution is based on sending only the change with respect to previously transmitted IE instead of the whole new IE. Another solution is based on combining IEs that have common elements, but authors leave as future work.

[27] proposed an advanced scheme for reducing MAC overhead due to size of control message about resource allocation i.e. DL-MAP and UL-MAP. The proposed scheme transmits MAP IEs piggybacked downlink data instead of broadcasting and uses fast feedback to converse the transmission reliability of MAP IE in the IEEE 802.16e TDD system.

[28] proposed a new format of compact DL-MAP control message for periodic fixed bandwidth assignment in IEEE 802.16e to reduce MAC overhead due to MAP size, but authors modify the standard.

[29] mentioned of inefficiency of the current DL-MAP control message and proposed compressed DL-MAP control message format to reduce DL-MAP overhead in OFDMA PHY. DL-MAP overhead is reduced by using compressed DL-MAP control message, saving 13 bytes (104 symbols in QPSK 1/2) per frame.

[30] proposed a new BS scheduler which consists of uplink scheduling block, downlink scheduling block, and channel information block, by considering the MAC overhead for the Wibro system. PF scheduling algorithm is used and modified by utilizing user based scheduling. To minimize MAP overhead, the proposed scheduler allocates the minimum number of user bursts in a frame.

[31] mentioned of inefficient aspect of existing MAP messages and proposed a further compressed MAP called Tiny MAP for OFDMA PHY. Authors determined the redundant Generic MAC Header (GMH) fields of DL-MAP such as header type, encryption control and encryption key sequence, type field etc. To reduce overheads and possibly optimize a frame, authors remove the redundant fields of GMH from the DL-MAP control message and move the base station ID and frame duration code

fields in DL-MAP control message to the Downlink Channel Descriptor (DCD) control messages which are broadcasted by the BS at a longer period than DL-MAP, but proposed scheme requires modification of the standard.

4. OUR PROPOSED SCHEME

UL-MAP is one of the control messages which is required for dynamic bandwidth allocation. Each SS decodes this message to send a packet with specified size and position when uplink bandwidth is allocated to the SS in the UL-MAP. If SS cannot decode this message, then SS can not send a packet to BS. Therefore this message has to be reliable by using quite robust modulation and coding type e.g. QPSK modulation techniques with 1/2 coding rate. Thus symbols used for UL-MAP increase significantly and BS assigns a great amount of bandwidth for broadcasting UL-MAP. Since UL-MAP is sent in the downlink subframe, the data capacity in the downlink will be decreased each MAP Information Element (IE) added to the UL-MAP. Thus MAC overhead due to size of the UL-MAP is increasing. MAP overhead due to size of UL-MAP increases linearly as numbers of scheduled SS increase in a frame.

4.1. Concept of Proposed Scheme

UL-MAP consists of basic information fields and UL-MAP Information Elements (UL-MAP IE) which indicates position and size of uplink bandwidth allocation. The structure of the UL-MAP is shown in Table 4.1.

Table 4.1. Structure of UL-MAP

UL-MAP
Message Type
Uplink Channel ID
Uplink Channel Decriptor
Allocation Start Time
UL-MAP IE
UL-MAP IE
UL-MAP IE
......

UL-MAP IE defines uplink bandwidth allocation and varies for different PHY layer. The UL-MAP IE contains information such as UIUC whose values specified in UCD, CID of granted connection etc. The format of the UL-MAP IE is given in Table 4.2.

Table 4.2. OFDMA UL-MAP IE format

Syntax	Size
CID	16 bits
UIUC	4 bits
if (UIUC == 12) {	
OFDMA Symbol offset	8 bits
Subchannel offset	7 bits
No. OFDMA Symbols	7 bits
No. Subchannels	7 bits
Ranging Method	2 bits
reserved	1 bits
} else if (UIUC == 14) {	
CDMA_Allocation_IE()	32 bits
else if (UIUC == 15) {	
Extended UIUC dependent IE	variable
} else {	
Duration	10 bits
Repetition coding indication	2 bits
}	
Padding nibble, if needed }	4 bits

To minimize MAC overhead due to UL-MAP size in the downlink subframe, we propose a new scheme called as Cyclic UL-MAP IE for UGS connections. UGS connection requires fixed size grants issued at periodic intervals. When SS with UGS connections are accessing the network, periodic fixed size grant is negotiated at connection setup time and BS sends continuously periodic grants to this SS. In our proposed scheme, instead of sending continuously periodic grant with UL-MAP IE, SS is informed of future periodic grants with using UL-MAP Extended IE. A UL-MAP IE entry with UL-MAP Extended IE indicates that the IE carries special information and its format conforms to the Table 4.3.

Table 4.3. OFDMA UL-MAP extended IE format

Syntax	Size	Notes
UL_Extended_IE() {		
Extended UIUC	4 bits	0x00..0x0F
Length	4 bits	Length in bytes of Unspecified data field
Unspecified data	Variable	
}		

UL-MAP Extended IE has information of how many future periodic grants that SS can use this grant as an uplink bandwidth allocation. We call the number of future periodic grants as a cycle in this thesis. After cycle is expired, BS sends UL-MAP IE with cycle information again.

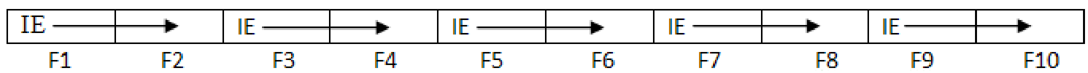

Figure 4.1. Concept of proposed scheme when cycle is one

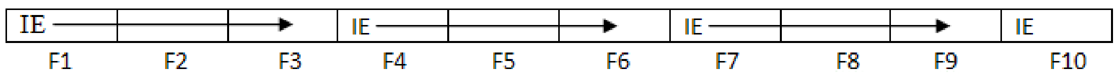

Figure 4.2. Concept of proposed scheme when cycle is two

In Figures 4.1, 4.2, and 4.3, we show the concept of the proposed scheme. Assume that connection requires grant in every frame. IE represents cyclic UL-MAP IE and consecutive frames are denoted as F1, F2, and F3 etc. With one IE, when we take cycle

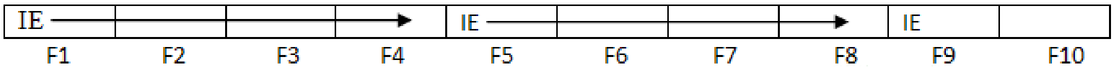

Figure 4.3. Concept of proposed scheme when cycle is three

as one we can use the same uplink bandwidth allocation in the next frame while BS does not send UL-MAP-IE at the beginning of the next frame in our proposed scheme. While Figure 4.1 describes the usage of our proposed scheme by taking value of cycle as one, Figure 4.2 and Figure 4.3 describe the usage of our proposed scheme by taking value of cycle as two and three respectively.

