CHAPTER 1

INTRODUCTION

Communication networks can be called upon to support an extremely wide range of services. These networks are routinely used to talk to people, to send an e-mail, to transfer files, and to retrieve information. Increasingly, the internet is being used to provide broadcast services along the lines of traditional radio and television. It is clear that the network must be designed so that it has the flexibility to provide support for current services and accommodate future services. To achieve this flexibility, an overall network architecture or plan is necessary. As a result, communication functions are grouped into related and manageable set called layers.

1.1 NECESSITY OF LAYERED ARCHITECTURE

From the literature of Hubert Zimmermann (1980), the Open Systems Interconnection (OSI) model is a widely known, well accepted framework for communication systems. The OSI model is composed of seven ordered layers viz., Physical, Data link, Network, Transport, Session, Presentation, and Application layers. Each layer is responsible for a subset of the system's operational functions. Messages are interchanged between entities of the same layer in both the transmitter and receiver. Each layer is aware of its own messages and embeds its information into upper layer messages when they go down in the layer stack, while it discards the lower layers' information when messages go up. This model has proved to be quite useful for developing smart algorithms and techniques for different communication systems, achieving proper working mechanisms. The advantage of such layered architectures is that the designer or implementer of the protocol or algorithm at a particular layer can focus on the design of that layer, without being required to consider all the parameters and algorithms of the rest of the stack.

1.2 LIMITATIONS OF LAYERED ARCHITECTURE

Wireless networks initially inherited the traditional OSI-layer-based architecture from wired networks. However, in current layered network implementations, each layer often optimizes its strategies and parameters individually. This generally results in suboptimal performance for the users / applications. An important aspect of wireless networks is their dynamic behavior. The conventional protocol stack is inflexible as various protocol layers communicate in a predefined manner. In such a case, the layers are designed to operate under the worst conditions as opposed to adapting to changing conditions. This leads to inefficient use of spectrum and energy. Adaptation represents the ability of network protocols and applications to observe and respond to channel conditions.

The existing wireless network design is not enough to satisfy various demands like handling a lot of integrated data, voice, audio, video and other media files. These different tasks have different characteristics and need different levels of Quality of Service (QoS). Real time multimedia transmissions such as audio and video require low delay but allow certain errors, whereas non-real time multimedia transmissions such as web access and file download require high reliability but allow certain delay.

Although a variety of different layer schemes have been designed for wireless systems in order to efficiently manage the scarce radio resources and provide certain QoS requirements to mobile users, the performance of such systems can be optimized by considering vertical coupling between layers. Among all the possible combinations of layers involved in this interlayer interaction, the inherent variability of the physical layer in wireless systems makes this the most suitable layer for participating in such kinds of mechanisms. Indeed, the system components such as Medium Access Control (MAC) protocols, radio link control mechanisms, radio resource management schemes, and routing algorithms can benefit from some degree of awareness of the time and frequency varying characteristics of the radio channel. The knowledge of certain information about the physical layer state allows higher protocol layers to adapt their behavior in order to improve network performance. Apparently, system performance improvements could arise from communications between different layers, considering certain smart interactions between them in the system design. This general concept is defined by Shakkottai et al (2003) and Carniero et al (2004) as Cross-Layer optimization. This cross-layer design is not to abandon the original layered method, but to regard the entire wireless network as a whole to carry out designing or maintaining layered structure and consider interactions of different protocols in different layers in order to co ordinate characteristic parameters which scatter in network layers. Such a network layer can put channel parameters in physical layer as a basis for routing which can optimize the routing algorithm.

1.3 CROSS-LAYER APPROACHES FOR WIRELESS NETWORKS

There are several reasons why cross-layer approaches are particularly well suited for wireless data networks.

(i) A wireless channel is inherently a shared medium. Efficient resource sharing mechanisms in this setting depend strongly on both the stochastic nature of user activity as well as the selection of physical-layer coding and modulation schemes, as in Gallager (1985) and Teletar and Gallager (1995).

