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Call Admission Control in Mobile and Wireless Networks

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1. Introduction

The increasing demand for advanced multimedia services combined with the resource constraints of the wireless networks indicate the need of efficient admission control schemes to achieve a competent resource management combined with adequate Quality of Service (QoS) levels for end users. QoS provision in wireless networks is closely related to the exploitation of available network resources and the maximization of the number of users. Call Admission Control (CAC) is one of the key issues in wireless mobile communications, concentrating great interest in research work about QoS. CAC algorithms are employed to ensure that the admission of a new call into a resource limited network does not violate the Service Level Agreements (SLAs) concerning ongoing calls.

CAC schemes for wireless networks have been widely studied under different network architectures and network administrator policies. The objectives of the chapter are to present thoroughly the main concepts of CAC design and QoS provision in wireless and mobile networks. The study will focus on system and traffic analysis employed to model the complexity of communication traffic. In next generation networks where multiple Service Classes (SCs) with different QoS characteristics are supported, the various call types are classified into SCs with precise characteristics and QoS demands. Each SC call is treated differently depending on the criteria set according to the operating principles adopted for the admission procedure. CAC schemes handle multiple call stream flows corresponding to different priority levels providing an efficient mechanism to deal with different QoS necessities. The demanding environment of wireless communications poses numerous challenges in CAC design concerning the resource constraints, the connection quality, QoS requirements, SC prioritization, mobility characteristics and revenue optimization. Another critical issue in admission control is the performance evaluation, through appropriate metrics of the proposed schemes to assess the provided QoS. The metric studied most is Call Blocking Probability (CBP).

Finally, the last section of the chapter provides a broad classification of different design approaches and strategies considered for efficient admission control. CAC schemes are classified upon different rationales, used to apply call admission policy, aiding to an elucidatory synopsis of CAC under different network parameters. The majority of CAC

schemes base their admission criteria on an efficient resource management, accounted for either in terms of channels or bandwidth units. The methods proposed usually set thresholds related to the desirable QoS for high priority SCs and handoff calls. Other CAC schemes examine Signal to Noise Ratio (SNR) levels to determine an admission criterion satisfying the QoS demands of end users. Such schemes have to deal with propagation and mobility issues. Under high traffic network conditions, an efficiency enhancing module may be incorporated into the CAC schemes employed, renegotiating the resource allocation of ongoing calls. Through QoS re-negotiation and resource re-allocation, available resources can be retrieved and managed dynamically to serve a high priority SC call request.

2. Call Admission Control in Mobile and Wireless Communication

2.1 Call Admission Control (Definition and Operating Principle)

During the last decades the wireless communication networks users have been rapidly increased along with their demand for new multimedia services. The need for high speed communications is in contrast to the scarce spectrum resources allocated for wireless systems in international organizations. Therefore, a proficient radio resource management (RRM) is vital, to allot the existing network resources among contenting users, taking into consideration their needs and respective priorities as to provide them with the required QoS. More in detail, RRM functionality intends to improve system performance by maximizing the overall system capacity in the wireless network preserving at the same time the QoS characteristics of mobile users.

A crucial RRM mechanism essential for QoS provision applied on wireless networks is CAC. The key idea of Admission Control (AC) is to ensure the QoS of individual connections by appropriately managing the network resources. The main characteristics that an efficient AC policy should provide are the following: a) establish a robust priority assigning mechanism for handoff calls and calls of different SCs, b) exhibit a low CBP, c) allocate resources fairly, d) achieve a high network throughput and e) avoid congestion. Moreover, a proficient CAC scheme should avoid congestion and system outages due to overloading. The admission of a new call, according to the CAC scheme employed, should not violate the SLAs of ongoing calls. Admission decision is based on not only the available network resources but also the QoS requirements of the requesting and ongoing users. Hence, the decision should be taken considering multiple parameters such as the network characteristics, the service type, user mobility and the network conditions. In the case that the decision is positive, an appropriate quantity of network resources should be reserved to maintain the QoS of the new user. Thus, CAC is strictly related to resource allocation, channel and base station assignment, power control and resource reservation.

CAC problem can be considered as a multi-objective optimization problem that is maximizing the efficiency, utility and revenue of the network while at the same time complying with the users QoS requirements. The latter are provided by the users SLAs agreements. The admission criteria employed in the decision making part of the CAC scheme could be the Signal-to Interference Ratio (SIR), the ratio of bit energy to interference density ratio (E_b/I_0), the Bit Error Rate (BER), the Call Dropping Probability (CDP), the QoS at connection level as determined by the data rate and the delay bound. For instance, a CAC scheme may minimize the CBP by admitting a large number of call requests, provided that the BER violation probability does not exceed a satisfactory level ϵ_1 (Wu, 2005).

$$\Pr\{BER > BER_{thr}\} \leq \varepsilon_1,$$

where BER_{thr} denotes the BER threshold. In the case that CBP values are available the above constraint can be rewritten as

$$CBP \leq \varepsilon_2.$$

Generally, CAC schemes can be designed to provide different priority levels which correspond to the various SCs supported by the network.

2.2 Necessity for Call Admission Control and Quality of Service Provision

CAC algorithms are employed to ensure that the admission of a new call into a resource constrained network does not violate the SLAs of ongoing users. To decide whether to admit a new call or not, many factors are taken into consideration, most of them contradictory such as optimizing the use of radio resources, maximizing revenue, providing fairness, etc. Thus, CAC constitutes a mechanism which is used to determine the number of call connections so that different priorities are given among users with different QoS characteristics, network utilization is increased and congestion is prevented. Thus, when a call request from a mobile user is initiated, it may be accepted or blocked. The blocking probability, defined as the probability that a new call request is denied service by the network is called CBP and is subjected to the relevant decision made by the CAC scheme employed. Efficient CAC policies should achieve low CBPs.

Implementing practical CAC schemes is difficult; because traffic in communication networks is inherently chaotic and bursty, and traffic bursts are extremely difficult to be predicted. CAC schemes in wireless networks are complicated due to variable link quality and to users mobility. In particular, a call admitted in a certain cell may have to be handed off to a neighboring cell due to the users mobility. The main consideration in handoff procedures is to preserve the continuity of the call while at the same time offering at least the minimum acceptable QoS. During a call, a mobile user may cross several cell boundaries, thus requiring a corresponding number of successful handoffs. With regard to the handoff process, the new cell may not have any available resources to serve a handoff call, resulting in handoff failure commonly known as call dropping. In the literature, the probability that an ongoing call is terminated (dropped) is called CDP. It is widely accepted that users are more annoyed by call dropping than by call blocking; thus, efficient CAC schemes should keep CDP as low as possible. A simple way implemented in most CAC schemes, to achieve low CDP levels, is to assign higher priorities to handoff calls compared to new calls. Therefore, the admission criteria for new and handoff calls are different.

With regard to the number of active connections preserved, handoff schemes can be classified into hard handoff and soft handoff schemes. In the hard handoff schemes, a mobile terminal releases the channel from the original cell before its connection to the new Base Station (BS) is accomplished. Thus, a mobile terminal is connected to one BS at a time. In this case, the call is short-interrupted during the process of changing BS. In hard handoff schemes two ways leading to a handoff failure exist. The first is related to the way the handoff is implemented since if the old radio link is released before the network completes the assignment of a new channel, the call is dropped. This demonstrates the susceptibility of hard handoff schemes to the link transfer time. The second way may be attributed to the resource allocation mechanism since, if there are no channels available in the new cell, then the handoff call is forced-terminated.

In soft handoff schemes, the handoff process is triggered at the boundaries between neighboring cells. As cells in wireless systems overlap to assure complete coverage, the boundary areas may be served by more than one BS. Thus during the handoff, a mobile terminal may communicate with multiple BSs simultaneously, employing different radio links to achieve the communication with the network. When a channel from a BS is successfully assigned to a mobile terminal according to the specific handoff scheme QoS parameters, its originally occupied channels are released. In this case, the handoff procedure is insensitive to the duration of the handoff process, resulting in lower CDP compared to hard handoff schemes.