To do that, we create two grant tables at SS and BS. Grant table store UL-MAP IE and cycle information. When BS generates UL-MAP IE for the uplink bandwidth request, BS checks scheduling service of connection which request uplink bandwidth allocation. If the scheduling service of the connection is UGS then BS queries the grant table by using CID of the uplink bandwidth request whether UL-MAP IE with the same CID and its cycle greater than zero exists or not for this connection. If it exists, then BS does not create UL-MAP IE and subtracts one period from cycle of found UL-MAP IE entry in the grant table. Otherwise BS creates UL-MAP IE with UL-MAP Extended IE and puts it in UL-MAP when scheduling service of the connection is UGS. After putting it in UL-MAP, BS also adds a copy of cyclic UL-MAP IE with cycle information in its grant table for future use. In our proposed scheme, BS also keeps tracks of available next symbols and subchannels in the uplink subframe since next available symbols and subchannels is varying according to the grant table in every frame.

When UL-MAP is broadcasted by the BS, each SS decodes UL-MAP control message. If UL-MAP contains cyclic UL-MAP IE destined to it, SS extracts cycle information and then adds this cyclic UL-MAP IE with cycle information in its grant table for future usage of periodic grant up to cycle times. SS checks its grant table at the start of every frame and searches all appropriate UL-MAP IE with cycle which is greater than zero from grant table for the current frame to deliver grant to its connection queues and then subtracts one period from cycle of found UL-MAP IE in the grant table at the same time. UL-MAP entry with cycle information is removed from grant tables in SS and BS, when its cycle is equal to zero.

We can take value of cycle at most three in this thesis since if channel condition varies fast then it may be inefficient to send grant even in bad channel.

5. ANALYSIS & SIMULATION RESULTS

5.1. Analysis

An UL-MAP control message varies for different physical layers. In this thesis, we use IEEE 802.16-2004 standard and OFDMA PHY layer. The size of the UL-MAP IE and cyclic UL-MAP IE (UL-MAP IE entry with UL-MAP IE Extended IE) are given in Table 5.1. Assume that we have one BS and one SS with one UGS connection which

Table 5.1. Size of MAP IE

UL-MAP IE (bits)	cyclic UL-MAP IE (bits)
60	76

requires fixed size grant in every frame. We can take 0, 1, 2, up to 3 as a value of cycle. We also assume that channel is slow fading channel. Otherwise it may be inefficient to send grants even in bad channel. Since QPSK modulation with 1/2 coding rate is used in UL-MAP, size of MAP IE and cyclic MAP IE in symbols are 60 and 76 respectively. Let us denote T_{F}, F_{D}, C, IE_{send} and IE_{notsend} as total frame in a second, frame duration, cycle, number of frames per second in which uplink bandwidth allocation is sent and number of frames per second in which uplink bandwidth allocation is not sent respectively. T_{F} depends on F_{D} and it is equal to $\frac{1000msec}{F_{\mathrm{D}}}$.

$$IE_{\mathrm{notsend}} = \begin{cases} \Big(T_{\mathrm{F}} \ / \ (\mathrm{C}+1) \Big) * \mathrm{C} & \mathrm{R}=0 \\ \Big((T_{\mathrm{F}} \ / \ (\mathrm{C}+1)) * \mathrm{C}\Big) + \mathrm{R}\text{-}1 & R > 1 \end{cases} \tag{5.1}$$

where R is the residue of $\frac{T_{\mathrm{F}}}{(C+1)}$. IE_{notsend} is calculated by Eq 5.1. IE_{send} is simply equal to (T_{F} - IE_{notsend}).

In Table 5.2, we will present bandwidth required for MAP IE with unit of symbols per second (sps) in our proposed scheme and its conventional counterpart. We will also present gain with unit of sps and gain with bits per second (bps) by using 64-QAM with 3/4 coding rate. We will not present values of 10 msec frame duration when cycle is greater than 2, and values of 20 msec frame duration due to assumption of slow fading channel. When taking the value of cycle is zero, UL-MAP IE without cycle information is used in our proposed scheme. Therefore cyclic UL-MAP IE and UL-MAP IE are the same size when cycle is zero.

With the analysis of the proposed scheme given in Table 5.2, our gain increases as cycle increases. Since our analysis contains one SS with one UGS connection, it is obvious that when the numbers of SS with UGS connection increase, our gain in the downlink subframe increases. We also take the advantage of using less robust modulation type and coding rate supported in the downlink subframe to increase data capacity for saved symbols from UL-MAP IE.

Table 5.2. Gain of proposed scheme

F_D	T_F	C	IE_{notsend}	IE_{send}	BW (sps)	Gain (sps)	Gain (bps)
2	500	0	0	500	30000	0	0
2	500	1	250	250	19000	11000	49500
2	500	2	333	167	12692	17308	77886
2	500	3	375	125	9500	20500	92250
2,5	400	0	0	400	24000	0	0
2,5	400	1	200	200	15200	8800	39600
2,5	400	2	266	134	10184	13816	62172
2,5	400	3	300	100	7600	16400	73800
4	250	0	0	250	15000	0	0
4	250	1	125	125	9500	5500	24750
4	250	2	166	84	6384	8616	38772
4	250	3	187	63	4788	10212	45954
5	200	0	0	200	12000	0	0
5	200	1	100	100	7600	4400	19800
5	200	2	133	67	5092	6908	31086
5	200	3	150	50	3800	8200	36900
8	125	0	0	125	7500	0	0
8	125	1	62	63	4788	2712	12204
8	125	2	83	42	3192	4308	19386
8	125	3	93	32	2432	5068	22806
10	100	0	0	100	6000	0	0
10	100	1	50	50	3800	2200	9900
10	100	2	66	34	2584	3416	15372

5.2. Simulation Analysis

5.2.1. OPNET 11.5 Wimax Module Implementation Details

We have implemented our proposed scheme by using OPNET 11.5 Modeler with WiMAX model. Help of the WiMAX model, we can analyze network performance in WMAN. The engine of OPNET modeler is designed with finite state machine model using Proto-C [32]. WiMAX model includes the features of the IEEE 802.16 standard. It provides state machine of WiMAX MAC process model which is shown in Figure 5.1. The actions of a component at a particular state are defined in Proto-C code. This

