A QoS-Aware Call Admission Control Algorithm for 3G Cellular Wireless Networks

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Abstract— **The 3G cellular mobile systems which are based on WCDMA technology are expected to be interference limited. Soft capacity is one of the main characteristics of 3G (i.e, UMTS) and it requires new radio resource management strategies to serve diverse quality of service requirements. In this paper, a WCDMA prioritized uplink call admission control (CAC) algorithm for UMTS, which combines QoS negotiation and service differentiation by priority, is studied. This CAC scheme gives preferential treatment to high priority calls, such as soft handoff calls, by reserving some bandwidth margin (soft guard channel) to reduce handoff failures. In addition, queuing is also used to enhance the handoff success probability. The algorithm uses the effective load as an admission criterion and applies different thresholds for new and handoff calls. Finally, the study considers two types of services: voice and data calls. Results indicate that this algorithm reduces the drop handoff calls and increases the total system capacity; hence the GoS and the system performance can significantly be improved especially in case of high mobility environments.**

Index Terms — **Connection Admission Control, Load Estimation, Queuing, SIR, Soft Handoff, WCDMA.**

I. INTRODUCTION

Third generation radio communication systems are designed to offer multimedia services, including voice and video telephony and high-speed Internet access. In Universal Mobile Telecommunication System (UMTS), the radio interface is based on the Wideband Code-Division Multiple Access (W-CDMA) technology. UMTS WCDMA is a Direct Sequence CDMA system (DS-CDMA). WCDMA has two basic modes of operation: Frequency Division Duplex (FDD) and Time Division Duplex (TDD). In the FDD mode, uplink and downlink transmissions use different frequency bands while for the TDD mode, uplink and downlink transmissions can be implemented on unpaired bands but separated by a guard period. In this paper DS-CDMA (FDD) is considered [1]-[3].

The measurement of the resource capacity in a spread-spectrum system is distinct from that for conventional TDMA/FDMA systems. In conventional TDMA and FDMA systems such as IS-54 (TDMA) and GSM (hybrid TDMA/FDMA), the number of traffic channels is fixed. It is determined by the number of time slots in the TDMA system or by the number of non-overlapping frequencies in the FDMA system. The spread spectrum system, such as WCDMA, does not have a fixed number of channels. Instead, the capacity of the CDMA system is limited by the total interference the system can tolerate. Such a system is referred to as an interference-limited system. Each additional active mobile user will increase the overall level of interference. Normally, the interference level increases rapidly when the system load reaches a certain level. Users with different traffic profiles and attributes such as the service rate, the signal-to-Interference ratio (SIR) requirement, media activity, etc. introduce different amounts of interference to the system. These factors are especially important in 3G wireless networks that support multimedia services [8]-[13].

The coverage of WCDMA is assumed uplink limited in high-load scenarios. Referring to [11], the capacity of DS-CDMA networks depends on the reverse link (uplink) rather than the forward link (downlink). Uplink call admission control strategies play a very important role in the performance of CDMA systems as it directly controls the number of users in a cell and thus limit the interference in the system. In this paper only the uplink direction is considered.

The rest of this paper is organized as follows. In section II the admission control strategy in the uplink direction with the general problem formulation is presented. In section III, the formulas for calculating the uplink capacity and estimating the increase in the load level caused by incoming user are derived. Section IV describes the system model and explains the proposed admission control in WCDMA systems while section V presents the simulation model, the obtained results, as well as the discussion. Finally, the paper is concluded in section VI.

II. UPLINK ADMISSION CONTROL AND RELATED WORK

A call admission control algorithm is needed to limit the interference by controlling the number of accepted flows. The CAC is performed for the uplink and downlink transmissions separately because the traffic load can be asymmetric. The new user is admitted into the system only if the both uplink and downlink admission control requirements are fulfilled. In this paper only the uplink admission control is considered.