CAC schemes operate in real-time; hence, the algorithm used should be executed very fast. Moreover, the exact situation concerning the available resources at the BSs controller should be known as input data to the CAC algorithm. The design and implementation of a CAC scheme should be done very carefully aiming at minimizing false rejections and false admissions. A false rejection occurs when a call is rejected though the network has enough resources to serve it. In this case, optimization of network resources is not achieved, capacity is wasted and the operator's revenue is not maximized. On the other hand, a false admission occurs when a call request is accepted even if there are no available resources. In this case, the QoS level is not guaranteed and the CDP is increased, resulting in degradation of users satisfaction.

2.3 Challenges in Call Admission Control Design

The basic operation of CAC schemes is to decide whether a call should be admitted by the network or not. This decision is based on several criteria which are related to the network parameters and to the specific QoS characteristics of the call request. Although the QoS characteristics of the call are a priori determined, the network parameters are variable and adjustable in time. Thus, the CAC scheme employed should assure that the QoS characteristics of ongoing calls will not be violated throughout their whole duration. The factors employed in CAC schemes are presented below:

- Network load/resources: The limited network resources constitute a critical factor in CAC design. CAC schemes based on this criterion must know the resources available in each cell before the decision is taken. In this case, the network load after the admission of a new call must be predicted; if the predicted network load remains below a certain threshold, the new is admitted; otherwise, it is blocked. As handoff calls are treated differently by most CAC schemes, a set of channels may be reserved at each cell for handoff calls. Therefore, the admission of a new call is more difficult, as the respective threshold employed in most CAC schemes is lower, than the relevant threshold of handoff calls. These CAC schemes are widely known as Guard Channel (GC) schemes.
- Connection/link quality: Link quality is an essential parameter that should be taken into account when designing CAC in interference-limited wireless networks. Link quality refers to the radio link between the user terminal and the BS. For its estimation, the signal strength received at a mobile terminal and the interference caused to this link by other mobile terminals in the area are used. Thus, CAC schemes admit a new call if they can maintain the link quality of the admitted calls above a certain threshold. Otherwise, if the admission of a new call will result in an unacceptable deterioration of the link quality, the call is rejected. CAC schemes based on link quality usually employ the SIR

or the Signal-to-Noise-plus-Interference Ratio (SNIR) as an admission criterion; hence, they are called SIR or SNIR-based schemes.

- QoS requirements/call context: Since users may request services characterized by different QoS requirements with regard to mean throughput, mean delay, BER and bandwidth demands, the call requests are classified into various SCs. For every SC call request different admission criteria can be employed taking into consideration the respective QoS constraints and the network resources available. Thus, CAC schemes can be classified with regard to the number of the SCs supported. CAC scheme for single SC constituted a simple and appropriate model for first and second generation (2G) wireless networks, as they were mainly destined for voice services. The growing need for new services combined with the diffusion of new technologies, such as the 2.5 and 3G networks and also the Next Generation Networks (NGN), indicated the need to support multiple SCs with multimedia traffic and enhanced QoS characteristics. Thus, during the last decade, advanced CAC schemes supporting multiple SCs were introduced, classifying stream flows and call requests into different SC types according to their QoS characteristics. CAC design for multiple SCs is more challenging since different CAC criteria are employed for the SCs supported often resulting in high complexity and difficulties considering their implementation in practice.
- Call priority/SC prioritization: This CAC criterion is solely related to SC prioritization. Assigning higher priority to some SCs over the rest is a common technique in CAC schemes for multiple SC networks. In particular, it is widely accepted that Real Time (RT) services have higher priority over Non-Real Time (NRT) ones, e.g. a voice call is considered of higher priority compared to internet browsing. Moreover, different priorities can be assigned even within the same SC reflecting the differentiation among different user classes, stemming from subscription fee policy. Also, higher priorities are assigned to handoff calls or to calls related to emergency services. Different priority levels reflect different CAC criteria, which are more strict for low priority SC calls and relaxed for high priority ones.

Prioritization schemes can be implemented mainly through: channel borrowing, queuing and reservation schemes. In channel borrowing schemes, if a cell has all its channels reserved, it can borrow channels from neighboring cells to serve high priority SC calls. In queuing schemes, if a cell has all its resources occupied, a high priority call request is set into a queue until resources, sufficient to accommodate the call request are released in the cell. Queuing schemes can be applied either to high priority call requests or to all incoming call requests (regardless of their priority). In the latter case their position into the queue is adjusted according to the respective requests priority. On the other hand, the reservation schemes were first used to give priority to handoff calls by permanently reserving on a permanent basis a number of channels exclusively for serving handoff requests. These schemes have been extended to support multiple SCs by assigning different priority levels through reserving channels for high priority SC calls.

- User's mobility characteristics: Users mobility is a critical factor in wireless networks as users travel across multiple cells; thus, the traffic in the cells is variable and it cannot be precisely predicted as an active terminal may move from one cell to a neighboring one, resulting in calls handoff. If a handoff call cannot be served by the BS of the new cell, it is dropped increasing the call dropping rate. Since users are more sensitive to call dropping than to call blocking, CAC schemes are employed to reduce the handoff failure

probability. Most schemes in the literature assign higher priorities to handoff calls resulting in less strict admission conditions for the admission of handoff calls. These schemes are the same with the prioritization schemes mentioned above with the difference that they are destined to prioritize handoff calls.

- **Transmission rate:** CAC schemes are employed to guarantee the minimum bandwidth requirements for ongoing calls. Moreover, every SC call may also have a maximum bandwidth requirement. Based on the available resources, a CAC scheme aims at providing the highest possible bandwidth between the minimum and maximum requirement to every call and, at the same time, reducing CBP. To this end, certain CAC schemes incorporate QoS renegotiation, a mechanism which is activated when the cell resources of network cell are not sufficient, to reduce the transmission rate of ongoing calls, as much as required for the admission of a new call. The reduced transmission rate may be increased when resources are released due to the termination of a call.
- **Revenue optimization:** By applying a proper network utilization policy, an efficient CAC scheme may provide a high revenue for the network operator. On the other hand, there are strict limitations imposed by the total bandwidth constraints and the QoS guarantee through the SLAs. Any admitted call contributes to the revenue increase but it may also cause a penalty if the QoS of ongoing calls is deteriorated. The reward may be represented by the number of users or the portion of occupied bandwidth whereas the various penalties may be defined via the probability of QoS deterioration. To determine in real time the optimum equilibrium between reward and penalties is a rather complicated problem. The relevant CAC schemes are named revenue optimization or economic CAC schemes.
- **Fairness in resource assignment:** The main drawback of CAC schemes basing their admission criterion on the call priority is that high priority calls often monopolize the network resources. This results in a severe blocking of low priority calls and, consequently, in high CBP levels for the low priority traffic flows. This is observed not only in networks supporting multiple SCs where different priority levels are assigned to each SC, but also among different users in the same SC with different SLAs and mobility characteristics. Specific CAC schemes exist which take into consideration fairness criteria based on various network parameters, such as the network throughput or the CBP achieved, to ensure that no SC or user class dominates the network resources.

3. Mobile & Wireless Networks Modeling and Traffic Analysis

3.1 Traffic Model and System Analysis

The majority of the studies concerning CAC in wireless networks make certain standard assumptions to provide a tractable analysis. Most system models were obtained through common traffic theory and have been extended to cellular networks. These networks are not necessarily represented by these traffic models, since users mobility and the emerging multimedia services necessitate new teletraffic assumptions and models that take into account the new aspects of wireless networks.

A fundamental assumption in modeling wireless networks with regard to CAC is that the new call arrivals in a cell follow the Poisson distribution, that is, the new calls arrive in cell i according to a Poisson distribution with rate $\lambda_{n,i}$. If the network is assumed homogeneous, the arrival rate is the same for every cell and the analysis may be limited to only a single cell.