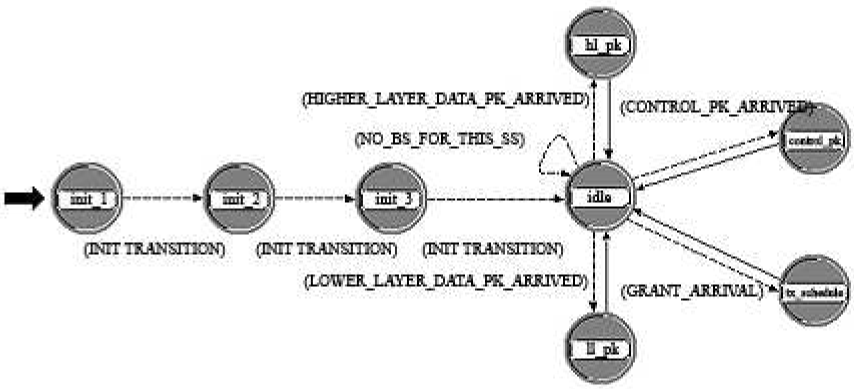

Figure 5.1. IEEE 802.16 MAC state machine in OPNET

allows us to implement our proposed scheme in the WiMAX MAC process model. In particular, the supported features are:

- MAC messages such as MAC PDU, Management Messages (Dynamic Service Addition messages, bandwidth request, UL-MAP, DL-MAP).
- Radio link control.
- Scheduling services (UGS, rtPS, nrtPS, BE).
- Automatic Retransmission Request (ARQ).
- Packet loss modeling.
- Bandwidth allocation and request mechanisms.
- Network entry and initialization.

- QoS.
- PHY modeling including OFDM, OFDMA, and SC profiles.
- Convergence sublayer.
- Broadcast and multicast traffic.

In OPNET 11.5 Modeler WiMAX Model, control and data plane are separated in MAC. WiMAX MAC process has BS and SS child processes and it is called WiMAX-bs-control and WiMAX-ss-control respectively in the model. WiMAX-bs-control child process shown in Figure 5.2 is invoked when the parent process hands a control packet (this includes remote bandwidth requests), the parent process submits a local bandwidth request and generating MAPs. MAP function is called at the beginning of each frame in order to generate UL-MAP and DL-MAP. We implement our proposed scheme in this function so that BS can create cyclic UL-MAP IE for the SS with UGS connections and make other functionalities mention earlier for our proposed scheme. Like

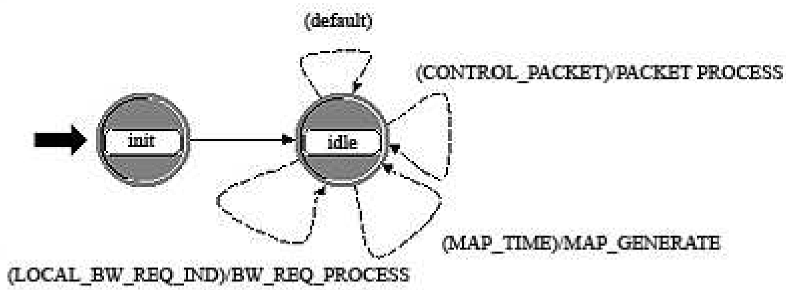

Figure 5.2. BS control child process

WiMAX-bs-control child process, WiMAX-ss-control child process shown in Figure 5.3 is invoked when parent process hands control packet. In this process, there exists a function which decodes UL-MAP control message and then delivers these grants to each connection in the data plane. We implement a new function here so that SS can detect cyclic UL-MAP IE and store it in grant table and make other functionalities mentioned earlier for our proposed scheme.

5.2.2. Assumptions

The following assumption are made for all simulations

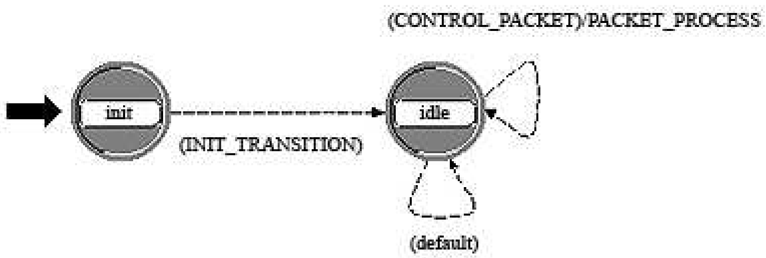

Figure 5.3. SS control child process

- IEEE 802.16-2004 standard is used.
- PMP topology is used.
- OFDMA PHY profile is used.
- Error free channel is used.
- Distance from nearest/farthest SS to BS is between 100 meters and 1500 meters
- We use OPNET Modeler 11.5 WiMAX Model default packet scheduler algorithm. In packet scheduling algorithm, UGS connections are scheduled first. If space left on the frame, then scheduler use Modifed Deficit Round Robin (MDRR) algorithm to schedule rtPs and nrtPS bandwidth request queues. If space still left, scheduler will process bandwidth request from the queue containing bandwidth request for the BE connections.
- We use OPNET Modeler 11.5 WiMAX Model default admission control. In admission rate check,
  - UGS : guaranteed Max. Sustained Traffic Rate.
  - rtPS : guaranteed Min. Reserved Traffic Rate + polling for Max. Sustained.
  - nrtPS: guaranteed Min. Reserved Traffic Rate + polling for Min. Reserved.
  - BE : no guarantee, so they are always admitted.
- Grant per connection mode is used.
- 64-QAM with 3/4 coding rate is used.
- TDD duplexing technique is used.
- Packing and fragmentation functionality is enabled.
- ARQ is disabled.
- Running time of the all simulation is 120 msec.

5.2.3. Simulation Scenarios and Parameters

We test our proposed architecture with different set of scenarios to show the effectiveness of our cyclic UL-MAP IE scheme. We have used OPNET 11.5 Modeler WiMAX Model for simulations. OFDM PHY profile parameters are given in Table 5.3.

Contention part of the uplink subframe is the subchannel in index order on UL-MAP. The entire subchannel is dedicated to bandwidth request and ranging messages in the model. 60% percentage of the contention area that is allocated to bandwidth requests and the rest is allocated to ranging messages.

In our scenarios, we use different application types such as Voice over IP (VoIP), Hypertext Transfer Protocol (HTTP), and File Transfer Protocol (FTP). We use G711 codec for the VoIP application. This codec is used for quality voice calls. G711 uses Pulse Code Modulation to produce a data rate 64 Kbps. We use UGS scheduling type whose maximum sustained rate and minimum reserved rate are 312 Kbps for the VoIP applications.

For HTTP application, we use web browsing (Heavy HTTP 1.1) in which page interarrival times are exponentially distributed with mean 5 sec and each page has 5000 byte of text and 40 large images each size randomly picked with a uniform distribution on [2000,10000] bytes. We use Best Effort scheduling type whose maximum sustained rate and minimum reserved rate are 512 Kbps, 256 Kbps respectively for the HTTP traffic.