Several uplink CAC algorithms have been developed in UMTS [1]. Some of them are based on a predetermined maximum number of users in the system. For the number-based call admission control schemes (NCAC), the QoS requirement, in terms of bit-error-to-interference ratio, is mapped into a maximum number simultaneous users that can be accommodate in the system. Other algorithms are more CDMA-oriented and consider the SIR as the determinant parameter in accepting or not accepting a new call. Those algorithms are commonly called Interference-CAC (ICAC) [1]-[7]. Based on previous studies [1]-[7], the interference-based schemes can be further classified into:

- *Wideband Power-based CAC*: This method computes the increase in the interference (power) caused by the establishment of a new user in the cell in uplink and accepts the call only if the total interference does not exceed a predefined threshold.
- *Throughput-based CAC*: A throughput-based CAC algorithm computes the increase in the load caused by the establishment of a new user in the cell in uplink and accepts the call only if the total load does not exceed a predefined threshold.
- *Signal to noise interference ratio-based CAC*: This algorithm computes the minimum required power for the new user and accepts it if it is not below a predefined minimum link quality level.

A. Research Contributions of this Paper

In this paper a variant of the throughput-based CAC is considered. This scheme differentiates between two types of services and gives the higher priority to soft handoff calls by using a soft load factor margin and by implementing queuing techniques. Rejection of soft handoff requests causes forced termination of an ongoing real-time call, which is a severer problem than blocking of new call attempts. This admission control scheme can guarantee a higher QoS for the soft handoff requests of real-time services in 3G DS-CDMA systems by introducing the idea of soft guard channel to prioritize soft handoff calls. Unlike FDMA or TDMA systems, which use frequency bands or time slot as resources for 'hard' guard channels, the resources in CDMA cellular systems are interference limited. To prioritize the soft handoff calls, a certain amount of cell load is reserved exclusively soft handoff calls. In addition, queuing is also used to enhance the handoff success probability.

B. Relation to Previous Work

In [5] A CAC algorithm using total received power as thresholds when there exist multiple types of services is proposed. By setting the higher threshold to voice traffic, the voice traffic is given a higher priority than data traffic. Multiple threshold schemes are investigated and their performance is compared with that of a single threshold-based scheme. Also In [1], a received power based algorithm is proposed, and when higher priority is desired for handoff calls, it allows different thresholds for new calls and handoff calls. In [3] an interference-based admission control strategy with multi level threshold is analyzed. Two classes of traffic are considered and the higher priority class is given higher threshold. The reference in [4] provides a study of threshold-based call admission control in CDMA. Different interference thresholds are employed for new and handoff calls. The interference threshold for handoff calls is higher than that for new calls.

Our algorithm differs from those algorithms in terms of using the cell load as an admission criteria and also using queuing as an additional priority techniques for handoff calls. Also, the handoff calls is divided into two classes (voice and data), each has its own QoS requirements. In addition, the capacity estimate of WCDMA systems is formulated. So, before presenting the description of this uplink admission control studied in this paper, the next section will present the uplink capacity calculation and load estimation (in term of interference) for the WCDMA system. This estimation provides the key criterion in designing the admission control.

III. CAPACITY AND LOAD ESTIMATION IN W-CDMA SYSTEMS

To implement the admission control for WCDMA systems, first an estimate of the total interference should be computed to be employed in the decision process of acceptance or rejection of new connections. In this section the uplink capacity and load estimation of a homogenous, uniformly loaded network will be presented. The analysis carried out will focus on the UTRA–FDD mode. Furthermore, the analysis assumes perfect power control operation. Hence, a mobile station (MS) and its home base station (BS) use only the minimum needed power in order to achieve the required performance. The CDMA capacity has been subject to extensive research work,[8]-[13], hence only a short description is given here.

The value of the bit-energy-to-noise-density ratio E_b / N_o corresponds to the signal quality, since it determines the bit error rate, BER. Let ρ be the target bit-energy-to-noise-density ratio required to achieve a particular BER, or equivalently a particular frame error rate ($E_b / N_o \geq \rho$). That means the maximum bit (BER) or blocks (BLER) error rates, can be mapped into an equivalent E_b / N_o constraint denoted by ρ .If we assume perfect power control, then $E_b / N_o = \rho$. The resulting BER can then be approximated using:

$$Q\left[\sqrt{\frac{2E_b}{N_o}}\right] \approx \frac{e^{-\frac{E_b}{N_o}}}{2\sqrt{\pi \frac{E_b}{N_o}}} \tag{1}$$

In the uplink, the criteria for the received power for i^{th} MS can be written as:

$$(E_b / N_o)_i = \frac{G_i * P_i}{I_{own}(1+f) - P_i + I_o} \geq \rho_i \; ; i = 1,2,...N \tag{2}$$

