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A Study on a Resource Allocation Scheme for Multiuser OFDMA Systems

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지도교수　신 석 주

이 논문을 공학석사학위신청 논문으로 제출함.

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요약

다중사용자를 위한 OFDMA 시스템 에서위 자원 할당 기법 연구

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이동통신망에서의 하향링크 무선 자원 할당 기법은 상향링크로 보고되는 채널상태정보에 기반하여 각 사용자 별로 채널상태정보를 추정, 비교하여 사용 가능한 자원의 subset 을 할당하는 기법이다. 또한, 다중사용자 다이버서티(MUD)는 채널 상에 존재하는 다중 사용자로부터 최적의 사용자를 기회주의적으로 선택함으로써 시스템의 처리률을 증대시킬 수 있는 방식으로 다양한 무선 통신 시스템에서 사용되고 있다.

다중 사용자 OFDMA 시스템에서의 자원할당 기법은 모든 사용자가 상향링크의 피드백 채널을 통해 모든 혹은 일부의 서브채널에 대한 채널 품질 정보(CQI)를 기지국에 전송하고, 기지국은 주어진 정보로부터 기회주의적 선택 기반으로 최적의 사용자와 사용자의 서브채널 정보를 획득한다. 이때, 사용자가 모든 서브채널에 대한 CQI 정보를 피드백 하는 경우의 스케줄링 기법을 scheduling full feedback scheduling 이라 부른다. 그러나 full feedback scheduling은 시스템에 액티브한 사용자의 수가 큰 경우 uplink feedback 오버헤드가 크다는 단점을 가지고 있다. Feedback 오버헤드 문

제를 해결하려면, 두 가지 통상적인 feedback scheme 인 Best-M Feedback(BMF)scheme과 threshold feedback scheme이 이러한 오버헤드를 감소시키려는 접근방식으로 연구되었다. BMF scheme이 시스템에서 feedback overhead 을 상당히 줄일 수 있으나 스브채널에 대한 CQI 정보가 부족하여 full feedback scheme에 비해 낮은 시스템 처리율을 갖는다는 단점이 있다. Threshold feedback scheme은 처리률 관점에서 Best-M scheme을 개선 하였으나, 사용자간 자원 할당이 공정하지 못하다.

본 논문에서는 다중사용자 OFDMA 시스템을 위한 partial feedback 자원할당을 연구하고 분석하여 BMF scheduling 의 시스템 처리율을 개선하였다. 우리가 제안한 Adaptive Best-M Feedback (ABMF) scheduling 에서 M은 시스템의 사용자수에 따라 결정되는 파라미터이며 제한된 오버헤드 총량을 기반으로 계산된다. 이론적 분석 및 컴퓨터 시뮬레이션을 통해, 제안된 기법을 해석하였으며 다음과 같은 결과를 도출하였다: (i) downlink 처리률을 높이면서 up-link 오버헤드를 최소화하는 결과도출, (ii) Best-M에 비해 동시에 시스템에서 지원할 수 있는 사용자의 수가 증가.

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Acronyms

ABMAS	Adaptive Best-M Feedback Assisted Scheduler
ABMF	Adaptive Best-M Feedback
AMC	Adaptive Modulation and Coding
BER	Bit Error Rate
BMAS	Best-M Feedback Assisted Scheduler
BMF	Best-M Feedback
BPSK	Binary Phase Shift Keying
BS	Base Station
CQI	Channel Quality Information
DL	Downlink
FDD	Frequency Division Duplex
FFAS	Full Feedback Assisted Scheduler
IFFT	Inverse Fast Fourier Transform
ISI	Inter-Symbol Interference
MUD	Multiuser Diversity
OFDM	Orthogonal Frequency Division Multiplex
OFDMA	Orthogonal Frequency Division Multiple Access
PFLS	Preferred Feedback Load Size
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
SNR	Signal to Noise Ratio
TDD	Time Division Duplex
WiMAX	Worldwide Interoperability for Microwave Access

I. Introduction

A. Research Overview

In order to opportunistically enhance the utilization of the scarce radio resource in wireless communication systems, Multiuser Diversity (MUD) has recently been paid much attention [1]-[5]. The rationale behind MUD technique is to exploit benefits from the independent channel characteristics that different users in the system are having at the common reference time. For example, in a cellular wireless system, if the Base Station (BS) has knowledge of channel characteristics of all active users, it can preferably select those which can receive data at higher rates. Such selection (user scheduling) eventually maximizes the system efficiency.

Orthogonal Frequency Division Multiple Access (OFDMA) is a well-known multiple accesses technique for the next generation networks. There are some reports [3]-[5] that attempt to exploit MUD in OFDMA cellular network. In order to let BS exploit MUD in downlink OFDMA subchannel, every user should report their Channel Quality Information (CQI) on each subchannel. For a practical OFDMA cellular system with high number of users and subchannels, the increased feedback overhead heavily waste uplink channel capacity which eventually shadows the throughput gain achieved in downlink exploiting MUD. Thus, different approaches have continuously been sought to reduce the CQI overhead in multiuser OFDMA system.

Best-M feedback (BMF) scheme [5]-[7] and threshold based feedback scheme [7]-[8] are the two popular schemes that significantly reduce CQI overhead. In the BMF scheme, each user sends CQI of its selected *M* subchannels, instead of all subchannels, that have the highest signal strength. However, since each user selects their best *M* subchannels based on its local channel information, in the global view (system view) there might be chances that the selected *M* subchannels from some users could be worse than the subchannels which could not include themselves in the top-M list of some other users. As a consequence, best-M feedback assisted scheduler cannot fully exploit MUD, resulting in much lower throughput performance in comparison to the full feedback assisted scheduler which perfectly exploits MUD. Threshold based feedback scheme improves the drawback of the BMF scheme. Under this scheme, each user sends CQI of only those subchannels that exceed a certain predetermined threshold. Throughput performance of the threshold-based feedback assisted scheduler is better than that of the best-M feedback-based assisted scheduler. Threshold-based feedback assisted scheduler, however, brings unfairness among the users.

In this thesis, we present an approach to further enhance the throughput performance of the best-M feedback assisted scheduler for downlink OFDMA systems. More precisely, we present an approach to adaptively determine *M*, unlike the fixed *M* in the original BMF scheme, according to the active number of users in the system. Using computer simulations, we show that the proposed scheme outperforms the best-M scheduling in three ways. Firstly, it offers greater or equal downlink throughput with remarkably reduced uplink overhead. Secondly, it increases the number of users that can be simultaneously supported in the system. And the last, but not the least, the proposition gives a method to use more efficiently the uplink system capacity.

B. Research Objective

Due to harsh wireless channel conditions, scarce bandwidth, limited power resources and ever increasing demand of users for high data rates at guaranteed Quality of Service (QoS) levels, communication networks require an intelligent allocation scheme. Many literatures have dealt with the resource management problem in the OFDMA systems. The overall transmission power is minimized in a multiuser wireless environment [17]; the total utility is maximized in a multiuser OFDM system [18]; the total throughput is maximized in a multi-cell environment [19]; slot allocation is studied in [20] to improve efficiency of using system bandwidth.

In this thesis, we study on bandwidth allocation for multiuser OFDMA systems. In particular, we focus on feedback-based (channel-aware) scheduling. From widely available literatures, we can easily find out that different types of feedback-based scheduling has been proposed so far for improving system throughput in multiuser networks. The feedback-based schemes have been categorized into full feedback scheme and partial feedback scheme. In practice, the full feedback scheme is not used because it causes feedback overhead at uplink channel. The partial feedback scheme, on the other hand, has been widely studied and used in multiuser networks recently. The BMF scheme and the threshold feedback scheme are two popular partial feedback schemes. By studying and analyzing two kinds of foresaid partial feedback scheme, we find out that the BMF scheme significantly reduces feedback overhead in the system; however, it also performs lower throughput performance in comparison to the full feedback scheme. The threshold based feedback scheme improves the best-M scheme in term of throughput; however, it is unfair.

