QoS and Radio Resource Management in Multimedia Packet Transmission for 3G Wireless IP Networks

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Abstract— **This article presents an overview of radio resource management schemes for support of multimedia applications in Packet CDMA-based systems, which are flexible to support traffic services with various QoS requirements. Packet transmission combined with Wideband Code Division Multiple Access (WCDMA) access technique defined in the Universal Mobile Telecommunication System (UMTS) provides high flexibility in resource allocation. However, this flexibility requires to design effective resource management strategies (Power, Load control, Admission Control and Packet Scheduling, and Handover Control) able to control the number of active users in a system where capacity varies according with the level of interference. Traffic and demand characterization is needed in order to map QoS requirements in the application layer into appropriate parameters that can be controlled at the physical level by these radio resource strategies (spreading factors, power). The impact of mobility into the resource availability and into the user capacity demands needs to be considered at the same time as new methodologies for network design and resource dimensioning to make an efficient use of radio resources.**

I. INTRODUCTION

As mobile communications and Internet converge, packet based evolutions of the currently developed 3G cellular access systems are believed to be significant segments of future global IP networks. This work concentrates on the 3G-uplink air interface based on the WCDMA access technique, defined in the UMTS System and focuses on effective radio resource management strategies [1] and traffic handling mechanisms in order to optimize QoS [2] in two levels: 1) grade of service (GoS) i.e. the new call blocking rate (P_{BLOCK}), and handoff failure probability (P_{LOSS}) and 2) packet level QoS, i.e delay and packet loss probability.

Current WCDMA standard (Rel'99,Rel'4,Rel'95) supports both circuit and packet switched services using fixed and variable data rates and considers circuit switched mode as the natural way for transmissions of real time services (RT) [3]. However, the standard will continue evolving for sometime, being packet transmission the most topical for future popular services. An enhancement technique in the uplink is to consider a more frequent and lower latency mobile station (MS) transport format updating, to better manage the uplink interference, controlling the time and rate transmission of MS users [4]. In order to perform this principle, a centralized demand assignment protocol has been considered in this work and implemented in the Medium Access Control (MAC) level [5]. Transmissions of both RT and non real-time services (NRT) have been performed in packetized form over the physical data channel (DPDCH). Once the dedicated channel (code) is assigned, the MS needs to wait for the base station (BS) to specify the Transport Format (TF), power and the times in which it can transmit. The scheduling disciplines at BS (Node B), in coordination with a power criterion in order to minimize intercell interference [6], are responsible for arranging packet transmissions within their specified QoS requirements, being channel conditions of MS's in mind.

The packet transmission approach provides high flexibility and higher network utilization. Benefiting from statistical multiplexing requires to characterize the performance and to known the operation limits of the low level resource allocation (physical and link level) in addition to an efficient coordination of the two traffic control mechanisms: call admission control (CAC) and flow control. Extending the scheduling and admission control separation principle introduced for broadband switching into wireless networks could be desirable in order to simplify the CAC operation [7]. CAC should only make decisions by comparing the resources required by an incoming connection request with the resources currently available in the network or with the scheduling region limits. However, this procedure implicitly assumes that network capacity remains constant over the time. This can be more or less the case of FDMA/TDMA wireless networks but not the case of CDMA systems, where the capacity varies due to stochastic changes in the interference level. The number of connections cannot longer specify a direct measure of the available capacity. It is evident that to design an effective CAC has associated a first main design problem: to set an effective CAC threshold. The acceptance of a new user connection must be conditioned by the fact that signal to interference ratio (Eb/No) values can be achieved by each existing connection once a new one is activated. Once a new connection is accepted, achieving each user transmission rate, delay requirement and error rate is closely connected with power allocation and the efficiency of the scheduling strategy implemented in the node B. In this context, results obtained from packet level should be taken into account in order to infer and support an efficient method for CAC.

