CHAPTER 6

CONCLUSION AND SCOPE FOR FUTURE WORK

Due to the great success of wireless multimedia applications and wireless mobile communications, there has been a dramatic demand for wireless data access. Within a layered architecture, it is possible to yield significant gains if the system optimizes the performance by making use of the interaction across different protocol layers. Thus, in this thesis, focus is made on employing cross-layer techniques for scheduling and resource allocation in wireless networks. The main objective is to improve the system performance by incorporating the information from the physical layer and MAC layer into the design of resource management. The conclusions arrived from the research work carried out and the future scope of the work are discussed in this chapter.

6.1 CONTRIBUTIONS OF THE RESEARCH

The study of cross-layer and resource allocation performed on wireless networks brought out the following results and conclusions:

(i) In order to guarantee QoS satisfaction, an Adaptive Cross-layer Packet Scheduling (ACPS) algorithm is proposed for wireless networks under IEEE 802.11b standard. This algorithm adapts to changes in variables like packet delay on the link layer and channel bit rates on the physical layer across two system. This accurately characterizes the influence of physical layer infrastructure on diverse QoS performance at the higher protocol layers.

The cost function employed in the ACPS algorithm is a weighted estimate of the average normalized packet delay of packets in the queue. This algorithm attempts to minimize the average packet delay at every chance of scheduling. Also by allowing high bit rate packets with more urgency through the channel for transmission at good SNR conditions, this algorithm is achieving more throughput than the conventional WFQ algorithm. By comparing ACPS algorithm with WFQ algorithm, it is shown that ACPS outperforms WFQ when 64 bytes sized packets are used with any priority class file. When the packet size is 128 bytes, the average throughput performance improvement in ACPS algorithm is very minimal. For 192 bytes packet sizes, WFQ algorithm is showing better average user throughput performance than that of ACPS algorithm. It is because of the larger delay experienced, completion of maximum admissible lifetime in the network and more loss of packets in ACPS algorithm.

Similarly, when the performance of ACPS and WFQ algorithms are compared, our proposed ACPS algorithm always shows better delay performance independent of packet size as well as priority classes. For example, simulation results show that the average packet delay time taken by P3 class files with 64 bytes packets using ACPS algorithm (950 μs) is nearly 21 times lower than that of the average packet delay time taken by 64 bytes packets using WFQ algorithm, (20 ms). Similarly delay of P1 file with 64 bytes packets is 21μs, which is nearly 950 times lower than that of the delay experienced by WFQ algorithm, i.e., 20 ms. Thus the outperformance of the proposed ACPS algorithm for all three priority classes than WFQ algorithm is verified.

(ii) The effective capacity based cross-layer scheduling algorithm is developed to support the real-time multimedia QoS by allocating channel resources adaptively for downlink heterogeneous mobile wireless networks under IEEE 802.16 standard. According to the channel fading statistics, the diverse QoS requirements and traffic characteristics, the time slots are allocated as system resource to the users. Analytically an admission control and time slot allocation conditions are derived to guarantee the statistical delay-bound for real-time users. The problem of physical layer impact on the statistical QoS provisioning performance and the influence of adaptive channel state information feedback delay on the proposed algorithm are studied. From the numerical results, it is understood that the effective capacity based cross-layer scheduling algorithm is providing significant (for e.g., 6 audio time slots and 5 video time slots) reduction in the number of time slots for the same type of services over conventional constant power approach. As the SNR increases, generally the number of time slots taken or assigned for transmission decreases and vice versa. Thus the proposed effective capacity based scheduling algorithm reveals improved significance in terms of minimum number of time slots allocated to the audio and video services over conventional constant power approach. It is also observed that the conventional constant power control scheme achieves the similar QoS violation performance by using much more resources (i.e., time slots) than proposed QoS-driven power control approach.