The primary objective of this research is to propose an approach to further enhance the downlink throughput performance of the legacy BMF scheme. In original BMF scheme, we find out that a fixed value of *M* is used. With fixed value of *M,* BMF assisted systems having variable number of active users don't have good trade-off between system throughput and uplink overhead, resulting in low throughput performance for systems having small number of users. We propose a relation to compute sub-optimal value of *M* based on number of active users. The adaptive *M* is thereafter introduced into original BMF scheme to become a new scheme named Adaptive Best-M Feedback (ABMF) scheme. The proposed scheme is promising to further increase throughput performance of the legacy BMF assisted system.

C. Research Layout

The research layout we followed was in accordance with the object of the carried research. A new scheduling algorithm named adaptive best-M feedback scheme has been proposed to further enhance the throughput performance of multiuser OFDMA systems. For the analysis, a multiuser OFDMA cellular system with BMF scheduling is illustrated in figure 1-1.

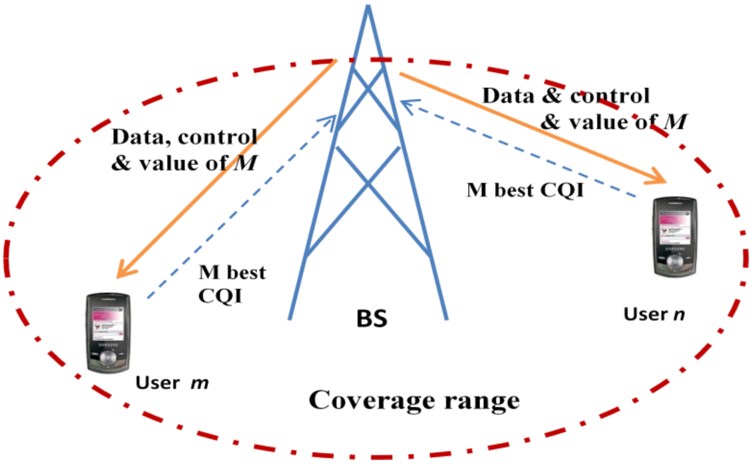

Figure 1- 1 Diagrammatic representation of carried research.

D. Thesis Contribution

The characteristic parts of the carried research work are summarized under the title of the thesis contribution. A new scheduling algorithm named ABMF scheme is proposed. The ABMF scheme, an uncomplicated partial feedback scheme, is an improved version of the traditional BMF scheme. The ABMF scheme allocates bandwidth to users as the same behaviour which the BMF has done. However, unlike the BMF scheme, the ABMF scheme adaptively computes and uses value of M based on number of active users in the system. The benefits of the ABMF scheme are as follows.

- Firstly, it offers greater or equal downlink throughput with remarkably reduced uplink overhead in comparison with the traditional best-M scheme.
- Secondly, it increases the number of users that can be simultaneously supported in the system.
- And the last, but not the least, the ABMF gives a method to use more efficiently the uplink system capacity.

E. Thesis Organization

The content of this thesis is organized in modular chapters. Chapter II is devoted to give brief overview of preliminary concepts on top of which our scheme is built. Particularly, overviews of OFDM and OFDMA-TDD and radio resource allocation are presented. An overview of the feedback-based resource allocation in multiuser OFDMA systems is also included in this chapter. This chapter also gives an analysis of BMF scheme and its problems. In chapter III, we introduce and comprehensively discuss the proposed scheme, the adaptive best-M feedback scheme. In chapter IV, we present the simulation settings, simulation results and discussions. Lastly, in section V we present concluding remarks.

II. OFDMA and Radio Resource Allocation

Nowadays, the ever-increasing growth of multimedia and broadband services demands high data rate and high quality transmission. Many applications demand more bandwidth either in downlink channel or in uplink channel. Researching on radio resource allocation for wireless communication systems always has been an opened and exigent problem. The radio resource may be power, bandwidth or time, etc. Orthogonal Frequency Division Multiple Access (OFDMA) is regarding as the superior and preferred choice for multiple accesses to support high speed transmission of broadband traffic. Researching on bandwidth resource management for multiuser OFDMA system has been paid much attention by researcher communities for the next generation networks [5]-[8], [17]-[20]. In this chapter, an overview of relating knowledge that covers over the thesis will be presented. Firstly, the concepts of OFDM and OFDMA –TDD (Time Division Duplex) will be shown in part A [15]-[16], [21]. In part B, an overview of multiuser diversity and concepts of radio resource allocation will be mentioned [1]-[3]. Particularly, a feedback-based scheduling in the multiuser OFDMA system is shown in this part. Full feedback scheduling is also briefly presented. In part C, we present two popular partial feedback-based schemes: Best-M feedback scheme and threshold scheme. The problem of best-M feedback scheduling is briefly included as well.

A. Orthogonal Frequency Division Multiple Access

1. Orthogonal Frequency Division Multiplexing: An overview

In a Single Carrier Modulation (SCM) [25] system, signal stream is transmitted over bandwidth *B*. It means that system's sampling frequency is equal to bandwidth *B.* Length of each sample is as follows.

$$T_{SC} = \frac{1}{B} \tag{2-1}$$

Where T_{SC} is the length of sample in second, *B* is system bandwidth in hertz. The Energy Spectral Density (ESD) of modulated SCM signal is illustrated in figure 2-1.

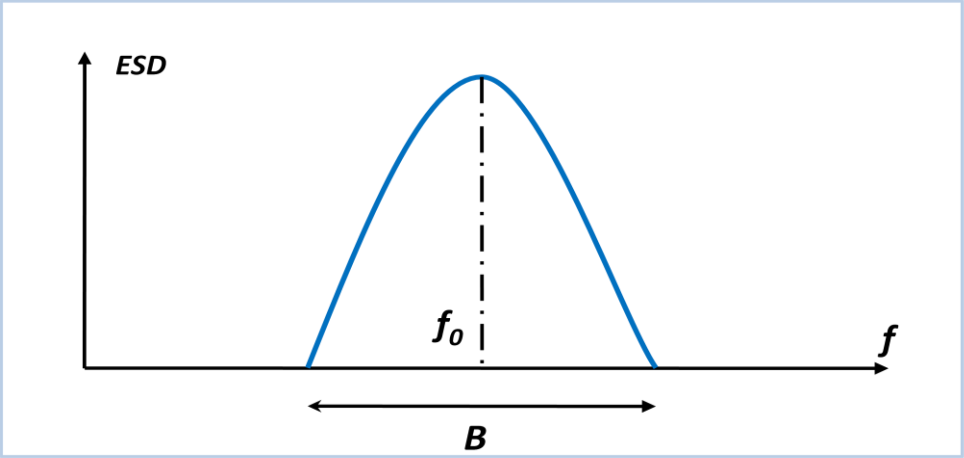

Figure 2- 1 Spectral density of SCM system.

In the broadband wireless communication, a radio channel is usually a frequency selective channel. The sampling rate in broadband communication is large, which results in a very small T_{SC} (following 2-1). As a result, the SCM technique has several weaknesses:

- Influence of ISI caused by multipath fading is large,

- Influence of fading on frequency selective channel, which effects on quality of received signal,
- Complexity in designing interference filters.

Therefore, a Multicarrier Modulation (MCM) technique [25] named Frequency Division Multiplexing (FDM) is studied to deal with the SCM's weaknesses. In a FDM system, bandwidth *B* is divided into many subcarriers as in the figure 2-2 (a). Under this modulation technique, the influences of ISI and frequency selective fading significantly reduce. However, because FDM need a guard gap between each pair of adjacent subchannels to avoid interference, it decreases efficiency of using spectra. OFDM is used to enhance spectral efficiency in communication networks.

