Call Admission Control in Third Generation Mobile Networks

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Abstract

Third generations mobile networks will be required to accommodate various services such as voice, data, and multimedia calls. Each of these services has different specific QoS requirement parameters and also different resource requirements. Because of these QoS requirements and limitations on the available spectrum, a suitable call admission control (CAC) algorithm must be designed. Call admission control algorithm decides whether accept or reject a call request. The third generation radio link is based on CDMA, which uses bandwidth more efficient than FDMA and TDMA that used for the GSM network. But design of the CAC algorithm in the third generation networks is more difficult than for the GSM.

In this paper we review some researches that have been done to design such an algorithm for third generation mobile network. The goals of CAC algorithms and related QoS metrics are introduced and then the parameters that must be considered in the design of these algorithms are described. The most important parameters are user interferences in the CDMA networks, modeling of user mobility and handoff call priority problem, the effect of power control and variable bit rate techniques in the performance of the CAC algorithms.

Keywords: CDMA-based call admission control, third generation cellular communication systems, spread spectrum systems.

1   Introduction

Next generation mobile networks will be required to accommodate various services such as voice, data, and multimedia calls. Each of these services has different specific QoS requirement parameters and also different resource requirements. One of the most critical resources of the network is radio link resource. In the third generation mobile networks CDMA is basic technique used for radio link and multiple accesses. Because of soft capacity characteristic of the CDMA systems, radio resource allocation is more efficient and also more difficult than the FDMA and TDMA based systems. However the main problem in a multiservice network is how many users of different services must be accepted in each period, in order to network throughput be maximized and users of different services experience a suitable QoS. Many researchers have been answering this question in form of the different call admission control (CAC) algorithms. In this paper we review attempts of researchers to answer this question.

This paper is organized as follows. In section 2, the goals of CAC algorithms are introduced. In section 3, QoS metrics which used for evaluating the efficiency of networks and CAC algorithms, are presented. In section 4, different approaches for modeling of the user interferences in order to design of CAC algorithm is presented. The modeling of user mobility and handoff call priority will be discussed in section 5. In section 6, CAC algorithms that use variable bandwidth techniques are introduced. Section 7 discusses about the CAC algorithms which consider the power control problem and finally paper is concluded in section 8.

2   CAC Purposes

The design purpose of a CAC algorithm is strongly dependent on the service providing policies in mobile network. For example if providing voice service is the first priority of the network this fact must be considered in the design of the CAC algorithm. But the main three ordinary purposes of the CAC are: providing a suitable QoS for users of different services, setting the service priority and improvement of the network throughput that will be explained more in the rest of this section.

Third generation services have different QoS requirements like delay, jitter (delay variations), packet loss and throughput which should be satisfied. For example real-time services such as voice calls are sensitive to delay and jitter, in the way that delay for the user access to the network must not exceed a threshold and having jitter more than 75 ms is not acceptable during voice conversations. When a service was accepted by the CAC, it means that the network must support its QoS requirements until the call end. In the other hand, non-real-time data services are not sensitive to the delay and jitter but are to the error (packet loss), and then CAC can use queuing methods for data users.

The second purpose of CAC algorithm is to give different priorities for different services to access to the network. The voice calls priority over the data calls and the handoff calls priority over the new calls are some example of service priority.

The last above-mentioned purpose of the CAC algorithm is the improvement of the network throughput. There are Different criteria for measuring the throughput such as the number of the accepted voice users per unit time or the average data transfer rate for the data users.

3   Quality of Service (QoS) Metrics

There are various considered QoS metrics in literature which depend on applications and contracts between users and service managers (SLA). In this section we have an overview on the most important QoS metrics which used in the cellular CDMA networks. In these networks, there are two kind of switching techniques: the first one is circuit switching for voice calls and the second is packet switching for data packets. In addition data services naturally have been divided into two categories: real-time and non-real-time data services. Then actually we have three categories of metrics here: real-time circuit switching voice communications, real-time packet communications (e.g. multimedia, packet voice, etc.) and non-real-time data communication (e.g. file transfer, paging, etc.) which described below.

