Chapter 1

Introduction

1.1 Motivation

The new paradigm for wireless systems provisionw multimedia services and applications to end users, and therefore the multimedia flavor has been added into the ”anytime, anywhere” concept. In the wireless network, it should be capable of providing wide range of services, wide bandwidth, guaranteeing the specific quality of services, and good flexibility in radio resource management. CDMA technology can achieve higher spectrum efficiency, multipath resistance, frequency diversity, and soft capacity. One of the challenges is to support various services over common air interface and guarantee the required QoS for each type of services [1]. Some services are delay sensitive and of more tolerance to loss; while other services have opposite QoS requirements. Moreover, customized services imply the variant characteristics of the content sources, and cause further performance degradation to the wireless networks. To overcome this challenge, an effective radio resource management mechanism is necessary to attain good system performance and provide all the requirements for the multimedia applications.

The *Radio Resource Management* is quite a critical issue for the system performance of WCDMA cellular systems. In [2], several radio resource management aspects are described, including *Mobility Management*, *Admission Control*, *Radio Bearer Control*, *Dynamic Resource Allocation*, *Power Management*, and *Codec Control*. Among the management aspects, *Admission Control*, *Radio Bearer Control*, *Dynamic Resource Allocation*, and *Power Management* are directly related to the resource allocation for a whole connection in a cell, that is, the initial resource admission and allocation, the resource adaptation to system condition during the connection. By these algorithms, the QoS requirements of a connection can be guaranteed and the system can operate stably without overloading. In [1], the QoS architecture for WCDMA cellular systems is defined in a hierarchical fashion in which QoS requirements of packet level (the radio bearer related requirements) and the QoS requirements of call level (the radio access bearer related requirements across the overall radio access network) are specified. To provide high flexibility in QoS control for customized multimedia applications, several kinds of radio bearers can be configured to convey different types of services with quite different nature. For real time services, dedicated channels are usually assigned with predefined amount of resource to reduce the transmission delay; on the other hand, for the bursty and delay insensitive services, shared channels are assigned in a TD/CDMA fashion. To execute specific radio resource management on different channels is quite a different work with different design factors.

Moreover, due to the different characteristics, radio resource management functions are usually designed in different approaches for uplink and downlink. In the uplink, the transmission control of each active connection is distributed and the system capacity is limited by the overall received interference at the base station side. To ensure the QoS requirements of all connections, the radio resource management function can control the statistics of the received interference process. In [3], the system load is measured in terms the interference, and resource control can be designed according to the system load and the interference generated by each connection. Therefore, call admission control is the most important and effective mechanism to keep the QoS requirements guaranteed in uplink which can admit feasible number of connections. In the downlink, on the other hand, the interference and channel quality are location-dependent and different for connection by connection. Moreover, a centralized and fast radio resource allocation is possible with the fast channel quality information reports. Scheduling algorithm is the most critical RRM functionality that impacts significantly the system performance. The schedulability of the adopted scheduling algorithm can be used as the admission control criteria for the downlink. Therefore, the call admission control for uplink transmission and the scheduling algorithm for downlink transmission are the critical schemes to provide multimedia applications in CDMA systems.

In the wideband CDMA systems, admission control performs two levels of functions. The first one is to check whether the QoS of all existing calls are still guaranteed as the new call request is accepted. It is not enough to merely fulfill the requirement of the new call because there might exist connections with different QoS requirements deteriorated below the desired ones. For instance, the interference-based admission example in [2] illustrates the concepts of this CAC strategy. The second one is to determine whether the system affords to setup a bearer connection for the new call fulfilling its request. In order to estimate the capacity occupied by the new call, CAC can be designed based on a mapping with the property that the function mapping transforms the parameters of a connection in any service class into a unified resource index. This will greatly reduce the difficulty to develop the admission control mechanism. If this property is not available, the number of type of services will drastically increase, because that connections with different parameters will be separated into several types of services. This will result in more complicated derivation of the control scheme for customized multimedia applications.

In this dissertation, we introduce the concept of the equivalent interference estimator for the uplink transmission in CDMA systems. It aims to compute the equivalent amount of interference generated by a new call in terms of user's profile and to implicate the interference impact on the system if the new call is accepted. This concept comes from the effective bandwidth method for high-speed networks [4], [5]. It performs as an mapping from the parametric space, which is constituted by traffic parameters and the QoS requirements, to the measurement space, which is with unified and fair measurement metric to each different service. The capacity occupied by a connection will depend on the characteristics of the traffic source and the QoS requirements. The higher packet rate the source generates, the more resource should be allocated; the more strict the requirement is, the more resource should be reserved for the connection, too.