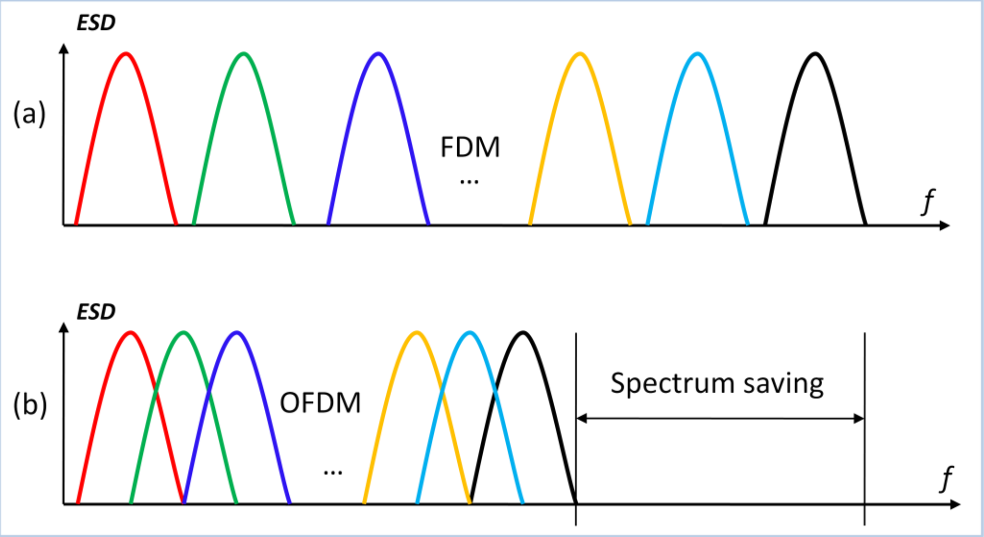

Figure 2- 2 Concept of FDM (a) and OFDM (b).

OFDM is a special form of FDM. Different from FDM, each subcarrier in OFDM [15]-[16] is orthogonal to the others, resulting in permitting to overlap between adjacent subcarriers as presented in figure 2-2 (b). To guarantee the orthogonality between subcarriers, OFDM is modulated by Inverse Fast

Fourier Transform (IFFT) algorithm. By using OFDM technique, a communication system significantly increases efficiency of using spectra.

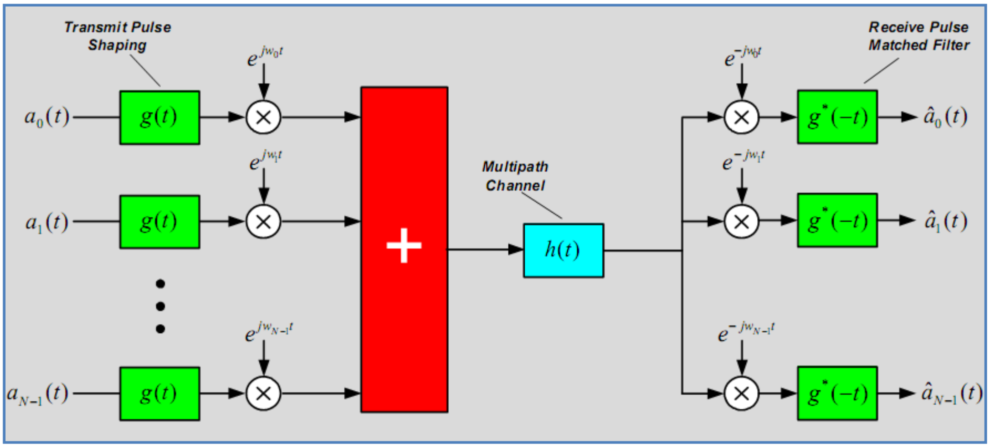

Figure 2- 3 Basic architecture of an OFDM system.

Additionally, in an OFDM system as shown in figure 2-3, the input stream is divided into many parallel sub-streams of reduced data rate (thus increased symbol duration). The increased symbol duration improves the robustness of OFDM to delay spread. Furthermore, the introduction of the Cyclic Prefix (CP) can completely eliminate ISI as long as the CP duration is longer than

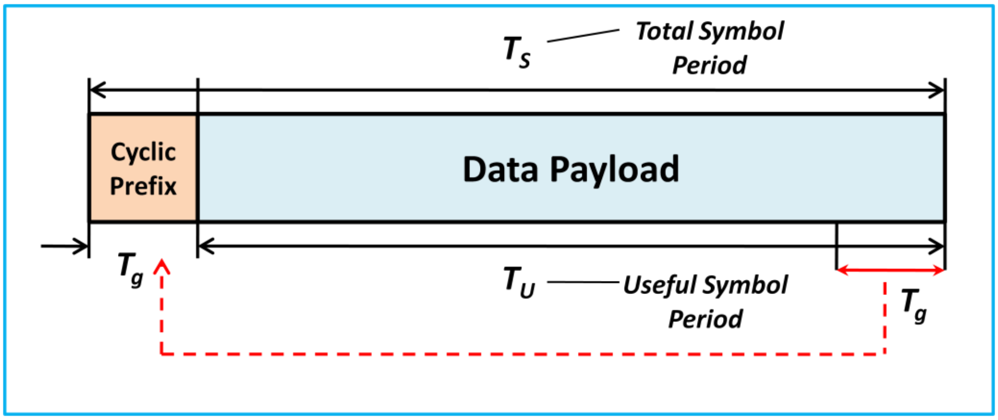

Figure 2- 4 Insertion of cyclic prefix.

the channel delay spread. The CP is typically a repetition of the last samples of data portion of the block that is appended to the beginning of the data payload, what is shown in figure 2-4. The CP prevents inter-block interference, makes the channel appear circular, and permits low-complexity frequency domain equalization. A perceived drawback of CP is that it introduces overhead, which effectively reduces bandwidth efficiency. For all above reasons, OFDM has been widely used in communication networks for broadband traffic recently.

2. Orthogonal Frequency Division Multiple Access – Time Division Duplex

Orthogonal Frequency Division Multiple Access (OFDMA) [16] is a multiuser version of the OFDM digital modulation technique. In order to have multiple user transmissions, a multiple accesses scheme such as Time Division Multiple Access (TDMA) or Frequency Division Multiple Access (FDMA) has to be associated with OFDM. Multiple accesses are achieved in OFDMA by assigning groups of subcarriers (subchannel) to individual users at each given time. The number of subcarriers in each subchannel is dependent on what kind of technology is used; for example, Long Term Evolution (LTE) or Worldwide Interoperability for Microwave Access (WiMAX). The subcarriers forming one subchannel may be adjacent or not. There are three types of subcarriers in OFDMA symbol structure as shown in figure 2-5. Those are data subcarriers for data transmission, pilot subcarriers for estimation and synchronization purpose, and null subcarriers (or DC subcarriers) for no-transmission, which used for guard band and zero hertz subcarriers. Only active (data and pilot) subcarriers are grouped to become subchannels.

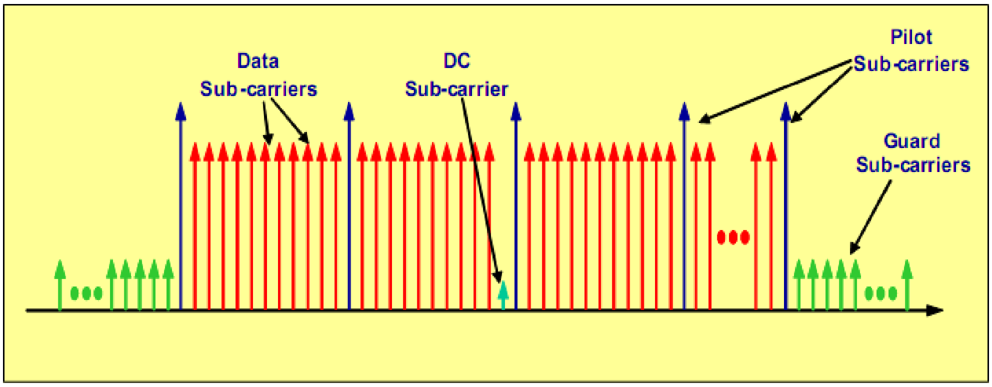

Figure 2- 5 OFDMA subcarrier structure.

In an OFDMA system, resources are available in the time domain by means of OFDMA symbols and in the frequency domain by means of subchannels. The time and frequency resources can be organized into slots for allocation to individual users.

Allocating equally resources in both uplink and downlink becomes bottleneck for the system as uplink remains underutilized while downlink gets strained. The 802.16e PHY [21] supports Time Division Duplex (TDD) and Full and Half-Duplex of Frequency Division Duplex (FDD) operation; however the initial release of certification profiles will only include TDD. To counter interference issues, TDD does require system-wide synchronization. Nevertheless, TDD is the preferred duplex mode for the following reasons:

- TDD enables adjustment of the downlink/uplink ratio to efficiently support asymmetric downlink/uplink traffic. Whereas with FDD, downlink (DL) and uplink (UL) always have fixed and generally, equal DL and UL bandwidths.
- TDD assures channel reciprocity for better support of link adaptation, MIMO and other closed loop advanced antenna technologies.