(ii) In wireless networks where channel quality can vary dramatically in both time and frequency, knowledge of the channel state can be exploited by the system to significantly improve performance, as studied in Goldsmith and Chua (1997). In a multiuser setting, Knopp and Humblet (1995) expressed that the channel quality varies across the user population, which results in the phenomenon of Multiuser Diversity, whereby as the number of users in a system increases, the probability that some user has a very good channel also increases. This must be balanced with network layer issues such as fairness and delay.

(iii) The efficient use of energy in mobile devices is of paramount concern in wireless networks. Particularly, reducing the transmission energy used at the physical layer may result in higher error rates or lower transmission rates, which again affects the network layer performance.

All of the above inter-related effects demonstrate the need to consider network layer quality of service issues such as throughput and delay jointly with physical-layer issues such as channel fading, coding and modulation.

1.4 GENERIC CLASSIFICATION OF CROSS-LAYER POTENTIAL INFORMATION

In general, cross-layer designs and their achievable benefits are not free. Wang and Abu-rgheff (2003) mentioned that some extra cost in the system may present at least in terms of additional signaling needed to extract relevant parameters from one layer that could be useful to other layers and also in terms of the control plane information that should be exchanged and the corresponding required transmission resources occupied and the increase in computation complexity of all the protocols involved as well. In this sense, the identification and selection of relevant cross-layer parameters to be exchanged among layers will depend on the functionalities being considered for cross-layer interaction and possibly on specific end-user application constraints and objectives. However, a generic classification can be established for cross-layer potential useful information to be exchanged between layers, as referred in Verikoukis et al (2005):

1. Channel state information (CSI), including channel impulse response estimation, both in time and frequency domains, location information, terminal speed, signal strength, interference level and interference modeling.

2. QoS-related parameters, including delay, throughput, Bit Error Rate (BER), and Packet Error Rate (PER) measurements for each layer involved in cross-layer interaction, especially concerning the end-to-end requirements.

3. Resources made available in the corresponding node, such as multi-user reception capabilities, number and type of antennas, and battery depletion level.

4. Traffic pattern offered by each layer to the others, including data traffic information, knowledge of the data rate (constant or variable), data burstiness, data fragmentation, packet sizes, and information about queue sizes.

Berry and Edmund (2004) focused on characterizing fundamental performance limits, taking into account both network layer QoS related parameters viz. throughput and delay and physical layer performance. It is highlighted that significant performance gains can be achieved by various cross-layer approaches, i.e., approaches that jointly consider physical layer and higher networking layer issues in an integrated framework.

Most of the available works by Liu et al (2004), Wei et al (2005), Shan (2005) and Vander Schaar et al (2003) focus on a jointly PHY and MAC layers adaptation. They show that PHY and MAC layers are very important especially in wireless networks and must be taken into account during cross-layer adaptation and optimization. Moreover, the APP layer has been used in several cross-layer adaptation schemes. While the above mentioned layers (PHY, MAC and APP) have been extensively researched in cross-layer adaptation schemes, there has been little work done in the whole protocol stack. The transport / session layer can play important role in cross-layer adaptation for wireless networks and a number of adopting mechanisms in this layer have been extensively evaluated in wired networks, revealing adaptation opportunities in wireless networks. Although the network layer cannot be used directly for cross-layer adaptation, it can be used indirectly for cross-layer adaptation through QoS schemes implemented at the network layer.

Each layer offers a number of different parameters through which adaptation can be achieved. The optimization of each layer parameters includes the selection of the applicable parameters which could lead to better results. Particularly, the adaptation of a parameter in one layer, may and most likely, will influence the parameters in other layers. Therefore, the adaptation of the parameters in each layer should be done by taking into account the above mentioned assumption. Thus, any approach for optimal selection of the adaptation parameters should consider the following two actions:

- Optimization of the parameters that only affect the layer in which they appear.
- Optimization of the parameters that affect two or more layers.

The following Table 1.1 shows the various parameters that can be involved in cross-layer adaptation.