Based on the concept of equivalent interference estimator, we propose an general architecture for call admission control strategy for multimedia connections. Figure 1.1 shows the general architecture of the call admission controller. It contains an *Equivalent Interference Estimator*, a *System Load Estimator*, a *Mean Interference estimator*, and a *Admission Controller*. Below the intelligent admission controller, a packet level access control is located. The access control refers to the channels used for the transmission, that is, dedicated and shared channel, where different channel types have different access mechanism. The admission controller collects the information of estimated system load, equivalent interference of the new call, the mean interference, and the packet and call level performance measures to make the admission decisions.

To support customized multimedia service, an sophisticated scheduling algorithm is the most effective mechanism in the downlink. QoS requirements and weighted fairness are two conventional considerations for the scheduling algorithm in general networks to address the diverse QoS requirements and variant source characteristics. However, the

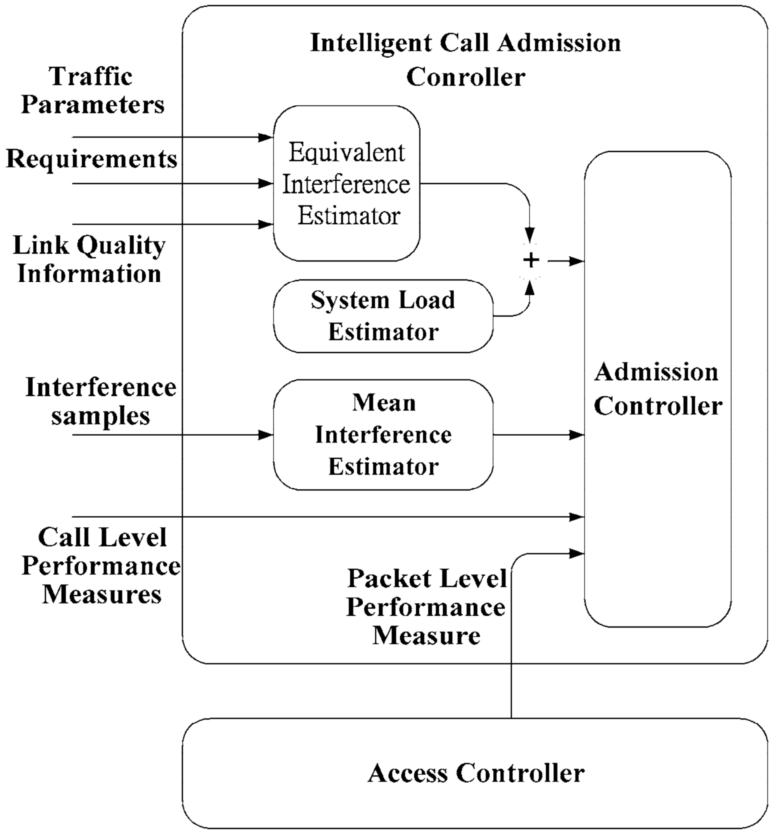

Figure 1.1: The block diagram of packet based admission controller.

radio channel in wireless networks has quite different characteristics which impacts greatly the system performance and even the QoS requirements and the weighted fairness. The transmission error probability in wireless links is of several order greater than that in wireline links. To achieve the desirable BER requirement, and the available maximum transmission rate to each connection is location-dependent and time-varying due to link loss, shadowing, and multi-path fading. Furthermore, since the air-interface is shared by all active connections according to the MAC protocol, the multiple access interference (MAI) from other connections and other base stations will greatly impact on the available

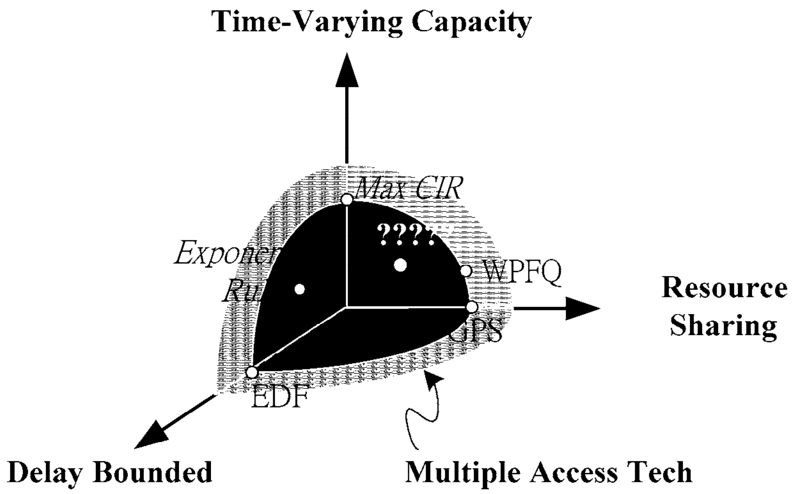

Figure 1.2: Three design aspects of scheduling algorithm in wireless networks.

