Abstract

Operations managers in a service system are often faced with the task of balancing the trade-off between the cost of providing good service and the cost of customer or machine waiting time. In service systems delays should be short enough so that customers do not become unhappy, but not so short that the cost of providing such service yields an unprofitable business for the operator. Such service scheduling problems arise naturally in communication systems. In a communication system, customers are replaced with packets to be communicated between a source destination pair, and the underlying communication link acts as a server. The service control objective is to release the packets as fast as possible while satisfying the underlying communication link constraints and/or minimizing the associated service costs.

The $c\mu$ rule is one of the landmark results in service scheduling for wired communication (queueing) networks. The rule defines an algorithm for allocating service of a single server among various classes of customers (packets) while minimizing a weighted sum of queueing delays. Research in the area of wireless communication in the past decade mainly concentrated on designing good power control algorithms to achieve transmission reliability in a time varying environment, and resource reservation algorithms to meet prespecified grades of service. Recently, there has been a lot of interest in service control problems arising in wireless communication networks. In a wireless system, resources such as transmission bandwidth and battery power being limited, the service scheduling problem becomes more interesting than that for a wired communication system. Moreover, the time varying or fading nature of a wireless channel (link) results in a time varying service rate, and hence demands adaptive scheduling of transmissions in order to capture such dynamics of the wireless system.

In this thesis, we design stochastic control algorithms for controlling transmission power and rate in wireless multiaccess networks. We consider a packet communication model where packets generated at several sources need to be communicated to a central station for forwarding to their destinations. The packets generated at the sources get queued at the transmitter buffers which are assumed to be of infinite capacity. Depending upon the source, there are certain quality of service requirements, such as a long run average packet transmission delay, that the communication system must meet. The central theme of this work is to design transmission control (scheduling) algorithms to achieve target quality of service requirements while satisfying battery life and other constraints imposed by the wireless multiaccess system.

The work focuses on algorithms at the medium access control (MAC) level. MAC algorithms define rules for sharing the wireless medium and their performance is studied in terms of performance measures such as throughput, delay, stability, fairness and service differentiation (scheduling, access priorities). Our work recognizes the increasing importance of cross-layer designs by incorporating into the models simple but appropriate abstractions of the physical layer, primarily via information theoretic models. Thus our work will apply to physical layer technologies such as time division multiple access, code division multiple access, multiuser detection, orthogonal frequency division multiplexing and multi-antenna wireless systems. Based on these technologies, we can divide MAC algorithms into two categories: single transmission that allow only one transmission at a time, and parallel transmission. Single transmission algorithms are further subdivided into two subclasses: conflict-free and contention based. In a conflict-free scheme or a polling scheme, a central station ensures that each transmission is successful by specifying which terminal should transmit (e.g. TDMA), whereas in a contention based scheme, transmissions might collide as there is no central controller. In the latter case, some form of distributed conflict resolution is employed, typically random backoff and reattempt (e.g. Aloha). In parallel transmission models, many simultaneous transmissions can be received by the receiver and decoded successfully (e.g. CDMA). These parallel transmission models differ in the way the encoding-decoding is carried out at the receiver. As the quality of service measures, we consider long run transmission delay for streaming applications, packet loss rate for voice telephony (owing to its strict delay requirements) and long run average throughput for applications involving elastic file transfers.

1. For centralised polling based multiaccess scheme, we design algorithms to determine which terminal to poll and how much the terminal should send to achieve the desired quality of service for each admitted terminal. The controller has the information about the channel fading conditions and the queue lengths at each terminal. The transmissions are further constrained by a peak transmitter power constraint.

2. For the random access scheme, we design algorithms to control the duration of the interval between successive transmission attempts in a distributed manner based on the local information such as the fading, queue length and the estimated load at other terminals to achieve the desired quality of service for each admitted terminal. The transmissions are again constrained by a peak power constraint. We obtain throughput optimal policy and show that a class of vacation policies can result in a significant improvement in terms of mean delay.

3. For parallel transmission systems, we design policies to optimally assign power and rate dynamically as a function of the fading and the queue lengths to achieve the desired quality of service. The transmissions are constrained by long-run average or peak transmitter power constraint. We consider successive as well as the independent decoding scheme at the receiver.

We use Markov decision theory to design the said algorithms. The problems as stated above fall into the category of constrained average cost Markov decision problems (MDP). More often than not, analytically solving an MDP for an optimal solution is very difficult, however, interesting structural properties of the optimal policy can be characterized. Also at times, it is not as important to obtain an optimal policy, as to obtain an implementable simpler policy. We obtain structural results for the optimal control policies and define simple but suboptimal policies for the said multiaccess control problems. The main ideas used for obtaining suboptimal policies are based upon the Whittle relaxation for restless bandit problems.