CHAPTER 1

INTRODUCTION

Since the early eighties, wireless phone penetration has increased exponentially. In many developing countries mobile wireless phones are the dominant and popular means of communication and there is a huge market for wireless development. New generations cellular mobile wireless networks are aimed at increasing the user capacity and providing good multimedia capability.

1.1 DIVERSITY WIRELESS SYSTEMS

There has been a remarkable evolution in the field of wireless communications. With the increasing use of diverse wireless facilities, the demand for bandwidth or capacity becomes vital. All Radio communications systems, whether mobile radio networks like 3GPP, UMTS or wireless radio networks like WLAN, must continuously provide higher data rates. Such systems in use today are predominantly Single-Input Single-Output (SISO) systems. Because of the multi-path propagation in wireless channels, the capacity of single wireless channel is very low. In addition to conventional methods, such as introducing higher modulation types or providing larger bandwidths, researchers have focused on ways to make more efficient use of this limited capacity and have accomplished remarkable progress. On the one hand, efficient techniques have been invented to increase the bandwidth efficiency and on the other hand, advances in scheduling make it feasible to reach almost Shannon capacity. The fundamental problem affecting the SISO systems is time-varying multipath fading which makes the reliable
transmission difficult. The multipath may add destructively in the propagation media and the severe attenuation may make it impossible for the receiver to determine the transmitted symbol correctly. Hence, we must provide some less attenuated replica of the transmitted symbol to the receiver for the correct detection. This is termed diversity and is the most important contributor to the reliable wireless transmission.

The basic idea of diversity is that, if two or more independent samples of a signal are sent and fade in an uncorrelated manner, the probability that all the samples are simultaneously below a given level is much lower than the probability of any one sample being below that level. Thus, properly combining various samples greatly reduces the severity of fading and improves reliability of transmission. Diversity combining consists of receiving redundantly the same information-bearing signal over two or more fading channels, then combining these multiple replicas at the receiver in order to increase the overall received signal-to-noise-ratio (SNR). It offers one of the greatest potentials for radio link performance improvement to many of the current and future wireless technologies. The intuition behind this concept is to exploit the low probability of concurrence of deep fades in all the diversity channels to lower the probability of error and of outage. Depending on the domain where replicas of the same information-bearing signal are obtained, several different diversity modes are used to make radio communications more robust, even with varying channels. These include time diversity (different timeslots and channel coding), frequency diversity (different channels, spread spectrum), and also spatial diversity. The space diversity can be achieved by using multiple antennas while the time diversity can be achieved by using multiple time slots separated by at least the coherence time of the channel. Multiple Input Multiple Output (MIMO) terminology refers to mapping of a data stream to multiple parallel data streams and de-mapping multiple received data streams into a single data
stream. MIMO systems offer higher data rate, high spectral efficiency, better interference suppression, lower bit error rate and resistivity to fading. One of the prominent advantages of multiple-antenna systems is that they provide better reliability in transmission by using diversity techniques without increasing transmit power or sacrificing bandwidth. The antennas of a MIMO system can be used for four different purposes: (i) Beam forming, (ii) Diversity, (iii) Interference suppression and (iv) Spatial multiplexing (transmission of several data streams in parallel).

Multi-user MIMO (MU-MIMO) is an enhanced form of MIMO technology that enables multiple independent radio terminals to access a system enhancing the communication capabilities of each individual terminal. MU-MIMO offers the following significant advantages that come at a cost of additional hardware (antennas and processing) and also obtaining the channel state information which requires the use of available bandwidth.

- MU-MIMO systems enable a level of direct gain to be obtained in a multiple access capacity arising from the multi-user multiplexing schemes. This is proportional to the number of base station antennas employed.

- MU-MIMO appears to be affected less by some propagation issues that affect single user MIMO systems. These include channel rank loss and antenna correlation - although channel correlation still affects diversity on a per user basis, it is not a major issue for multi-user diversity.

- Multi-user MIMO is still in its infancy, and many developments are underway to determine the optimum formats for its use. Coding types, multiuser scheduling as well as levels of channel state indication are being determined as these use up valuable resource and can detract from the
overall data throughput available. MU-MIMO exploits the maximum system capacity by scheduling multiple users to be able to simultaneously access the same channel using the spatial degrees of freedom offered by MIMO.

Scheduling is a method of allowing multiple users to share a common resource. In the wireless context, scheduling allocates systems resources (e.g., transmit power, time slot, bandwidth, modulation scheme, antenna), to optimize a measure of goodness (e.g., throughput, BER, delay). Scheduling was traditionally used for the allocation of antenna resource in MIMO system. In this thesis various threshold-based scheduling techniques are aimed for multiuser MIMO downlink system to improve the BER performance.