Table 1.1 Parameters for Cross-Layer Adaptation in Wireless Networks

Layer	**Parameters**
PHY	Signal modulation
MAC	ARQ, FEC, QoS
Network	QoS (Diffserv, IntServ), IPv6
Transport / session	Adaptive Transmission Rates

1.5 LINK ADAPTATION

Wireless networks, as illustrated in Figure 1.1, will be driven by a variety of ubiquitous broadband services such as portable telephony, mobile Internet, Voice over IP (VoIP) and Internet Protocol TeleVision (IPTV) that would require different QoS. Hence, a key design issue is satisfaction of QoS requirements for different service classes. For example, if an operator supports video, voice, and streaming, three different service classes can be defined by the operator containing different sets of QoS parameters such as throughput and delay.

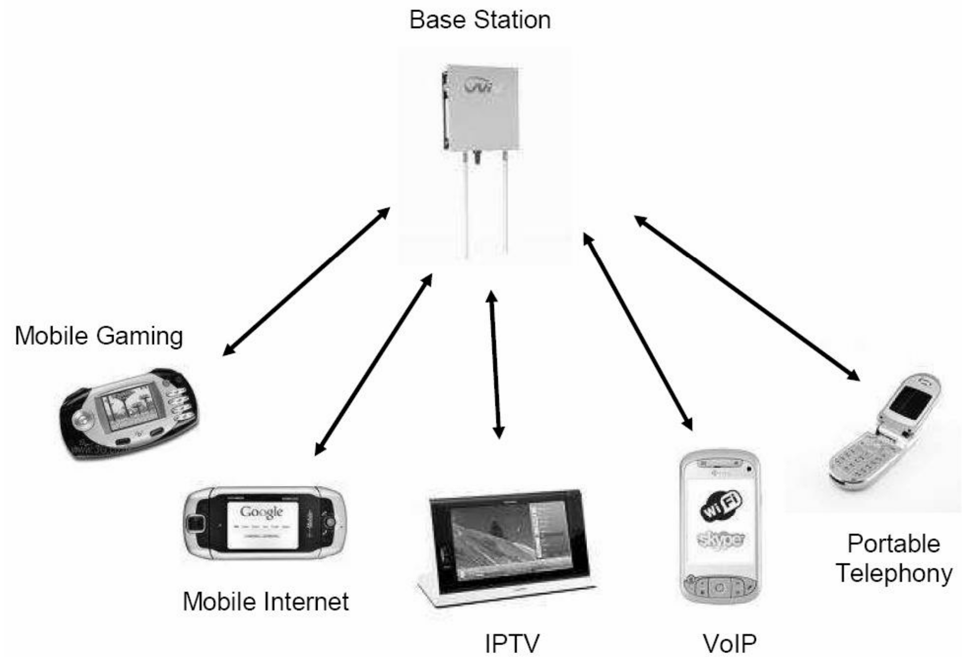

Figure 1.1 Wireless Networks with a Variety of Ubiquitous Broadband Services (*After Kibeom, 2008*)

A recent breakthrough in wireless communications is the application of link adaptation to reduce the performance loss from channel fading. Channel fading is inevitable in a wireless environment and is caused by signal scattering of a number of objects in the channel (Goldsmith 2005). Traditionally, fading is considered as a detrimental effect and the design focus was on circumventing this effect through the use of diversity techniques. It is understood that if CSI like channel gain is available at transmitter, fading can be exploited by adapting the transmit power and data-rate allocation according to the channel conditions (Goldsmith and Varaiya 1997). The receiver's CSI can be delivered to the transmitter via a reliable feedback link, or if Time Division Duplex (TDD) mode is utilized, channel reciprocity can be assumed and the transmitter can equate downlink CSI with the estimated uplink CSI. It is proved by Goldsmith and Chua (1997a) that opportunistically using the channel fluctuations, can significantly increase the achievable throughput.

The link-adaptation technique employed by Starr et al (1999) was first utilized in a stationary channel for Digital Subscriber Line (DSL) systems, where it is called loading. Link adaptation can be extended to wireless systems by carefully considering more rapid channel variations. The multi-user scheduling issues in wireless systems have become more interesting with the link-adaptation technique, which provides better capability to meet a variety of QoS requirements.