(iii) Efficient algorithms for resource allocation in wireless multicarrier networks are presented based on cross-layer optimization. With the adaptive subcarrier and power allocation considering cross-layer system dynamics, the cross-layer scheduling has been shown to be very effective to boost the spectral efficiency of OFDM systems through multi-user diversity while guaranteeing the heterogeneous delay requirements of users based on the assumption that CSIT is perfect. It was shown that the cross-layer scheduler designed with perfect CSIT assumption is very sensitive to CSIT errors. In order to properly address this important problem, a jointly optimal delay-sensitive subcarrier and rate allocation policy is studied under obsolete

CSIT to maximize the total successfully deliverable data rate from the system in terms of throughput while satisfying the heterogeneous user delay requirements. The proposed optimization framework involves both information theory (to model the multi-user OFDM physical layer) as well as queuing theory (to model the delay dynamics). By transforming the average delay constraints into the average rate constraints, the delay-sensitive cross-layer scheduling problem is formulated into a mixed convex and combinatorial optimization problem. Further, it is shown to have robust system performance as well as guaranteeing delay constraints.

The proposed optimal subcarrier assigning scheduling provides substantial throughput enhancement over opportunistic and fixed assignment scheduling in the presence of CSIT error $(\sigma_{\Delta h}^{2} = 0.05)$. It is observed that at low scheduled data rate traffic i.e., at moderate and high SNR regime (above 7 dB), the number of users waiting for transmission is less and the system throughput is higher when delay requirement of the users are more stringent. This is because in high SNR regime, the power levels are the same for all users and thus the optimal subcarrier allocation reduces to the conventional delay-insensitive scheduling policy. In low SNR regime (below 7 dB), when the scheduled data rate traffic is above 6 Mbps (heavy loading), the throughput performance is degrading because of the increment in the number of users waiting for transmission regardless of the value of the imposed delay constraint. This is because more urgent users with heavy traffic loading (higher arrival rate) will have higher transmission power and thus have higher chances of seizing subcarriers for transmission. It is also observed that the minimum required power to support all delay constraints of the user would increase as the delay requirements become more stringent.

In fixed assignment scheduling algorithm, each subcarrier is always assigned to a fixed user and the power is evenly distributed among subcarriers. So the delay performance is constant for all arrivals rates. In opportunistic assigning scheduler, each subcarrier is assigned to the user holding the best channel gain. As arrival rate of background user increases, the channel gain degrades significantly. Therefore, the delay performance of all users under opportunistic scheduling degrades significantly. It is also noted that by using the proposed optimal subcarrier assigning scheduler, with the increase in traffic loading (number of packets per time slot), 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.

Also it is shown that the delay performance of the proposed optimal subcarrier assigning cross-layer scheduler is very robust even at moderate to high CSIT errors, whereas the delay performance of fixed assigning strategy and opportunistic based schedulers is very sensitive even at low CSIT error variance. This robustness to CSIT errors introduced by the proposed scheduler is significant for practical implementation on OFDMA-TDD system in which obsoleteness of CSIT is often not negligible.

(iv) The use of rate adaptation and packet scheduling exploits the characteristics of wireless channels such as time variance, frequency selectivity, and statistical independence among different users, to obtain the multiuser diversity. A joint channel- and queue-aware scheduling in OFDM based networks with emphasis on designing joint channel- and queue-aware scheduling algorithms for multicarrier networks is developed. In the proposed QoS Proportional Fair (QPF) scheduling algorithm, several packets from different users can simultaneously be scheduled so as to exploit the multiuser diversity. This algorithm allocates the subcarriers and schedules the packets in the downlink of multiuser OFDM systems to achieve proportional fairness criterion while improving the individual user's packet level QoS performance. In this two step algorithm, a greedy proportional fair method is used to achieve proportional fairness and then a subcarrier reassignment procedure is utilized to improve the packet-level QoS performances according to the queue analysis. When the numbers of users increase, the dropped and delayed packets also increase if there is no QoS control. Because CPF and MCPF algorithms do not consider the QoS, the number of dropped packets and delayed packets are higher than that of QPF and hence there is a decrease in average system throughput of CPF and MCPF algorithms compared to the proposed QPF algorithm. When the traffic density is high, e.g., $K > 20$, the throughput variances significantly increase with the number of users due to the resource competition among users. When the traffic density is low, e.g., $K \leq 20$, the throughput variances among the users for both MCPF and QPF algorithms are similar to each other, because under these conditions, an individual user may obtain enough resources to satisfy its throughput and QoS requirements.