1.2 LITERATURE SURVEY

In multiuser wireless communications, different scheduling techniques have been proposed to exploit the multiuser diversity. While user scheduling aims to maximize the system throughput, the fairness in resource allocation among the users is a key parameter and should be taken into consideration. As a full-fair scheduling scheme, round-robin scheduler is a simple scheme, where all users have the same priority for accessing the channel, but it does not exploit the multiuser diversity. On the other hand, the best-user scheduler, the so called opportunistic or greedy scheduler or max throughput, selects the user with the highest throughput. The greedy scheduler achieves a higher throughput than round-robin scheduler does, but at the price of unfairness in resource allocation among users. In the greedy scheduling scheme, some users who are closer to the base station will have more chance to access the channel, leading to unequal distribution among users. The proportional fair (PF) scheduler has been proposed for exploiting multiuser diversity while maintaining the fairness among users. In PF scheduler, there is
a tradeoff between the total throughput and the fairness. Instead of selecting the best user with highest absolute-throughput or absolute-SNR, PF scheduler (Viswanath et al 2002 and Sharma et al 2005) chooses the user with the highest normalized-throughput or normalized-SNR (normalized to its own average). Currently, these three major scheduling methods, round robin (RR), max throughput and proportional fair (PF) are deeply studied and widely utilized in many systems such as WCDMA, CDMA2000 system. Of the three scheduling algorithms, RR does not need any channel state information at the transmitter (CSIT), max throughput and PF need the CSIT feedback by each user to determine which user should be scheduled. Thus, the performance of max throughput and PF depends largely on the accuracy and timeliness of the feedback.

Some user schedulers analyzed by different researchers are as follows. The max–min fairness scheduler (Bertsekas and Gallagar 1992) picks the user with the smallest mean throughput at each time slot. Knopp and Humblet (1995) introduced a maximum carrier-to-interference ratio (max-C/I) scheduler that maximizes the system capacity by compromising the fairness. A PF scheduling (Jalali et al 2000) promises a tradeoff between the maximization of average throughput and user fairness. At each time instant, the user experiencing the highest instantaneous rate with respect to its average rate is scheduled. Caire et al (2007) studied the system throughput under hard fairness and PF constraints, where “hard fairness” indicates that every user transmits at its desired rate independently of its channel conditions, and the system struggles to accommodate each user’s rate request. Shirani-Mehr et al (2008) proposed a modified PF that takes into account the “predictability” state of user terminals and outperforms the classical PF in the presence of prediction errors. The proposed scheme of Da and Ko (2009) aims at maximizing the total system capacity while having constraints on the total
available power. The above schedulers are mostly used in second and third generation wireless networks for performance improvement.

Multiuser scheduling schemes (Tse 2001) rely on time division multiple access (TDMA) type of systems to schedule the user with the best channel quality to either upload or download data. With this type of system, the average spectral efficiency (ASE) can be maximized because the selected channel supports the highest possible rate. However, this high spectral efficiency comes at the expense of a high feedback load. To simplify the selection process and reduce the feedback load, Holter et al (2004) proposed a multiuser switched diversity scheme. By using an SNR threshold a multiuser switched diversity was shown to reduce the feedback load (Holter et al 2004, Gesbert and Alouini 2004). In this scheme, the BS probes significant users in a sequential manner and look for an acceptable user. In addition to the reduction in feedback load, this scheme was shown to experience minimal ASE loss and an increase in fairness by randomizing the probing sequence from one scheduling round to the next.

The TDMA-based scheduling schemes mentioned above schedule only one user at a given time. In order to improve the frequency of access, a multiuser simultaneous scheduling scheme (Ma and Zhang 2006) was proposed based on generalized selection combining (GSC). In this scheme, the scheduler selects in each time-slot the $Ns$ users with the largest SNRs among the N active users ($Ns \leq N$). Similar to the selection-based TDMA scheme, the scheme (Ma and Zhang 2006) needs to probe and then rank all the active N users. Nam et al (2009) proposed two new parallel multiuser scheduling schemes that rely on an SNR threshold to reduce the complexity of implementation and increase the user frequency of access without
experiencing a considerable ASE loss in comparison with the GSC-based scheduling scheme (Ma and Zhang 2006). The first scheme, termed, on-off based scheduling (OOBS) scheme, is based on the absolute threshold generalized selection combining (AT-GSC) scheme (Simon and Alouini 2002) and the on-off type of schemes (Gesbert and Alouini 2004, H’om’al’ainen and Wichman 2006) that selects in each time-slot all the users with an SNR above a preselected SNR threshold. The difference between the OOBS scheme and the AT-GSC scheme is that there is no combining process in the OOBS scheme. The second scheme, termed, switched based scheduling (SBS) scheme, is based on the switched diversity concept (Holter et al 2004, Yang and Yang 2005). Along the spirit of multiuser switched diversity transmission (Louie et al 2009), the scheduler selects $N_s$ users with acceptable SNRs instead of the ones with the best $N_s$ SNRs. When the acceptable $N_a$ users are less than $N_s$, the scheduler selects also the best unacceptable ($N_s - N_a$) users. The SBS scheme approaches the outage performance of the GSC-based scheduling scheme as SNR threshold $\gamma_T$ increases. However, the SBS scheme needs less than N feedback whereas the GSC-based scheduling scheme needs always full N feedback during the guard time period. Numerical results show that the proposed schemes (Nam et al 2009) can offer some decrease in the average feedback load without an important degradation in average bit error rate and average spectral efficiency.