The handoff call arrivals in cell i are also assumed to follow the Poisson distribution with rate $\lambda_{h,i}$. Such an assumption is not so obvious in the case of handoff calls as the handoff traffic is solely related to the user mobility characteristics. It has been proven (Chlebus & Ludwin, 1995) that this assumption is valid provided there is no blocking in the network. As this is an ideal case, in the same work a blocking scenario is assumed to examine how accurate is the assumption that handoff arrivals follow the Poisson distribution. The results indicate that through this approximation of the real situation the performance exhibited is satisfactory. Moreover, in the same work it is argued without providing the proof that in blocking environment handoff traffic is a smooth process which means that the variance is less than the mean value. It must be noted that in Poisson distribution the variance is equal to the mean value. Apart from adopting the Poisson distribution for modeling the arrival rate, other traffic models have been proposed in the literature. In (Rajaratnam & Takawira, 2000) the authors suggest that the call arrival process in wireless networks should be modeled according to general distribution (Rajaratnam & Takawira, 1999). Moreover, they have shown that the handoff traffic is a smooth process if the channel holding times follow the exponential distribution.

The channel holding time is defined as the time that a channel is assigned to a call in a certain cell. The channel is released after the call is either terminated or handed off to a neighboring cell. Another important term in wireless networks is the call holding time (also referred to the literature as service time or Requested Call Connection Time, RCCT), defined as the total connection time originally requested by a call. The call holding time varies according to the type of the call, as calls belonging to different SCs may also have different durations. How long a call stays in a cell is another fundamental parameter in wireless networks and is widely called as Cell Residence Time (CRT) or cell dwell time. CRT is mainly dependent on users mobility characteristics and on the geometry of the cells.

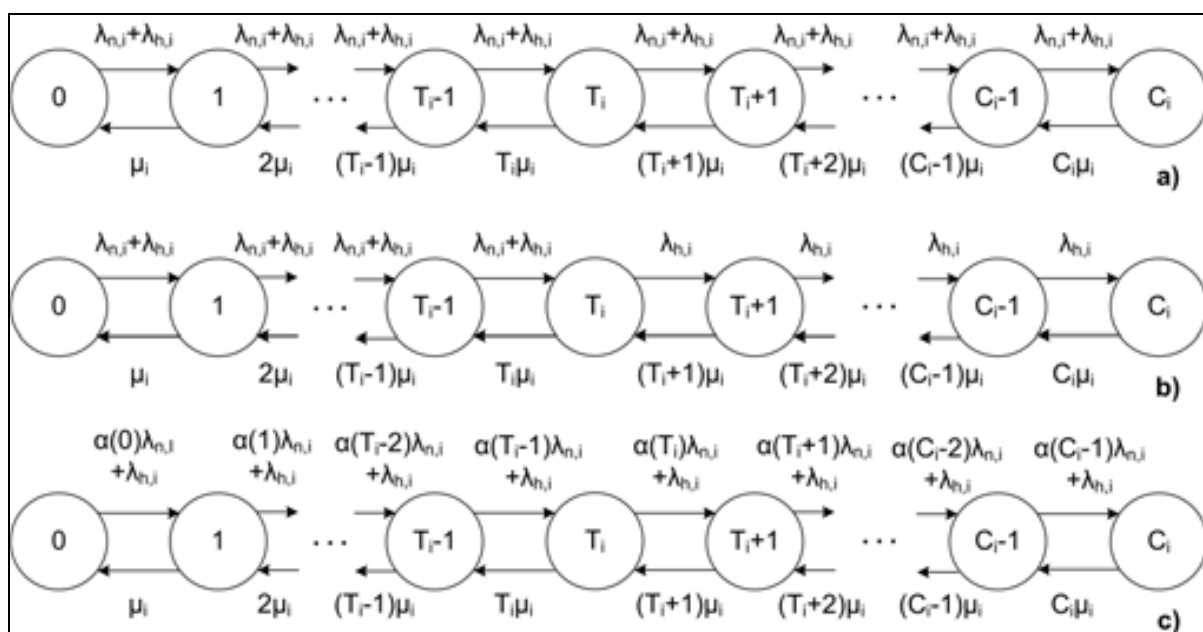


Fig. 1. Transition diagrams considering network state. a) Complete resource sharing scheme, b) Guard Channel scheme and c) Fractional Guard Channel scheme.

The majority of the analyses existing in the literature assume that the channel holding times follow the exponential distribution for both new and handoff calls. However, the channel holding time follow the exponential distribution, only under certain conditions investigated in (Fang, Chlamtac, & Lin, 1998), where it is proven that channel holding time follows the exponential distribution if the CRT is also exponentially distributed. In all the other cases, the channel holding time cannot be modeled according to the exponential distribution whereas neither the handoff traffic nor the new incoming traffic flow follow the Poisson distribution. Some researchers adopt other distributions to model the channel holding time such as the lognormal (Jedrzycki & Leung, 1996) and general distribution (Rajaratnam & Takawira, 1999). Although modeling the cell residence time and the channel holding time is not straightforward, most researchers model both these characteristics through the exponential since under this assumption the relevant analysis becomes tractable yielding analytical formulas for the CBP. A more rigorous approach is beyond the scope of this chapter; therefore, both new and handoff incoming traffic will be assumed as Poisson arrivals whereas the channel holding time and cell dwell time in cell i will be modeled through the exponential distribution with mean $1/\mu_i$.

In a complete resource sharing scheme (Lai, Mistic, & Chanson, 1998) a call is admitted as long as there are sufficient network resources to accommodate the call; otherwise it is rejected. The same policy is applied for new and handoff calls. By defining the state of a cell i at time t $\{c_i(t) | t \geq 0\}$ as the number of occupied channels in cell, the cell state can be modeled as a Continuous-Time Markov Chain (CTMC). If the respective number of channels is C_i , the system model is a typical $M/M/C_i$ queue (Figure 1a). Note that to adopt the $M/M/C_i$ model an assumption should be made that when the network operates under congestion a new or handoff call arrival is blocked. This assumption reduces the analysis from $M/M/C_i/K$, where K is maximum number of calls waiting to be served, into $M/M/C_i$, where no buffer is used. The truncated state space of cell i is represented by S_i , where

$$S_i = \{n_i; 0 \leq n_i \leq C_i\}.$$

Let $\pi(n_i, n_i')$ be the transition rate from state n_i to state n_i' , where $n_i, n_i' \in S_i$. Then, the transition probabilities for adjacent states are obtained from

$$\begin{aligned} \pi(n_i, n_i+1) &= \lambda_{n_i} + \lambda_{h,i} \\ \pi(n_i, n_i-1) &= n_i \mu_i. \end{aligned}$$

Based on the transition diagram depicted in Figure 1a the following global balance equation is derived

$$(\lambda_{n_i} + \lambda_{h,i}) p(n_i) = (n_i + 1) \mu_i p(n_i + 1),$$

where $p(n_i) = \lim_{t \rightarrow \infty} \text{Prob}[c_i(t) = n_i]$ denotes the steady state probability that the number of ongoing calls in cell i is n_i , $n_i = 0, 1, \dots, C_i$. From the global balance equation the steady state probabilities are obtained from

$$p(n_i) = p(0) \rho^{n_i} / n_i!, \quad 0 \leq n_i \leq C_i,$$

where $\rho = (\lambda_{n,i} + \lambda_{h,i}) / \mu_i$ is the traffic intensity and $p(0)$ is the normalization factor defined as

$$p(0) = \left[\sum_{n_i=0}^{C_i} \frac{\rho^{n_i}}{n_i!} \right]^{-1}.$$

A new call destined for cell i is blocked if all its channels are occupied; hence, the new call blocking probability in cell i is given by

$$P_n^b(i) = p(C_i).$$

Since no prioritization for handoff calls has been assumed in this general analysis, the handoff failure probability $P_h^b(i)$ in cell i should be equal to $P_n^b(i)$. Therefore

$$P_h^b(i) = P_n^b(i) = p(C_i).$$

This analysis may be extended to multiple SCs and multiple cells but it proves very complicated (Li & Chao, 2007) as the transition diagram has multiple dimensions rendering the corresponding global balance equation difficult to solve. In most cases, different traffic flows, each of which corresponds to a specific SC, are considered to be independent; therefore, multiple one-dimensional transition diagrams are obtained, reducing the complexity of the problem. An interesting and mathematically robust analysis concerning this problem is provided in (Li & Chao, 2007) where expressions for CBPs, handoff rates and QoS (also called grade of service) are obtained in closed form.