Table 5.3. Simulation parameters

Frame duration	5 msec
Symbol duration	100.8 microseconds
Number of subcarriers	2048
FCH	2 symbols
Frame preambles	1 symbols
TTG	5 microseconds
RTG	5 microseconds
Boundary between DL and UL	Fixed
Space taken on the frame by the UL	% 50
Base Frequency	5GHz
Bandwidth	20 MHz
UL Zone	
Number of null subcarriers Left	184
Number of null subcarriers Right	183
Number of data subcarriers	1120
Number of subchannels	70
Allocation quantum	1
Usage Mode	Partial usage of subchannels (PUSC)
DL Zone	
Number of null subcarriers Left	184
Number of null subcarriers Right	183
Number of data subcarriers	1440
Number of subchannels	60
Allocation quantum	2
Usage Mode	PUSC

For FTP application, we use File Transfer Heavy in which 25 % transfers from clients to servers, 75 % transfer from server to clients and the time between each client's file transfer requests, is exponentially distributed with mean 10 seconds. All files are 1.000.000 bytes. Our scheduling type for FTP traffic is nrtPS whose maximum and minimum reserved rates are 512 Kbps, 256 Kbps respectively.

All scenarios in simulation has a PMP network topology consisting of one BS, high numbers of SS with UGS connection, zero or more than one SS with non UGS connection, and one or two Local Area Networks (LAN). LAN is connected to BS via switch. The sample network topology is shown in Figure 5.4.

Figure 5.4. Sample network topology

5.2.4. Simulation Results

Firstly, we test our proposed scheme with only SS with UGS connection. VoIP application is used in all SSs. BS is connected to a Local Area Network (LAN) via switch. The LAN consists of workstations which can support VoIP application. The number of workstation is equal to the number of SS in this network topology. We create two scenarios for different cycle values. In these scenarios, we bound voice packet end to end delay and evaluate our proposed scheme in terms of network capacity with its conventional counterpart.

When voice packet end to end delay is bounded within the range of 50 msec and 60 msec in these scenarios (Figure 5.5, Figure 5.6), while our proposed scheme supports 68 SSs with cycle as one and 71 SSs with cycle as three, its conventional counterpart supports 64 SSs. This result is expected since our proposed scheme saves symbols from UL-MAP in the downlink subframe when there are high numbers of SS using UGS connection and the saved symbols are used for data transmission. Thus our proposed

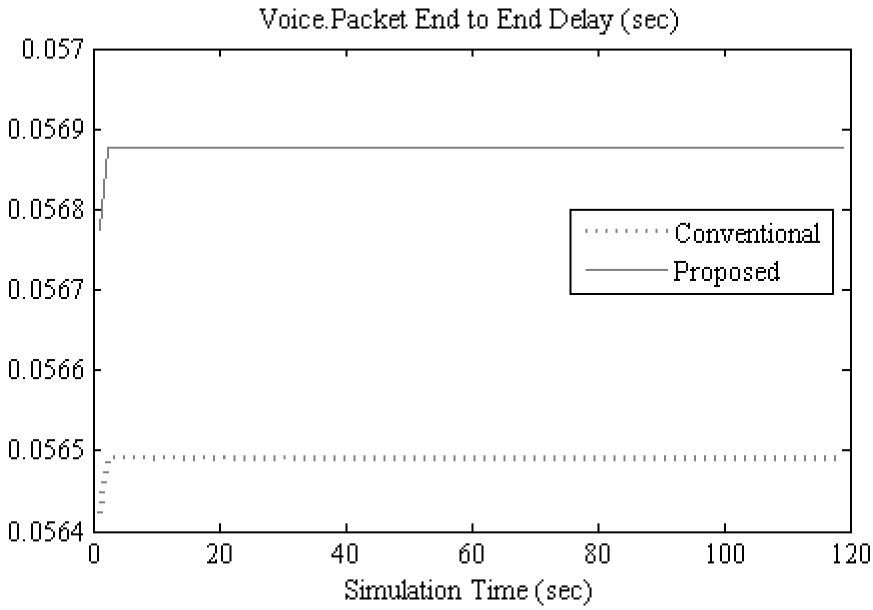

Figure 5.5. Voice packet ETE delay when cycle is one

scheme improves the system capacity about 6.2 % when cycle is one and 10.9 % when cycle is three. These results also show that as the value of the cycle increases, our gain also increases.

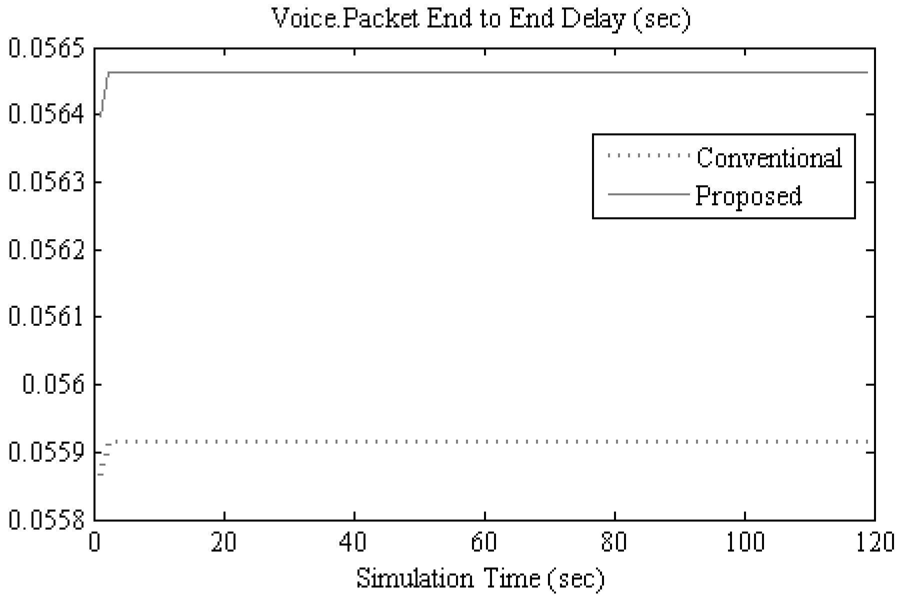

Figure 5.6. Voice packet ETE delay when cycle is three

In the second set of scenarios, we use different application types such as VoIP and HTTP. Our network topology consists of 40 SSs using VoIP application and 70 SSs using HTTP application. There are two LANs connected to BS via switch. First LAN includes 40 workstations which supports VoIP applications. Second LAN consists of 70 HTTP servers which supports HTTP application. We take 70 HTTP servers in the second LAN to avoid loading server more than its capacity. Therefore there is no performance problem in HTTP LAN.

