AN IMPROVED RESOURCE ALLOCATION SCHEME FOR WIMAX USING CHANNEL INFORMATION

KHALID MAHMOOD AWAN

A thesis submitted in fulfilment of the
requirements for the award of degree of
Doctor of Philosophy (Computer Science)

Faculty of Computing
Universiti Teknologi Malaysia

MAY 2014

Dedicated to my beloved parents and family, without their love and support this research would have never been completed.

ACKNOWLEDGEMENT

Thanks to **Allah SWT** for everything I was able to achieve and for everything I tried but I was not able to achieve.

First of all, I would like to take this opportunity to gratefully acknowledge the wholehearted supervision of **Professor Dr. Abdul Hanan Bin Abdullah** during this work. His dedication, skillful guidance, helpful suggestions and constant encouragement made it possible for me to deliver a dissertation of appreciable quality and standard.

I would also like to say special thanks to my lab fellows for their kind support and encouragement in establishing my confidence in order to achieve this goal.

I am forever indebted to my parents for their patience and understanding, alleviating my family responsibilities and encouraging me to concentrate on my study.

I must express my sincerest and heartiest thanks to my wife, children Rafay and Manan for their continuous support, duaa and love when it was most required. Without their help and encouragement, it was difficult to achieve this success.

ABSTRACT

In recent years, tremendous progress has been made in wireless communication systems to provide wireless coverage to end users at different data rates. WiMAX technology provides wireless broadband access over an extended coverage area in both fixed and mobility environments. Most of the existing resource allocation schemes allocate resources based on respective service class of the incoming users' requests. However, due to variation in channel conditions, user mobility and diverse resource requirements QoS based resource allocation either results in over or under utilization of allocated resources. Therefore, resource allocation is a challenging task in WiMAX. This research proposes an improved resource management mechanism that performs resource allocation by taking into consideration not only the user service class but also the respective channel status. Based on these two parameters, this research aims to achieve improved resource allocation in terms of resource utilization, fairness and network throughput. First, a Channel Based Resource Allocation scheme is introduced where priority in resource allocation is given to users' requests with relatively higher service classes and better channel status. To maintain fairness in resource allocation process, a Fair Resource Allocation Based Service mechanism is developed where priority is given to users' requests having less additional resources demand. Finally, to improve throughput of the network, a Channel Based Throughput Improvement approach is proposed which dynamically selects a threshold level of channel gain based on individual channel gain of users. During resource allocation process, users above the threshold level are selected for resource allocation such that priority is given to users with high channel gain. Different simulation scenario results reveal an overall improved resource utilization from 87% to 91% and the throughput improves up to 15% when compared to existing schemes. In conclusion the performance of resource utilization is improved if channel status is considered as an input parameter.

ABSTRAK

Sejak kebelakangan ini, banyak kemajuan hebat telah dicapai di dalam sistem-sistem komunikasi tanpa wayar bagi menyediakan liputan tanpa wayar kepada pengguna-pengguna pada kadar data berbeza. Teknologi WiMAX memberi akses jalur lebar tanpa wayar merangkumi kawasan liputan yang luas dalam persekitaran-persekitaran tetap dan bergerak. Kebanyakan skim pengagihan sumber yang wujud mengagihkan sumber-sumber berdasarkan kelas perkhidmatan mengikut kehendak seseorang pengguna. Tetapi, disebabkan kepelbagaian keadaan-keadaan saluran, pergerakan pengguna dan pengagihan sumber berasaskan QoS dengan pelbagai keperluan sumber membawa kepada sama ada terlebih atau terkurang penggunaan sumber-sumber teragih. Maka, pengagihan sumber menjadi satu tugas mencabar dalam WiMAX. Kajian ini mencadangkan satu mekanisme pengurusan yang diperbaiki yang menjalankan pengagihan sumber dengan mengambil kira bukan sahaja kelas perkhidmatan pengguna tetapi juga status saluran berkaitan. Berdasarkan kepada dua parameter tersebut, kajian ini bertujuan menghasilkan pengagihan sumber yang lebih baik di dalam penggunaan sumber, keadilan dan penghasilan jaringan. Pertama, satu skim *Channel Based Resource Allocation* diperkenalkan di mana keutamaan dalam pengagihan sumber diberi kepada permintaan-permintaan pengguna dengan kelas-kelas servis yang secara relatifnya lebih tinggi dan berstatus saluran yang lebih baik. Untuk mengekalkan keadilan dalam proses pengagihan sumber, satu mekanisme *Fair Resource Allocation Based Service* dibangunkan dengan keutamaan diberi kepada permintaan-permintaan pengguna yang berkehendakan kurang sumber-sumber tambahan. Akhirnya, bagi memperbaiki penghasilan jaringan, satu kaedah *Channel Based Throughput Improvement* dicadangkan yang dapat memilih secara dinamik suatu tahap ambang dapatan saluran mengikut dapatan saluran individu pengguna. Semasa proses pengagihan sumber, para pengguna yang melepasi tahap ambang dipilih bagi pengagihan sumber dengan keutamaan diberi kepada mereka yang mempunyai dapatan sumber yang lebih tinggi. Keputusan-keputusan senario simulasi berbeza menunjukkan peningkatan penggunaan sumber keseluruhan daripada 87% kepada 91% dan penghasilan bertambah sehingga 15% bila dibandingkan dengan skim-skim sedia ada. Kesimpulannya, prestasi penggunaan sumber dipertingkatkan jika status saluran diambil kira sebagai satu parameter input.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ALGORITHMS

LIST OF ABBREVIATIONS

ASN	-	Access Service Network
BE	-	Best Effort
BS	-	Base Station
CBRA	-	Channel Based Resource Allocation
CBTI	-	Channel Based Throughput Improvement
CSL	-	Convergence Sub Layer
CSN	-	Connectivity Service Network
DL	-	Down Link
EBG	-	Extra Bandwidth Granting
EDF	-	Earlier Deadline First
ertPS	-	extended real time Polling Service
FDD	-	Frequency Division Duplex
FIFO	-	First In First Out
GWF	-	Generalized Weighted Fair
MS	-	Mobile Station
nrtPS	-	non real time Polling Service
PDU	-	Protocol Data Unit
PF	-	Proportional Fair
QoS	-	Quality of Service
RR	-	Round Robin
rtPS	-	real time Polling Service
FRABS	-	Fair Resource Allocation Based Service
SDU	-	Service Data Unit
SS	-	Subscriber Station
TDMA	-	Time Division Multiple Access
TDD	-	Time Division Duplex