a. Circuit switching voice communication: In this class the most important QoS requirements are call dropping probability, bad call probability, call blocking probability and connection delay. The call dropping probability is the probability that an admitted call will be terminated prematurely before the call completion. The bad call probability denotes the proportion of calls whose frame error rate exceeds the acceptable level for the service. The probability that a new call is not admitted into the system is the blocking probability. The connection delay is a time needed to establish a voice connection [1, 3, 25, 31].

b. Real-time data communications: In this class of applications, throughput, delay, jitter and packet loss are considerable. The throughput is the effective number of data units transported per unit time (e.g., bits/second), this parameter is usually specified as a "bandwidth guarantee". The delay is the time interval between the departures of data from the source to the arrival at the destination, this is usually referred to as e2e delay and connection delay could be included in it. The jitter is usually referred to as "delay variation". The loss is the percentage of data units that did not make it to the destination in a specific time interval. It is usually represented as a probability of loss [31, 32].

c. Non-real-time data communications: This class is similar to second class, except that jitter and delay are not so important but packet loss is much more important [2, 25].

4   CAC and Interference Modeling

CAC design for a CDMA based system is much more difficult than the FDMA and TDMA based systems, because the CDMA system capacity is restricted to the interference. In viewpoint of considering interference, CAC algorithms have been classified in two major categories: *SIR-based* and *measure-based*.

4.1   SIR-based CAC

These CAC algorithms predict the signal to interference ratio by an accurate modeling of the channel and also the complex computations. In viewpoint of the accuracy in interference computations, researchers have considered three level of approximation in channel modeling, which have called *single cell, neighbor,* and *precise* models. Apart of these three models, type of network from aspect of single or multiple service providing, is another parameter that must be considered in channel modeling. In continuation of this section we have an overview on these topics.

The *single cell* models consider only *intracellular interference*. They are limited just to the users of the same cell [2, 25]. The *neighbor models* compute the intracellular and the intercellular interference from the *neighbor cells* of the home cell [3]. QoS criteria resulted from these methods are better than single cell methods, but they spend more calculations.

A *precise SIR-based* CAC algorithm consider the interferences produced by all users of the network. Akl et al introduced such an algorithm for a network of only voice service [1, 5]. They considered *SIRs* in form of equation (1) for all of the *M* network cells. Equation (1)

shows *SIR* as a function of K_{ji} and n_i. Where K_{ji} is the intercellular interference from cell j to cell i and n_i is the number of accepted voice calls in cell i.

$$\left(\frac{E_b}{I_0}\right)_i = \frac{E_b/N_0}{\alpha\left(E_b/N_0\right)\left(n_i - 1 + \sum_{j=1}^{M} n_j \kappa_{ji}\right)/\left(W/R\right)+1} \tag{1}$$

Then with keeping the *SIRs* greater than an acceptable threshold and achieving an off-line *complex* computation, they determined the vector $N = (N_1,...,N_M)$ to equalize call-blocking probabilities in all of the cells and also to maximize a net revenue function. This revenue function is a decreasing function of the new call blocking and the handoff dropping probabilities. Finally each call request is accepted if:

$$n_i \le N_i \ for \ \ i=1,2,..,M \tag{2}$$

The main drawback of this method is high computation complexity. That's why the method is limited to off-line process of only voice service.

Multi service SIR-based CAC: Type of service is another parameter which must be considered in channel modeling, because interference effect of different services such as voice and data is different so. This parameter adds more complexity to channel modeling. With attention to this problem we can see that most of the papers in the recent literature have dedicated to the single-service interference model as described above. In continuation of this section we mention some SIR-based capacity model with multi-service consideration.

Koo et al proposed a single cell multi-service capacity model by considering each data calls as β voice calls [25]. Also Mahmoudi et al has used this approach for extending method of Akl et al [27] to present a precise multi-service capacity model [28]. Although this approach has been showed good results some other works have been done to obtain more accurate model. Yang et al proposed a method for developing mixed method which has been presented as a hyper plane in multi dimensional space [29]. In addition Mahmoudi et al [30] with using Ayyagari et al capacity model [3] presented a new multi-service CAC algorithm. In their method with management of single or double code assignment to data user, they obtained better resource usage and good QoS metrics.