Simulation results show that our proposed solution improves the system throughput about 3.2 % (Figure 5.7) and provides almost the same voice end to end delay values as its counterpart (Figure 5.8) when cycle is one. When we take cycle as three, our proposed solution improves the system throughput about 5.5 % (Figure 5.9) also provides almost the same voice end to end delay values as its counterpart (Figure 5.10).

In the third set of scenarios, we use FTP and VoIP applications. Instead of using values of cycle as one and three, we use values of cycle as two and three. Our network topology consists of 40 SSs using VoIP application and 36 SSs using FTP application. There are two LANs connected to BS via switch. First LAN consists of 40

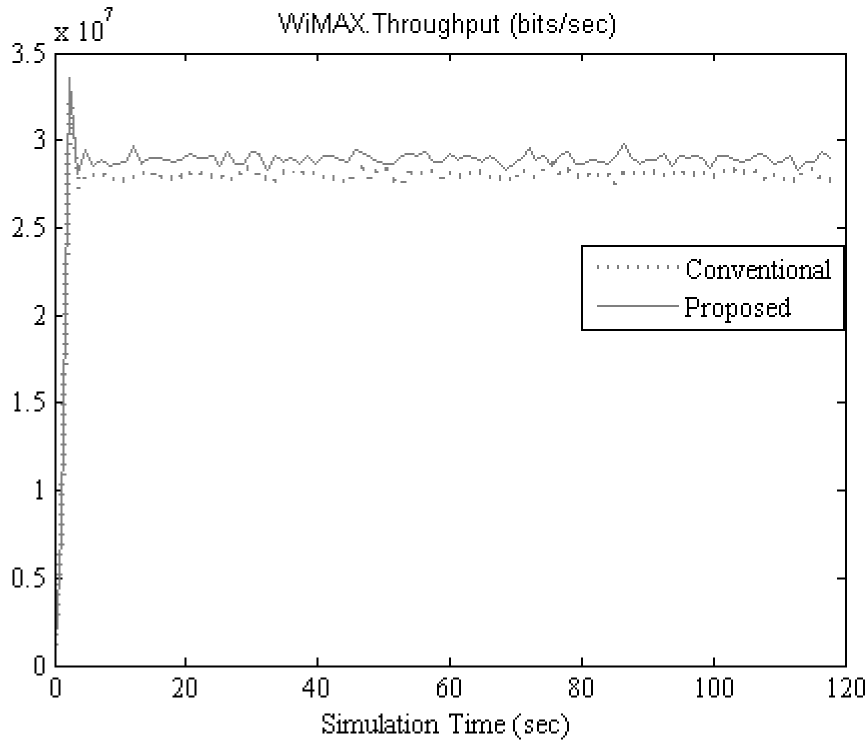

Figure 5.7. WiMAX throughput when cycle is one

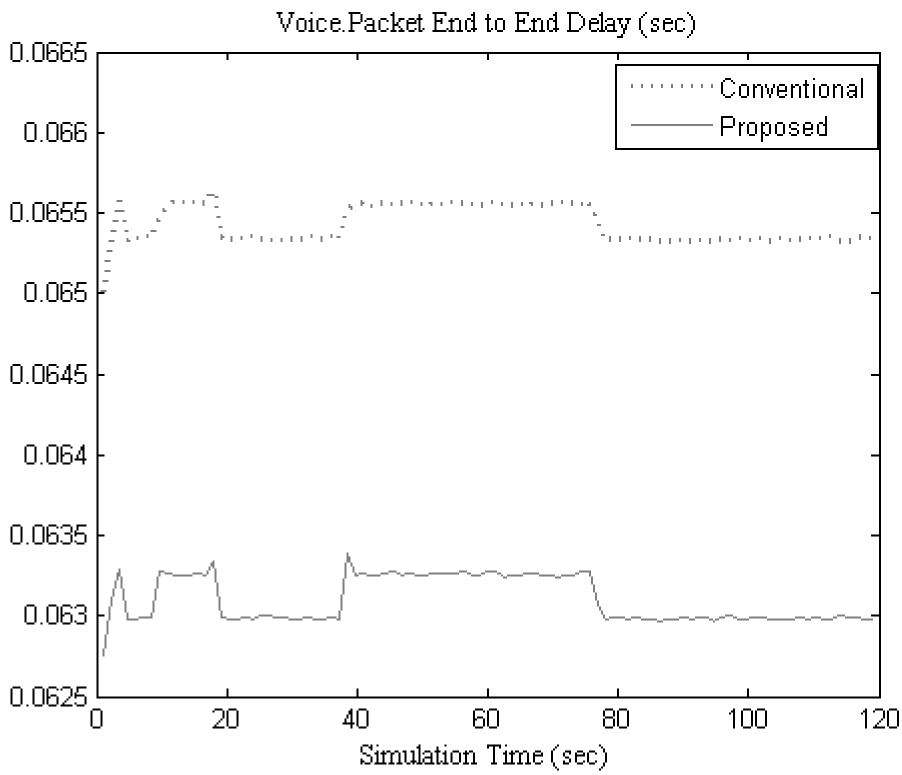