Realization of link adaptation for multi-user communication systems requires optimal allocation of communication resources, such as the transmit power and data rate. Much research work focused on this information-theoretic approach to resource allocation. However, since these approaches ignore the randomness in packet arrivals and queuing, they have difficulty in guaranteeing each user's throughput or delay requirement. Therefore, satisfaction of each user's QoS requirement needs to consider Queue State Information (QSI), like the current queue backlog size, in addition to CSI when the scheduler selects each user's operating data rate. In each transmit dimension, service rates are determined by a scheduler in the MAC and the corresponding power and rate allocation are determined by the PHY. Because of this interplay between MAC and PHY, such a combination of queue-channel-aware scheduling and power / rate allocation is known as cross-layer resource allocation. This cross-layer approach to resource allocation to account for queuing parameters has been studied in Andrews et al (2001), Viswanathan and Kumaran (2001), Neely et al (2003), Swannack (2004) and the references therein.

Conventionally, wireless voice networks have been designed to deliver a fixed bit rate stream that can be decoded correctly by all the users in the network (disregarding their position in the cell). As a result, the worst case (cell edge users) is usually considered to fix the maximum throughput. Thus, the channel capacity of other users close to the base station is much underestimated. However, wireless data networks where the channel access is done periodically (given by the packet rate) use the channel state in order to obtain the maximum attainable throughput given a certain Bit or Packet Error Rate (BER or PER).

In a typical adaptive modulation procedure, dynamic variations in the modulation order (constellation size) and Forward Error Correction (FEC) code rate are undertaken. In practice, the receiver feeds back information about the channel state, which is then used to control the adaptation procedure. The Adaptive Modulation and Coding (AMC) can be used in both up- and downlink modes. On the other hand, the power can also be adapted on ‘per a user’ basis according to the channel gain experienced by each user. Different open-loop and closed-loop power control algorithms have been proposed for most of the wireless and mobile communications systems, mainly concentrating to compensate the channel attenuation by transmitting more power on those faded bands. A number of fast closed-loop power control algorithms have been proposed for the Universal Mobile Telephone Systems (UMTS) and Worldwide Interoperability for Microwave Access (WiMAX) systems where the power is adapted on ‘per frame basis’ (e.g. 0.5-5ms). As a result, the channel fluctuations can be practically removed using accurate power control procedures as mentioned in 3GPP TS V.3.12.0 (2002). Nevertheless, recent researches on power adaptation have demonstrated that the channel capacity can be increased if the power is assigned to those parts of the spectrum where the channel is more beneficial. In that case, more bits can be loaded per sub channel achieving higher spectral efficiencies.

1.6 NETWORK CAPACITY REGION

Neely et al (2003) define network capacity region as a set of all packet arrival rate vectors for which it is possible to keep every queue length finite. For bursty input traffic, it is generally difficult to estimate the packet-arrival rates. Thus, resource allocation solely based on CSI is unable to update rate allocation properly according to the dynamics of the input traffic. As a result, even for a packet arrival rate vector within the network capacity region, some users' queue backlogs may become unacceptably large, causing long queuing delay as well as buffer overflow. Certain schedulers assume infinite queue backlog and simply consider CSI only. On the other hand in the packet switching systems, the channel can be described by the circuit connection, so the concept of CSI is irrelevant. The above two schedulers are called `channel-aware scheduler' and `queue-aware-scheduler' respectively, to distinguish them from the queue-channel-aware scheduler. The network capacity region may not be achievable with channel-aware scheduler that ignores queuing dynamics. In addition, each user's queuing delay, which is an important QoS parameter, is uncontrollable without considering queue sizes in scheduling. Therefore, it is essential to design an intelligent scheduler that considers both CSI and QSI. It has been shown by Tassiulas and Ephremides (1992), Neely et al (2003) and Yeh and Cohen (2003), that the entire network capacity region can be achieved by using this approach in the fading broadcast channel and medium access channel.