Looking previous CAC research studies, the following approaches can be found in the most of them:

- CAC that derives an average cell capacity threshold based on the allowed number of active connections [8].
- CAC based on the transmitted power limits, which prevents the power control to reach a new equilibrium in power assignment [18]. A good behavior requires a complete knowledge of the propagation conditions or allowing the new call to enter the system for a trial period.
- CAC that adopt the total interference level at the base station as load measure in the admission procedure [9]. Although this threshold, coordinated with an appropriate flow control in the packet level could guarantee the signal to interference ratio for all admitted connections, packet level quality in terms of BLER is not assured within delay constraints requirements unless the appropriate threshold value was recomputed by simulations and adapted in order to guarantee QoS.

A possible approach to handle the randomness of both interference and traffic sources is to consider an effective capacity, lying between the mean and peak value, in a similar way that the effective/equivalent bandwidth concept associated to the variable bit rate sources used by CAC on asynchronous transfer mode (ATM) networks. This paper considers this approach, which has been shown effective in [10].

On the other hand, preventing forced termination of handoff calls and limiting the risk of blocking new calls is the other key requirement. In this paper we evaluate the performance of a variable channel reservation based on the estimated position and movement of mobiles stations (MS's), in order to protect the handoff connections from the new connections. Performance is evaluated considering both hard and soft-handoff. Analytical performance analysis of the proposed techniques thought Roberts approach [11] has been considered and it has been shown effective.

II. PACKET SCHEDULING

In the uplink, an optimum power allocation frame to frame, considering N scheduled MS, it is only possible if [6]:

$$\sum_{j=1}^{N} C_j = \sum_{j=1}^{N} 1 \Big/ \left(\frac{W}{r_{j,k}\gamma_j} + 1 \right) \le \frac{1-\eta(t)}{(1+f(t))} = C_{max}(t) \quad (1)$$

where r_j is the data rate, γ_j is the required signal energy per bit (E_b) divided by the total interference density (N_o) received at the base station, in order to achieve a certain quality in terms of maximum block (BLER) error rates for a user j when that is connected at data rate r_j. $f(t)$ represents the other-cell-to-same-cell interference ratio seen by the base station receiver, and $\eta(t)$ it is a parameter in order to limit the total power received at the Base Station (Node B) guarantying the output power constraints to MS's in a frame. This parameter is conditioned by the most power demanding transmitted user. $C_{max}(t)$ is the maximum available capacity in the cell and C_i is the consumed capacity by a MS in a frame. According with scheduling strategies at node B, described in [5], only a subset of the MS that has traffic to send is allowed to transmit at any given time guaranteeing condition (1). Controlling the time and MS transmissions reduces latencies in rate control, exploits fast channel quality variations and consequently allows a most efficient and correctly control of uplink interference levels.

A. Scheduling in Soft-Handoff

Soft-Handoff has been implemented according with parameters, definitions and the algorithm defined in [1] in order to incorporate to or remove cells from the cell active set. Although soft handoff has been shown to increases system capacity it requires a more complex control of MS transmissions in the packet level. Given that more than one BS (Node B) control the cells where MS is present, there are several alternatives as to the location of the scheduling entity that controls the MS transmissions. The more interesting is to consider that more than one cell could be considered as valid scheduling entities. We have considered that. This approach obviously requires the implementation of a decision procedure in the MS when receives the scheduling assignment from multiple BS. MS choose the indication that requires the minimum power. This decision ensures that the level of interference, in all the scheduling BS, is maintained below the threshold they have estimated in order to guarantee E_b/N_o for all scheduled MS's. While, MS in soft handoff is ensured to transmit with a minimum rate.