Figure 5.8. Voice packet ETE delay when cycle is one

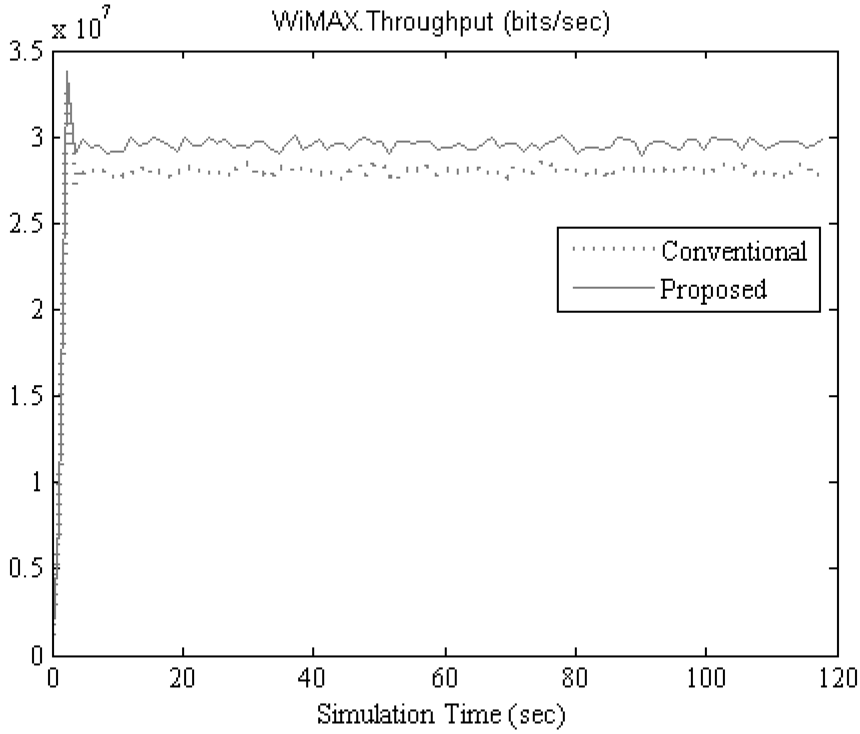

Figure 5.9. WiMAX throughput when cycle is three

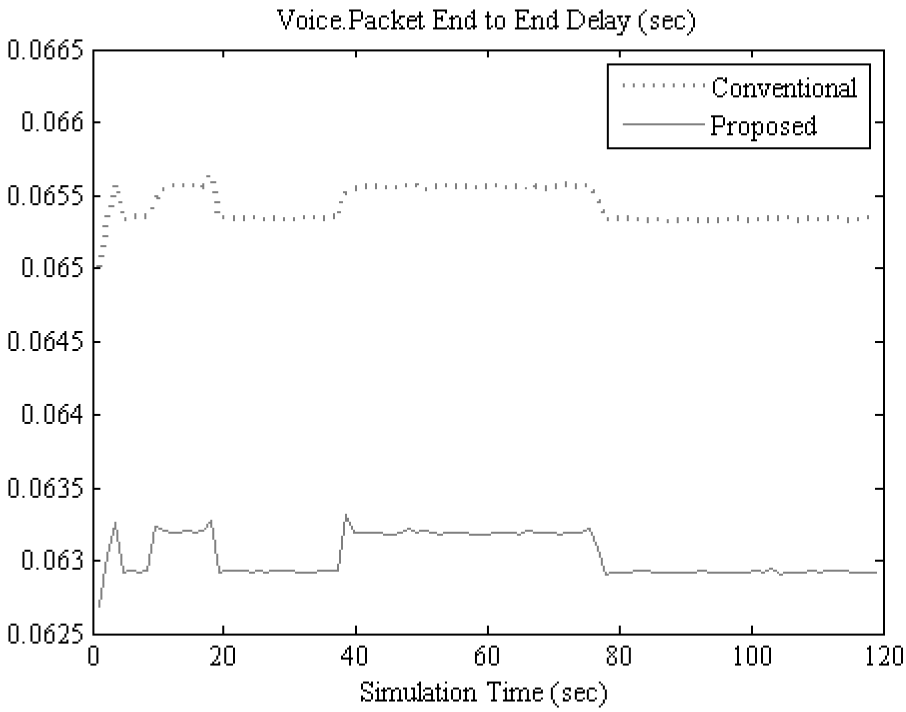

Figure 5.10. Voice packet ETE delay when cycle is three

workstations using VoIP application. Second of these LANs consists of 36 FTP servers which supports FTP application. We take 36 FTP servers due to avoiding performance problem which may occur at FTP servers.

Simulation results of third set of scenarios show that our proposed solution improves system throughput about 4.4 % when cycle is two (Figure 5.11). Improvement on throughput is increasing when cycle is increasing. As cycle is three, our proposed solution improves system throughput about 5.6 % (Figure 5.13). Our proposed solution provides almost the same voice end to end delay values as its counterpart in this set of scenarios (Figure 5.12, Figure 5.14).