- Unlike FDD, which requires a pair of channels, TDD only requires a single channel for both downlink and uplink, providing greater flexibility for adaptation to varied global spectrum allocations.
- Transceiver designed for TDD implementations are less complex and therefore less expensive.

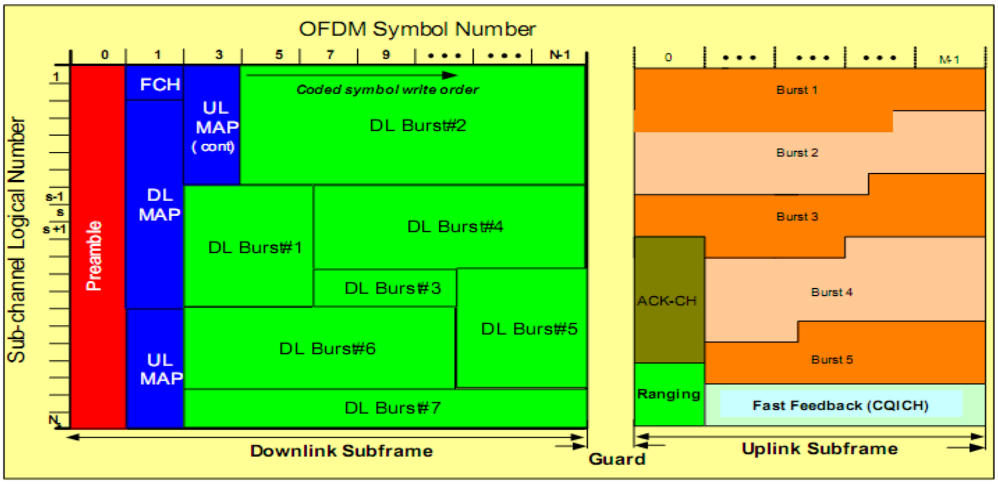

Figure 2- 6 OFDMA-TDD frame structure.

For all above reasons, TDD is preferred for duplex technique to FDD in OFDMA systems. Figure 2-6 illustrates the OFDMA frame structure for a TDD implementation. Each frame is divided into DL and UL sub-frames separated by Transmit/Receive and Receive/Transmit Transition Gaps (TTG and RTG, respectively) to prevent DL and UL transmission collisions. In a frame, the following control information is used to ensure optimal system operation:

- **Preamble:** The preamble, used for synchronization, is the first OFDM symbol of the frame.
- **Frame Control Header (FCH):** The FCH follows the preamble. It provides the frame configuration information such as MAP message length and coding scheme and usable subchannels.

- **DL-MAP and UL-MAP:** The DL-MAP and UL-MAP provide subchannel allocation and other control information for the DL and UL sub-frames respectively.
- **UL Ranging:** The UL ranging subchannel is allocated for Mobile Stations (MS) to perform closed-loop time, frequency, and power adjustment as well as bandwidth requests.
- **UL CQICH:** The UL CQICH (Channel Quality Information Channel) is allocated for the MS to feedback channel quality information.
- **UL ACK:** The UL ACK is allocated for the MS to feedback DL HARQ (Hybrid Automatic Repeat Request) acknowledge.

B. Radio Resource Allocation

Due to harsh wireless channel conditions, scarce bandwidth, limited power resources and ever increasing demands of users for high data rates at guaranteed Quality of Service (QoS) levels, communication networks require an intelligent allocation scheme. Seeking an excellent allocation scheme has been paid much attention recently.

In this subsection, we study on radio resource allocation for multiuser wireless systems. Particularly, we focus on feedback-based (channel-aware) scheduling for multiuser OFDMA systems. For more detail, the original concepts of multiuser diversity and bandwidth allocation problem for OFDMA systems will be presented. A brief of full feedback scheduling is also included in this subsection.

1. Multiuser diversity

The concept of diversity in a communication system is similar to the everyday life concepts of diversity. For example, do not store all your money at only one money box in a room if you don’t want to lose it. Assuming that there is a thief who knows where is your money’s room and he wants to steal it. Your money will be safer if there is more than one money box in the room instead of only one box. Indeed, the thief can’t know exactly which box is containing money; and the thief also need more time to break all boxes’ locks. In communication networks, the diversity can be understood like that [1]-[3]. A same packet is sent over different random channels. If one channel turns out to be bad, there is still a chance of successful reception through the other better channels. The different channels can be different transmit and/or receive antennas (space diversity), different time-instants (time diversity) or different frequencies (frequency diversity) [24]. Space diversity is used in Multiple Input Multiple Output (MIMO) technique; time diversity is used to combat that the transmissions channel may suffer from error bursts due to the time-varying channel conditions; whereas frequency diversity is rarely used due to scarce spectrum.

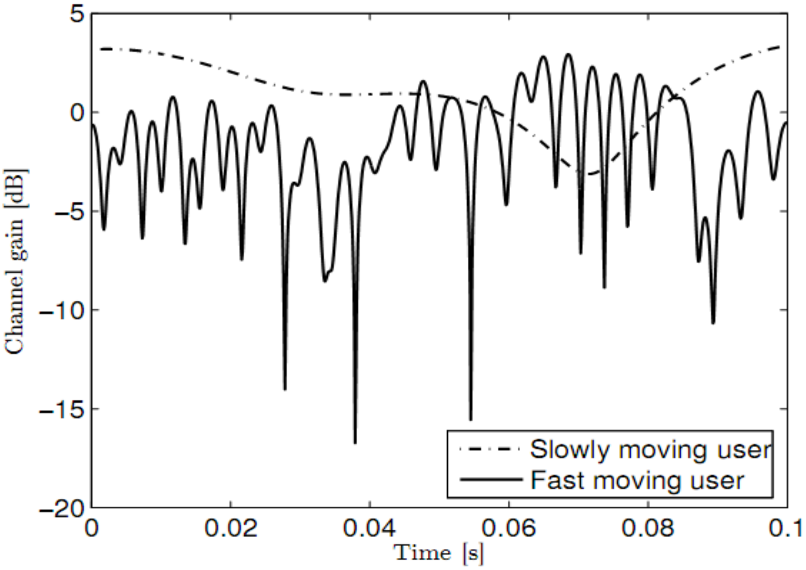

Figure 2- 7 Channel gains of two users vary with time due to fast fading.

The Multiuser Diversity (MUD) effect was first noticed in an information theoretic context. Knopp and Humblet [14] studied the uplink of a single cell system with users experiencing on time-varying fading channels. The figure 2-7 is an example of how the channel gains of two users vary with time due to fast fading. In a multiuser system [1]-[3], there are many users that want to use radio resource to communicate, where users locate at different positions and move with different velocities. As a result, the Channel Quality Information (CQI) of each user on each subchannel is time-varying due to independent path loss, fading, and shadowing. Thus, at any considered time, there exists a situation where some of the users have strong channel condition in comparison to the others. If the radio resources are allocated, by the scheduler residing at base station, to those users having strong channel conditions, system throughput increases for the same used resource. Such schemes are called opportunistic scheduling which exploits the diversity among channel conditions of multiple users [2]-[3].

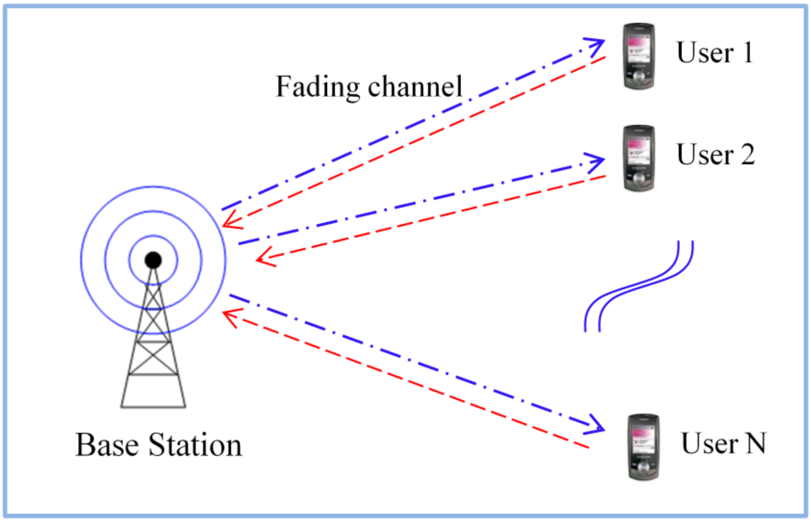

Figure 2- 8 Multiuser diversity in a mobile communication network.