1.7 ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

With increasing demand for high data-rate services, Orthogonal Frequency Division Multiplexing (OFDM) has drawn much attention as a promising technique. OFDM has been widely applied to a variety of telecommunication systems such as WLAN, Digital Video Broadcasting

(DVB), and to DSL systems in Discrete Multi-Tone (DMT) form. It converts a frequency selective fading channel into parallel frequency flat fading sub channels. It is proved that OFDM achieves high spectral efficiency as well as lower equalization complexity for channels with large delay spread (Cioffi 2005). With perfect CSI at both base station and mobile terminals, as the number of tones goes to infinity, OFDM with link adaptation is shown to achieve the capacity of Gaussian Broadcast Channel (BC) and MAC with Inter Symbol Interference (ISI), or with frequency selective fading. OFDM inherently provides a variety of advantages such as Fast Fourier Transform (FFT) realization, simple channel equalization, no ISI, and high degree of design flexibility. Due to its application to multi-user systems, multi-user OFDM, also called as Orthogonal Frequency Division Multiple Access (OFDMA), has been considered as a strong candidate for the platform of the future wireless systems. In multi-user OFDM systems, multiple users are allowed to transmit simultaneously from the intelligent tone assignment to each user, which has triggered much work on the power / rate allocation issues in this system.

1.8 CROSS-LAYER RESOURCE ALLOCATION AND SCHEDULING

Usually, when two nodes of a network intend to exchange information following the Open System Interconnection (OSI) reference model, there is a flow of information through seven layers each of which is in charge of a specific function of the communication process. At the bottom of the protocol stack is where the interchange of information through a physical medium is carried out by the physical layer. The PHY layer then decides, according to the current channel state, about the optimum transmission power, as well as the modulation and coding scheme to assign. The medium access control layer provides the addressing and the multiple channel access mechanisms that allow several terminals to share the radio communication medium.

However, it has been established in Georgiadis et al (2006) that more efficient transmission can be achieved if the information about the time varying channel condition is provided to the MAC layer. Also it is proved if the channel is in outage, the transmission can be postponed. Further, in Broadband Wireless Access (BWA) where the channel may be highly frequency selective (some parts of the spectrum present much better conditions than others), the MAC layer can decide in which frequencies the transmission should be established. Nevertheless, in a multiuser scenario where several users attempt to access over the channel communication in the uplink mode, or whether the base station must transmit data to the active users, the shared resources (power and time / frequency transmission intervals) must be assigned following a certain strategy to optimize the radio resources. In order to maximize the channel capacity, as well as the QoS required by the users' services, several cross-layer designs have been proposed by Shakkottai et al (2003), Song and Li (2005), Song (2005a) and Georgiadis et al (2006). In these cross-layer designs or approaches, a number of physical layer and access layer parameters are jointly considered. Apart from the increase of complexity introduced by the implemented cross-layer strategies, the main benefits are higher spectral efficiencies, higher system load and a higher control in reaching the QoS requirements. However, the main drawback of the previously mentioned research works is that they did not consider realistic conditions where the users' requirements may also change within short periods of time, and the required signaling in both downlink and uplink derived from the cross-layer based implementations. Hence, despite of its proved theoretical benefits, it is still difficult now-a-days to get commercial equipments that include inter / multiple layer interactions.

In a single user OFDM / OFDMA based wireless network, where the frequency and the time resources are efficiently divided into subcarriers and time symbols respectively, the use of power and modulation and coding scheme adaptation over each subcarrier, and / or the dynamic subcarrier assignment can significantly improve the performance. On the other hand, in multiuser systems where users' channel characteristics are almost mutually independent, the communication system can also take benefits from the multiuser diversity by assigning dynamically the different subcarriers and hence each user is allocated with those subcarriers, where higher spectral efficiencies can be achieved.

The dynamic cross-layer resource allocation may be performed based on several criteria such as the channel capacity maximization, the maximum fairness, the minimum delay, etc. The resource allocation problem usually turns into a Non-Polynomial hard combinatorial problem. Therefore, finding the optimal solution in a real time implementation is almost unfeasible.

Several mathematical tools have been proposed, for e.g. utility theory by Kibeom et al (2006), convex programming by Haipeng et al (2007), genetic algorithm by Yu and Zhou (2007) and neural network by Garcia et al (2008) for resource allocation. However, these proposals still imply high computational requirements, and as a result less complex heuristic algorithms are usually applied in order to solve the multiuser resource allocation problem in real-time applications.