III. CALL ADMISSION CONTROL

A. Call Admission Threshold and Policy

Effective capacity (introducing the rate and delay constraint QoS requirements), associated to MS of class i $C_{i,ef}$ can be calculated as (2), where $E[C_{max}]$ is the mean of the available capacity, C_{max} , estimated in a period of time T, and N_{ma} the capacity of the system in terms of number of MS's. To obtain N_{max}, an analytical model is used in order to compute the delay distribution for individual sources considering their BLER and service rate requirements, the variable wireless capacity and the error control scheme (selective repeat algorithm is implemented) [18]. Stochastic changes in the available capacity are obtained both considering stochastic nature of ratio f in addition to changes in own cell interference due to statistics changes on traffic source transmissions. $C_{i,ef}$ associated to non real time services is calculated considering their mean bit rate in capacity C_i.

$$C_{i,ef} = E[C_{max}(T)] / N_{max} \quad (2)$$

$$N_{max} = \max(Ni \big| \ \forall_{k=0:N_i} \ \Pr[delay_k > D\max_k] \le \varepsilon_i) \quad (3)$$

For an integration of several real time users with different BLER and rate requirement, it is immediate considering the effective capacity computed separately for each type of traffic. So, a linear approximation can be used to find the total resources required by all the MS's. However when different delay requirements are considered, it could be necessary, in some cases, to define a little reserve of capacity in order to prevent little deviations from the linear approximation.

B. Call Admission Policy

Provision of QoS in the call level focuses on developing call admission policies to minimize the forced termination of handoff calls and the risk of unnecessary block of new calls. Allocate resources in all future cells that the MS may visit for the time interval during which the MS will reside in each cell, it is only feasible if exact knowledge of the mobile path and arrival and departure times to every cell along the path is available. Obtaining exact knowledge of MS mobility is not possible in most cases, due to the uncertainty of the mobile environments and the difficulty in specifying the mobility profiles of MS. In our case, CAC decision is made in a distributed manner. Each BS makes an admission decision by exchanging state information with the adjacent cells periodically. BS's estimate the future MS handoffs using information of power and quality measurements reported by each MS. We assume that the power measurements will come from the current and adjacent cells. The control system knows which of the adjacent cells are potential candidates to handoff, especially when channel degradation becomes important. A MS placed in a degradation area, defined in the limits of the cell, has high probability to handoff within a time interval. Using information about the evolution in the power levels received by a MS in this region, it could be possible predict in some cases the direction of movement of the MS and prevent in some cases unnecessary resource reservation.

Therefore, when a MS i is predicted to handoff an indication of a reserve of capacity equal to $C_{i,ef}$ is sent to the predicted destination in order to pre-allocate resources for the expected handoff. A reservation may be estimated no longer required and be cancelled. Reserves are interchanged periodically between cells. So, a handoff call is accepted if:

$$\sum_{i \in cell} C_{i,ef} + C_{new\_handoff,ef} < E[C_{max}] \quad (4)$$

whereas a new call is only admitted if:

$$\sum_{i \in cell} C_{i,ef} + C_{new,ef} + \sum_{j \in adj\_cells} C_{j,pr\_adj\_handoff} < E[C_{max}] \quad (5)$$

where $C_{j,pr\_adj\_handoff}$ is the reserve of capacity associated to the

MS's from the adjacent cells. Note that false reservations increase the blocking probability for new call request. However, call handoff requests are treated equally independently that the specific MS had made a reservation or not. All the reserved capacity at any moment is used in a complete shared way to serve handoff requests. After a successfully handoff, the reserve of capacity, if available, is decreased in the corresponding $C_{i,ef}$.