UGS	-	Unsolicited Grant Service
UL	-	Up Link
WiMAX	-	Worldwide inter-operability for Micro Wave Access

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

In recent years, immense development has taken place in the area of telecommunication systems and wireless networks. Worldwide interoperability for Microwave Access (WiMAX) networks is a cost effective solution. WiMAX is an emerging technology which offers stable services to users. This service is considered as equivalent to Digital Subscriber Line (DSL). WiMAX technology supports long range coverage with QoS provided through scalable architecture with high data throughput. It is easy to deploy and provide service to a large coverage area. WiMAX is an IEEE 802.16 services standard. It can operate in both infrastructure and infrastructure-less mode. WiMAX consists of Base Station (BS) and Mobile Station (MS) or Subscriber Station (SS). Each BS communicates with multiple MS with-in its coverage area. BS is connected with backbone to the core network, and the subscriber uses premise's equipment for the connectivity. This technological advancement has greatly improved connectivity. In current WiMAX network development, a great deal of attention is given to fulfil user’s requirements. There are numerous applications for the different wireless technologies. The implementations of these technologies depend on the requirements of the users. Each of these applications has different Quality of Service (QoS) requirements that make the management of the telecommunication system more complex. During recent years, most of the research in the telecommunication system has focused on meeting user requirements and providing an optimum level of service.

The motivation behind this research is to design a mechanism that provides resources to users. This mechanism is based on the channel status and required QoS class. The main focus of this research is to address the problem of resource allocation and its impact on fairness and throughput of the network. This research provides a mechanism for improvement in utilization of existing resources in WiMAX network. Moreover, the effect of the proposed mechanism is analysed for fairness and throughput of the network.

1.2 Problem Background

Recently, researchers have focused on enhancing the different aspects of WiMAX implementation such as resource allocation, QoS, scheduling, fairness, throughput, security and complexity of algorithms (del Castillo Waters *et al.*, 2013) (Farhadi, 2011; Girici *et al.*, 2010; Gopalan *et al.*, 2012; Shu'aibu and Syed-Yusof, 2011; So-In *et al.*, 2009b). WiMAX forum was formed to solve problems and promote solutions based on IEEE802.16 standard (Standard, 2010). IEEE 802.16 standard 2004 focuses on Point to Multi Point (PMP). The enhanced version of the standard was released in 2009 and it supports mobility along with QoS parameters (Ruangchaijatupon and Ji, 2009). It is important to note that WiMAX systems face challenges similar to the existing cellular networks. While working in wireless network environment different subcarriers have a different channel gain, and each sub carrier fades independently for different Subscriber Station (SS) (Zhang and Li, 2008). Such diversity motivates this work which is to design a mechanism for resource allocation in WiMAX network.

i. Resource Allocation in WiMAX

Bandwidth in any network is a limited asset; hence the performance of a system depends on efficient resource utilization. A proper resource allocation mechanism improves the spectrum efficiency and provides the available resources to the user in the

best and most efficient manner (Liu *et al.*, 2003). In WiMAX, bandwidth is divided into sub-carriers (Krishana Ramada 2008). These sub-carriers are allocated to the subscriber and controlled by the BS. The policy of resource allocation depends on the BS scheduling algorithm. Groupings of these sub-carriers are known as sub-channels, and these sub-channels are represented by different Orthogonal Frequency Division Multiplexing (OFDM) symbols known as slots. In WiMAX standard, a slot is the minimum resource which can be allocated to a SS (Shu'aibu, 2011). WiMAX frame is further sub divided into two sub-frames i.e. Up-Link (UL) and Down-Link (DL) sub-frames. Both UL and DL support Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD). In TDD communication is achieved by using the same channel in different time slots. DL and UL sub-frames are separated by the receiver transmit transition gap (RTG). In FDD, simultaneous communication is achieved by using different sub-channels. The throughput of UL or DL is proportional to the number of sub-carriers allocated to the corresponding SS and the achievable rate of each sub-carrier (Ruangchaijatupon and Ji, 2009). Various researchers have worked on the efficient utilization of resources in WiMAX network, scheduling for resource allocation and modulation based on channel condition (Da and Ko, 2009).

Resource allocation is to assign the resources to different demanding entities within the system. In OFDM system, resource allocation is a process to allocate sub-carriers with adequate resources while retaining connection with the network so that the SS can conveniently communicate with another SS or BS (Han and Liu, 2008). In Ashish Pandharipande (2002) the resource allocation of a sub-carrier is proposed by assuming equal sub-carrier allocations irrespective of the channel status and the data rate. The ideal channel state information is assumed by using fixed modulation for all sub-carriers to all users (Cheong Yui *et al.*, 1999; Pietrzyk and Janssen, 2002).

In real scenarios, the sub-scribers have different data rates at different locations from the BS, so the approach used by Zukand (2003) does not reflect the practical solution. However, the approach discussed by Da and Ko (2009) reflects the practical real scenarios. Wong (2004) proposed an approach in which users are allowed to set their data rates based on the QoS and proportional rate constraint. Each user’s data rate can be

satisfied with constraint to the channel status of the user. In enhanced One Column Striping with non-increasing Area first mapping algorithms (eOCSA), user demand is computed and users are sorted in decreasing order, which fails to preserve the QoS order (So-In *et al.*, 2009a). The resources are segregated for allocation in partition based scheduling algorithm, which may lead to over allocation and in some cases waste of resource (Shu'aibu *et al.*, 2010).