An exploitation of MUD in a mobile communication network is illustrated in figure 2-8. To exploit MUD in a system, the scheduler residing at the system must know the instantaneous channel quality of the all users. In a Time Division Duplex (TDD) system, the same frequency band is used for both uplink and downlink communication during different time slots. The downlink channel quality can be estimated from the uplink quality and vice versa. We assume that the time variations are not too fast in relation to the duplex time, which results in that the channels is not time-varying. In a Frequency Division Duplex (FDD) system, where the uplink and downlink communication are in different frequency bands, this is more difficult to exploit MUD. In this thesis, we address a TDD multiuser diversity system.

2. Resource allocation in multiuser OFDMA system

Radio resource allocation is a technique that assigns a subset of the available radio resources to each user in the system according to a certain optimality criterion on the basis of the experienced channel quality. The radio resource may be power, time, or bandwidth and so on. Due to harsh wireless channel conditions, scarce bandwidth, limited power resources and ever increasing demands of users for high data rates at guaranteed QoS levels, communication networks require an intelligent allocation scheme. Many literatures have dealt with the resource management problem in the OFDMA networks. The overall transmission power is minimized in a multiuser frequency selective fading environment [17]. The total utility is maximized in a multiuser OFDM system [18]. The total throughput is maximized in a multi-cell environment [19]. Slot allocation is studied in [20] to improve efficiency of using system bandwidth.

In this thesis, we study on bandwidth allocation for multiuser OFDMA-TDD systems. Exploiting MUD into OFDMA cellular networks has been studied in some previous literatures [3]-[5]. In order to let BS exploit MUD in downlink OFDMA subchannels, every user should report their Channel Quality Information (CQI) of all subchannels in form of uplink feedback. Such scheduling scheme is called a full feedback-based scheme.

In the full feedback-based scheme, the amount of CQI feedback increases as the number of users in the system increases. Consequently, feedback overhead becomes a serious problem in a full feedback assisted OFDMA system where has large number of users, which eventually reduces throughput in the downlink system. Hence, a partial feedback scheme is necessary in a multiuser OFDMA system. Clearly, the goal of partial feedback is to reduce the feedback load, but at the same time, the throughput performance of the system can be decreased due to the insufficient feedback information. Therefore, the key challenge for researching on a partial feedback scheme is keeping feedback minimal while guaranteeing that proposed scheme achieves a comparable performance to case of full feedback scheme.

C. Partial Feedback Resource Allocation Scheme

Nowadays, there have been many researches on the partial feedback-based scheme. The existing feedback partial schemes can be mainly classified into two categories: Best-M based feedback scheme [5]-[7] and threshold based feedback scheme [7]-[8]. For more information, we summarized the two partial feedback schemes in the following sub-sections.

1. Best-M based scheduling

In order to reduce feedback overhead in multiuser diversity systems, best-M feedback scheduling has been previously mentioned in some literatures [5]-[7]. Under this scheme, each user sends CQI of its selected top-*M* subchannels, instead of all subchannels, that have the highest signal strength. The principle of best-M reporting scheme is illustrated in figure 2-9 where best-4 is used. In the best-4 scheme, each user only reports CQI of 4 strongest subchannels to BS.

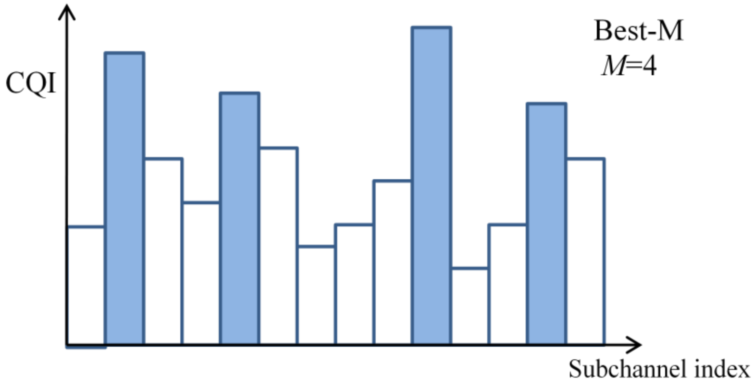

Figure 2- 9 Best-M reporting scheme.

By not-sending CQI information of bad subchannels, the BMF scheme significantly decreases unnecessary feedback reports in the multiuser system. For example, let’s consider a multiuser OFDMA system having K subchannels and N active users. Let the size of feedback of each subchannel be one Report Unit (RU). With full feedback assisted scheduler, total number Report Units (RUs) all users report in each given time is $N \times K$. Whereas, for BMF assisted scheduler (BMAS), total number of RUs is $N \times M$. Because $1 \leq M < K$, the number of unnecessary feedback reports in the system considerably decreases. In other words, best-M feedback scheduler reduces uplink overhead as much as $N \times (K - M)$ RUs.

However, since each user selects their best M subchannels based on its local channel information, in the global view (system view) there might be chances that the selected M subchannels from some users could be worse than the subchannels which could not include themselves in the top-M list of some other users. As a consequence, best-M feedback assisted scheduler cannot fully exploit MUD, resulting in that it performs much lower throughput in comparison to the full feedback assisted scheduler which perfectly exploits MUD.

2. Threshold based scheduling

The threshold based feedback scheme has been used in [7]-[8] to reduce feedback overhead in multiuser cellular systems. Under this scheme, the BS’s scheduler selects at any time instant users whose channel gains in the available subchannels equal or exceed a predetermined CQI threshold. In the threshold based scheme, only users who can maximize system throughput on the available subchannels are assigned to transmit data, which eventually enhances the system throughput. The principle concept of threshold based feedback scheduling is illustrated in figure 2-10.

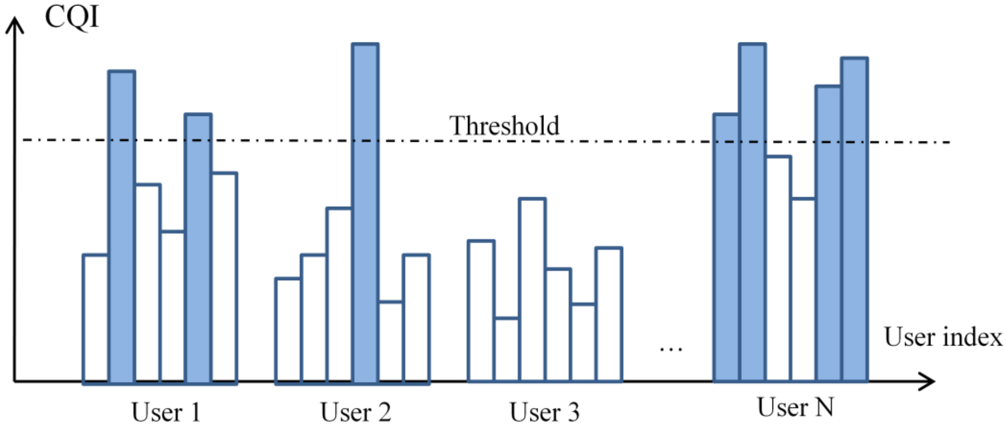

Figure 2- 10 Threshold reporting scheme.

By choosing the best user for each available subchannel, the threshold based feedback scheme improves the best-M scheme in term of throughput. However, threshold based feedback assisted scheduler brings unfairness problem among the users. Indeed, the user with bad channel conditions has lesser chance to report its CQI feedback information (for example, user 3 in figure 2-10), which results in fairness-oriented scheduling schemes such as Proportional Fairness Scheme (PFS) can’t help those users improve their throughput. Furthermore, complexity of exploiting threshold based CQI scheme is also a problem.

III. System Model and the Proposition: ABMF Scheduling

In this section we elaborate the system model in which the proposed scheme is to be used and describe the original concepts based on which the proposed scheme is designed. A proposition named Adaptive Best-M Feedback (ABMF) scheme is introduced in this section in order to further enhance throughput of legacy BMF scheme.