As previously mentioned, in the case of multiple independent SCs, the previous analysis is carried out separately for every SC. Consider U SCs with arrival rates

$$\lambda_{u,i}(n_{u,i}) = \lambda_{nu,i}(n_{u,i}) + \lambda_{hu,i}(n_{u,i})$$

and death rates

$$\mu_{u,i}(n_{u,i}) = \mu_{u,i} n_{u,i},$$

where $u=1, \dots, U$ and $\lambda_{nu,i}(n_{u,i})$, $\lambda_{hu,i}(n_{u,i})$ are the respective call arrival rates for new and handoff u SC calls in cell i and $\mu_{u,i}$ is the respective mean cell residence time. The steady state probability of having $n_{u,i}$ channels in cell i occupied by u SC calls is

$$p_u(n_{u,i}) = \left(\frac{\lambda_{nu,i} + \lambda_{hu,i}}{\mu_{u,i}} \right)^{n_{u,i}} \frac{1}{n_{u,i}!} p_u(0),$$

where $p_u(0)$ is the normalization factor given by

$$p_u(0) = \left[\sum_{n_{u,i}=0}^{C_i} \left(\frac{\lambda_{nu,i} + \lambda_{hu,i}}{\mu_{u,i}} \right)^{n_{u,i}} \frac{1}{n_{u,i}!} \right]^{-1}.$$

Considering now the total number of SCs supported in cell i , the truncated state space is

$$S'_i = \{n_i = (n_{1,i}, n_{2,i}, \dots, n_{U,i}); n_{1,i} + n_{2,i} + \dots + n_{U,i} \leq C_i\}.$$

The steady state probability that the network is at state n_i is given by

$$p_{u,i}(n_i) = p_{u,i}(0) \prod_{u=1}^U \left(\frac{\lambda_{nu,i} + \lambda_{hu,i}}{\mu_{u,i}} \right)^{n_{u,i}} \frac{1}{n_{u,i}!},$$

where $p_{u,i}(0)$ is the normalization factor given by

$$p_{u,i}^{-1}(0) = \sum_{n_i \in S'_i} \prod_{u=1}^U \left(\frac{\lambda_{nu,i} + \lambda_{hu,i}}{\mu_{u,i}} \right)^{n_{u,i}} \frac{1}{n_{u,i}!}.$$

For the complete resource sharing scheme, the CBP and CDP for u SC in cell i are equal to the probability that cell i is under congestion, e.g. all its channels are occupied. Thus, the corresponding probability is given by

$$P_h^b(u,i) = P_n^b(u,i) = p(n_i^*),$$

where $n_i^* = (n_{1,i}^*, n_{2,i}^*, \dots, n_{U,i}^*); n_{1,i}^* + n_{2,i}^* + \dots + n_{U,i}^* = C_i$.

In literature, there are two approaches concerning the whole network problem where J cells are supported, $i=0,1,\dots,J$. In the first case, the network may be assumed as homogeneous; then, it suffices to examine one cell only with its results representing the whole network behavior. Therefore, the CBP and CDP determined previously for cell i apply for the whole network. In the second case, the network traffic is not uniformly distributed over all the cells supported; then, appropriate analysis should be carried out to determine the admission failure probabilities. This analysis is analytically presented in (Li & Chao, 2007) where additional QoS network parameters are examined.

3.2 Service Classes Classification

Former generations of wireless networks used simple traffic shaping schemes where all traffic was shaped uniformly by rate. This model was realistic as only one service (voice calls) was offered. As modern wireless networks offer a variety of services, the incoming traffic should be classified into different traffic types. Each traffic type is called SC and the procedure followed to determine in which class a new call request falls into is called classification. Each SC has its own QoS characteristics with regard e.g. to bitrate, packet delay, duration etc. Therefore, each SC should be treated differently to differentiate the

service destined for the user. Despite the increased complexity due to multiple SCs supported by the network, the control mechanisms are more flexible in resource allocation management and QoS provision. Apart from different QoS characteristics for each SC concerning physical and network layer, different priority levels are applied to different SCs supported employing certain policies. This SC prioritization is usually based on the QoS requirements, the pricing policy followed by the administrator and the users SLAs. This differentiation of the incoming calls can be utilized by a network operator to treat the various SC calls in different ways with regard to bandwidth allocation, call admission process, pricing policy, etc.

A usual classification is the differentiation of the incoming calls into two general SCs, real-time SCs and non-real-time SCs (Tsiropoulos, Stratogiannis, Kanellopoulos, & Cottis, 2008). This classification is primarily based on the latency characteristics of the various calls. In general, there is a deadline for a data packet to be delivered to its destination. If for a certain call this requirement is strict or lenient; the call is characterized as RT call or NRT, respectively. In modern wireless networks supporting multimedia traffic a broader call classification is required. Apart from taking into consideration the latency of each call, additional QoS requirements are considered such as the bandwidth required and the call duration. Therefore, calls are classified into multiple SCs (Tragos, Tsiropoulos, Karetos, & Kyriazakos, 2008) such as voice, messaging, internet browsing and file transfer, teleconference etc.

Recent trends in traffic control classify the incoming calls into three SCs: Premium, Gold and Silver (Tragos, Tsiropoulos, Karetos, & Kyriazakos, 2008) (Guo & Chaskar, 2002). Premium SC calls are assigned with the highest priority level and they are offered the negotiated bandwidth all the time, regardless of congestion, interference or degradation of channel quality. A lower priority level is assigned to Gold SC calls and the lowest one to Silver SC calls. The resources are allocated to calls according to the respective SC priority level. Thus, in case of congestion, Premium SC calls are still served under their initially requested QoS characteristics, whereas Gold and Silver SC calls are subject to QoS degradation in proportion to their priority levels so that congestion is mitigated. According to this classification of calls, each mobile user may associate each application with either of three SCs according to its QoS expectations and the pricing scheme applied (Guo & Chaskar, 2002). Thus, for a certain call, say a voice call, a user may associate it with the Premium SC, whereas other users may associate a voice call with the Gold SC. Regardless of the call classification scheme adopted, call classification simplifies the network analysis and enhances QoS provision, as calls are managed in groups and not independently

3.3 Efficiency and Performance Evaluation

CBP Estimation

The common criteria employed to evaluate the performance of all the CAC schemes proposed are CBP and CDP. When the assumptions made allow the application of Markov chain analysis, analytical formulas for CBP and CDP are derived (Li & Chao, 2007; Fang & Zhang, 2002; Tsiropoulos, Stratogiannis, Kanellopoulos, & Cottis, 2008). Therefore, the assessment of the CAC schemes employed can be based on these criteria. In measurement-based CAC schemes, CBP and CDP are estimated by measuring the calls blocked or dropped, respectively, during a predefined time window. The CAC scheme proposed in the

literature aim at reducing as much as possible both these probabilities by adopting an appropriate decision making procedure. Moreover, the QoS requirements of the ongoing calls should be satisfied at the same time providing prioritization to handoff calls. Both CBP and CDP are mainly dependent on the input traffic load, the number of ongoing calls, the bandwidth requirements of each call and the policy applied for handoff calls (Tragos, Tsiropoulos, Karetos, & Kyriazakos, 2008).