$(W / R_i)_i = G_i$: is the spreading factor or the processing gain for MS i.
R_i : The bit rate of MS i
W : The chip rate of the WCDMA (3.84 Mcps)
ρ_i : The required E_b / N_o for the mobile i and for a certain service quality
P_i : received power of the desired signals
$P_{j,j \neq i}$: The power of unwanted signals
I_o : The thermal noise (background noise power in the case of an empty cell relieved at base station)..
I_{own} : The power received from the MSs connected to the same BS as the desired MS (including the impact of wanted signals).
I_{oth} : The power received from the MSs connected to the other cells, and
vi : the average voice activity factor indicating the portion of time when the user is actively transmitting.
Using the above definitions, the total interference on the uplink, I_{total} , is the sum of I_{own}, I_{oth} in addition to the thermal noise, I_o. Finally, the ratio of I_{oth} to I_{own} is denoted by *f*, i.e.

$$f = \frac{I_{oth}}{I_{own}} \tag{3}$$

Form (2), it is easy to derive the minimum required power (sensitivity), *Pi*:

$$P_i = \frac{1}{(\frac{G_i}{\rho_i} + 1)} * I_{total} = \Delta\eta_i * I_{total} \tag{4}$$

Where $\Delta\eta_i$ is called load factor increment for the new user *i* (load factor of one connection).therefore,

$$\Delta\eta_i = \frac{1}{(\frac{G_i}{\rho_i} + 1)} \tag{5}$$

The total load factor η of such an interference system is the sum of the load factor increments brought by *N* active mobile users. Therefore,

$$\eta = \sum_{i=1}^{N} \Delta\eta_i = (1+f) \sum_{i=1}^{N} \frac{1}{(\frac{G_i}{\rho_i} + 1)} v_i \tag{6}$$

Assuming perfect power control on the reverse link, and that every user has the same service rate (constant *R*, *v*, and ρ), equation (1) Can be rewritten as

$$\rho = \frac{G * P}{I_{own}(1+f) - P_i + I_o} = \frac{G * P}{(N-1)Pv(1+f) + I_o} \tag{7}$$

Using (7) one can calculate the maximum number of simultaneously active users which can be permitted as:

$$N = \left\lceil 1 + \frac{\eta G}{\rho v(1+f)} \right\rceil \tag{8}$$

When the system is 100% loaded, it has reached pole capacity or the maximum theoretical capacity of WCDMA system. Letting the $\eta \rightarrow 1$ in (8) yields:

$$N_{POLE} = \left\lceil 1 + \frac{G}{\rho v(1+f)} \right\rceil \tag{9}$$

IV. SYSTEM MODEL AND ASSUMPTIONS

This section provides a brief description of the system under study. The throughput-based CAC algorithm computes the increase in the load caused by the uplink admission of a new user in the cell $\Delta\eta_i$ and accepts the new connection only if the following inequality is satisfied,

$$\eta_i + \eta \leq \eta_{Thr.i} \tag{10}$$

Where η_i is the current uplink load of the cell and $\eta_{Thr.i}$ is the uplink load threshold.

We consider a single cell with perfect power control in a homogenous and uniformly loaded network. Since the network is assumed to be homogeneous, the performance of the system can be deduced from the performance of a single cell analyzed in isolation. Only uplink direction is considered and it is assumed that whenever the uplink channel is assigned the downlink is established. Two types of services are considered, voice and data. Each type has two classes, newly originating calls and soft handoff calls. The soft handoff calls have higher priority than new calls. The system contains a separate queue for each handoff calls type and a predetermined load threshold. The system model is depicted in Fig. 1.