A. System Model

In this thesis, we consider a single-cell OFDMA cellular system which consists of a BS and multiple users. Figure 3-1 depicts the basic TDD frame structure for the considered system where separate sub-frames are provisioned for the uplink and the downlink. In each frame, time-axis is portioned into a finite number of slots and the frequency-axis is divided into multiple subchannels that consist of multiple subcarriers. Channel resource corresponding to one subchannel for the duration of one slot is the least

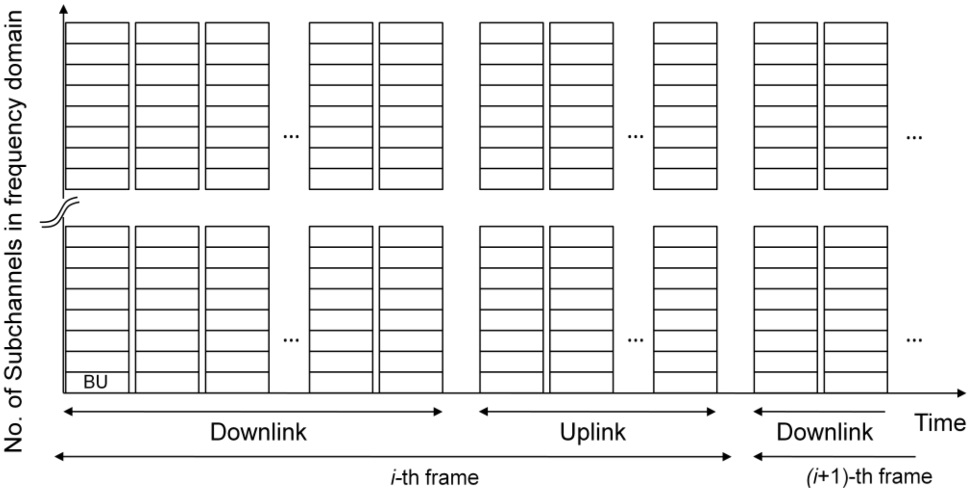

Figure 3- 1 TDD/OFDMA frame structure.

possible channel resource that can be allocated to the users. Each slot contains three OFDMA symbols. We denote that fraction of channel resource as one Basic Unit (BU).

BS uses a downlink scheduler to allocate available BUs to different users based on the CQIs that each user has reported as the uplink feedback. We consider Signal to Noise Ratio (SNR) to be the CQI. Each user measures SNR for each subchannel based on the received pilot signals as mentioned in [12]. In frequency selective fading environment, SNR of user *n* at subchannel *k* can be represented as

$$SNR_k^n = \frac{P_p \cdot |h_{k,n}|^2 \cdot PL_n}{N_0 \cdot W}, \tag{3-1}$$

where $|h_{k,n}|^2 . PL_n$ is the subchannel gain, P_p is the transmitted power of the pilot signal, N_0 is noise power spectral density, and W is subchannel bandwidth. Note that the subchannel gain is a random variable that represents both the path loss (PL_n) and the fading (in *k*th subchannel) of the *n*th user. In the cell where users are differently located, path loss for user *n* is equal to

$$PL_n(d_n) = PL_n(d_0) + 10 \cdot \beta \cdot log\left(\frac{d_n}{d_0}\right) + X_\sigma\ , \tag{3-2}$$

where d_0 and d_n are reference distance and distance from BS to user n, respectively. β is the path loss component and X_σ is the shadowing component which can be represented with a Gaussian random variable with standard deviation *σ.*

B. Adaptive Best-M Feedback Assisted Scheduling

1. Previous works

According to the considered system model, CQI of each user on each subchannel is time-varying due to independent path loss, fading and shadowing. Hence, at any considered time, there exists a situation where some of the users have strong channel condition in comparison to the others. If the radio resource is allocated, by the scheduler residing at BS, to those users having strong channel condition, system throughput increases for the same used resource. Such schemes are called opportunistic scheduling which exploits the diversity among channel conditions of multiple users [2]-[3].

Ideally, to use a MUD exploiting opportunistic scheduler at BS, each user must report its CQI of all K subchannels to BS. Let us denote such scheduler as Full Feedback Assisted Scheduler (FFAS). Since FFAS makes scheduling decision based on the complete knowledge of channel of each user, it can perfectly exploit MUD. Thus it significantly enhances downlink throughput. However, due to the detail feedback including CQI of each subchannel, it incurs high uplink overhead. The uplink overhead becomes severe especially when the number of users in the system is high or the OFDMA channel has large number of subchannels [4]-[8].

To overcome the uplink overhead problem, Best-M Feedback (BMF) scheme has been studied. Under BMF, each user identifies, selects and sends CQI of only M $(1 \leq M < K)$ subchannels that have the highest values. Let the size of feedback of each subchannel be one Report Unit (RU). As such, the number of unnecessary feedback reports in the system considerably decreases. In other words, BMF scheme reduces uplink overhead as much as $N \times (K - M)$ RUs. It should be noted that, if M is large MUD exploitation would be easy but uplink overhead doesn't decrease much. On the other hand, if M is less MUD exploitation would be poor but the uplink overhead significantly decreases. Hence, M should suitably be selected to reflect this trade-off.

2. Adaptive best-M assisted scheduling

In this section, we present an approach to adaptively select M to meet the aforesaid trade-off. The value of *M* is closely related to a number of active users. This approach when applied to BMF scheme results in an ABMF scheme.

For a given system having N users, there exists an optimal M which maximizes system throughput without increasing feedback size beyond the predetermined Preferred Feedback Load Size (PFLS). The PFLS is a system parameter that depends on uplink system capacity. As such, we propose the following relation to compute *M.*

$$M = \begin{cases} 16 & if \left\lfloor \frac{PFLS}{N} \right\rfloor \geq 16 \\ \left\lfloor \frac{PFLS}{N} \right\rfloor, & otherwise \end{cases} \tag{3-3}$$

where $\lfloor x \rfloor$ is the largest integer not greater than x. Note that users in the cellular network are unaware of the total number of active users in the system. Hence, we assume that BS is responsible for periodically computing and broadcasting information about value of M to users according to (3-3).

Next, the dynamically calculated M will be applied to the BMF assisted scheduler residing at BS. We call this scheduler an Adaptive Best-M Feedback Assisted Scheduler (ABMAS). With information about value of

M is periodically computed and broadcasted by BS based on number of active users N, each user reports CQI of the best M subchannels following legacy BMF scheme. For each given time, ABMAS allocates BUs to users as same as BMAS behaves. However, note that in the current scheme, M adaptively varies according to N unlike the fixed M in the legacy BMF scheme. For more information, the functions of BS and each user in the ABMAS system are as follows.

BS Function

- Updating number of active user N
- Computing M following (3-3)
- Periodically broadcasting M to users
- Receiving best-M CQI[1] feedback from users
- Selecting the best user, n^*, for subchannel k at time slot t Basic Unit $BU_{k,t}$ following the relation as in [8]

$$n^* (k,t) = argmax_{n=1 \ldots N} (SNR_k^n(t))$$

User Function

- Receiving value of M from BS
- Choosing M best subchannels
- Reporting CQI information of best-M subchannel on feedback channel

---

[1] CQI of user n on subchannel k is equal to SNR_k^n

IV. Simulation Results and Discussions

A. Simulation Environment

We consider a TDD OFDMA cellular system (DL : UL = 29:18) with a single cell having radius of 2 Km. The 10 MHz bandwidth of OFDMA system is divided into 16 subchannels. Parameters for the path loss in (3-2) are considered to be $d_0 = 100m$, and $\sigma = 8\,\mathrm{dB}$. The reference path loss, $PL_n(d_0)$, and path loss component β are computed following COST-231-Hata model [13] with carrier frequency of 2GHz; BS height of $50m$; and user height $h_m = 2m$. We fix the PFLS to 300 RUs and the targeted BER to 10^{-3}. For quick reference, we summarized all these parameters in table 4-1.

Table 4- 1 Simulation parameters.