The Network Utility Maximization approach is presented for scheduling of resources (Jianfeng *et al.*, 2009). In this approach, the resources are allocated by considering QoS Class. However, proposed work improves existing technique for better utilization of resources and better resource allocation by using the QoS in conjunction with channel status.

ii. QoS in WiMAX

QoS is an important parameter for allocation. WiMAX handles QoS mechanism at the MAC layer and supports different QoS classes (Singh, 2010). Providing QoS to different classes is a challenging task because the characteristics of a wireless link are unpredictable both on time and location based. Longer distance and multipath fading are also another factor which affects QoS. The key issue is how to meet QoS requirements for different classes to allocate resources among the users (Letaief and Zhang, 2006).

QoS requirements and the mobility of users within the network area with variable channel make the process more complex for fair and efficient allocation of resources (Gang *et al.*, 2008; Karthick *et al.*, 2009). Ensuring QoS some researchers have proposed different algorithms, which are variations of commonly used scheduling algorithms (Hawa and Petr, 2002; Nascimento *et al.*, 2008). In each of the classes, different priority based scheduling algorithms are used, such as First in First Out (FIFO), Round Robin (RR), Weighted Fair Queue (WFQ) and Earliest Deadline First (EDF).

WiMAX standard IEEE 802.16e supports five service classes namely, (1) Unsolicited Grant Service (UGS), (2) Extended Real Time Polling Service (ertPS), (3) Real Time Polling Service (rtPS), (4) Non Real Time Polling Service (nrtPS) and (5) Best Effort (BE)(Moh and Moh, 2010). Each service class has different characteristics and requires different QoS. UGS class meets guaranteed latency and is used for real time service like E1 and T1. The second service class (ertPS) requires dynamic allocation and reserves bandwidth during connection setup and this service class supports variable bit rate like VoIP. The third service class i.e. rtPS class supports variable data size and dynamic resource allocation, while nrtPS class supports File Transfer Protocol (FTP) traffic with minimum reserved rate. BE class is used for web traffic and does not provide a service guarantee and delay may occur during transmission.

Channel status is also very important in wireless network for the provision of QoS. Channel status is a measure of signal strength with respect to noise. The ratio is calculated in decibels (dB). The estimation of channel loss is calculated using different algorithms based on status of the channel (Coleri *et al.*, 2002). To achieve QoS, accurate channel estimation affects the resource utilization and throughput of the network (Shen and Martinez, 2007).

iii. Fairness in Resource Allocation

Theoretically, all users should receive the same service but due to mobility and network load, the service provider faces challenges in the fair allocation of resources. The service provider cannot fix the number of slots for any service as the currently used channel of the user is unpredictable and the user is unable to utilize the fixed resource properly.

If the service provider fixes the number of slots and the user is in a low signal area, the service provider allocates more resources to achieve same QoS as compared to the user in the normal area. This additional resource allocation affects the throughput of

the network. If the service provider does not provide extra resources to the user in low signal area, fairness issues arise in terms of QoS. To achieve fairness, the service provider can implement Proportional Fairness (PF) and Generalized Weighted Fairness (GWF) algorithms to ensure the QoS. To monitor fairness Jain's fairness index is used (Dianati *et al.*, 2005; Ruangchaijatupon and Ji, 2008).

In IEEE 802.16e mobile WiMAX networks, several other scheduling techniques are applied depending on the QoS and signal strength (Shu'aibu and Syed-Yusof, 2011). The two main types are defined as temporal fairness and throughput fairness (So-In *et al.*, 2010). In this proposed work, extra bandwidth is allocated to provide the fairness in the network.

iv. Throughput in Resource Allocation

Throughput is utilization of the available resources. Throughput of the system can be improved through channel status and other constraints (Fantacci *et al.*, 2009). Allocation of resources based on the fixed allocation scheme results in the decrease of utilization due to variation in channel status. Increasing network throughput, a mechanism is required that should consider channel status as well as QoS. Resource allocation based on threshold value is normally used to gain throughput in WiMAX (Sulyman, 2011). Another approach used to improve the throughput of the WiMAX network is by allocating resource on demand (Sun and Liu, 2010).

Algorithm proposed by Lin (2006) ensures allocation only on the basis of resource availability but the problem of dropping packets is a major issue. Extra Bandwidth Granting (EBG) scheme is used to improve the efficiency based on the average packet size for the QoS classes. Yasir (2011) presented an optimization technique considering the maximum carrier to an interference ratio. Xinning (2008) proposed time frequency allocation with the channel condition for ensuring QoS based on priority. Therefore scheduling is given special attention and considered a key issue in WiMAX.

The existing work on resource allocation is based on the scheduling of existing resources and the modulation technique is applied based upon the node distance and the SNR of the channel. Best utilization of existing resources requires QoS and SNR of the channel.

Kaarthick (2011) proposed a dynamic uplink channel allocation scheme based on signal to interference and noise ratio to reduce the overhead and to increase the throughput of the network. Huang (2010) proposed a scheme for better utilization of bandwidth and reduction in interference, Genetic Algorithm is used for resource management. Fantacci and Jo (2009) used an adaptive modulation to maximize the throughput based on traffic throughput between two available adaptive resources adjustment schemes. In order to achieve the higher resource utilization, Weighted Round Robin scheduling is used. This algorithm improves delay time and multi-cast traffic throughput using SNR modulation technique. An efficient algorithm is proposed to achieve optimum throughput for spatial reuse using the concept of dynamic programming in order to investigate the conflicts (Gunasekaran *et al.*, 2010).

Current work on WiMAX focuses on mobility specified in IEEE 802.16-2009 released standard. This standard does not provide any specific mechanism for resource allocation. Resource allocation is an open issue for researchers to design new mechanisms (Li *et al.*, 2007). Considering the QoS in WiMAX and the scheduling of the resources based on the channel SNR, modulation scheme is selected along with the code rate (Fantacci *et al.*, 2009). The resource allocation in wireless network is a critical problem (Chakchai So-In, 2010). The objective of resource allocation is to maintain the QoS, fairness and throughput of the system. In order to achieve QoS, fairness and throughput there is a need to investigate and estimate the status of channel which can significantly affect the performance of the network. The applied modulation technique depends upon the channel status and distance of the user from BS. In order to optimize the cross layer scheduling problem (Jianfeng *et al.*, 2009) Genetic algorithm and SNR of the channel are used. To schedule the earlier deadline a dual partitioning of bandwidth is proposed which depends on the SNR (Chakchai *et al.*, 2009; Gang *et al.*, 2008). Farhadi (2011) presented a cross layer scheduling algorithm which is more efficient in terms of delay and channel status.