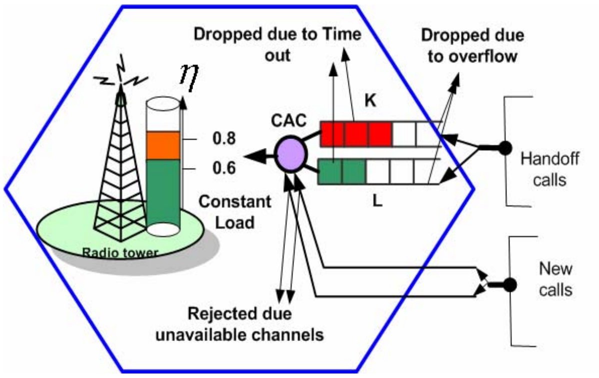

Fig.1 : Detailed Cell Model

The arrival process of new and handoff calls is Poisson with rates, λ_{h1}, λ_{h2}, λ_{n1}, λ_{n2} for voice handoff call , data handoff calls, voice new calls and data new calls, respectively. The channel holding time for each type of calls is exponentially distributed with mean μ^{-1} while the queuing time of each handoff calls class is exponentially distributed with mean γ_j^{-1}. This algorithm has the following steps:

When a call arrives, load factor threshold for new and handoff calls η_{Thr} and QoS requirements (in term of BER) are determined firstly using (1). Then the load increase of the arrived call and the current cell load factor before accepting the arrived call are calculated, η_{new} using(6). After calculating the current load of the target cell η_i, it is compared with the load factor threshold of the arrived call of type i, $\eta_{Thr.i}$. If the current cell load factor plus the load increase is less than or equal the required load factor threshold for the arrived call, then the arrived call can be admitted to enter the target cell. Otherwise, the arrived call is queued or rejected based on queue availability. Queued soft handoff calls can be accepted if sufficient bandwidth gets available, or can be terminated due to timeout.

V. SIMULATION RESULTS

A. Simulation Parameters

In this paper, two services are simulated, voice and data. Characteristics of these services are listed in Table1.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Radio Access Mode	WCDMA (FDD)
Service classes	Voice ,data
Bit rates	Voice:12.2Kbps; Data: 144Kbps
Required E_b/N_o	Voice :5.6dB; Data : 3.2dB
activity	Voice :0.4; Data : 1
Fractional load	62.5% - 65%
Interference factor (f)	0.5
Chip-rate	3.84Mbps
Thermal noise	1.0 e-15 W
Channel holding time	3 min
Arrival rate	Poisson (0.2-2 calls/sec)
Channel holding time	Exponential (3 min)
Queue limit	0,5
Queuing time	Exponential (15 s)

The system bandwidth is 5MHz, and power control is assumed to be perfect.

B. System Performance

This proposed Algorithm is evaluated based on three Quality of Service (QoS) metrics: The blocking probability for newly originating calls, the forced-termination probability and the total system carried traffic. The blocking probability is the probability that a new call is denied access to the system, while the forced-termination probability is the probability that a call that has been admitted will be terminated prior to the call's completion. The Grade of service is considered here to evaluate the system performance and defined as:

$$GoS_j = \alpha * P_{hj} + P_{nj} \tag{11}$$

Where $P_{hb,i}$ is the handoff blocking probability, and $P_{nb,i}$ is the new call blocking probability of calls belonging to traffic of type j. $\alpha = 10$, which indicates priority level for handoff call to new call. Smaller GoS means better system performance. The system capacity is evaluated using the total carried traffic (i.e., rate of call departure), so as the total carried traffic increase the system capacity in term of supporting more calls increases. The total carried traffic is evaluated using:

$$CT = \lambda_{h1}(1-P_{h1}) + \lambda_{h2}(1-P_{h2}) + \lambda_{n1}(1-P_{n1}) + \lambda_{n2,j}(1-P_{n2}) \tag{12}$$

C. Result Discussions

New calls and handoff calls are treated differently. Handoff calls are given higher priority to new calls, and load factor threshold for handoff calls and new calls are different. Handoff calls share residual capacity exclusively besides sharing available capacity with new calls. In simulation we consider the following three scenarios:

Scenario1: All call services classes (new calls and soft handoff calls) are treated equally where they have the same load threshold and no queuing is used.

Scenario2: Same as 1, and in addition to that, the handoff calls are allowed to be queued till the resource is available or the time out is reached.

Scenario3 (proposed algorithm): Same as 2, and in addition to that, the handoff calls have higher load threshold than new calls. This scenario is repeated using different channel holding times.