transmission rate. Scheduling for radio resource of wireless networks is to determine which connection and how long this connection can use the system resource so that the utilization of radio resource can be maximized while performance measures of each connection can be efficiently retained at its QoS requirements.

We can categorize the design criteria into three main directions: the efficiency of the utilization of radio resource with respect to the link quality, the QoS requirement achievement, and the fairness among all connections. Fig. 1.2 shows the general design aspects of scheduling algorithm for wireless multimedia networks. Different scheduling algorithm can be located at different point in this figure. Also, the multiple access scheme will impact on the link state and should be considered in the design of scheduling algorithms. In this dissertation, we propose an scheduling algorithm jointly consider the three design criteria of via the utility-based approach so that customized multimedia services in the downlink can be effectively provided.

1.2 Paper Survey

The CAC algorithms for uplink connections in CDMA systems has several design considerations. The QoS requirements of both packet and call levels, the resulting soft capacity, the source characteristics of each connection, the system load, the access schemes, and also the handoff control are the major factors that affects the performance of the CAC mechanism.

The capacity of a system is the basis for a CAC mechanism which decides the maximum number of connection accepted to ensure the specific QoS requirement. In the CDMA systems, due to its interference limited property, the capacity is called soft dependent on its QoS requirements, and is different from that in TDMA/FDMA systems. For the packet level QoS requirements of BER, or equivalently E_b/N_0, the capacity of CDMA systems was derived in [6] and [7]. To applied the factor of capacity on the CAC design, Liu and Zarki [9] proposed an uplink signal-to-interference (SIR)-based CAC, which adopted a *residual capacity* algorithm, for a DS-CDMA cellular system with pure voice traffic. To further consider the source characteristics, Yang and Geraniotis [10] derived optimal admission policies for integrated voice and data traffic in a CDMA packet radio network. Dziong, Jia, and Mermelstein [11] proposed an adaptive traffic admission control by estimating the uplink interference at the base station. It employed a linear Kalman filter driven by the interference measurement.

In recent years, call level QoS requirements are also considered, ex. outage probability. References [12]-[18] studied the QoS-based CAC. Kim, Shin, and Lee [14] extended the work in [9] but fulfilled the outage requirement. However, only single class of service was considered. With closed blocking probability performance, this scheme successfully kept the outage probability guaranteed.

Ishikawa and Umeda [15] developed two strategies for CAC: one is based on the number of users and the other is based on the interference level. Although the theoretical expression for the blocking rate and the loss probability of communication quality as functions of traffic intensity and CAC threshold were obtained, integrated traffic and differentiated QoS requirements were not studied. Evans and Everitt [17] utilized an effective bandwidth concept [4] to transform the traffic generated by a user into an equivalently occupied bandwidth. The per class outage requirement was not supported, and the system state dimensions grew with an increasing number of cells, making the computational complexity intractable. Kim and Han [18] also proposed a CAC scheme which considered dual classes of services. This scheme measured the received interference and estimated the power requirement for the new user to predict the resulting SIR. The outage probability might overwhelm in some traffic load region.

In the uplink transmission, the interference limited property and the randomness property, due to which the wireless terminals cannot get the state information about other terminals, will make the performance of CDMA systems poor. In [22], it was shown that CDMA system is not suitable for bursty type of services. It is because that the more bursty the source behavior is, the higher the probability of excess multiple access interference beyond the threshold would be. The CAC schemes described above were all designed for dedicated channels without transmission control. For the services with bursty traffic process, shared channels are used for the transmission , and the access control for uplink must be applied to regulate the transmission for CDMA systems [23]-[25]. However, over the shared channel, the call level QoS requirements will be packet dropping ratio in steady of the outage probability, and therefore, the soft capacity under the access control is changed.