Resource allocation problem is divided into two sub problems: the scheduler problem which decides the amount of required resource and the allocation problem which decides how the granted resources are allocated (del Castillo Waters *et al.*, 2013). Linear Search Technique (Zukang *et al.*, 2003) and Root Finding Method (Da and Ko, 2009; Wong *et al.*, 2004) were used for the allocation of resources. Bandwidth partition introduced to allocate resources (Shu'aibu *et al.*, 2010). In linear search technique, resources are allocated to the users by first calculating the total bandwidth required and the data rate of the user. Then all sub-carriers are searched and sorted in descending order according to their channel gain. Sub carriers are allocated to each user and this process is repeated until all the users are served or the channels are occupied. First, this method does not find the number of resources required by each user and second, it does not consider the channel quality of the user (Wong *et al.*, 2004; Zukang *et al.*, 2003).

1.3 Problem Statement

IEEE 802 mobile WiMAX has the capacity to support high data rate and QoS. Present work focuses on mobility specified in IEEE 802.16-2009 released standard. This standard does not provide any specific mechanism for resource allocation. Resource allocation is an open issue for researchers to design new mechanisms. In some cases, QoS and scheduling of resources in WiMAX based on the channel status and modulation scheme is selected along with the code rate. Resource allocation in wireless networks is a critical problem. The objective of resource allocation is to maintain the QoS, fairness and throughput of the system. Achieving QoS, fairness and throughput, there is a critical need to investigate and estimate the status of channel to enhance network performance. In the problem background, it was shown that several algorithms and techniques have been introduced. The limited resources in a wireless network needs to be distributed for better resource utilization. This thesis addresses the problem of resource allocation, which ensures fairness and throughput in resource allocation.

In resource allocation process, QoS is not the only parameter used to optimize resource allocation. Allocation of resources based on channel status is unable to distribute the resources fairly. Allocation of resources based on QoS classes is not sufficient enough to deliver optimum throughput and results in the service provider compromising on throughput. Hence, there is a need to develop a mechanism for allocation of the available resources which provides fairness and improves throughput of the network depending on the channel status.

1.4 Research Questions

This research aims to address the following questions.

i. How to design and develop a channel aware resource allocation scheme for WiMAX network?
ii. How to design and develop an algorithm for fair allocation of resources for mobile WiMAX network?
iii. How to design and develop an approach to improve the throughput of WiMAX network resource based on channel status?
iv. How to make a trade-off between fairness and throughput of the network?

1.5 Research Goal

The goal of this research is to design and develop a resource allocation mechanism based on channel status and the QoS demanded by users. The research also considers the impact of the resource allocation problem on improving the fairness and throughput of the network.

1.6 Research Objectives

The research addresses the following objectives for resource allocation in mobile WiMAX to improve the fairness and throughput.

i. Propose a channel aware resource allocation scheme based on channel status and required QoS class in WiMAX network to improve resource utilization.

ii. Propose a mechanism for fair resource allocation based on the channel status and QoS class in mobile WiMAX network to improve fairness.

iii. Develop an approach to enhance the throughput of WiMAX network resources based on channel status.

1.7 Research Scope

The scope of this research is limited to the following:

i. Mobility of the user is considered as normal movement of the pedestrian user.
ii. The maximum number of users selected for allocation of resources in each experiment is 25 out of 30.
iii. IEEE 802.16e is used as underlying standard
iv. Computation complexity is out of scope of this study.

1.8 Significance of Study

Resource allocation and management are key factors in efficient utilization of the resources. Following points describe the significance of this research.

- To allocate resources efficiently to help service providers in effective utilization of the resources in WiMAX network.

- The implementation of this scheme provides capacity management for handling more users in WiMAX networks, which results in economic benefits for service providers.

- This mechanism helps the subscriber in low coverage areas and provides a solution to service providers to provide better service to low signal users. This mechanism improves the user satisfaction level by providing fair allocation of resources.

1.9 Organization of Thesis

Rest of the thesis is organized as follows:

Chapter 2 provides an exhaustive literature review of the background, problems and solutions to WiMAX resource allocation, fairness and throughput. Different mechanisms, used for fairness and throughput to maintain the QoS classes are also discussed in detail.

Chapter 3 highlights the flow of research methodology which is used in this research. This is followed by a proposed research framework in order to design and develop a channel aware resource allocation mechanism. Chapter 4 outlines the implementation of the proposed mechanism for resource allocation based on the channel condition and the service classes. Chapter 5 describes two phases. The first phase consists of design and development of a fair resource allocation based service mechanism to provide fair service to users. Second phase presents a channel based throughput improvement approach. Chapter 6 describes the results of the proposed mechanism and its comparison with existing algorithms. Chapter 7 presents the conclusion, describes the contributions made by this study and suggests directions for future research.

REFERENCES

Ahmadi, S. Mobile WiMAX: A systems approach to understanding IEEE 802.16 m radio access technology, 2010. Academic Press. USA.

Ahmed Iyanda, S. Throughput Gain Using Threshold-Based Multiuser Scheduling in WiMAX OFDMA. *EURASIP Journal on Wireless Communications and Networking*, 2011. (15): 15-21

Ala'a, Z., Al-Howaide, A. S. D. and Khamayseh, M. Y. Performance evaluation of different scheduling algorithms in WiMax. *IJCSEA International Journal of Computer Science, Engineering and Applications*. 2011 1(5): 81-94.

Ali-Yahiya, T., Beylot, A.-L. and Pujolle, G. Downlink resource allocation strategies for OFDMA based mobile WiMAX. *Telecommunication Systems*, 2010. 44(1-2): 29-37.

Ali, N. A., Dhrona, P. and Hassanein, H. A performance study of uplink scheduling algorithms in point-to-multipoint WiMAX networks. *Computer Communications*, 2009. 32(3): 511-521.