In single SC networks the assessment of CAC schemes with regard to their failure probabilities is focused on handoff prioritization (Fang & Zhang, 2002; Yavuz & Leung, 2006). The divergence between CBP and CDP becomes greater as the policy for handoff prioritization becomes stricter. In GC schemes this is realized by lowering the threshold level T whereas in fractional schemes the probability $\alpha(n_i)$ becomes lower. To measure the prioritization achieved between new and handoff calls an appropriate priority index (PRIN) is defined as the fraction of CBP to CDP

$$\text{PRIN} = \frac{\text{CBP}}{\text{CDP}}.$$

To achieve handoff prioritization, PRIN should be higher than unity, as the CBP should be greater than CDP.

A similar analysis is applied in multiple SC networks. Apart from prioritizing handoff calls, different SCs should also be assigned with different priority levels. Thus, considering that a SCs should have priority over SC $u+1$, (where $u, u+1 \in U$), then CBP_u and CDP_u should be lower than CBP_{u+1} and CDP_{u+1} . Therefore, the divergence between failure probabilities among different SCs is more critical in multiple SC networks. The PRIN index can be modified to incorporate the prioritization level of different SCs. In particular,

$$\text{PRIN}(u, u') = \frac{\text{CBP}_u + \text{CDP}_u}{\text{CBP}_{u'} + \text{CDP}_{u'}}.$$

measures the prioritization achieved among u and u' SC, $u, u' \in U$, where $\text{PRIN}(u, u') > 1$ if $u < u'$ or $\text{PRIN}(u, u') < 1$ if $u > u'$.

4. Call Admission Control Design Approaches

4.1 Classification of Call Admission Control Schemes

CAC schemes can be classified into general categories based either on the criteria considered in the decision part of the CAC scheme or on specific design characteristics. The admission criteria considered by CAC schemes are usually related to various QoS parameters and have been discussed earlier. Each design characteristics has its own advantages and disadvantages. The selection among different CAC approaches should be based upon the wireless technology used, the SCs supported and the geographical characteristics of the region where the network is installed.

With regard to the centralization level of CAC schemes, they are classified into centralized, distributed or collaborative. In centralized schemes, CAC is implemented at the Mobile Switching Center (MSC) which is responsible for handling the services supported by the

network. The information from the BS of a cell must be aggregated at the MSC where the admission decision is taken; then, the BS is commanded to act accordingly. The main advantage of centralized CAC schemes is their high efficiency, but the high level of complexity along with the increased redundancy due to the control data required, makes them unrealistic in practice. In distributed CAC schemes the decision making part is installed at the BS of each cell and completes the CAC procedure independently of the other cells. Therefore, they are more reliable and more easily implemented. However, they are less efficient as they lack global information about the network parameters, information available only in centralized CAC schemes. The collaborative schemes (O'Callaghan, Gawley, Barry, & McGrath, 2004), constitute a promising hybrid design option. In such schemes, information concerning resource allocation and admission control is exchanged between neighboring cells, though the decision is taken by the BS of each cell. Hence, the advantages of centralized and distributed CAC schemes are combined in effective powerful architecture offering high efficiency and increased reliability. The main disadvantage of collaborative schemes is the high overhead required.

CAC schemes can also be discriminated into traffic-descriptor-based - also called proactive - or measurement - based - also called reactive. In the former scheme, the admission decision is based on the traffic pattern which is available for the application of these schemes, which check whether the already reserved bandwidth increased by the bandwidth demand of the new call exceeds the cell capacity. In this case, the call is blocked otherwise it is admitted. The most common traffic-descriptor-based CAC scheme is the simple sum scheme (Tragos, Tsiropoulos, Karetos, & Kyriazakos, 2008) (Jamin, Shenker, & Danzig, 1997) which simply ensures that the sum of the requested resources does not exceed the cell capacity. A new call with maximum bandwidth demand r_{α} is admitted under the condition that the already occupied bandwidth demand increased by r_{α} remains below the cell capacity μ , that is if:

$$v+r_{\alpha}\leq\mu.$$

As multimedia traffic is bursty in nature, traffic-descriptor-based CAC schemes overestimate the bandwidth demands since traffic descriptors specify the maximum bandwidth demand in each call which is rarely used. On the other hand, traffic-descriptor-based CAC schemes are very simple; ergo they are widely used by switch and router vendors.

In measurement-based CAC schemes the decision making module employs the actual network characteristics such as the actual traffic load, the packet error rate etc which are appropriately measured and, consequently, realistic. Some interesting measurement-based CAC schemes considered in (Tragos, Tsiropoulos, Karetos, & Kyriazakos, 2008; Jamin, Shenker, & Danzig, 1997) are based on the actual traffic flow, the occupied bandwidth, the network load and packet loss accompanied with revenue award. The fundamental parameter in measurement-based CAC schemes is the measuring mechanism itself, in other words how the parameter employed in the CAC procedure is measured (Jamin, Shenker, & Danzig, 1997; Warfield, Chan, Konheim, & Guillaume, 1994; Dziong, Juda, & Mason, 1997; Casetti, Kurose, & Towsley, 1996). The measurement procedure is performed either by directly measuring the proper network parameter every sampling period following a time-window policy (Jamin, Danzig, Shenker, & Zhang, 1997), or by computing a relevant average value based on current and/or previous measurements (Jamin, Shenker, & Danzig,

1997; Floyd, 1996). Most CAC schemes employed in CDMA systems are designed according to the measurement-based technique (Stasiak, Wisniewski, & Zwierzykowski, 2005).

Another interesting classification of CAC schemes can be made based on the amount of information available at the decision making module. This information may include the number of available or occupied cell channels, the total bandwidth allocated to ongoing users, the mean packet delay for each traffic flow etc. If this information can span over the whole network, the scheme is characterized as global. As expected, these schemes achieve high efficiency but exhibit exceptional complexity and require the exchange of a huge amount of information among the network cells. If the information exchange is done within a limited area including at least the neighboring cells of the cell under consideration, the CAC scheme is called semi-local. These schemes achieve also high efficiency and are less complex compared to global ones but they still require a lot of information exchange. Apart from information exchanging schemes, local CAC schemes exist which base their admission decision only on the information concerning a specific cell. Local schemes are simple to implement; however, they are less efficient compared to global or semi-local schemes since they do not take into account that, due to users mobility the load of a cell is influenced by the load of the neighboring cells.

Many CAC schemes are available in literature proven to achieve the optimal solution to the CAC problem, according to the inputs for the admission decision process. However, optimal CAC schemes often require a high computational power for their implementation, due to the large number of states associated with the Markov Decision Problem (MDP). The large scale of the problem and the multiple interdependent network parameters employed in optimal CAC schemes result in high complexity and increased processing time. Thus, theoretically optimal CAC schemes are not applicable in practice, as the admission decision must be taken instantaneously upon a call request. As an alternative approach to optimal CAC schemes, suboptimal CAC schemes have been proposed which operate online with significantly lower complexity. Suboptimal CAC schemes obtain a near-optimal solution to the CAC problem, usually by employing intellectual techniques (heuristic functions, alternative approaches, etc) to reduce the complexity of the original problem.

CAC schemes can be also classified based on information granularity (Jain & Knightly, 1999) which depends on the traffic model adopted, the spatial distribution of network users and the way network information is obtained. CAC schemes may adopt a specific users mobility pattern, otherwise a simple resource policy for mobile users will be used. In the first case, the exact knowledge of the users mobility characteristics, such as direction and velocity, helps to predict the handoff traffic load destined to each cell. The spatial users distribution may be uniform or non-uniform; consequently, the wireless network is considered as homogeneous or non-homogeneous respectively. Information can be obtained at each cell for either each call or each SC stream flow. As the information about the network increases, the complexity of the CAC scheme increases along with its efficiency.