C. Mobility and Traffic Characterization

From the point of view of the mobility, the most interesting parameters are the channel holding time and the handoff probability. These parameters are necessary to obtain an accurate analysis of P_{BLOCK} and P_{LOSS}. The channel holding time is defined as the time spent in a cell by a user in communication prior to handoff (or subsequent handoff) or the time until the call completion. It is the minimum of two random variables associated with the call/connection holding time and the cell dwell time, respectively. Cell dwell time or the cell residence time is the time a MS spends within BS covering so that a link of acceptable quality can be maintained. Depending on whether a call is originated in a cell or handoff from a neighbouring cell, two different cell residence times must be specified: the new call residence time, $\overline{\tau}_{dwell} = 1/\mu_{i,dwell}$, and the handover call cell residence time, $\overline{\tau}_{dwell\_sub} = 1/\mu_{i,dwell\_sub}$, respectively. Both times are two random variables whose distributions have to be found. A realistic characterization is important in order to have an appropriate traffic model that reflects the traffic situation and the user mobility patterns. For the sake of convenience and tractability, most traffic analysis made the assumption that call holding and dwell time are exponentially distributed and consequently the channel holding time, although the assumption could be not too realistic. Factors such as mobility and cell shape and size cause the dwell time to have different probability distribution function to that of call duration. This difference could be greater to higher mobility and smaller cell sizes. Several authors suggest more realistic random variables in order to model new and handover call residence time. A gamma, lognormal or a mixture of lognormals, sum of hyper exponentials, or hyper_erlang distribution could be considered [16]. However, in general the objective is to retain the Markovian properties that are required to model call system performance by a multidimensional birth-death process.

Nevertheless, given that P_{BLOCK} and P_{LOSS} are insensitive to channel holding time distribution, when the assumption of both new and handoff call arrival is Poisson distributed is true; we have adopted the exponential assumption. Analytical models will likely have to be coupled with measurement based mechanism in order to estimate mean dwell times for each traffic class according from its mobility pattern, given that handoff probabilities are easy derived from new and handoff channel holding times. Note that although effects of using exponential distribution in general network analysis could be relative, these affects shall higher if we planning to apply them to the estimation of the amount resources we must to reserve in a cell. In this case, obviously it is necessary a more accurate model. Reservation of resources and MS call arrival prediction are closed related. An accuracy prediction of the mobile's path reduces the number of BS that may reserve resources for handover calls and consequently the overall system efficiency.

D. Analytical models

Once an effective capacity is derived for the variable rate connection, the behavior of the wireless multimedia system could be considered like a multirate circuit-switched or virtual circuit-switched system. Really, the effective capacity depends on QoS and on the mix of other traffic sources. However, simulation results shows that most of the time it is possible to consider conservative equivalent bandwidths that can be shown as independent on the mix of traffic sources and or which suffer only very slight variations. In these cases, to obtain an analytical solution, under the assumption of Poisson arrivals, there are two basic approach: the first one is based on multidimensional Markov chains, where the system states are described by the number of active calls of each traffic class. The multi-dimensional state space has as many dimensions as the number of traffic classes. In the absence of a product form, this is the case of considering adaptive resource reservation schemes, calculating the resource occupancy distribution involves numerically solving the balance equations, with is prohibitively demanding. Alternatively, as a second approach, is possible to use several methods for approximating the blocking probabilities. In [11] are considered and evaluated one-dimensional methods based on solving the marginal distribution of resource occupancy (*Roberts* and *Convolutional* approach); and two-dimensional approximations where it is considered the joint distribution of the pairs: total amount of capacity in use and amount of capacity in use by each class of traffic sources. In *Roberts* method, the multi-dimensional the state space is mapped into a one-dimensional state space without affecting the resulting blocking and handoff loss probabilities. The number of occupied basic resource units defines the states of the traffic model and a recursive solution is proposed in order to obtain GoS parameters. Each call classes can be required a variable number of resources and the method can be extended to trunk/adaptive reservation schemes. Although multi-dimensional approach is more accurate, in most cases of practical interest results provided by the simplest one-dimensional approach could be considered enough.