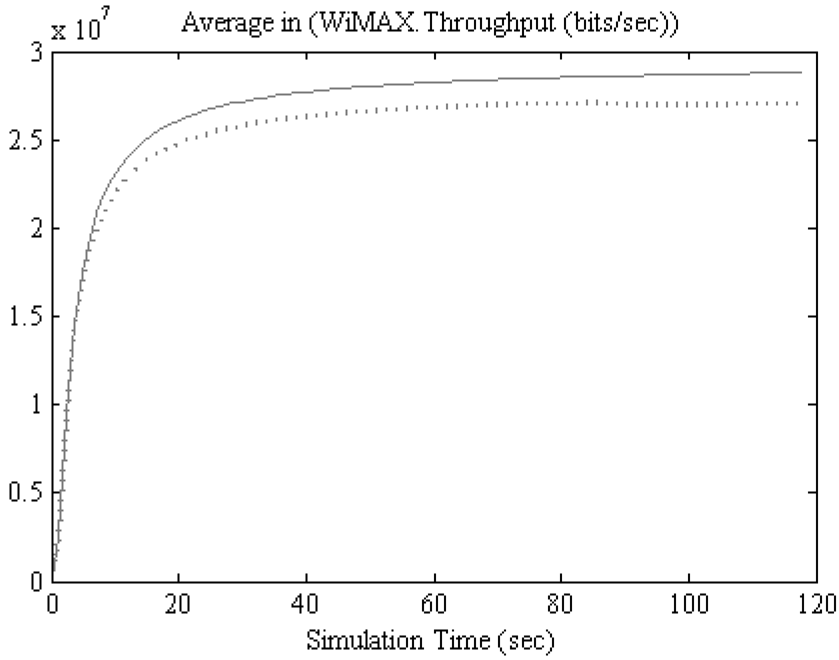

Figure 5.11. WiMAX throughput when cycle is two

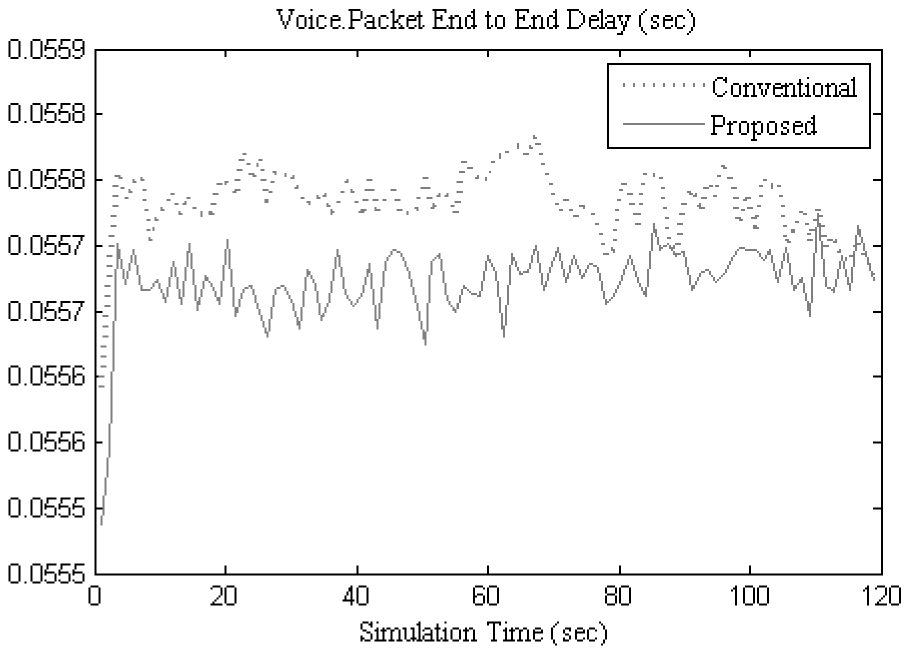

Figure 5.12. Voice packet ETE delay when cycle is two

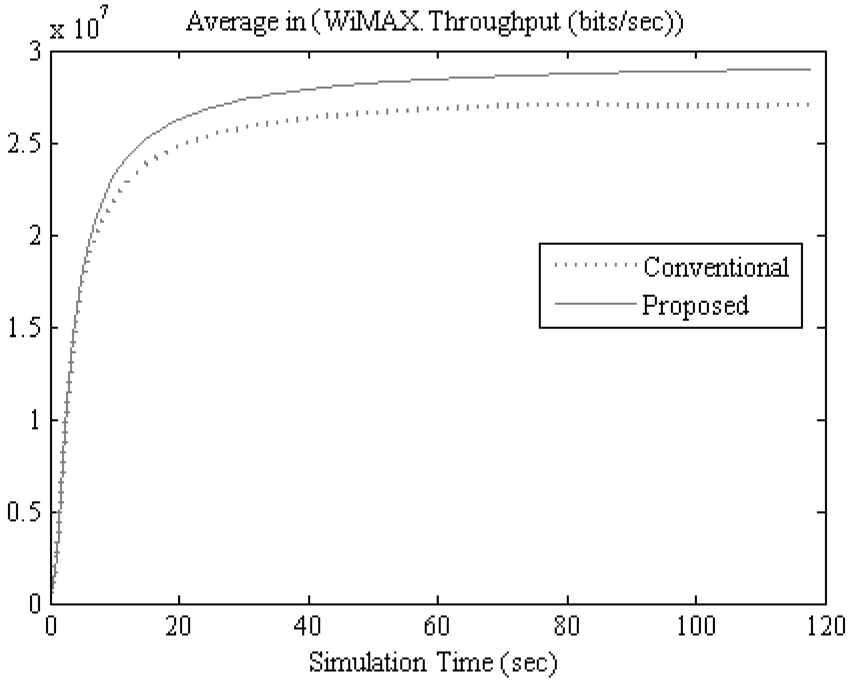

Figure 5.13. WiMAX throughput when cycle is three

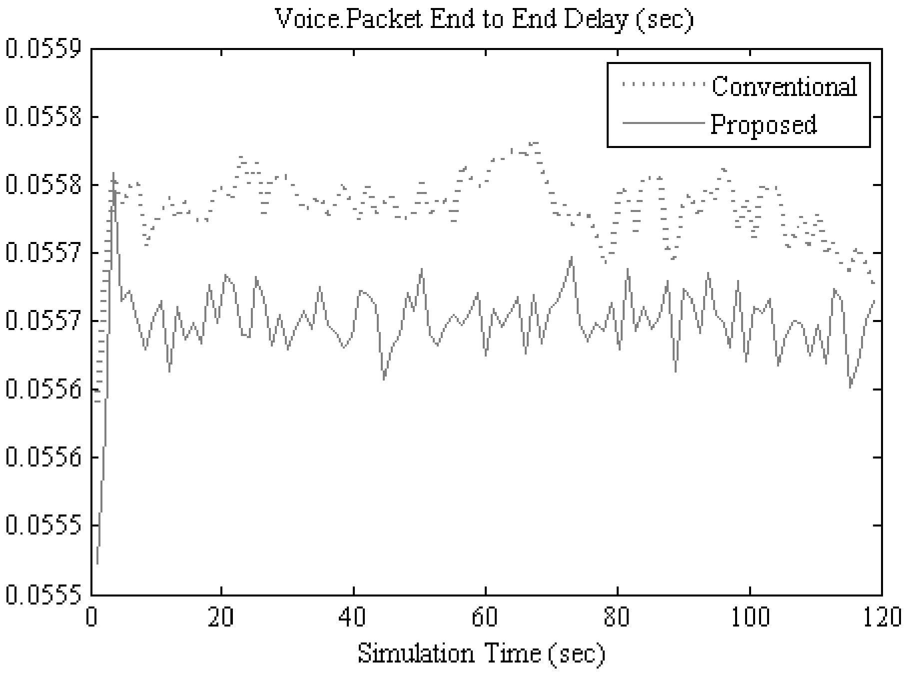

Figure 5.14. Voice packet ETE delay when cycle is three

6. CONCLUSIONS & FUTURE WORK

UL-MAP is one of the control messages that contain usage of the uplink subframe. It is broadcasted in the downlink subframe by the BS. Therefore size of UL-MAP affects downlink data transmission inversely.

In this thesis, we propose cyclic UL-MAP IE scheme in order to reduce MAC overhead due to size of UL-MAP. Cyclic UL-MAP IE informs SS of future periodic fixed size grants to prevent sending next periodic fixed size grant information in the next UL-MAP for SS with UGS connection. Thus UL-MAP usage is decreasing. Our proposed scheme is suitable for IEEE 802.16 networks which contains high numbers of SS with UGS connections.

Our numerical and simulation analysis results show that our proposed scheme reduce MAC overhead due to size of UL-MAP and improves cell throughput and capacity. The gain in cell throughput and capacity depends on the number of UGS connections and cycles. As the number of UGS connections or value of cycle increases, our gain also increases in the downlink subframe.

As a future work, there are many issues that should be further investigated.

- We simulated our proposed scheme in error free channel. We will investigate how the high failure rate condition affects the performance of our proposed scheme.
- The proposed scheme is applied only UGS connections. We will investigate performance of ertPS and rtPS connections with our proposed scheme.
- In the cell, each SS has not the same channel conditions. Instead of announcing the same cycle as proposed in our solution, we will investigate broadcasting cycle to SS with UGS connection according to its channel condition.
- To provide interoperability, we will implement a mechanisms to differentiate SS according to its capability of understanding cyclic UL-MAP IE.

REFERENCES

1. IEEE 802.16-2004, “IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems,” October 2004.

2. IEEE 802.16-2005, “IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems for Mobile Users,”December 2005.

3. http://wirelessman.org/published.html

4. C. Eklund, R.B. Marks, K.L. Stanwood, S. Wang, “IEEE Standard 802.16: a technical overview of the WirelessMAN air interface for broadband wireless access,” IEEE Communications Magazine 40 (6) (2002) 98107.