An additional classification of CAC schemes can be done based on the differentiation of the data rates between the uplink and the downlink. Unlike traditional voice services, the demand for bandwidth between uplink and downlink is asymmetric in many multimedia applications. In relevant systems, if the CAC scheme employed allocates equal bandwidth to both uplink and downlink traffic, system capacity might be limited by the downlink traffic (Yang, Feng, & Kheong, 2006); then resources are used inefficiently, bandwidth is wasted and efficiency performance of the CAC scheme is low. Some CAC schemes adopt a joint

admission policy, by accepting a new call provided that enough resources can be allocated to both uplink and downlink according to the QoS characteristics of the new call.

4.2 Call Admission Control based on Signal Quality

In modern wireless access technologies, interference poses critical constraints concerning mainly the signal quality. This situation has an impact not only on network conditions but also on systems capacity. Particularly, in CDMA wireless networks interference is the dominant factor affecting their performance in terms of capacity and QoS provision to end users. Thus, the SINR is an adequate metric of the signal quality. CDMA-based air interfaces are mainly influenced by interference caused by other users from the same network instead of Gaussian noise, so the noise effect is usually neglected focusing mainly on SIR.

Therefore, CAC schemes implemented for interference - limited networks employ as admission criterion either the interference levels caused by a new incoming call or the signal quality levels achieved. Hence, interference based CAC schemes admit new calls only if the SNR/SIR values can maintain a minimum signal quality level. The SNR/SIR levels correspond to predefined QoS levels for new and ongoing users. This simple approach offers a tool to reduce interference in wireless networks, while on the other hand is constitutes an efficient admission criterion.

Two simple SIR-based solutions were first proposed by (Liu & Zarki, 1994) for controlling the signal quality. This is achieved by checking the achievable SIR value by the new call. The call is admitted provided that this value is higher than the minimum SIR value. Both implemented schemes are based on the residual capacity of the cell formulating each time an appropriate admission criterion. In the first scheme the residual capacity of the network is defined as

$$R_k = \left[\frac{1}{SIR_{th}} - \frac{1}{SIR_k} \right],$$

where SIR_k is the uplink SIR value in a cell k and SIR_{th} is the threshold value that imposes whether a call is admitted or not. The residual capacity of the cell is calculated when a new user arrives and if is greater than zero the incoming call is admitted otherwise the call is rejected. The second proposed algorithm follows the same rationale taking also into account the impact of admitting one call on cell k itself and its adjacent cells $C(k)$ as well. This is done by encompassing an interference coupling parameter β in the above definition of the residual capacity leading to

$$R_{k,j} = \left[\frac{1}{\beta} \left(\frac{1}{SIR_{th}} - \frac{1}{SIR_j} \right) \right], \quad j \in C(k).$$

These simple algorithms were evolved taking into account inter-cell interference. In residual capacity estimation, the parameter $L_m(j,k)$ is used, representing the predicted additional intercell interference. The use of this parameter results into service enhancement in terms of reduced CBPs. QoS guarantees are also provided by using certain bounds for threshold,

maintaining specified levels for blocking rate (Kim, Shin, & Lee, 2000). The residual capacity is estimated by

$$R_{k,j} = \left[\frac{1}{SIR_{th}} - \frac{1}{SIR_j} - \frac{1}{L_m(j,k)} \right] j \in C(k).$$

The SINR is a sufficient metric for the signal quality providing also supplementary information. In particular, through SINR measurement BER can be estimated given the coding and modulation techniques applied. Additionally, from SNR/SIR values E_b/N_0 and energy per bit to interference density ratio (E_b/I_0) can be calculated respectively. CAC schemes control the signal quality employing as a decision criterion the equivalent constraints applied on E_b/N_0 . Such SIR based schemes were developed for multicode CDMA systems (Ayyagari & Ephremides, 1998). The proposed scheme orders users based on the E_b/N_0 required. Before admitting a user, the CAC scheme checks whether the user can be assigned a minimum number of codes (corresponding to the minimum transmission rate) beginning from the user with the lowest E_b/N_0 . If the minimum number of codes can be assigned without violating the constraints on E_b/N_0 , the user is admitted. In the next step, additional codes are attempted to be assigned to the user to increase the transmission rate up to the maximum designated rate. Then, the system proceeds to the next user until all users are checked. Therefore, every user is either admitted and allocated multiple codes or rejected due to system infeasibility.

The SIR-based CAC schemes offer a reliable platform for dynamic adaptive admission control facing the problems of non-stationary and non-uniform traffic. This is realized through either the adoption of a local adaptive scheme employing the traffic parameters and the channel characteristics or a global scheme collecting information from all the neighbouring cells. Dziong & Jia (1996) proposed a relative framework that estimates the mean and variance of the interference level measuring them via a Kalman filter and predicts mean and variance of the interference concerning the new call. The total interference is assessed as the sum of the estimated interference of all calls, the predicted interference emerged by the admission new call and the reservation threshold (a reservation for the estimated interference variance and errors). Then, the admission decision is taken comparing the total interference to the maximum tolerable interference threshold I_{max} .

Apart from interference – limited CDMA networks CAC schemes based on signal quality control were developed for TDMA systems. This kind of system suffers from signal quality constraints especially when a tight frequency reuse plan is employed to increase the number of available channels. Thus, in TDMA networks SIR based CAC schemes are utilized to guarantee SIR_{min} since cochannel interferers are in close distance one each other, causing significant problems in signal quality. The CAC scheme checks all available time slots in the cell and admits the user if at least one time slot has $SIR > SIR_{min}$. If SIR remains below SIR_{min} throughout the call duration, the call is reassigned to a different time slot that satisfies the SIR requirements offering the desired QoS (Haleem, Avidor, & Valenzuela, 1998). Moreover, CAC schemes remain a prevailing solution for hybrid T/CDMA systems combining multicode techniques with SIR based CAC (Casoni, Immovilli, & Merani, 2002).

SIR based CAC schemes performance can be improved employing optimization techniques. In such schemes a constrained optimization problem is formulated employing an objective

function including the signal quality constraints. Through the optimization of the objective function, the system capacity is maximized avoiding high failure probabilities. An optimum CAC policy for multiservice networks is proposed by (Singh, Krishnamurthy, & Poor, 2002), accomplishing to minimize blocking probability for one class, while using as constraints blocking rates for the supported SCs and the SIR conditions. The problem of optimization is solved by means of linear programming. Applying these techniques the efficiency of the CAC scheme is increased leading to an advanced resource management

4.3 Handoff and Service Class Prioritization Schemes

Complete resource sharing schemes cannot guarantee a certain QoS level for handoff calls, especially during network congestion, as the total numbers of channels are allocated to new and handoff calls with no discriminations. Therefore, GC schemes, also called reservation schemes, have been first proposed by Hong and Rappaport (1986) in the mid 80s to prioritize handoff calls over new ones. The basic concept behind this scheme is to reserve a certain number of channels only for serving handoff calls. The rest of the channels are available for both new and handoff calls. Thus, assuming that the total number of channels in cell i is C_i and that the number of channels available for common use are T_i ($T_i < C_i$), the number of channels dedicated to handoff calls only is $C_i - T_i$. Therefore, T_i operates as a threshold, implying that a new call is admitted provided that at least $C_i - T_i + 1$ channels are available, whereas the admission of a handoff call requires only one available channel. Under the same network assumptions as with the single SC complete resource sharing scheme the transition diagram for the CTMC is shown in Figure 1b, represented by the same truncated state space S_i . The transition probabilities to adjacent states in GC schemes are given by

$$\begin{aligned} \pi(n_i, n_{i+1}) &= \lambda_{n,i} + \lambda_{h,i} \quad \text{for } 0 \leq n_i \leq T_i - 1 \\ \pi(n_i, n_{i+1}) &= \lambda_{h,i} \quad \text{for } T_i \leq n_i \leq C_i - 1 \\ \pi(n_i, n_{i-1}) &= n_i \mu_i. \end{aligned}$$