Average service time for all services is 180 seconds. Arriving rates of all services are changed. Scenario3 is repeated using different service times (120s and 90sec). Fig. 2 depicts voice (GoS) vs. arrival rates while Fig. 3 depicts data (GoS) vs. arrival rates. From these figures, it is clear that the performance improves as we use the queue and the soft guard channel. Also, as the channel holding time decreases (for example mobility increases) the system performance increases. So as the service time decreases the waiting calls will have better chance to get the channel before they timed out.). Fig. 4 depicts the total system carried traffic vs. the total offered traffic. It is clear that our proposed algorithm has better system capacity and this improvements increase as channel holding time decreases. In general as shown in these figures, the system has a better performance under this proposed algorithm.

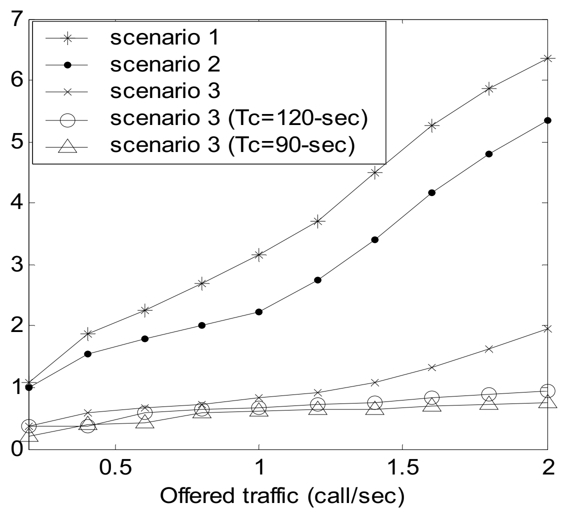

Fig. 2 :GoS for voice calls

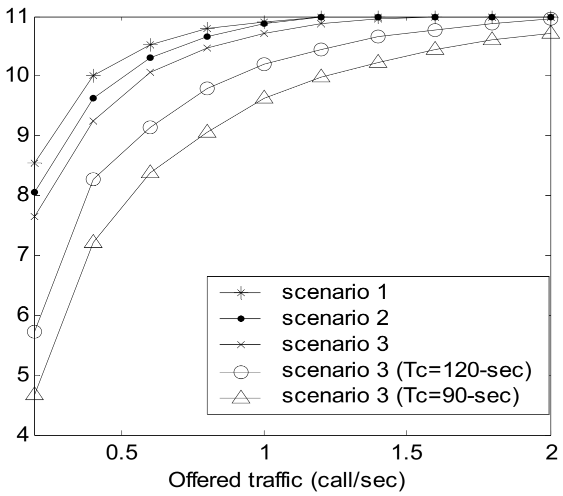

Fig. 3 : GoS for data calls

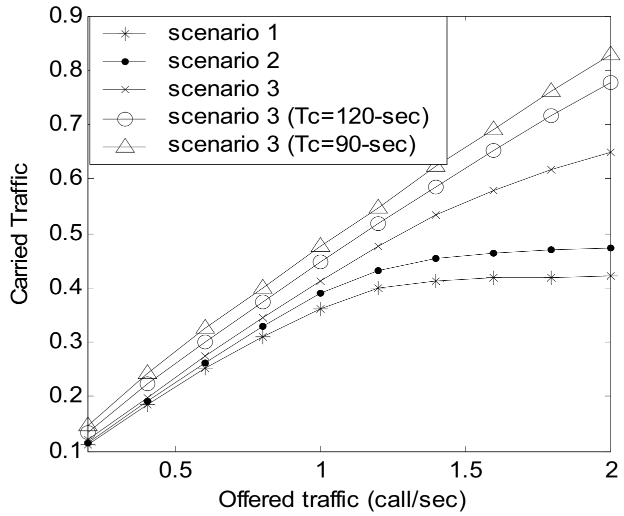

Fig. 4: System Carried traffic

VI. CONCLUSION

Call admission control is a very important measure in CDMA system to guarantee the quality of the communicating links. In future wireless networks multimedia traffic will have different QoS requirements. In this paper, the uplink capacity and load estimation formulas is formulated. Then, a prioritized throughput-based uplink call admission control algorithm for a WCDMA cellular system with perfect power control is presented. To give priority to soft handoff calls, we introduce queuing techniques and the idea of 'soft guard channels', which is represented by reserving a small fraction of the cell load for the higher priority calls. The performance of this admission control with different scenarios is studied. Based on simulation results, we conclude that this algorithm reduces the dropped soft handoff calls and improves the over all system capacity.

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