Parameters	Value
Cell radius (in Km)	2
Reference distance (in m)	100
Carrier frequency (in GHz)	2
Height of base station (in m)	50
Height of mobile (in m)	2
Preferred feedback load size (in RUs)	300
Path loss exponent (β)	3.37
Shadowing standard deviation (σ in dB)	8
Number of subchannels (K)	16
Frame length (in ms)	5
Duplex method	TDD
DL/UL	29/18
Total bandwidth (in MHz)	10
Bit error rate	10^{-3}

To make the considered system more realistic, we additionally consider that the users can perform Adaptive Modulation and Coding (AMC) based on their SNR on each subchannel. Table 4-2 shows the considered mapping relations of AMC levels and required SNRs, following [10], under BER constraint of 10^{-3}.

Table 4- 2 Adaptive modulation and coding.

Index	**SNR_{req} (dB)**	**Modulation**	**Coding rate**
AMC_1	-3.5	BPSK	1/2
AMC_2	0.5	QPSK	1/2
AMC_3	3.7	QPSK	3/4
AMC_4	6.3	16 QAM	1/2
AMC_5	10.5	16QAM	3/4
AMC_6	15.2	64QAM	3/4

We choose system throughput, R, as the performance indicator. R is the total rate of all users on all subchannels. The system throughput, R, is computed by two ways.

Firstly, for the system what supports AMC capable users, R is equal to sum of data rate of all users on all subchannels. The data rate of each user on each subchannel is computed based on which modulation and coding scheme is used. Following [23], the data rate each user on each subchannel in an OFDMA symbol is evaluated as follows.

- AMC_1 = BPSK 1/2, R_1 = 0.5 bit/ subchannel / OFDMA symbol,
- AMC_2 = QPSK 1/2, R_2 = 1 bit/ subchannel / OFDMA symbol ,
- AMC_3 = QPSK 3/4, R_3 = 1.5 bits/ subchannel / OFDMA symbol,
- AMC_4 = 16 QAM 1/2, R_4 = 2 bits/subchannel / OFDMA symbol,

- AMC_5 = 16 QAM 3/4, R_5 = 3 bits/subchannel / OFDMA symbol,
- AMC_6 = 64 QAM 3/4, R_6 = 4.5 bits/subchannel / OFDMA symbol.

Secondly, the upper bound of system throughput, R, is equal to sum of data rate of all users on all subchannels, where the data rate of each user on each subchannel is computed following Shannon's equation [9]. Numerically, it can be expressed as follows.

$$R = \sum_{n=1}^{N} \sum_{k=1}^{K} r_{n,k}(t) \cdot \alpha_k^n(t) \tag{4-1}$$

Where

$$r_{n,k}(t) = W \cdot log_2(1 + a \cdot SNR_k^n(t)) \tag{4-2}$$

is the rate of *n*th user on *k*th subchannel at a given time *t*, $\alpha_k^n(t)$ is a binary variable indicating the occupancy of subchannel (1 if a subchannel is assigned and 0 if it is unassigned), and $a \approx -1.5/ ln(5\, BER)$, where BER is the targeted bit error rate in the subchannel.

B. Simulation Results and Discussions

In this subsection, we will compare the simulated performance results of the proposed ABMAS with FFAS and BMAS. The Matlab 7.1 simulator is used to simulate our system.

Figure 4-1 depicts an upper bound downlink system throughput of ABMAS, BMAS, and FFAS, that is evaluated following (4-1). As expected, FFAS offers the highest downlink throughput since it can perfectly utilize MUD during making scheduling decision. The proposed scheme outperforms BMAS when the number of active users in the system is small since in such situation the proposed ABMAS can adaptively use suitable (larger) M.

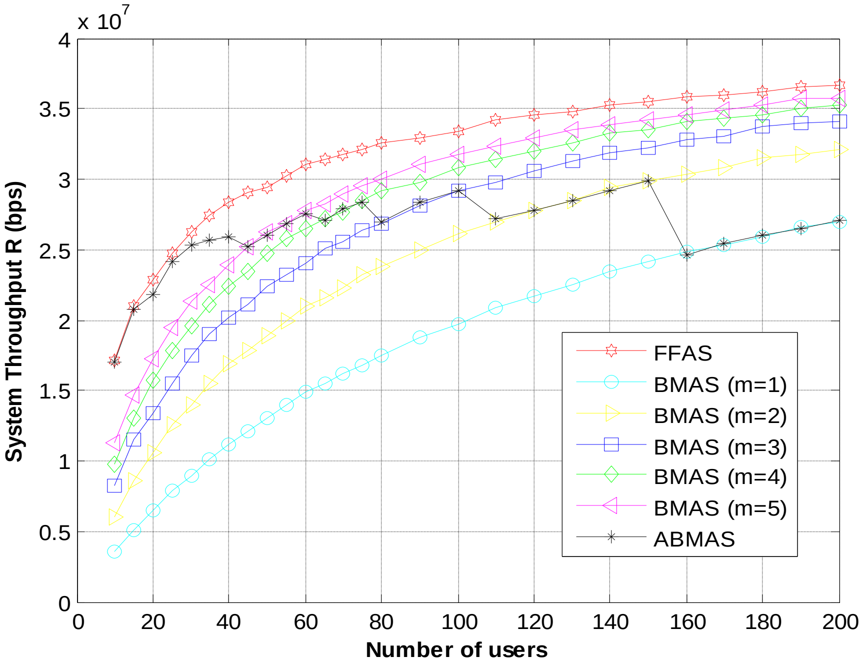

Figure 4- 1 Upper bound of downlink system throughput.

Figure 4-2 compares the three schedulers namely ABMAS, BMAS, and FFAS in terms of downlink system throughput for the OFDMA system where all users are capable to perform AMC. Following the similar performance trend in figure 4-1, FFAS offers the highest downlink throughput. ABMAS outperforms BMAS in this realistic wireless settings as well. Note that there is a slight difference in the corresponding system throughput values that are shown in figure 4-1 and figure 4-2. In the former figure, since we were interested in knowing system throughput bound we have directly used Shannon's formula in (4-2) while in the case of later figure we have obtained the realistic downlink throughput of the OFDMA system with AMC capable users.

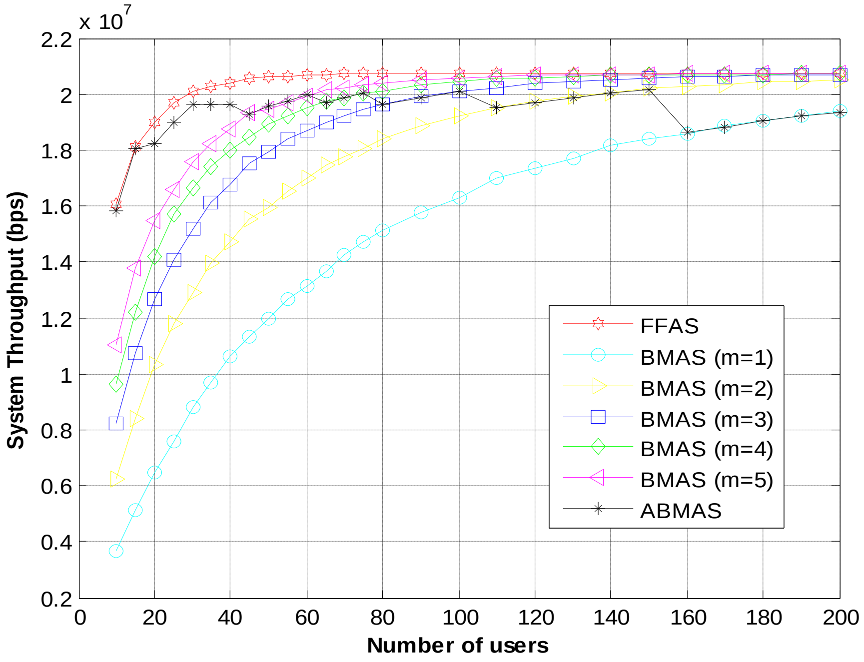

Figure 4- 2 Downlink system throughput with AMC capable users.

It is noteworthy to mention that although FFAS outperforms the proposed ABMAS scheme in terms of downlink system throughput, it incurs higher uplink overhead and eventually exceeds PFLS (shaded part in table 4-3). In the last column of the table, sub-optimal *M,* which is evaluated following (3-3), is shown. Feedback load size (in unit of RUs) for different possible values of M is also shown. Hence, jointly considering the downlink throughput performance in figure 4-1, figure 4-2 and uplink feedback load size in table 4-3, we reach to a conclusion that by adaptively selecting and using sub-optimal value of *M,* the proposed ABMAS is able to maintain better trade-off between downlink system throughput and uplink feedback overhead. From the table it is also evident that for the given PFLS, the proposed scheduling mechanism can support higher number of simultaneous users than FFAS and BMAS.