OFDM divides an entire channel into many orthogonal narrowband sub channels (subcarriers) to deal with frequency-selective fading and to support a high data rate. Furthermore, in an OFDM-based wireless network, different subcarriers can be allocated to different users to provide a flexible multiuser access scheme as proposed in Chuang and Sollenberger (2000) and

McKeown et al (1999), exploiting multiuser diversity. Since channel frequency responses are different at different frequencies and for different users, data rate adaptation over each subcarrier, Dynamic Subcarrier Assignment (DSA), and Adaptive Power Allocation (APA) can significantly improve the performance of OFDM networks. Using data rate adaptation as employed by Goldsmith and Chua (1997) and Nanda et al (2000), the transmitter can send data at higher rates over the subcarriers with better channel conditions so as to improve throughput and simultaneously to ensure an acceptable Bit Error Rate (BER) at each subcarrier. Despite the use of data rate adaptation, deep fading on some subcarriers still leads to low channel capacity. On the other hand, channel characteristics for different users are almost mutually independent in multiuser environments. The subcarriers experiencing deep fading for one user may not be in a deep fade for other users. Therefore, each subcarrier could be in a good channel condition for some users in a multiuser OFDM wireless network. By dynamically assigning subcarriers, the network can benefit from multiuser diversity.

Resource allocation issues and the achievable regions for multiple access and broadcast channels have been investigated in Tse and Hanly (1998) and Li and Goldsmith (2001), respectively, which have proved that the largest data rate region is achieved when the same frequency range is shared with overlap by multiple users in broadcast channels. However, when optimal power allocation is used as in Goldsmith and Effros (2001), there is only a small range of frequencies with overlapping power sharing. Thus, optimal power allocation with dynamic subcarrier (non-overlap) assignment can achieve a data transmission rate close to the channel capacity boundary. Tse (1997) investigated optimal resource allocation in multiuser OFDM systems to minimize the total transmission power while satisfying a minimum data rate for each user. The numerical optimization algorithms have been proposed in Yu and Cioffi (2002) for characterizing the uplink rate region achievable in

OFDM with inter-symbol interference. Several algorithms have been presented in Kivonc et al (2003) and Rhee Cioffi (2000) for subcarrier and power allocation.

1.9 MOTIVATION

With the increasing demands on multimedia services from applications such as video streaming and IPTV, a variety of ubiquitous real-time and non-real-time broadband services need to be simultaneously supported in the future wireless networks, where each service demands a different QoS. Non-real-time best effort traffic such as web-browsing and FTP service targets maximization of throughput while tolerating some degree of packet delay. On the other hand, real-time traffic such as portable telephony has a more strict delay constraint with much lower data rate. In order to satisfy these diversified QoS demands, design of intelligent multi-user packet schedulers becomes a key issue in wireless systems. In particular, schedulers must carefully use both CSI and QSI to achieve better throughput, delay, and fairness properties.

TDMA has been widely applied in wireless systems where only one user transmits at each time slot. However, many promising wireless systems under development such as mobile WiMAX and 3GPP LTE (The 3rd Generation Partnership Project Long Term Evolution) adopt OFDMA (Orthogonal Frequency Division Multiple Access). In these applications OFDM modulation allows simultaneous transmission by multiple users where each tone can be occupied by only one user.

The allocation and management of resources are crucial for wireless networks, in which the scarce wireless spectral resources are shared by multiple users. In the OSI layered networking architecture, each layer is designed and operated independently to support transparency between layers.

Among these layers, the physical layer is in charge of raw-bit transmission, and the medium access control (MAC) layer controls multiuser access to the shared resources. However, wireless channels suffer from time-varying multipath fading and the statistical channel characteristics of different users are different. The sub optimality and inflexibility of this architecture result in inefficient resource use in wireless networks and hence an integrated adaptive design across different layers is required. Therefore, cross-layered design and optimization across the physical and MAC layers are desired for wireless resource allocation and packet scheduling.

For cross-layer optimization, channel-aware scheduling strategies are proposed to adaptively transmit data and dynamically assign wireless resources based on CSI. The key idea of channel-aware scheduling is to choose a user with good channel conditions to transmit packets. Taking advantage of the independent channel variation across users, channel-aware scheduling can substantially improve the network performance through multiuser diversity in which network gain increases with the number of users.