Although good access control may regulate the traffic and enlarge the system capacity region as much as possible, however, the multiple access interference may be too large such that access control can't guarantee the required QoS. This situation may also severely interfere the terminals among adjacent cells. Therefore, sophisticated admission control is required to limit the reasonable number of active terminals according to their service rate and their traffic characteristics. Liu and Silvester [16] proposed a joint admission/congestion control for wireless CDMA systems supporting integrated services. An adaptive admission control policy was developed to adjust the priority of voice traffic, and a data traffic control scheme was adopted to maintain the packet error rate of real-time voice traffic, while allowing itself to utilize the residual channel capacity. However, the work focused mainly on designing an access control scheme based on the admitted number of users but not on the CAC policy. [26] and [27], focused on the resource allocation and provided simple admission conditions. In general, the design of the CAC schemes for connections over shared channel considering different QoS requirements and variant source characteristics is still an important issue for further study.

Also, there were literatures working on the CAC problem with further consideration of handoff protection. The handoff calls should be prioritized than new calls due to the requirement on forced termination probability. Shin, Cho, and Sung [28] proposed to reserve a number of radio channels to protect handoff calls in DS-CDMA cellular systems, where the amount of interference of a connection is quantized as one radio channel, and the system capacity is then regarded as a fixed number of radio channels. The number of reserved channels for handoff was derived according to the handoff rate and the arrival rate, as it was done in TDMA systems. The change of interference to the destination cell was not even considered. Kuo and Ko [29] adopted probability reservation concept for handoff calls to improve the call dropping probability. The probability reservation scheme reserves resource in all the possible cells for the call that will handover. This scheme was inefficient for radio resource management in CDMA environments. Jeon and Jeong [30] utilized the property of soft capacity in CDMA systems, and designed prioritization by setting SIR threshold of handoff calls lower than that of new calls. However, the forced termination probability still cannot be guaranteed. In the practical simulation model for CDMA system, i.e. the continuous movement of the mobile connection and the correlated shadowing, we can find that the moving speed and the handoff margin will impact on the variation of mean interference and the capacity of a QoS guaranteed cellular system. Therefore, a more robust CAC scheme for hard handoff should be elaborately designed.

For the downlink scheduling algorithms, QoS requirement, link adaptation, and fairness are major design aspects. In the wireline networks, many scheduling algorithms were proposed to achieve the fluid fairness among all active connections. Generalized processor sharing (GPS) [32], [33] are an idealized fluid model to service all backlogged connections simultaneously with perfect fairness. In the practical networks, packetized version of GPS should be designed to mimic the properties of ideal GPS scheme. Packetized GPS (PGPS) (also called WFQ) [34], worst-case fair weighted fair queueing (WF^2Q), and etc, were proposed to approximate the GPS scheduler in packet networks. On the other hand, several scheduling algorithms were proposed to meet the delay bound and delay jitter requirements. Earliest deadline first (EDF) scheduling scheme [36] was proposed for real-time class of connections with hard delay bound requirement. As an extension, the scheduling scheme proposed in [37] guaranteed the delay jitter across the network node. Note that for connections without hard delay and jitter bound requirements, weighted fairness among all connections is the reasonable criteria to share the system capacity; on the other hand, for those with explicit delay and jitter requirements, the scheduling algorithms of EDF class work better than the algorithms in GPS class within the QoS guaranteed region.

In the wireless networks, the radio channel has quite different characteristics, such as location-dependent and time-varying properties. Several literature studied the resource scheduling and allocation among connections in wireless networks with consideration of physical layer processing, power control range, and link conditions [38]-[39]. Bhargharvan, Lu, and Nandagopal [40] proposed a framework to achieve long-term fairness in wireless networks. Many extended schemes, such as *channel-condition-independent fair queueing*, *server-based fairness approach*, and *wireless fair service* [41], were proposed to approximate the idealized fairness. There are schemes considering either delay bound or minimum rate as its QoS requirements. For those schemes considering delay requirements, Varsou and Poor [42] studied the scheduling algorithm based on an EDF (earliest deadline first) concept adapted to wireless environments. They also proposed a simple analysis for the performance of generalized PEDF (powered earliest deadline first) and HOLPRO (head-of-line pseudo-probability assignment) scheduling schemes [43]. Stolyar and Ramanan studied a throughput-optimal scheduling algorithm for delay bounded system [44]; a variational scheduling algorithm for rate guarantee was also investigated. For non-real-time interactive connections, the rate guarantee is desirable. Kam and Siu considered the minimal rate guarantee with fairness in their proposed scheme [45]. Moreover, some schemes considered joint scheduling criteria to deal with complicated needs for systems. Shakkottai and Stolyar [46] considered both link quality and QoS requirements as the criteria and derived an exponential form of scheduling function via fluid Markovian techniques. Many of these scheduling algorithms above, [38]-[39], [44]-[47], were formulated in utility-based approaches.