4.2. Measure-based CAC

On the contrary of SIR-based CAC, Measure-based CAC doesn't need the accurate model of the channel and also the complex calculations. To obviate these drawbacks, they consider the interference by measuring it with some instruments. For example Chang et al. proposed a Measure-based intelligent CAC (ICAC) algorithm that guarantees a pre-defined QoSs for different services [4].
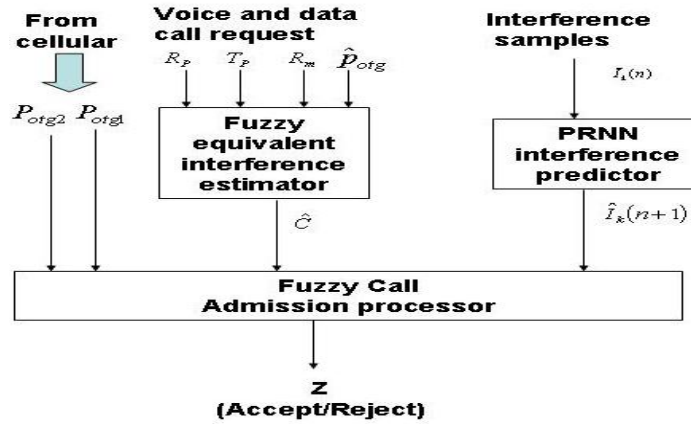
Figure 1. Measure-based intelligent call admission system

Figure 1 shows the main schema of ICAC. In this system, the neural network predicts the interference in the next time slot according to the interference measured in the last time-slots. The fuzzy equivalent interference estimator system estimates the interference produced by a new call according to its required parameters such as the maximum required bit rate (R_p), its time duration length (T_p), the average bit rate (R_m), and the maximum outage probability ($\hat{P}_{otg}$). The fuzzy call admission processor uses this information and also the information of feedback from the outage probabilities of each service to decide whether accepts the new call or not. The feedback from the outage probabilities guarantees the stability of the system. The results show the performance of ICAC is better than SIR-based algorithms, when the call blocking probability and the number of accepted users are considered as performance criteria.

5   Mobility and Call Admission Priority Problem

Call requests are classified in two categories: the new call requests from users of the home cell and handoff from users of the neighbor cells that coming to the home cell. Handoff traffic increases with increasing the mobility of the users. As accepting a handoff request have priority over a new call request, for designing a perfect CAC algorithm it is necessary to consider mobility modeling. The most important technique used for considering the handoff call priority is reserving a sufficient bandwidth in each cell for the handoff call requests from the adjacent cells. By increasing the amount of the reserved bandwidth the handoff call dropping probability is decreased but the new call blocking probability is increased. That's why, the most of methods avoid a *static* (fixed) reservation which maybe wastes the bandwidth, and prefer to achieve a *dynamic* (time varying) reservation [12-18, 22]. For example, Oliveira et al proposed a CAC algorithm, where the amount of reserved bandwidth is updated by measuring the two parameters: the average handoff dropping probability and the percent of the reservation bandwidth usage [12].

Finding a proper amount for the reserved bandwidth is an important problem. In this way, the proposed methods are classified in two classes: *statistical-based* methods [1, 12-14] and *track-based* methods [16-18].

5.1. Statistical-based methods

These methods by considering some parameters such as cells population, QoS parameters, and channel efficiency; estimate mobility of users between cells. Then this estimation determines the amount of reserved bandwidth for handoff users. For example, Akl et al proposed a CAC algorithm in this class [1]. They defined a net revenue function consists of two components: the revenue generated by accepting a new call and the cost of a forced termination due to handoff dropping. In order to consider the handoff call priority, handoff-dropping cost has a greater weight factor. With maximizing this function, they computed amount of extra capacity for cells with high mobility and amount of reduction capacity for cells with low mobility.

Epstein and Schwarz proposed another statistical-based CAC algorithm [13-15]. The one step prediction scheme (OSPS) technique is used for prediction of the necessary reservation bandwidth in the home cell and its adjacent cells in the next time slot. The main drawback of this method is that it is assumed that a user can move to all adjacent cells with equal probability. This drawback causes the waste of the bandwidth, which increases the call blocking probability.

5.2. Track-based methods

These methods are proposed to prevent the drawbacks of statistical-based methods in bad estimation and wasting the bandwidth. In this way track-based methods follow the path of each user between cells and try to forecast next step in path. With using this forecasting they obtain a precise amount for handoff reserved bandwidth.