To obtain the one-dimensional state space, a bandwidth discretization is used, where a basic bandwidth unit ΔC is defined. Considering that the maximum available capacity and the effective capacity are defined by $\hat{C}_{\max} = C_{\max}(T)/\Delta C$ and $\hat{C}_{i,ef} = C_{i,ef}(T)/\Delta C$, respectively; the stochastic variable representing the total amount of capacity in use is denoted by $C_c := \sum_{i=1}^{I} \hat{C}_{i,ef} n_i$, where n_i is the number of class i calls admitted in the system. Unnormalized state probabilities $p(c) = p(C_c = c)$ for $c=1,\ldots, C_{max}(T)$ may be recursively obtained , considering the CAC policy proposed using:

$$
\begin{aligned}
&p(c) \approx 1 && \text{if } \ c = 0 \\
&p(c) \approx 0 && \text{if } \ c < \min(\hat{C}_{i,ef}) \ \text{and} \ i = [0,\ldots I] \\
&p(c) \approx \frac{1}{c}\sum_{i=1}^{I}\left(\frac{\lambda_{i,n}}{\mu_{i,n}}u_n(c-\hat{C}_{i,ef}) + \frac{\lambda_{i,h}}{\mu_{i,h}}u_h(c-\hat{C}_{i,ef})\right)p(c-\hat{C}_{i,ef}) && \\
& && \text{if } \ \min(\hat{C}_{i,ef}) \le c \le \hat{C}_{\max}
\end{aligned}
\tag{6}
$$

where new and handoff arrival rates are Poisson process with rates $\lambda_{i,n}$ and $\lambda_{i,h}$, respectivelly and mean channel holding times $1/\mu_{i,n}$ and $1/\mu_{i,h}$. CAC for new class-i calls, $u_n(c-\hat{C}_{i,ef})$, and handover class-i calls, $u_h(c-\hat{C}_{i,ef})$, considering a system capacity occupation of $c-\hat{C}_{i,ef}$ units, are computed respectively as:

$$u_n(c-\hat{C}_{i,ef}) = p_r(r \le \hat{C}_{\max} - c) \quad (7)$$

$$u_h(c-\hat{C}_{i,ef}) = 1 \qquad \text{if } c \le \hat{C}_{\max}$$

The probability p_r represents the probability that the number of reserved resources, r, is at least equal to the remaining available capacity after the admission of the new or handover call. After normalization the state probabilities are computed using $p(c) = p(c) / \sum_{i=1}^{\hat{C}_{\max}} p(c)$. This approach is similar to the approximation by Roberts for the standard trunk reservation strategy with fixed admission thresholds.

In order to compute probability p_r we shall assume that the handoff process (and CAC process) and the capacity reservation processes are independent. This assumption is performed in order to provide analytical tractability to the problem. Obviously, correlation between handoffs and reservation request increases as long as the degradation area becomes larger and when soft handoff operation is considered. In this case analytical results provides and upper bound of the loss probability. Roberts approach will be also used in p_r calculus. We shall assume that the arrival of reservation request from class i calls is a Poisson process with rate $\lambda_{i,r}$. Capacity reservation holding time in a cell is assumed to be exponentially distributed with mean $1/\mu_{i,r}$. Due to the need of considering canceling false reservation, $\lambda_{i,r}$ and $1/\mu_{i,r}$ includes both right and false reservation arrival rates and holding times.

$$p_r(c) \approx 1 \qquad \text{if} \quad c = 0 \quad (8)$$

$$p_r(c) \approx 0 \qquad \text{if} \quad c < \min(\hat{C}_{i,ef}) \text{ and } i = [0,\ldots I]$$

$$p_r(c) \approx \frac{1}{c}\sum_{i=1}^{I}\left(\frac{\lambda_{i,r}}{\mu_{i,r}}\right) p_{res}(c-\hat{C}_{i,ef}) \quad \text{if} \quad \min(\hat{C}_{i,ef}) \le c \le \hat{C}_{\max\_r}$$

$$p_r(c) = \frac{p_r(c)}{\sum_{i=1}^{C_{\max\_r}} p_r(c)}$$

Blocking new calls and handoff loss probabilities for class-i calls are computer using expressions (9) and (10).