1.3 Dissertation Organization

In this dissertation, we discuss and design the major functionalities of radio resource management controller for both uplink and downlink connections in multimedia CDMA cellular systems. For the uplink connections, the access scheme of a connection is based on a distributed fashion, and the call admission control is essential for the system to avoid overloaded situation. For the downlink connections, due to availability of centralized control, the scheduling algorithm is important to allocate the radio resource in a short term fashion to take advantages of the link adaptation of the wireless channels.

In Chapter 2, the concept of equivalent interference for CDMA uplink transmission is introduced based on the interference limited property of CDMA systems. The radio resources for CDMA cellular system are defined and related to the system load in terms of the amount of interference. Then, two estimators of the traffic load over the uplink incurred by a connection are proposed according to the traffic parameters, packet level and call level QoS requirements for both dedicated and shared channel. For the equivalent interference over dedicated channels, no rate control is used for uplink transmission, and Gaussian approximation is applied to obtain the estimator in terms of the traffic parameters and QoS requirements of BER and outage probability. For the equivalent interference over shared channels, the random access for resource reservation is applied. Based on the operations of the up-link transmission over shared channels in WCDMA, a *radio resource index* (RRI) is derived to estimate the radio resource required for a call connection in WCDMA cellular systems. The RRI can transform traffic parameters and quality-of-service (QoS) requirements of the call connection into a measure of resource in a unified metric, while keeping QoS requirements of existing calls guaranteed.

In Chapter 3, a call admission controller, called intelligent call admission control (ICAC), for uplink connections in wideband CDMA cellular systems to support differentiated QoS requirements, guarantee the forced termination probability of handoffs, and maximize the spectrum utilization. The design of the ICAC is based on the concept of the equivalent interference. The ICAC contains a fuzzy call admission processor to make admission decision for a call request by considering QoS measures such as the forced termination (drop call) probability of handoff, the outage probability of all service types, the predicted next-step existing-call interference, the link gain, and the estimated equivalent interference of the call request. The pipeline recurrent neural network (PRNN) is used to accurately predict the next-step existing-call interference, and the fuzzy logic theory is applied to estimate the new/handoff call interference based on knowledge of effective bandwidth method. Several simulation scenarios are done to investigate the performance of the proposed ICAC scheme in different CDMA environments. We also examine the performance of the key design factors on several system performance measures to justify the effectiveness.

In Chapter 4, we discuss the major radio resource management functionality in downlink transmission for multimedia CDMA cellular networks, that is, the radio resource scheduler. Both dedicated and shared channels are considered in the system environments. Here, a cellular neural network and utility (CNNU)-based scheduler is proposed for multimedia CDMA cellular networks supporting differentiated quality-of-service (QoS). Three design aspects for scheduling algorithm are addressed which are the radio resource efficiency, QoS requirement achievement, and weighted fairness. The scheduling algorithm is formulated in the utility function-based approach, where a utility function characterizes the benefit of the allocation of radio resources. A relevant utility function for each connection is here defined as its radio resource function further weighted by both a QoS requirement deviation function and a fairness compensation function. The radio resource function is the maximum achievable rate function that can fulfill the BER (bit-error-rate) requirement of the connection; the QoS requirement deviation function of a connection indicates the extent of deviation from its call-level requirements; and the fairness compensation function sets the relative priority of a real-time connection over a non-real-time connection and makes the non-real-time connections fairly share the radio resource according to the predefined target weighted factors. The cellular neural network is powerful for complicated optimization problems and has been proved that it can rapidly converge to a desired equilibrium; the utility-based scheduling algorithm can efficiently utilize the radio resource for system and provide QoS requirements and fairness for connections. The CNNU-based scheduler determines a radio resource assignment vector for all connections so that the overall system utility is maximized and the system throughput can be achieved as high as possible. At the same time, the performance measures of all connections are kept closed to their QoS requirements in an efficient way. The stability and convergence of the proposed CNN are also detailed discussed in this chapter.

Finally, concluding remarks and future research topics are addressed in Chapter 5.