With using a track-based approach, Yu and Leung proposed a method for prediction of the next cell and the handoff time of a user [18]. This method records the mobility profile of each user by a sequence of events. For each event call elapsed time and cell ID number is recorded. The next term of the mobility profile sequence is predicted from its previous terms by using the Ziv-Lempel technique in data compression [26]. The output of this algorithm is the handoff probability from cell i to cell j. Then it will be calculated the required reserved bandwidth in the cell j (adjacent to the home cell i).

Pati et al introduced another track-based CAC algorithm named PBR[1] for precise bandwidth reservation [17]. In this technique the area of a cell is partitioned into 6 sectors as shown in figure 2. Using the directional antennas it can be determined the home sector of each user, therefore each user may travel only to an adjacent cell in each time, and the bandwidth must be reserved only in this cell. In this system, there are two kinds of movement: intracellular

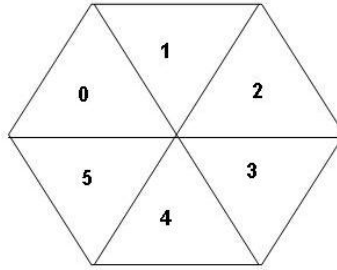[1]- Partitioned cell-based Bandwidth Reservation

Figure 2. Cell sectors partitioning for PBR technique

movement (between two sectors of a cell) and intercellular movement (between two different cells). In the first case, the previously reserved bandwidth in adjacent cell of current sector is released and a new bandwidth is reserved in the adjacent cell of new sector. In the case of intercellular movement the reserved bandwidth becomes active and the old activated bandwidth is reserved.

The PBR CAC algorithm is not very efficient method, because when a new call request is received the available bandwidth of the home cell and the adjacent cell to the home sector is considered. If there is enough bandwidth, the call is accepted and otherwise is blocked. It shows that call request of a motionless user may be blocked only for lack of bandwidth in adjacent cell. To overcome this drawback Pati et al introduced a modified version of PBR (MPBR[1]) [17]. In the MPBR method the reserved bandwidth in each cell is not only the function of active users' population in the adjacent sectors but also it is the function of their mobility. In fact the amount of this bandwidth linearly increases with the increasing of users' mobility.

6 CAC Using Variable Bit Rate Techniques

In this type of CAC algorithms, the CAC decides not only on accept or reject of a call request, but also on allocation of bit rate for an accepted call request. Variable bit rate (VBR) techniques can be implemented in some services such as non-real-time data. With using this property, the CAC algorithms have better control on the bandwidth and increase the maximum number of acceptable users or reduce the handoff dropping probability.

There are two approaches in the VBR-based CAC algorithms. The first one is based on using one or more DS-CDMA codes in *single RF channel* [2, 3, 23, 24]. The second approach is based on using multiple chip rates (MCR) in the *multiple RF channels* [6-8]. As a sample of the first approach, Oh and Wasserman proposed a spectrally efficient multiple access protocol for voice and data users, which is based on dynamic spreading gain technique [2]. In this algorithm, a relationship between the QoS parameters, active voice users, and data users is also derived. Finally with using this relationship and considering the number of voice and data users at the start of each time slot, the CAC algorithm calculates the optimum spreading

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[1]- Mobility adaptive Partitioned cell-based Bandwidth Reservation

gain for the data users. This optimum spreading gain is calculated so that the expected numbers of successfully transmitted data bits in each time slot become maximized.

In the second approach, the CAC accept the different service requests in different RF channels depend on their required bit-rate. For example some MCR systems use three different chip rates (subsystems) that are correspond to the three different RF bands narrow, medium and wideband [6, 7]. The voice users are restricted to spread their signal in a narrow band. The high bit rate services optionally can use the medium or the wideband depend on the required QoS. In comparison of the single RF channel, this approach provide better control on the bandwidth and reduce interference effects, but the computation of the SIR in such a system is complex and there is a few papers published about it [9, 10].

Kim et al introduced another MCR-based CAC algorithm named minimum power-increment [11]. In this algorithm when a new call request is received the base station investigates the existence of a subsystem that satisfies the required QoS parameters of the user. If there is no suitable subsystem, the call is blocked. If there is more than one subsystem that satisfies the conditions, the subsystem that causes minimum received power increment is chosen. The results show call blocking probability and throughput of this system is better than a system with randomly choose subsystem.