To guarantee fairness for resource allocation and exploit multiuser diversity, utility-pricing structures in network economics are usually preferred for scheduling design. The growth of Internet data and multimedia applications requires high-speed transmission and efficient resource allocation. To avoid inter-symbol interference, orthogonal frequency division multiplexing (OFDM) is desirable for wireless high-speed communications. OFDM-based systems are traditionally used for combating frequency-selective fading. From a resource allocation point of view, however, multiple channels in an OFDM system naturally have the potential for more efficient MAC since subcarriers can be assigned to different users. Another advantage of OFDM is that adaptive power allocation can be applied for a further performance improvement.

The basic problem that we need to solve in this thesis is how to effectively allocate resources on single carrier and multicarrier (OFDM) networks by exploiting knowledge of CSI and the characteristics of traffic to enhance the spectral efficiency and guarantee quality of service (QoS).

The objective of this thesis is to establish a theoretical framework and to develop efficient algorithms to support diverse QoS and statistical QoS with bounded delay requirements in single carrier networks and algorithms for resource allocation in wireless multicarrier networks based on cross-layer optimization. This research focuses on studies related to the mechanisms of efficiency, fairness, QoS provisioning and algorithm development for resource allocation in multiuser frequency-selective fading environments.

1.10 OVERVIEW OF THESIS

This thesis is organized as follows. In chapter 2, an adaptive cross-layer priority scheduling algorithm that achieves good user throughput while satisfying the varying delay requirements of any wireless systems is developed. When the system traffic is low, its throughput increases and hence the channel bit rate also increases which in turn reduces overall delays. With the increase in traffic loading, the traffic requirements of delay-sensitive users are satisfied, while the only price to be paid is an increased average delay for those delay-insensitive users. A cost function is defined to include the current channel qualities and delay states of the packets in the queue that negotiates between minimizing delay and maximizing throughput. Thus, improving system throughput / channel bit rates can have a positive effect on average normalized packet delay and the total number of missed packet deadlines.

In chapter 3, an effective capacity based cross-layer scheduling algorithm is proposed and statistical QoS guarantees are analyzed over wireless networks. The critical relationship between effective bandwidth and effective capacity is identified and the effective capacity function is obtained analytically in the proposed system configuration. The proposed scheme allocates time slots adaptively for real-time users to guarantee statistical delay-bound QoS requirements. The admission control and time slot allocation algorithms are developed by extending the effective capacity method of scheduling.

In chapter 4, a cross-layer design problem is formulated as an optimization problem with consideration to the imperfect Channel State Information at the Transmitter (CSIT), source statistics and queue dynamics of the OFDM systems. An analytical framework is proposed for the design of optimal subcarrier assigning cross-layer scheduler for delay-sensitive users with heterogeneous delay requirements in the presence of obsolete CSIT in multiuser OFDM systems. The optimal rate and subcarrier allocation solutions are obtained based on the optimization framework. It is shown that there is a good balance of maximizing throughput and providing delay differentiation of heterogeneous users with robust performance even at moderate to large CSIT error in the proposed work.

In chapter 5, a set of joint channel-aware and queue-aware multicarrier scheduling algorithms are investigated for OFDM networks from several important aspects. Based on different users’ channel conditions as well as their queue states, a cross-layer scheduling algorithm called QoS Proportional Fair (QPF) is proposed for the multimedia services in a multiuser OFDM system. The objective in the design of QPF is to achieve PF in the system while improving the different user’s packet level QoS performances with a relatively low computational complexity to allocate subcarriers to different users. Based on the analysis of the packet level QoS performance, a subcarrier reassignment procedure has been proposed to improve the QoS performance. Secondly, an Adaptive Cross-layer Packet (ACP) scheduling algorithm is proposed for the downlink multiuser multitasking OFDM systems with heterogeneous traffic. The proposed scheduling scheme provides significant performance advantages over the queue based M-LWDF (Andrews et al 2001), EXP and MDU (Song 2005a) and PD (Nan Zhou et al 2010) scheduling schemes in terms of the system throughput and QoS traffic delays with a wide range of number of users and a moderate to high SNR range.

Chapter 6 provides the concluding remarks of the works carried out and also the suggestions for future research in this area.