Table 4- 3 Comparison of uplink feedback size

N	FFAS	BMAS					ABMAS
		M=1	M=2	M=3	M=4	M=5	
10	160	10	20	30	40	50	160 (M=16)
20	320	20	40	60	80	100	300 (M=15)
30	480	30	60	90	120	150	300 (M=10)
40	640	40	80	120	160	200	280 (M=7)
50	800	50	100	150	200	250	300 (M=6)
60	960	60	120	180	240	300	300 (M=5)
70	1120	70	140	210	280	350	280 (M=4)
80	1280	80	160	240	320	400	240 (M=3)
90	1440	90	180	270	360	450	270 (M=3)
100	1600	100	200	300	400	500	300 (M=3)
110	1760	110	220	330	440	550	220 (M=2)
120	1920	120	240	360	480	600	240 (M=2)
130	2080	130	260	390	520	650	260 (M=2)
140	2240	140	280	420	560	700	280 (M=2)
150	2400	150	300	450	600	750	300 (M=2)
160	2560	160	320	480	640	800	160 (M=1)
170	2720	170	340	510	680	850	170 (M=1)
...	...	...	...	...	...	...	...
300	4800	300	600	900	1200	1500	300 (M=1)

To select a suitable value of PFLS for each particular cellular system, we consider and compare ABMAS systems having varied PFLS. Figure 4-3 illustrates upper bound downlink system throughput of three ABMAS systems when PFLS varies from 150 RUs to 450 RUs. Three ABMAS systems having number of active users in each system is 50, 100, and 150. As expected, there is an increasing performance trend in all three systems. Following figure 4-3, it shows that by changing the value of PFLS from 270 RUs to 300 RUs, the throughput quickly increases in all three systems. It means that PFLS has a critical value at 300 RUs for a system having number of active users between 50 and 150.

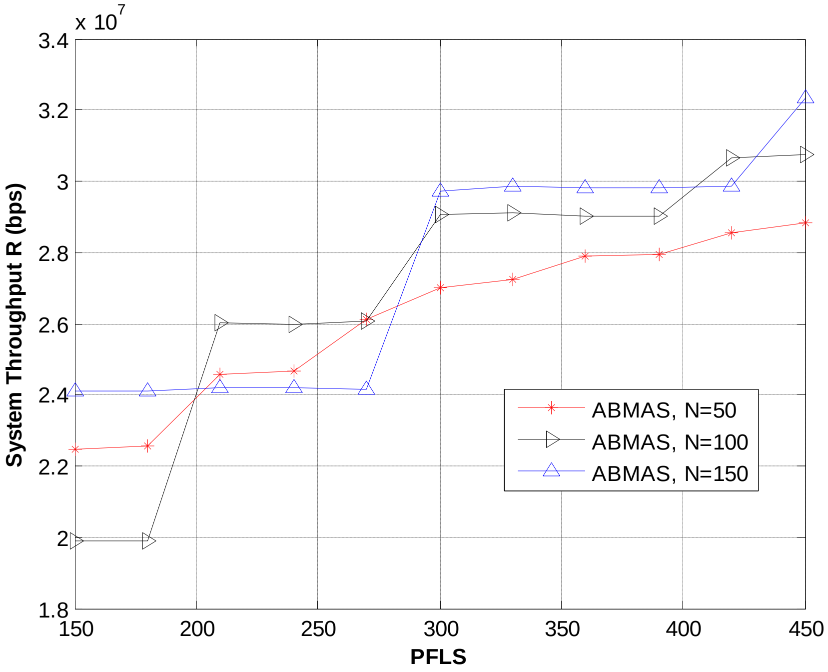

Figure 4- 3 Upper bound of downlink system throughput with varied PFLS.

Therefore, in practice, for each particular area in a cellular system, where we know a specific subscriber density, by setting up a critical PFLS value as an uplink parameter, we can save a part of uplink capacity which is used for

CQI feedback. As a result, the proposition has given a method to use more efficiently the uplink system capacity.

To present more detailed information about downlink system throughput of three considered systems, we summarize all values in table 4-4.

Table 4- 4 Upper bound of downlink system throughput with varied PFLS for three numbers of users

N PFLS	50	100	150
150	2.2456	1.9888	2.4173
180	2.2566	1.9886	2.4051
210	2.4539	2.5968	2.4153
240	2.4669	2.6015	2.4097
270	2.6083	2.6059	2.4091
300	2.7210	2.9109	2.9813
330	2.7190	2.8988	2.9816
360	2.7910	2.9018	2.9832
390	2.7998	2.8996	2.9800
420	2.8496	3.0664	2.9788
450	2.8873	3.0650	3.2181

V. Conclusions and Future Works

We analysed and discussed the radio resource allocation in multiuser OFDMA systems. The feedback-based (channel-aware) scheduling is elaborately studied. In particular, the partial best-M feedback-based resource allocation has been studied. We proposed a new scheduling algorithm named ABMF scheme to further enhance the system throughput of the legacy BMF scheme. We analysed the efficiency of the proposed algorithm and simulated in order to reveal that the ABMF scheme outperforms the legacy BMF scheme.

In the thesis, we analysed and found out that there is a problem in legacy BMF scheme. The legacy BMF scheme does not perform system throughput very well in a system having variable number of active users. To further enhance throughput performance in BMF scheme, we introduced a mathematical relation to compute the sub-optimal value of M based on number of active users in the system. The sub-optimal M is then applied into legacy BMF scheme to become an ABMF scheme.

Through computer simulation, the simulation results showed that the proposed scheme was able to maintain better trade-off between downlink system throughput and uplink feedback overhead in comparison to BMF scheme. The proposed scheduling outperforms the best-M scheduling in term of throughput. The number of users that can be simultaneously supported in the ABMAS system is more than that in original BMAS system. And the last, but not the least, the proposition gives a method to easily install the system and efficiently use the uplink system capacity.

The proposed scheduling algorithm we carried in this thesis can be used in wireless broadband systems such as LTE, WiMAX and so on. Introducing the proposed scheme into a particular system combining a fairness scheme might be a part of our future works.

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.

Abstract

A Study on a Resource Allocation Scheme for Multiuser OFDMA Systems

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Radio resource allocation is a technique that assigns a subset of the available resources to each user in the system according to a certain optimality criterion on the basis of the experienced channel quality. Multiuser Diversity (MUD) is a popular technique that has been used in different wireless communication systems to increase the system throughput by opportunistically selecting the best user from the pool of candidate users. Orthogonal Frequency Division Multiple Access (OFDMA) is regarding as the superior and preferred choice for multiple accesses to support high speed transmission of broadband traffic.

For the case of resource allocation in multiuser OFDMA systems, users are opportunistically selected based on the Channel Quality Information (CQI) they have reported to Base Station (BS) in the form of uplink feedback. This kind of scheduling is called full feedback scheduling. However, in the multiuser OFDMA systems using full feedback scheduling, uplink feedback overhead becomes a serious problem when the number of active users in the system is large. To address the feedback overhead problem, two popular partial feedback schemes, Best-M Feedback (BMF) scheme and threshold feedback scheme, have been previously studied in some literatures. By studying and analyzing two foresaid popular partial feedback schemes, we find out that the BMF scheme significantly reduces feedback overhead in the system; however, it also performs lower system throughput in comparison to the full feedback scheme. Threshold feedback scheme improves the best-M scheme in term of throughput; however, it is unfair.

In this thesis, we study and analyze partial feedback resource allocation for multiuser OFDMA systems. To further increase the system throughput of BMF scheduling, we propose an Adaptive Best-M Feedback (ABMF) scheduling, where *M* is adaptively calculated based on the number of active users. Through theoretical analysis and computer simulations, we show that the proposed scheme (i) offers greater or equal downlink throughput with remarkably reduced uplink overhead, (ii) increases the number of users that can be simultaneously supported in the system, in comparison to the best-M scheme, and (iii) gives a method to easily install the system and efficiently use the system capacity.

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