$$P_{i,BLOCK} = \sum_{c=0}^{\hat{C}_{\max}-\hat{C}_{i,ef}} \left(1 - p_r(r \le \hat{C}_{\max} - \hat{C}_{i,ef} - c)\right) p(c) + \sum_{c=\hat{C}_{\max}-\hat{C}_{i,ef}+1}^{\hat{C}_{\max}} p(c) \quad (9)$$

$$P_{i,LOSS} = \sum_{c=\hat{C}_{\max}-\hat{C}_{i,ef}+1}^{\hat{C}_{\max}} p(c) \quad (10)$$

IV. SYSTEM AND TRAFFIC MODEL

We propose a cellular system model composed by 19 hexagonal cells (radius=2Km). Only interference from the first-tier of adjacent cells is considered. Wrap-around technique is used to avoid border effect. Macrocell propagation model proposed in [13-14] is adopted for path loss. Log-normally distributed shadowing with standard deviation of $\sigma = 8dB$ is added [12] and a multi-path fading environment proposed in [14] is considered. MS's have a maximum output power of 27 dBm according with class 2 defined in [14], and move with a speed between 25 to 50Km/h. Initial localization is selected randomly (uniform distribution). MS can change its direction of movement within an angle of $\pm\pi/6$ each 1s and 20s.

Two kinds of traffic sources: Real Time Services (Class I.1- Data services with delay constraints of 300 ms and Class I.2 data services with delay 150ms) and Non-real Time Services (Class II - Data services with non-delay constraints) are considered. Convolutional coding rate ½ together with a retransmission scheme (ARQ) are used to achieve BLER=10^{-2} in both cases. Real-time sessions are based on Packet Calls with a number of packets exponentially distributed with mean 35 packets (Class I.1) and 40 packets (Class I.2), while a service of 36kps (transport block of 360bits and real transmission rate of 120kbps) is assumed. Average inter-packet arrival time is 10ms, while packet call inter arrival time is exponentially distributed with mean 1s. On the other hand we assume that each user generates a single connection/call and connection/calls arrive to the system according to a Poisson process of intensity λ. Call length is exponentially distributed with mean 180s and a user leaves the system as soon as the call ends. Non-real time traffic sources are based on the model presented in [15]. Two types are considered: 8kbps and 32Kbps data rate services.

V. SIMULATION RESULTS

We present some results in order to assess the performance of the connection admission control. Figure 1 compares variable reservation method for CAC with complete sharing for an integration of RT and web services (50% class II.1 and 50% class II.2) Results show that variable reservation improves results in terms of call blocking vs. handoff dropping probability. On the other hand, packet-dropping probability for real time services is always maintained under quality constraints. (1% is considered as quality criterion). Thus, CAC threshold has been shown effective.

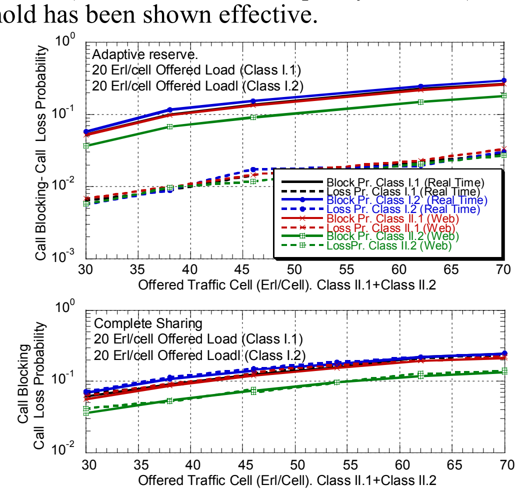

Figure 1. New call blocking and handoff call loss probability for adaptive and complete sharing