Andrews, J. G., Ghosh, A. and Muhamed, R. *Fundamentals of WiMAX: understanding broadband wireless networking*, 2007. Pearson Education. USA.

Pandharipande, A., Kountouris, M., Yang, H., & Park, H. Subcarrier allocation schemes for multiuser OFDM systems. *International Conference on Signal Processing and Communications (SPCOM'04) December*, 2004. 540-544.

Bacioccola, A., Cicconetti, C., Erta, A., Lenzini, L., Mingozzi, E. and Moilanen, J. Current Technology Developments of WiMax Systems A Downlink MAC Frame Allocation Framework in IEEE 802.16e OFDMA: *Design and Performance Evaluation Current Technology Developments of WiMax Systems*, 2009. 31-59 Springer. e-ISBN: 978-1-4020-9300-5 Singapore.

Banchs, A., Serrano, P., Patras, P. and Natkaniec, M. Providing throughput and fairness guarantees in virtualized wlans through control theory. *Mobile Networks and Applications*, 2012. 17(4): 435-446.

Bhagwat, P., Bhattacharya, P., Krishma, A. and Tripathi, S. K. Using channel state dependent packet scheduling to improve TCP throughput over wireless LANs. *Wireless Networks*, 1997. 3(1): 91-102.

Bhagwat, P., Bhattacharya, P., Krishna, A. and Tripathi, S. K. Enhancing throughput over wireless LANs using channel state dependent packet scheduling. *Fifteenth Annual Joint Conference of the IEEE Computer Societies. Networking the Next Generation*, 24-28 Mar 1996. 1133: 1133-1140.

Bin Bin, C. and Mun Choon, C. Proportional Fairness for Overlapping Cells in Wireless Networks. *Vehicular Technology Conference*, 25-28 Sept. 2006. 1-5.

Borcoci, E. WiMAX technologies: Architectures, protocols, resource management and applications. *International Conference on Biocomputation, Bioinformatics, and Biomedical Technologies*, June 29 - July 5, 2008. Bucharest, Romania IARIA, BIOTECHNO .

Chakchai, S.-I., Jain, R. and Tamimi, A. K. Scheduling in IEEE 802.16e mobile WiMAX networks: key issues and a survey. *Selected Areas in Communications, IEEE Journal*, 2009. 27(2): 156-171.

Chakchai So-In, R. J., and Abdel Karim Al-Tamimi. Generalized weighted fairness and its application for resource allocation in IEEE 802.16e Mobile WiMAX. *Computer and Automation Engineering (ICCAE), The 2nd International Conference*, 2010. 1: 784-788.

Chakchai So-In, R. J., and Abdel Karim Al-Tamimi. *Resource Allocation in IEEE 802.16 Mobile WiMAX*. Auerbach Publications, CRC Press, ISBN: 1420088246, April 2010

Chandur, P., Karthik, R. and Sivalingam, K. M. Performance evaluation of scheduling algorithms for mobile WiMAX networks. *Pervasive Computing and Communications Workshops (PERCOM Workshops), IEEE International Conference*, 2012. 764-769.

Chatzimisios, P., Verikoukis, C., Santamaria, I., Laddomada, M. and Hoffmann, O. Mobile Lightweight Wireless Systems: *Second International ICST Conference, Mobilight*, 10-12 May, 2010. Barcelona, Spain, Revised Selected Papers. (45).

Chen, G. J. and Hu, H. Y. New Blind Adaptive Channel Estimation Schemes Based on OFDM Systems. *Advanced Materials Research*, 2013. 709: 370-373.

Chen, M.-X. and Liu, S.-H. Hierarchical Deficit Round-Robin Packet Scheduling Algorithm .*Advances in Intelligent Systems and Applications*, 2013. 1: 419-427.

Cheong Yui, W., Tsui, C. Y., Cheng, R. S. and Letaief, K. B. A real-time sub-carrier allocation scheme for multiple access downlink OFDM transmission. *Vehicular Technology Conference*, 1999. 1122: 1124-1128.

Cicconetti, C., Lenzini, L., Mingozzi, E. and Eklund, C. Quality of service support in IEEE 802.16 networks. *Network,* 2006. 20(2): 50-55.

Coleri, S., Ergen, M., Puri, A. and Bahai, A. Channel estimation techniques based on pilot arrangement in OFDM systems. *Broadcasting, IEEE Transactions*, 2002. 48(3): 223-229.

Da, B. and Ko, C.-C. Dynamic Resource Allocation in OFDMA Systems with Adjustable QoS. *IEICE Transactions on Communications*, 2009a. E92-B(12): 3586-3588.

Da, B. and Ko, C. C. Resource allocation in downlink MIMO-OFDMA with proportional fairness. *Journal of Communications*, 2009b. 4(1): 8-13.

Del-Castillo, J. I., Delicado, F. M., Delicado, J. and Villalon, J. M. OFDMA resource allocation in IEEE 802.16 networks: A performance comparative. *Wireless and Mobile Networking Conference (WMNC), Third Joint IFIP*, 13-15 Oct. 2010.1-6.

del Castillo Waters, J. I., Delicado Martínez, F. M. and Villalón Millán, J. M. Efficient resource allocation for emerging OFDMA wireless networks. *Computer Communications*, 2013. 37: 92-105.

Dianati, M., Shen, X. and Naik, S. A new fairness index for radio resource allocation in wireless networks. *Wireless Communications and Networking Conference,* 2005. 2, 712-717.

Elayoubi, S.-E. and Fourestié, B. Performance evaluation of admission control and adaptive modulation in OFDMA WiMax systems. *IEEE/ACM Transactions on Networking (TON),* 2008. 16(5): 1200-1211.

Ernst, J. B. and Denko, M. K. The design and evaluation of fair scheduling in wireless mesh networks. *Journal of Computer and System Sciences*, 2011. 77(4): 652-664.

Etemad, K. Overview of mobile WiMAX technology and evolution. *Communications magazine,* 2008. 46(10): 31-40.