Due to growth of wireless networks and demand of high data rate, the fourth generation wireless networks attract the multiple input multiple output (MIMO) systems. Ajib and Haccoun (2005) presented an overview of user selection and scheduling algorithms in MIMO systems. Sang et al (2006) proposed alpha rule (weighted) based scheduler for MIMO systems. This rule provides a tradeoff between the aggregate throughput and the per-user
fairness by changing the value of alpha. When that parameter is set to one or infinity, the alpha rule becomes PF or max–min, respectively. A user utility function that jointly considers the throughput and fairness is proposed for MIMO systems (Aniba and Aïssa 2007) mainly for a high-speed downlink packet-access network. That function ensures an adaptive PF among the users. A similar problem was studied by Yang et al (2007) who proposed two forms of a hybrid multiuser scheduling scheme that provides a flexible tradeoff between the system achievable capacity and the fairness. The above proposed scheduling schemes are simply based on the SNR of different users.

Multiuser scheduling has been widely used to exploit the multiuser diversity as well as the antenna diversity of multiuser multiple-input multiple-output (MIMO) systems (Hochwald et al 2004, Chen et al 2006) and it has been observed that the so-called channel hardening can limit the benefits of multiuser MIMO systems. In order to overcome this limitation, antenna selection (Bai et al 2009) can be employed. The performance evaluation of joint antenna selection and user scheduling has been performed (Bai et al 2009, Chen et al 2008) assuming a homogeneous scenario with independent and identically distributed (i.i.d.) users and antennas. It has been shown that over a fast time-varying fading channel and in the presence of channel errors selecting more than one antenna yields a better result in high SNR regime (Chen et al 2008). From a practical point of view, this may justify the use of group transmit antenna selection. Torabi and David (2011) presented a performance analysis of multiuser OSTBC-MIMO with group transmit antenna selection under a heterogeneous scenario, where the channel SNR values of the users and antenna groups are independent and non-identically distributed (i.n.i.d.). In their paper BER numerical results are obtained for i.n.i.d. and i.i.d. scenarios. A significant gain from both multiuser and antenna
diversities can be obtained at the same time. Zhao et al (2009) introduced a 
distributed scheduling algorithm for multiuser MIMO downlink with adaptive 
feedback. Kang et al (2010) proposed two schedulers, which are denoted by 
the control variance (CV) scheduler and the control mean (CM) scheduler. 
These schedulers achieve nearly the maximum system throughput, and the 
Gaussian assumption and the approximation of the complementary error 
function cause a negligible error on the time-slot allocation ratio, even in 
MIMO systems equipped with a small number of antennas. The conventional 
multiuser switched diversity scheduling scheme uses a single feedback 
threshold for every user, where the threshold is a function of the average 
signal-to-noise ratios (SNRs) of the users as well as the number of users 
involved in the scheduling process. Nam and Alouini (2010) proposed a new 
scheme that constructs a sequence of feedback thresholds instead of a single 
feedback threshold such that each user compares its channel quality with the 
corresponding feedback threshold in the sequence. This scheme provides a 
higher system capacity than the conventional scheme. Diversity is one of the 
key enabling technologies that allow schedulers to achieve high system 
performance (Knopp and Humblet 1995).

Some schedulers used in different wireless system application are 
shown in Table 1.1.
### Table 1.1 Some schedulers used in different wireless systems