The fairness performance results of MCPF and QPF are observed to be much better due to their capabilities to balance efficiency and fairness for resource scheduling. But for CPF, which is not having such capabilities, the fairness performance is poor. Due to the process of QoS control in QPF algorithm, some transmission chances are switched from the QoS satisfied users to some other unsatisfied users. Hence the packets that would likely be dropped due to the deadlines missed or overflow when using MCPF without QoS consideration are successfully selected for transmission by the QPF. Thus, the radio resource is allocated in a fairer manner among users by using the QPF algorithm. A PDP violation occurs when the calculated average PDP at the end of one scheduling slot for a particular user is not satisfied. It is also observed that the QPF algorithm considerably improves the packet dropping performance than CPF and MCPF, particularly when the traffic density (i.e.) the number of users is high ($K > 20$) due to the consideration of QoS control.

From the simulation results, it is observed that the average packet delay of QPF algorithm is the smallest compared to the MCPF and CPF algorithms because it can control the packet level QoS and schedule the packets according to the CSI as well as QSI. In MCPF algorithm, due to high capacity, the delay can be relaxed to combat the channel fading for OFDM systems. But in CPF algorithm, the delay requirement is related to the maximum time for which a user can be starved during poor channel conditions. When the number of users increases, e.g., K > 25, the packet delay deadline also increases, in turn it creates more number of packet losses. So CPF algorithm takes more delay to complete its transmissions.

(v) For supporting multi-tasking services, the previously developed QPF algorithm is not sufficient to accommodate multiple users with multiple heterogeneous traffic queues simultaneously. An Adaptive Cross-layer Packet (ACP) scheduling is proposed to maximize the weighted sum capacity of the downlink multiuser multi-tasking OFDM systems. The simulation results show that the proposed Cross-layer based scheduling and resource allocation algorithms can provide an efficient and stable mechanism for spectral efficiency / throughput improvement and QoS differentiation. The ACP scheduling algorithm demonstrates significant performance advantages over other scheduling algorithms except MSC since it depends on the instantaneous data rate and schedules the packet only when the channel has high SNR or if less number of users are sharing the channel. The system throughput achieved by ACP increases with the increase in number of users, due to enhanced multiuser diversity. With given resources, when the number of users increases, there is a higher degree of freedom for resource allocation, resulting in enhanced multiuser diversity. With ACP, the packets with larger weights are served first on packet basis whichever queues they belong to, whereas with MDU, M-LWDF and EXP all packets in a queue which has a larger weight are served first on queue basis. Therefore average system throughputs of PD, MDU, M-LWDF and EXP benefit less from multiuser diversity. With a large number of users, the average system throughput achieved by ACP is much higher than that achieved by MDU, M-LWDF and EXP scheduling algorithms. With PD, the packet weights are determined based on the packet size, delay and QoS priority levels. So the performance is better compared with some other algorithms. The ACP achieves a much lower delay than PD, MLWDF, MDU and EXP since it determines the packet transmission order by assigning different weights to different packets, and therefore is more efficient than the conventional queue dependent scheduling.

6.2 SCOPE FOR FUTURE RESEARCH

In addition to the spectral efficiency, the other parameters fairness and QoS are crucial for resource allocation in wireless networks. It is often difficult to achieve the optimality for spectral efficiency, fairness and QoS simultaneously. For instance, scheduling schemes aiming to maximize the total throughput are unfair to those users far away from a base station or with bad channel conditions. On the other hand, the absolute fairness may lead to low bandwidth efficiency. Therefore, an effective trade-off among efficiency, fairness and QoS are desired in wireless resource allocation. It would be of great interest to extend our research towards the development of such trade-off scheduling algorithms.

Also, this thesis mainly considers multiple-access channels where the full coordination at the base-station is feasible. Of great interest is to study cross-layer resource allocation in interference channels or relay channels without full coordination. Interference channels can be encountered in many applications such as multi-cell wireless networks and DSL networks. Also, relay channels can be found in a multi-hop ad hoc wireless network where multiple hops are required for efficient communication between mobile nodes far apart as referred in Goldsmith et al (2002). With no or partial coordination, it becomes more challenging to satisfy each user's different QoS demand and to develop efficient power / rate optimization algorithms.