Fantacci, R., Marabissi, D., Tarchi, D. and Habib, I. Adaptive modulation and coding techniques for OFDMA systems. *Wireless Communications, IEEE Transactions,* 2009. 8(9): 4876-4883.

Farhadi, R. A Novel Cross-Layer Scheduling Algorithm for OFDMA-Based WiMAX Networks. *Int'l J. of Communications, Network and System Sciences*, 2011. 4(2): 98-103.

Furuskär, A., Lundevall, M. and Skillermark, P. *Method and Arrangement for Detecting a Channel Quality Offse,*. US Patent 2013. 20,130,094,388.

Gang, Z., Chungui, L., Feng, W. and Hongai, J. Quality of Service Scheduling Based on GPSS in IEEE 802.16 WiMax Networks. *Wireless Communications, Networking and Mobile Computing, WiCOM. 4th International Conference*, 12-14 Oct. 2008. 1-4.

Gao, D., Foh, C. H., Cai, J. and Zhang, H. Channel Resource Allocation for VoIP Applications in Collaborative IEEE 802.11/802.16 Networks. *EURASIP Journal on Wireless Communications and Networking*, 2010. 11

Gidlund, M. and Wang, G. Uplink scheduling algorithms for QoS support in broadband wireless access networks. *Journal of communications*, 2009. 4(2): 133-142.

Girici, T., Zhu, C., Agre, J. R. and Ephremides, A. Proportional fair scheduling algorithm in OFDMA-based wireless systems with QoS constraints. *Journal of Communications and Networks*, 2010. 12(1): 30-42.

Gopalan, A., Caramanis, C. and Shakkottai, S. On wireless scheduling with partial channel-state information. *Information Theory, IEEE Transactions*, 2012. 58(1): 403-420.

Gunasekaran, R., Siddharth, S., Krishnaraj, P., Kalaiarasan, M. and Rhymend Uthariaraj, V. Efficient algorithms to solve Broadcast Scheduling problem in WiMAX mesh networks. *Computer Communications*, 2010. 33(11): 1325-1333.

Hajipour, J., Mohamed, A. and Leung, V. C. Channel Aware and Queue Aware Scheduling in LTE Uplink. *Quality, Reliability, Security and Robustness in Heterogeneous Networks*. Springer, 2012. 116-127.

Han, Z. and Liu, K. R. Resource allocation for wireless networks: basics, techniques, and applications, 2008. Cambridge university press.

Hawa, M. and Petr, D. W. Quality of service scheduling in cable and broadband wireless access systems. *Quality of Service, Tenth IEEE International Workshop, 2002*. 247-255.

Huang, C.-J., Hu, K.-W., Chen, I. F., Chen, Y.-J. and Chen, H.-X. An intelligent resource management scheme for heterogeneous WiFi and WiMAX multi-hop relay networks. *Expert Systems with Applications*, 2010. 37(2): 1134-1142.

Hunukumbure, V. B. U. V. M. and Vadgama, V. S. Radio network dimensioning and planning for WiMAX networks. *Fujitsu Sci. Tech. J*, 2007. 43(4): 435-450.

Iyer, P., Natarajan, N., Venkatachalam, M., Bedekar, A., Gonen, E., Etemad, K. and Taaghol, P. All-IP network architecture for mobile WiMAX. System-level modeling of IEEE 802.16E mobile wimax networks: Key issues. *Wireless Communications,* 2007. 15(5): 73-79.

Jianfeng, S., Jiandong, L. and Changle, L. A Cross-Layer WiMAX Scheduling Algorithm Based on Genetic Algorithm. *Communication Networks and Services Research Conference,. Seventh Annual,* 11-13 May 2009. 292-296. Moncton, NB.

Jing, Q. and Zheng, Z. Distributed resource allocation based on game theory in multi-cell OFDMA systems. *International Journal of Wireless Information Networks,* 2009. 16(1-2): 44-50.

Jo, H. W., Jeon, J. H. and Lim, J. T. Bandwidth allocation for QoS using adaptive modulation and coding in IEEE 802.16 networks. *IEICE Transactions on Communications,* 2009. E92-B(12): 3919-3922.

Karthick, N., Venkatraman, K., Naren, J. and Amutha, B. A resource management mechanism for down linking in WiMax networks. *Advances in Computing, Control, & Telecommunication Technologies, International Conference,* .Trivandrum, Kerala 2009. 803-805

Karthikeyan, N. and Narayanasamy, P. An integrated system for QoS provisioning in cellular networks. *Cybernetics and Intelligent Systems (CIS), IEEE Conference,* Singapore. 28-30 June 2010. 218-224

Katz, M. and Fitzek, F. H. WiMAX evolution: Emerging technologies and applications. John Wiley & Sons, Inc, 2009. west Sussex, UK

Khatkar, A., Singh, Y. and Nandal, V. A QoS Oriented Analysis of ertPS, rtPS and nrtPS flows in WiMAX. *International Journal of Advanced Research in Computer Science and Software Engineering,* 2013. 3(7): 85-90

Kim, R. Y., Kwak, J. S. and Etemad, K. WiMAX femtocell: requirements, challenges, and solutions. *Communications Magazine,* 2009. 47(9): 84-91.

Korowajczuk, L. LTE, WiMAX and WLAN network design, optimization and performance analysis. John Wiley & Sons. 2011, UK

Ramadas, K., & Jain, R. WiMAX system evaluation methodology. *Technical report*. Wimax Forum, Jan 2007.

Lai, C.-F. Adaptive Packet Scheduling Scheme to Support Real-time Traffic in WLAN Mesh Networks. *KSII Transactions on Internet and Information Systems (TIIS),* 2011. 5(9): 1492-1512.

Lawrey, E. Multiuser ofdm. *Fifth International Symposium on Signal Processing and its Applications, ISSPA '99,* QUT, Brisbane, Australia 22-25 August, 1999. 761-764

Lee, J. M., Park, H.-J., Choi, S. G. and Choi, J. K. Adaptive hybrid transmission mechanism for on-demand mobile IPTV over WiMAX. *Broadcasting, IEEE Transactions,* 2009. 55(2): 468-477.