Based on the global balance equations provided by the CTMC depicted in Figure 1b, the following expression is derived for the state space probability $p(n_i)$, that is

$$\begin{aligned} p(n_i) &= p(0) \left(\frac{\lambda_{n,i} + \lambda_{h,i}}{\mu_i} \right)^{n_i} \frac{1}{n_i!} \\ p(n_i) &= p(0) \left(\frac{\lambda_{n,i} + \lambda_{h,i}}{\mu_i} \right)^{T_i} \left(\frac{\lambda_{h,i}}{\mu_i} \right)^{n_i - T_i} \frac{1}{n_i!} \end{aligned}$$

where $p(0)$ is the normalization factor defined as

$$p(0) = \left[\sum_{n_i=0}^{T_i-1} \left(\frac{\lambda_{n,i} + \lambda_{h,i}}{\mu_i} \right)^{n_i} \frac{1}{n_i!} + \sum_{n_i=T_i}^{C_i} \left(\frac{\lambda_{n,i} + \lambda_{h,i}}{\mu_i} \right)^{T_i} \left(\frac{\lambda_{h,i}}{\mu_i} \right)^{n_i - T_i} \frac{1}{n_i!} \right]^{-1}.$$

According to the CG CAC scheme, a new call is blocked if the total occupied channels in cell i exceeds T_{i-1} ; hence, the CBP is given by

$$P_n^b(i) = p(T_i) + p(T_{i+1}) + \dots + p(C_i).$$

As GC schemes provide prioritization to handoff calls, a handoff call is dropped if all channels of cell i are occupied; consequently CDP is given by

$$P_h^b(i) = p(C_i).$$

If T is equal to C , the CG scheme reduces to a complete resource sharing scheme. The main issue in GC schemes is the evaluation of the threshold value T that minimizes CBP under the constraint set for CDP (Ramjee, Towsley, & Nagarajan, 1997) (Harine, Marie, Puigjaner, & Trivedi, 2001). The stricter the constraint for handoff calls, the better is the QoS provided by the network. On the other hand, lower values of CDP result in higher values for CBP. Hence, there is a tradeoff between CBP and CDP, which is reflected in the evaluation of the threshold level.

As modern wireless networks support multiples SCs with different QoS characteristics, sophisticated CAC schemes should be employed to guarantee the various QoS levels. Thus, GC schemes, which were originally destined to prioritize handoff calls over new ones, may be modified by adopting different thresholds for each SC calls (new and handoff) in the relevant decision process. These schemes are commonly known in the literature as multi-threshold bandwidth reservation schemes (Haung & Ho, 2002) (Chen, Yilmaz, & Yen, 2006). In such schemes, two kinds of prioritization can be applied, SC priority and call type priority. The former characterizes the type of the service and addresses the problem of prioritizing different SC calls by employing different thresholds for the calls of each SC. The analysis is similar to the one presented above for the complete resource sharing scheme supporting multiple SCs.

The different SCs supported are usually RT and NRT SCs. In other cases, the SCs supported may be more than two (Tragos, Tsiropoulos, Karetos, & Kyriazakos, 2008) each with its own QoS requirements. The main problem of multiple threshold schemes is the exact evaluation of the threshold values. Several algorithms exist in the literature for the evaluation of thresholds mainly based on revenue optimization, but most of them are computationally expensive and difficult to solve (Chen, Yilmaz, & Yen, 2006). The evaluation of the proper threshold is a multi-constrained problem, where multiple network limitations should be taken into account.

The fixed number of channels reserved for handoff calls or high priority SC calls by GC or multi-threshold schemes, respectively, is determined mainly based on a priori knowledge of the traffic patterns. As they are static in nature, they lack adaptability thereby being unable to adapt to the network variations. In realistic situations, the call arrival rates are not static and cannot be efficiently described through traffic patterns. Hence, a network with time-varying traffic requires dynamic CAC schemes which usually achieve a better performance. Dynamic (also called adaptive) GC schemes are based either on mobility prediction employing the users mobility, the direction and the location of the mobile terminal, or on measurements of certain network parameters such as CBP, CDP or the available resources. Their main objective is to adapt the thresholds employed by the CAC scheme to optimize a given objective function formulated through a penalty - revenue approach concerning the

admission or rejection of incoming calls, a network utilization optimization policy, etc. Both the prediction of mobility and the measurement-based dynamic CAC schemes are strongly dependent on the efficiency of the mobility estimation algorithm or the measurement technique employed, respectively. The extensive results presented in the literature indicate that dynamic GC schemes outperform static GC schemes (Yu & Leung, 1997) (Bartolini & Chlamtac, 2001). On the other hand, dynamic GC schemes are more complex compared to static schemes, resulting in increased exchange of information between the BSs and large processing load.

Another variation of the GC schemes presented above is the Fractional Guard Channel (FGC) schemes. The FGC scheme was first proposed by Ramjee (1996) and was proven to be more general than the GC schemes. The basic idea of the FGC scheme lies in the admission of an arriving new call in cell i under a certain probability $\alpha(n_i)$, $0 \leq \alpha(n_i) \leq 1$, where the parameter $n_i = 0, 1, \dots, C_i$, depends on the number of busy channels in cell i . In general, this probability varies with the network status. If $\alpha(0) \geq \alpha(1) \geq \dots \geq \alpha(C_i)$, the stream of new call becomes thinner as the number of occupied channels increases. Handoff calls are unhinderedly admitted unless no channels are available. CBP and CDP vary significantly as the number of occupied channels varies. On the other hand, in FGC schemes the application of admission probabilities eliminates the use of threshold in admission decision providing a smoother variation of CBP and CDP.

Consider the operation a FGC scheme under the same network assumptions as in the CG schemes previous referred to. The network states, represented by the same truncated state space S_i , can be modeled according the CTMC depicted in Figure 1c. As observed in Figure 1c, the transition probabilities for adjacent states in FGC schemes are obtained from

$$\begin{aligned}\pi(n_i, n_{i+1}) &= \alpha(n_i) \lambda_{n_i} + \lambda_{h,i} \\ \pi(n_i, n_{i-1}) &= n_i \mu_i.\end{aligned}$$

Consequently, the global balance equation is obtained applying the fundamental rule of the birth-death process in Figure 1c "rate up equals rate down" (Cooper, 1981) as follows

$$(\alpha(n_i) \lambda_{n_i} + \lambda_{h,i}) p(n_i) = n_{i+1} \mu_i p(n_{i+1}).$$

Solving the global balance equation, the steady state distribution of the FGC scheme is obtained from

$$p(n_i) = \frac{\prod_{k=0}^{n_i} (\alpha(k) \lambda_{n_i} + \lambda_{h,i})}{\mu_i^{n_i} n_i!} p(0) \quad \text{for } 0 \leq n_i \leq C_i,$$

where

$$p(0) = \left[\sum_{n_i=0}^{C_i} \frac{\prod_{k=0}^{n_i} (\alpha(k) \lambda_{n_i} + \lambda_{h,i})}{\mu_i^{n_i} n_i!} \right]^{-1}.$$

CBP and CDP may be obtained from

$$P_n^b(i) = \sum_{n_i=0}^{C_i} (1 - \alpha(n_i)) p(n_i)$$

and

$$P_h^b(i) = p(C_i),$$

respectively.

When $\alpha(0)=\alpha(1)=\dots=\alpha(T_i)=1$ and $\alpha(0)=\alpha(T_{i+1})=\dots=\alpha(C_i)=0$, the FGC scheme reduces to the simple GC scheme with T_i acting as threshold for new calls. Also, setting all fractional probabilities equal to unity, e.g. $\alpha(0)=\alpha(1)=\dots=\alpha(C_i)=1$, the complete resource sharing scheme is obtained. Thus, the FGC schemes are proven more general with the GC and the resource sharing schemes being special cases. Due to the incorporation of the fractional probability $\alpha(n_i)$, the FGC schemes may be extended to comply with network administrator specifications and SCs QoS requirements in multimedia wireless networks.