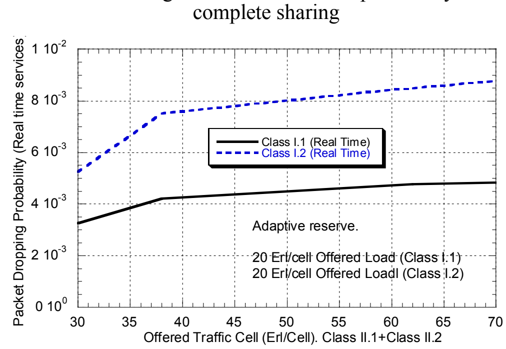

Figure 2. Real time packet dropping probability

Figure 3 shows, that for the same scenario, Roberts based analytical approach could be considered enough in order to compute loss and blocking probability. In order to compute GoS, mean dwell holding times for both new and handoff calls have been measured from simulations, while channel holding times, handoff probabilities and handoff arrival rates are derived considering exponential distributions for both call and dwell times. On the other hand reservation arrival rates and mean reservation holding times are derived from the simulation results.

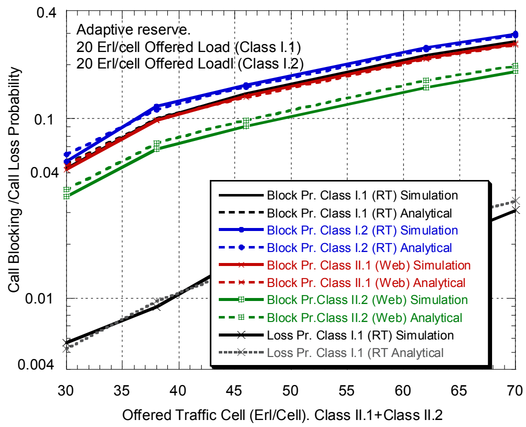

Figure 3. Analytical vs simulation new call blocking , handoff call loss probability

While results from Figures 1-3 are obtained considering hard handoff, Figures 4 and 5 show that the proposed CAC threshold also allows guarantee QoS in terms of dropping probability for real time services when Soft Handoff is considered. Decision procedure implemented in MS, although could be seem to be conservative, protects transmission of all scheduled MS's. The scenario considers a fixed offered traffic of class I.1 while offered traffic of class I.2 increases from 36 Erl/cell to 84 Erl/cell.

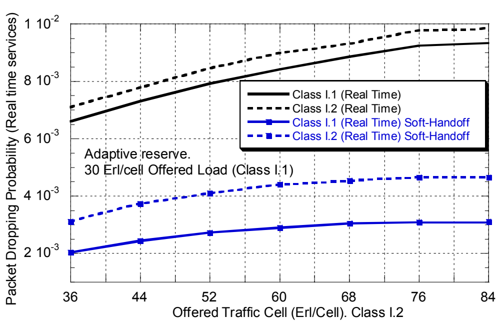

Figure 4. Hard vs Soft Handoff. Real time packet dropping probability

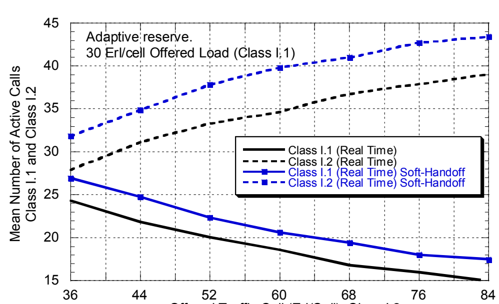

Figure 5. Hard vs Soft Handoff. Mean number of active calls.

Soft Handoff improves not only QoS at the link level (packet dropping probability - Figure 4) but also increases capacity in cells. A higher number of active calls are allowed in cells (Figure 5).

VI. Conclusions

In this work we have evaluated the performance of a CAC method for W-CDMA UMTS networks. Computer simulation results demonstrate the efficiency of the CAC threshold in a multimedia scenario and also the effective handoff priority provided by the proposed distributed-adaptive CAC policy. Performance is evaluated considering hard and soft-handoff several MS mobility behavior. In soft handoff we have considered that all BS in the MS active set are valid scheduling entities and that it is required an additional decision procedure in the MS when the MS receives the scheduling assignments. On the other hand, analytical performance analysis of the proposed techniques thought Roberts approach has been shown effective.

Acknowledgment

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