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<tr>
<th>Sl.No.</th>
<th>Wireless System</th>
<th>Different Schedulers Used</th>
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| 1.     | WCDMA, CDMA2000 system                   | • Channel-dependent scheduling  
• Maximum throughput scheduling  
• Opportunistic Scheduling (Kulkarni and Rosenberg 2003) |
| 2.     | HSDPA (High-Speed Downlink Packet Access) 3.5G cellular system | • Maximum carrier-to-interference ratio (max-C/I) scheduler (Knopp and Humblet 1995)  
• Best-user scheduler, so called opportunistic or greedy scheduler or max throughput scheduler (Viswanath et al 2002)  
• Proportional Fair Scheduler (PFS) or normalized-throughput or normalized-SNR  
• Max–min fairness scheduler (Bertsekas and Gallagar 1992)  
• Formula named (weighted) alpha rule (Sang et al 2006)  
• Modified PFS (Shirani-Mehr et al 2008) |
| 3.     | MIMO                                     | • Selective Multi-User Diversity (SMUD)  
• Optimal Rate, Reduced Feedback (ORRF)  
• Threshold based scheduling (Nam et al 2009)  
• Absolute Threshold Generalized Selection Combining (AT-GSC) scheme (Ma and Zhang 2006)  
• On-Off Based scheduling (OOBS) scheme (Nam et al 2009)  
• Switched Based Scheduling (SBS) (Nam et al 2009)  
• Per user Threshold scheduling (Nam and Alouini 2010)  
• Distributed scheduling algorithm with adaptive feedback (Zhao et al 2009) |
1.3 MOTIVATION AND OBJECTIVES OF THE WORK

MIMO systems have become popular due to the development of 3rd and 4th generation communication technologies. Multiple users are approaching a base station for limited resources, which is a common real-time issue. The resource allocation to all users without compromising in QoS with the stringent amount of resources needs smart schedulers. This introduced many challenges in multiuser MIMO systems such as diversity gain improvement, fairness, low computational complexity and resource utilization.

In recent works on threshold-based scheduling, a single user parameter is used to calculate the threshold. The existing schedulers address the QoS issues of MU-MIMO systems using the fixed threshold and this threshold is calculated for achieving required results. This technique introduces more computational complexity. Optimization on threshold is not well stated to improve the system performance without compromising computational complexity. Fairness has to be considered while allocating resources, especially for mobile users. To improve fairness, a threshold-based scheduling was proposed but at the prize of resource utilization. Consideration of multiple user parameters for scheduling was not addressed in that threshold-based scheduling. Performance of this type of threshold-based scheduling with coordinated base station was also not well studied.

Although significant research work has been carried out on the various schedulers in MIMO system, no scheduler considers the issues of performance improvement, resource utilization, fairness and complexity simultaneously. Hence in the present investigation a few low complexity scheduling techniques for improving performance and effective resource utilization with fairness have been proposed.
The specific objectives of the present work are stated as follows:

- To construct a low computational complexity threshold-based scheduler to improve the link quality of diversity systems.

- To design an Optimized Threshold Based Fair Scheduling (OTFS) scheme that schedules the multi-user based on threshold optimization for link level improvement in multi-user MIMO systems.

- To design an Efficient Scheduler (ES) that combines multiple schedulers in an adaptive manner to improve the resource utilization.

- To design a new Multi-Threshold-based Channel-Aware Scheduler (MTCAS) to improve the resource utilization under resource constrain environment.

- To design and construct a Multi-Parameter-based Scheduler (MPS) which considers multiple parameters of user under multi-threshold region to improve the BER performance and resource utilization without compromising user fairness.

- To design a Network Centric Multi-Parameter Scheduling (NC-MPS) for helpful resource utilization without compromising the BER performance in multi-user MIMO systems.
1.4 ORGANIZATION OF THE THESIS

The thesis is organized as follows

Chapter 1 gives a brief introduction to diversity system and a literature survey of different scheduling algorithms presented in 2G and 3G wireless systems. It also presents the motivation, objectives and the organization of the thesis.

Chapter 2 deals with a review of multiple input multiple output system and describes antenna diversity in MIMO system, space time coded MIMO system and scheduling algorithms for multiuser MIMO.

Chapter 3 discusses the concept of optimized threshold-based fair scheduler described for multi-user MIMO system and the need for such a scheduler. It also presents a comparison OTFS with conventional threshold-based scheduler and priority scheduler. Further, the proposed Efficient Scheduler (ES) scheme, which combines the quality of priority scheduler and optimized threshold-based fair scheduler is described in this chapter.

Chapter 4 introduces a novel scheduling approach called Multi-Threshold-based Channel-Aware Scheduler (MTCAS) which uses a multi-threshold region for scheduling the active user. It compares the performance of MTCAS with conventional scheduler under various resource conditions.

A new Multi-Parameter based Scheduler (MPS) for downlink MIMO system is presented in chapter 5. This scheduler is aimed at combining max-min scheduler, priority scheduler and threshold-based scheduler performance. This chapter also compares the Bit Error Rate (BER) performance of MPS with conventional threshold-based scheduling.
Chapter 6 discusses the concept of network centric environment where one base station resource is utilized for other base station through access controller. It also compares the performance of network centric system with non-network centric system with MPS.

Chapter 7 sums up the results obtained from the simulations and suggests the course of research for future work in scheduling.