The FGC schemes are further employed to prioritize high priority SCs in multimedia wireless networks. These schemes are also known as thinning or probabilistic CAC schemes (Wang, Fan, & Pan, 2008) (Tsiropoulos, Stratogiannis, Kanellopoulos, & Cottis, 2008). Each SC call is assigned with its own probability. SCs of higher priority are assigned with higher probabilities. In this case, the previous analysis of FGC schemes can be generalized according to the analysis employed for multi-SCs in complete resource sharing and GC schemes (Wang, Fan, & Pan, 2008).

4.4 Bandwidth Adaptation and Quality of Service Renegotiation

Wireless networks support a variety of services which can be classified into rate-adaptive applications and constant bitrate (CBR) services. In such services, e.g. voice calls, a bandwidth increase beyond the standard requirement will not improve the respective QoS. On the other hand, in rate adaptive services users specify, at their connection request, the minimum and maximum bandwidth required. Apart from specifying the bandwidth range required by every SC, rate variations may originate from the dynamic nature of the wireless environment along with the mobility of user terminals. Thus, in modern wireless networks bandwidth adaptation algorithms are employed to improve network utilization and guarantee the QoS of ongoing calls, assigning the minimum bandwidth required. When the network conditions are favorable and enough resources are available, they may be assigned to ongoing rate-adaptive users according to two general strategies based on SCs priorities (Li & Chao, 2007). According to the first strategy, the available resources are fairly assigned to all ongoing users without taking into account any priorities. According to the second, resources are first assigned to SC calls of high priority; until the resources are exhausted or all high priority SC calls have taken the maximum bandwidth required. If resources are still available, the scheme assigns them to SC calls of the next high priority. The procedure continues until all resources are exhausted or all calls are served with their maximum bandwidth demand. Apart from taking into account priorities, resource assignment in rate-adaptive services may be performed through more complicated schemes. In (Sen, Jawanda, Basu, & Das, 1998), an optimal resource assignment strategy is proposed for maximizing the

total revenue obtained, while in (Sherif, Habib, Nagshineh, & Kermani, 2000), an adaptive resource allocation scheme is proposed to maximize bandwidth utilization and attempt to provide fairness with a generic algorithm.

In general, when a call arrives in a certain cell, the network may either have enough resources to provide bandwidth between the minimum and the maximum demand or be congested, that is, it cannot provide the minimum bandwidth requested by the new call. In the first case the call is admitted, whereas in the second, bandwidth adaptation CAC algorithms, also known as rate-adaptive schemes, are applied to determine an optimal resource allocation aiming at serving as many users as possible while reducing the admission failure probability. This is accomplished by reducing the rate of some users when possible as much as required to accommodate the new call. In some bandwidth adaptation CAC schemes, this procedure is followed only for handoff or for call requests of high priority SCs (Tragos, Tsiropoulos, Karetos, & Kyriazakos, 2008; Lindemann, Lohmann, & Thümmler, 2004). However, it should be mentioned that user rates cannot be reduced below the minimum rate values required to assure QoS; thus, when all users operate at their lowest bandwidth requirement, a new call request will be rejected. Rate degradation may be enforced according to a prioritization or to a non-prioritization scheme. In the former, the rate degradation policy is first applied to the SC calls of the lowest priority. If the resources released are still not sufficient for the admission of a new call, the calls of the next priority level are examined. In the non-prioritization schemes, all calls served with higher rates than their minimum bandwidth demand reduce their rate to admit the call request. A useful metric in QoS renegotiation CAC schemes is the degradation ratio which is defined as the ratio of the number of degraded calls to the number of ongoing calls (Kwon, Choi, Bisdikian, & Nagshineh, 1999). Moreover, the degradation probability can be determined through network measurements. Higher or lower degradation probabilities correspond to how aggressive a CAC design approach is.

The reverse procedure is followed when enough available resources exist to offer higher rates to ongoing calls. This rate upgrade policy can be applied in two ways. According to the first one, a rate adaptive resource allocation scheme is employed to exploit the available resources (Li & Chao, 2007). According to the second one, the calls having had their rate decreased more recently are the first calls to have their rate restored (Tragos, Tsiropoulos, Karetos, & Kyriazakos, 2008). If enough available resources still exist, a resource allocation scheme is employed to assign them to ongoing users.

QoS renegotiation, especially rate degradation must be used carefully and should be the last step of a CAC scheme in an effort to acquire the resources necessary for the admission of a new call. There are many applications, such as voice calls or video streaming, with rates that cannot be reduced (QoS degradation) at not noticeable levels by the user. A drawback of rate adaptive CAC schemes comes up when a network operates near congestion. Then, a certain number of calls may undergo multiple rate degradations followed by respective rate restorations, as call requests arrive and ongoing calls are terminated, respectively. As users are sensitive to rate fluctuations, it is preferable to employ appropriate thresholds in the rate upgrade procedure which implies that a rate upgrade is done only if the available resources remaining after the upgrade are above the threshold (Tragos, Tsiropoulos, Karetos, & Kyriazakos, 2008).

5. Conclusion

In this chapter the importance of CAC in wireless networks for providing QoS guarantees has been investigated. CAC algorithms are important for wireless networks not only for providing the expected QoS requirements to mobile users, but also to maintain network consistency and prevent congestion. To address the problem of CAC the main term of QoS has been firstly examined. Different QoS levels supported by the network correspond to the various SCs offered to mobile users. Each SC has its own requirements and specifications which should be met to offer a satisfactory QoS to end users. Thus, various challenges arise in designing efficient CAC schemes that have been determined and thoroughly investigated in the present chapter. An important aspect of CAC schemes, to measure their appropriateness for a given network, is the criteria which should satisfy. The main idea of CAC scheme classification is that different schemes apply individual criterion on admission procedure. Moreover, various system architectures exist which demand different CAC schemes, properly designed to adapt to system characteristics. Furthermore, the concerns of the network administrator should be taken into account, applying the policy needed for revenue optimization and maximum resource exploitation through CAC. Analytical models for the most common CAC schemes have been exhibited. An efficient CAC scheme should achieve low failure probabilities, high network resources exploitation, fairness in resource allocation among different users and revenue optimization. To evaluate the performance of CAC schemes studied according to these aspects, various efficiency criteria have been presented. The key idea of this chapter, apart from offering a comprehensive study of CAC process in wireless networks, is to lay emphasis on the CAC method as a powerful tool to provide the desired QoS level to mobile users along with the maximization of network resource exploitation.

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Mobile and wireless communications applications have a clear impact on improving the humanity wellbeing. From cell phones to wireless internet to home and office devices, most of the applications are converted from wired into wireless communication. Smart and advanced wireless communication environments represent the future technology and evolutionary development step in homes, hospitals, industrial, vehicular and transportation systems. A very appealing research area in these environments has been the wireless ad hoc, sensor and mesh networks. These networks rely on ultra low powered processing nodes that sense surrounding environment temperature, pressure, humidity, motion or chemical hazards, etc. Moreover, the radio frequency (RF) transceiver nodes of such networks require the design of transmitter and receiver equipped with high performance building blocks including antennas, power and low noise amplifiers, mixers and voltage controlled oscillators. Nowadays, the researchers are facing several challenges to design such building blocks while complying with ultra low power consumption, small area and high performance constraints. CMOS technology represents an excellent candidate to facilitate the integration of the whole transceiver on a single chip. However, several challenges have to be tackled while designing and using nanoscale CMOS technologies and require innovative idea from researchers and circuits designers. While major researchers and applications have been focusing on RF wireless communication, optical wireless communication based system has started to draw some attention from researchers for a terrestrial system as well as for aerial and satellite terminals. This renewed interested in optical wireless communications is driven by several advantages such as no licensing requirements policy, no RF radiation hazards, and no need to dig up roads besides its large bandwidth and low power consumption. This second part of the book, *Mobile and Wireless Communications: Key Technologies and Future Applications*, covers the recent development in ad hoc and sensor networks, the implementation of state of the art of wireless transceivers building blocks and recent development on optical wireless communication systems. We hope that this book will be useful for students, researchers and practitioners in their research studies.

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