Lera, A., Molinaro, A. and Pizzi, S. Channel-aware scheduling for QoS and fairness provisioning in IEEE 802.16/WiMAX broadband wireless access systems. *Network,* 2007. 21(5): 34-41.

Letaief, K. B. and Zhang, Y. J. Dynamic multiuser resource allocation and adaptation for wireless systems. *Wireless Communications,* 2006. 13(4): 38-47.

Li, B., Qin, Y., Low, C. P. and Gwee, C. L. A survey on mobile WiMAX (wireless broadband access). *Communications Magazine,* 2007. 45(12): 70-75.

Li, Y., Wang, C., You, X., Chen, H.-H. and She, W. Delay and throughput performance of IEEE 802.16 WiMax mesh networks. *Communications, IET,* 2012. 6(1): 107-115.

Liu, X., Chong, E. K. and Shroff, N. B. Transmission scheduling for efficient wireless utilization. *Twentieth Annual Joint Conference of the IEEE Computer and Communications Societies*. INFOCOM. Anchorage, AK 22-26 Apr 2001. 2, 776-785.

Liu, X., Chong, E. K. and Shroff, N. B. A framework for opportunistic scheduling in wireless networks. *Computer Networks,* 2003. 41(4): 451-474.

Mäder, A. and Staehle, D. Spatial and temporal fairness in heterogeneous HSDPA-enabled UMTS networks. *EURASIP Journal on Wireless Communications and Networking,* 2009. 13: 1-12

Md Jonit, N. and Baba, M. D. First in first out (FIFO) and Deficit Round Robin (DRR) scheduling analysis in WiMAX network. In *Control and System Graduate Research Colloquium (ICSGRC),* Shah Alam Malaysia. 27-28 June 2011. 166-174

Moh, M. and Moh, T.-S. (2010). Supporting Multiple Quality-of-Service Classes in IEEE 802.16e Handoff. Quality of Service Architectures for Wireless Networks: *Performance Metrics and Management. Global publication, USA* EISBN13: 9781615206810

Nascimento, A., Rodriguez, J., Mumtaz, S., Gameiro, A. and Politis, C. Dynamic Resource Allocation Architecture for IEEE802.16e: Design and Performance Analysis. *Mobile Networks and Applications,* 2008. *13*(3-4): 385-397.

Othman, A. Y., HM Nerma, M. and AA Elmaleeh, M. Performance Evaluation of SISO/MISO WiMAX System Using Adaptive Modulation and Coding (Revised Version). *International Journal of Research in Computer Engineering & Electronics*. 2013 2(2):1-4

Pérez-Costa, X., Favaro, P., Zubow, A., Camps, D. and Aráuz, J. On the challenges for the maximization of radio resources usage in WiMAX networks. *Consumer Communications and Networking Conference,* Las Vegas, NV10-12 Jan. 2008. 890-896

Pietrzyk, S. and Janssen, G. J. M. Multiuser subcarrier allocation for QoS provision in the OFDMA systems. *Vehicular Technology Conference,* VTCl. IEEE 56th. 2002. 2. 1077-108.

Qin, Z. and Kuo, G.-S. Performance Optimization for Uplink Transmission in IEEE 802.16 e BWA Networks. *Consumer Communications and Networking,* Las Vegas NV, 10-12 Jan. 2008. 435-439.

Reddy, B. S. K. and Lakshmi, B. Adaptive Modulation and Coding in COFDM for WiMAX Using LMS Channel Estimator. *Conference on Advances in Communication and Control Systems (CAC2S) 2013 Atlantis Press*. Paris France. 23-29

Reddy, B., & Lakshmi, B. Adaptive Modulation and Coding in COFDM for WiMAX Using LMS Channel Estimator. *Conference on Advances in Communication and Control Systems* Atlantis Press, *2013*. 23-29

Rhee, W. and Cioffi, J. M. Increase in capacity of multiuser OFDM system using dynamic subchannel allocation. *Vehicular Technology,* Tokyo, 15-18 May 2000. 2. 1085-1089.

Roy, J. J. J. and Vaidehi, V. Analysis of Frequency Reuse and Throughput Enhancement in WiMAX Systems. *Wireless Personal Communications*, 2011. 61(1): 1-17.

Ruangchaijatupon, N. and Ji, Y. Simple proportional fairness scheduling for OFDMA frame-based wireless systems. *Wireless Communications and Conference,* Las Vegas, NV March 31 -April 3 2008.1593-1597.

Ruangchaijatupon, N. and Ji, Y. Proportional fairness with minimum rate guarantee scheduling in a multiuser OFDMA wireless network. *International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly,* Leipzig, Germany. 21-24 June, 2009. 1102-1106.

Sau'aibu, D. S. A Cross Layer Approach for Packet Scheduling at Downlink of Wimax IEEE 802.16e. *European journal of Scienctific Research*, 2010. 45(4): 10.

Seo, S. S., Kang, J. M., Agoulmine, N., Strassner, J. and Hong, J. W. K. FAST: A fuzzy-based adaptive scheduling technique for IEEE 802.16 networks. In *Integrated Network Management (IM),IFIP/IEEE International Symposium*. Dublin. 23-27 May 2011. 201-208

Shahajahan, M. and Hes-Shafi, A. A. Analysis of propagation models for WiMAX at 3.5 GHz. Master thesis *Department of Electrical Engineering Blekinge Institute of Technology,* 2009. Karlskrona, Sweden.

Shen, Y. and Martinez, E. WiMAX channel estimation: algorithms and implementations. Application Note, *Freescale Semiconductor*. Document Number: AN3429 Rev. 0, DRAFT A, 07/2007.

SHI, H., Prasad, R., Onur, E. and Niemegeers, I. Fairness in Wireless Networks: Issues, Measures and Challenges. *IEEE Communications Surveys & Tutorials*, 2013. 99:1-20.

Shu'aibu, D. S. *Radio Resource Management for Mobile WiMAX*. PhD Thesis. Faculty of Electrical Engineering University Technolgy Malaysia, 2011. Johor Malaysia.