7   CAC with Optimum Power Control

For considering relationship between the CAC and the power control problem, first of all it must be noted that the restrictive parameters for acceptance of the calls in the uplink and downlink is perfectly different because the resources in these links are different. So it is better to discuss the role of power control in CAC algorithm in two separate sections as follow:

A. Downlink power control

In uplink all of receivers in the base station experience the same interference while in the downlink the interference experienced by the mobile station is dependent on its position and its distance from the base station. Because the signals received in the downlink are synchronous and the downlink capacity is often more than uplink, the interference in downlink is not a too restrictive parameter such as uplink interference. In fact interference restricts the capacity of the uplink and the maximum base station available power restricts the downlink capacity.

Kim et al introduced a CAC algorithm with power control in downlink [19]. After calculation of the interference for voice and data users, they showed the power allocated for the data users in the downlink must be δ_f times greater than for voice users, where δ_f is a function of the activity factor and the desired SIR of voice and data users. In this CAC algorithm a call is accepted if the required power is available in the base station and in addition number of users of each service must not exceed a specific threshold. These thresholds guarantee the desired SIR of all services in the uplink.

B. Uplink power control

The power control in the uplink mainly used for providing the QoS needs of the mobile users. For example Andersin et al introduced such a CAC algorithm [21]. In their algorithm a vector contains the power values of the mobile users is called power vector $P = (p_1, p_2, ..., p_J)$ is considered. If the maximum transmittable power of user j be P_j^{max} then:

$$p_j \leq p_j^{max} \quad \text{for} \quad 1 \leq j \leq J \tag{3}$$

Where J is the number of active users. As the signal to interference experienced by each user is dependent on its power and power of other users in power vector, the introduced power control CAC algorithm update the power vector in some iterations to maintain the interference level of the all services below their desired interference level.

When a user with initial power of P_0 is accepted in the network, the interference level for other active users increases, then they must update their power so that keep their QoS. If there is not desired power vector then the QoS of some users is not satisfied. For solving this problem when a call request is received, the user is accepted for a trial period and then the power vector is updated iteratively. If the power update algorithm converges to the desired power vector, then the user will be accepted and otherwise will be blocked. The drawbacks of this interactive method are the network signaling load increment and the low rate of convergence. To cover the drawbacks of this method Kim proposed a modified version of interactive method with better coverage rate [20].

8   Conclusion

Call admission control algorithms have an important role in traffic engineering of 3G mobile networks. These algorithms attempt to do resource management for obtaining the main three purposes: providing a suitable QoS for users of different services, setting the service priority and improvement of the network throughput.

The most important factor that must be considered in design of a suitable CAC algorithm is the soft capacity of the CDMA systems. The main restricting factor of network capacity is interference. The interference is not limited to interference generated by the users of the same cell, but the intercellular interference must be noticed. In some papers in order to avoid the computation complexity of the system, only the intercellular interferences are modeled and in some other only the interferences produced with the users of the home cell and its neighbor cells are considered and some others use intelligent systems such as neural networks and fuzzy systems for avoiding the complexity of the interference modeling.

The mobility modeling and the handoff call priority problem is another important factor in CAC algorithms. The most researchers attempt to solve this problem with dynamic bandwidth reservation. Two approaches are presented for dynamic reservation statistical-based and track-based methods. Statistical-based approaches try to change the reserved bandwidth using some

measurements such as the handoff dropping rate and the percent of the reserved bandwidth utility. In the second approach, it is attempted to estimate the position of the user and then predict the future path of him/her, then the bandwidth must be reserved only in cell where the user will be traveled to it. Most of these methods have computation complexity and also the existence of the positioning systems such as GPS is assumed.

Another important characteristic of the 3G networks is the existence of the users with different services, which their bit rate, power, traffic models, and also their QoS requirements are quite different. This problem increase the complexity of the interference modeling for the CAC algorithm, but also it is a freedom degree for optimization of the CAC performance in the design process. The CAC algorithm can allocate the bit rate and the power of the new and existing users (according to their service type) in order to increase the capacity of the system. In the power control based algorithm two important restrictions must be noticed: the maximum available power in the base station and maximum transmittable power in the mobile station.

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