5. M. Cao, W. Ma, Q. Zhang, X. Wang, W. Zhu, “Modelling and performance analysis of the distributed scheduler in IEEE 802.16 mesh mode,” in: ACM 6th International Symposium on Mobile Ad Hoc Networking and Computing 2005 (MobiHoc 05), Boston, MA, USA, 2005, pp. 7889.

6. S.J. Vaughan-Nichols, “Achieving wireless broadband with WiMax,” IEEE Computer Magazine 37 (6) (2004) 1013.

7. R. Bellman, “WiMax: broadband wireless access and beyond, Business Communications Review,” 8 (11) (2004) 4653.

8. A. Barry, G. Healy, C. Daly, J. Johnson, “Overview of Wi-Max IEEE 802.16a/e, in: 5th Annual Information Technology and Telecommunications,” 2005 (IT& T, 05) Cork, Ireland, 2005, pp. 779784.

9. WiMAX Forum, Certified program for Fixed WiMAX

http://www.wimaxforum.org/technology/downloads/WiMAX_Forum_Fixed_Certification_White_Paper_Jan_07.pdf, 2007.

10. Kuran M.S.; T. Tuğcu, “A survey on emerging broadband wireless access technologies,” Elsevier Computer Networks, Vol. 51, Issue 11, pp. 3013-3046, Aug 2007.

11. Howon Lee , Taesso Kwon , Dong-Ho Cho “An efficient uplink schedulink algorithm for VOIP services in IEEE 802.16 BWA systems,” IEEE Vehicular Technology Conference ,2004 IEEE 60th Volume 5.

12. Hongxi Wang,Jianfeng Chen,Wenhua Jiao “A service flow management strategy for IEEE 802.16 broadband wireless access systems in TDD mode,” Vehicular Technology Conference, 2005. VTC-2005-Fall. 2005 IEEE 62nd

13. Hongxi Wang,Jianfeng Chen,Wenhua Jiao “An integrated qos control architecture for IEEE 802.16 broadband wireless access systems,” Global Telecommunications Conference, 2005. GLOBECOM ’05. IEEE

14. Dong-Hoon Cho, Jung-Hoon Song, Ki-Jun Han,Min-Su Kim “Performance analysis of the IEEE 802.16 wireless metropolitan area network,” Distributed Frameworks for Multimedia Applications, 2005. DFMA ’05. First International Conference

15. Deng Wang, GuoSong Chu, Shunliang Mei ’A QoS architecture for the MAC protocol of IEEE 802.16 BWA system,” Communications, Circuits and Systems and West Sino Expositions, IEEE 2002 International Conference

16. Claudio Ciconetti, Allessandro Erta, Luciano Lenzini, Enzo Mingozzi ’Performance Evaluation of the IEEE 802.16 MAC for Qos Support,” IEEE transaction on Mobile Computing , vol 6 No.1 2007

17. Merakos, L. ; Passas, N. ; Xergias, S.A. “Flexible Resource Allocation in IEEE 802.16 Wireless Metropolitan Area Networks,” Local and Metropolitan Area Networks, 2005. LANMAN 2005. The 14th IEEE Workshop

18. Ganz, A.;Wongthavarawat, K. "IEEE 802.16 based last mile broadband wireless military networks with quality of service support" Military Communications Conference, 2003. MILCOM 2003. IEEE

19. Daniele Tarchi; Roamano Fantacci; Marco Bardazzi "Quality of service management in IEEE 802.16 Wireless Metropolitan Area Network," IEEE ICC 2006

20. M. Hawa and D.W.Petr "Quality of service scheduling in cable and broadband wireless Access systems," 10th IEEE International workshop on Quality of Service, May 2002 ,pp 247-255

21. Das, D.;Jayaram, D.;Sreenivasulu, N.;Vinay, K. "Performance Evaluation of End-to-end Delay by Hybrid Scheduling Algorithm for QoS in IEEE 802.16 Network" Wireless and Optical Communications Networks, 2006 IFIP International Conference

22. Wu, Jing; Mo, Jeonghoon; Wang, Ting; "A Method for Non-Real-Time Polling Service in IEEE 802.16 Wireless Access Networks," Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th Sept. 30 2007-Oct. 3 2007 Page(s):1518 - 1522

23. Mukul, R.; Singh, P.; Jayaram, D.; Das, D.; Sreenivasulu, N.; Vinay, K.; Ramamoorthy, A.; "An adaptive bandwidth request mechanism for QoS enhancement in WiMax real time communication," Wireless and Optical Communications Networks, 2006 IFIP International Conference on 11-13 April 2006 Page(s):5 pp

24. M.; Puleri, M.; Garritano, S.; Testa, P.; Albanese, R.; Mancini, M.; Lo Curto, V., "Performance analysis of an efficient packet-based IEEE 802.16 MAC supporting adaptive modulation and coding Settembre," Computer Networks, 2006 International Symposium on 16-18 June 2006 Page(s):11 - 16

25. Qingwen Liu; Xin Wang; Giannakis, G.B., "A cross-layer scheduling algorithm with QoS support in wireless networks," Vehicular Technology, IEEE Transactions

on Volume 55, Issue 3, May 2006 Page(s):839 - 847

26. A.E. Xhafa, S. Kangude, X. Lu, "MAC performance of IEEE 802.16e",IEEE Vehicular Technology Conference, Fall 2005, vol. 1, pp. 685-689,Dallas, TX, Semptember 2005.

27. Kim, Ju Yeop; Cho, Dong-Ho, "Piggybacking Scheme of MAP IE for Minimizing MAC Overhead in the IEEE 802.16e OFDMA Systems," Vehicular Technology Conference, 2007, Vol. 66 , pp. 284-288 , September 2007

28. Yongjoo Tcha, et al, "A Compact MAP Message to Provide a Vir-tual Multi-frame Structure for a Periodic Fixed Bandwidth Assignment Scheme," IEEE C802.16e-04, 368r2, November 2004.

29. Itzik Kitroser, et al, "Compressed DL-MAP Format for OFDMA PHY', IEEE C802.16d-03/63, September 2003.

30. Juhee Kim, et al, "A New Efficient BS Scheduler and SchedulingAlgorithm in WiBro Systems" International Conference on AdvancedCommunication Technology 2006, Vol. 3, pp. 1467-1470, February 2006

31. Kim, H.S.; Yang, S., "Tiny MAP: An efficient MAP in IEEE 802.16/WiMAX broadband wireless access systems" Computer Communications, Vol. 30, pp. 2122-2128 ,Issue 9, 1 June 2007

32. http://www.opnet.com