Shu'aibu, D. S. and Syed-Yusof, S. K. Link aware earliest deadline scheduling algorithm for WiMAX. *International Journal of Communication Networks and Information Security*, 2011 3(1): 83-88.

Shu'aibu, D. S., Syed-Yusof, S. K. and Fisal, N. Partition-based bandwidth management for mobile WIMAX IEEE802.16e. *International Review on Computers and Software*, 2010. 5(4): 443-452.

Shu'aibu, D. S. Slot Allocation Algorithm for Real Time and None Real Time Traffics of Mobile WiMAX IEEE802.16e. *International Journal of Computer Applications* 2010. 8(7):12-16.

Singh, H., & Singh, M. Performance Analysis of QoS in PMP Mode WiMax Networks. *Computer Science & Telecommunications*, 2010. *27*(4):16-21.

So-In, C., Jain, R. and Al-Tamimi, A.-K. A scheduler for unsolicited grant service (UGS) in IEEE 802.16 e mobile WiMAX networks. *Systems Journal*, IEEE 2010a. 4(4): 487-494.

So-In, C., Jain, R. and Al Tamimi, A.-K. eOCSA: An algorithm for burst mapping with strict QoS requirements in IEEE 802.16e mobile WiMAX networks. *Wireless Days (WD)*, 1-5 May 2013. 19(4): 547-558.

So-In, C., Jain, R. and Al Tamimi, A.-K. Generalized weighted fairness and its application for resource allocation in ieee 802.16 e mobile wimax. *Computer and Automation Engineering (ICCAE), The 2nd International Conference*, Singapore 26-28 Feb. 2010. 1.784-788.

So-In, C., Jain, R. and Tamimi, A.-K. Scheduling in IEEE 802.16 e mobile WiMAX networks: key issues and a survey. *Selected Areas in Communications, IEEE Journal*, 2009b. 27(2): 156-171.

Song, G. and Li, Y. Utility-based resource allocation and scheduling in OFDM-based wireless broadband networks. *Communications Magazine,* 2005. 43(12): 127-134.

Soy, H., Özdemir, Ö., Bayrak, M., Hamila, R. and Al-Dhahir, N. Decentralized Multiuser Diversity with Opportunistic Packet Transmission in MIMO Wireless Sensor Networks. *AEU-International Journal of Electronics and Communications*, 2013. 67(11): 910-925.

IEEE Std 802.16. IEEE Draft Amendment to *IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems Improved Coexistence Mechanisms for License-Exempt Operation*. IEEE Unapproved Draft Std P802.16h/D15, March 2010.

IEEE Std 802.16e. IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigendum 1, *IEEE Std 802.16e-2005*

Sulyman, A. Throughput Gain using Threshold-based Multiuser Scheduling in WiMAX OFDMA. *EURASIP Journal on Wireless Communications and Networking*, 2011. 1 (15).

Sulyman, A. I. Using threshold-based PUSC for throughput enhancement in WiMAX OFDMA. *Local Computer Networks (LCN) Conference.* Denver, CO. 10-14 Oct. 2010. 749-751.

Majid Taghipoor, Saeid MJafari and Vahid Hosseini. Scheduling Algorithm and Bandwidth Allocation in WiMAX, *Quality of Service and Resource Allocation in WiMAX*, ISBN: 978-953-307-956-1, InTech, 2012. Shanghai, 200040, China.

Theodoridis, G. and Pavlidou, F.-N. A combined resource management and admission control scheme for optimizing uplink performance of M-WiMAX systems. *Computer Networks*, 2011. 55(17): 3975-3986.

Wang, S.-Y. and Lin, C.-C. NCTUns 6.0: a simulator for advanced wireless vehicular network research. *Vehicular Technology Conference,* Taipei, Taiwan 16-19 May 2010. 1-2.

Wong, I. C., Zukang, S., Evans, B. L. and Andrews, J. G. A low complexity algorithm for proportional resource allocation in OFDMA systems. *Signal Processing Systems,* 13-15 Oct, 2004. 1-6.

Wong, R., Almuhtadi, W. and Srinivasan, A. WiMAX network with Quality of Service for streaming multimedia applications. *Wireless Communications and Mobile Computing Conference (IWCMC),* Sardinia. 1-5 July 2013. 1199-1205.

Xinning, Z., Jiachuan, H., Song, Z., Zhimin, Z. and Wei, D. An Adaptive Resource Allocation Scheme in OFDMA based Multiservice WiMAX Systems. *Advanced Communication Technology, ICACT* Gangwon-Do, 17-20 Feb 2008. 1. 593-597.

Yasir, M. and Kiani, A. K. Optimization between throughput and fairness in WiMAX network. *Wireless and Optical Communications Networks (WOCN), Eighth International Conference,* Paris, 24-26 May 2011. 1-5.

Zhang, R. and Hanzo, L. *Wireless cellular networks. Vehicular Technology Magazine, IEEE,* 2010. 5(4): 31-39.

Zhang, X. and Li, B. Joint network coding and subcarrier assignment in OFDMA-based wvireless networks. *Network Coding, Theory and Applications, NetCod,* Hong Kong. 3-4 Jan. 2008.1-6

Zhang, X., Zhang, X., Xiao, L., Zhang, Y., Zhou, S. and Wang, J. Pilot allocation for doubly selective channel estimation in OFDM systems. *Wireless and Optical Communication Conference (WOCC),* Chongqing, 16-18 May, 2013. 151-155.

ZhenTao, S. and Ning, L. Improving throughput by On_Demand Bandwidth Allocation for WiMAX. *Computer Engineering and Technology (ICCET),* Chengdu 16-18 April 2010. 570-574.

Zhou, N., Zhu, X. and Huang, Y. Genetic Algorithm Based Cross-Layer Resource Allocation for Wireless OFDM Networks with Heterogeneous Traffic. *European Signal Processing Conference (EUSIPCO),* Glasgow, Scotland. 24-28 August, 2009. 1656-1659.

Zukang, S., Andrews, J. G. and Evans, B. L. Optimal power allocation in multiuser OFDM systems. *Global Telecommunications Conference. GLOBECOM '03*. San Francisco, CA, 1-5 Dec, 2003. 331: 337-341.