QoS and Load Management via Admission Control in UMTS Forward Link

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***Abstract*— In downlink WCDMA systems, QoS and load management can be performed by a Call Admission Control (CAC) algorithm. The objective of CAC is to guarantee high capacity and system stability, by accepting or denying an arriving bearer service access to the system depending on the system load, the interference it adds to and receives from the existing connections and the Base Station (BS) power limitation. Our contribution envisages the proposal of a flexible CAC framework regarding handover resource reservation, traffic activity monitoring and initial power allocation, in order to maximize the system capacity, while meeting Quality of Service (QoS) requirements throughout the dynamism of the connection duration.**

I. Introduction

Radio Resource Management (RRM) algorithms for the forward link of UMTS networks have engaged lots of attention recently, since it seems to be that the capacity of such systems will be limited by the downlink direction, mainly in asymmetric traffic scenarios [1]. Among the RRM techniques, Call Admission Control (CAC) is one of the most important algorithms in wireless mobile communications networks. Although it has been studied extensively in the uplink, there is an interesting room for research concerning adaptive CAC in the downlink [2]–[4].

The objective of CAC is to guarantee high capacity and system stability, by accepting or denying an arriving bearer service access to the system depending on the system load, the interference and the BS power limitation.

There are two resources that must be allocated and shared properly in order to accomplish an efficient trade-off between capacity and quality in the forward link of UMTS systems: BS transmission power, which is a limited resource, and interference, which is highly dependent on the user location and channel conditions. The former is responsible for blocking and dropping calls due to power unavailability, thus impacting the system capacity. The latter must be kept below a tolerable level in order to avoid congestion situations and guarantee a reasonable quality represented by the Frame Erasure Probability (FEP) of the whole connection. In this way, a call admission procedure is employed to decide whether accept or reject a new bearer service depending on the BS downlink power limitation and the system interference, aiming to enhance the system revenue.

In this contribution, we present a flexible CAC framework focusing on the minimization of the blocking and dropping probabilities with guarantee of acceptable QoS for the conversational service class over downlink dedicated channels (DCH). Not only will the dynamism of RRM algorithm functionalities be taken into account but the traffic pattern of such traffic class and system load feasibility as well. Power reservation for handover calls and inactive connections and initial transmission power scaling for new calls will be assessed in a unified manner.

II. Dynamic Simulation Modeling

In order to perform a complete dynamic system-level evaluation of the UMTS WCDMA-FDD system, a simulation tool named $WIDE_{SIM}$ (WCDMA Downlink Dynamic System-Level Simulator) was projected. Particularly, the mutualism among the Call Admission Control and other radio resource management algorithms, such as Power Allocation, Power Control and Handover control is investigated.

The simulation environment is an hexagonal multi-cell deployment with uniformly distributed mobile terminals. The simulated system consisted of 16 cell sites, each serving three hexagonal sectors. A wrap around technique is used to avoid border effects in interference calculations.

The multi-rate strategy used in $WIDE_{SIM}$ is the single-code transmission scheme and the Conversational traffic class (12.2 kbps) is assessed. Connections are initiated following a Poisson process and call durations are exponentially distributed. The ON-OFF traffic pattern modeled in the simulator is based on [5].

The macrocell test environment that was considered is the Vehicular Test Environment with low-speed users at 3 km/h [5]. The propagation effects considered are mean path loss, slow variation in the signal due to shadowing, and rapid variation due to multipath effects and scattering. The impact of multipath propagation on channel fading, downlink orthogonality loss and RAKE receiver performance are included in the simulations.

Our power and handover control strategies are strongly based on the UMTS proposal [1], [6], [7]. In order to focus on really remarkable issues of this specific research, an active set size equal to 1 is considered, since soft handover gains in the downlink is still an open research topic.

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III. CAC ALGORITHM CONCEPTION

The proposed power-based CAC algorithm is closely related to the initial power allocation strategy. An open-loop power control based on [8] is used to provide a coarse initial power setting at the beginning of the connection using downlink measurement reports from the user terminal. Consider that the k^{th} user demands a dedicated channel allocation from the i^{th} BS. Thus, the initial downlink power is estimated by Eq. 1.

$$P_{k,i}^{DCH} = \frac{R_k}{W} \cdot \Gamma_{k,target}^{DCH} \cdot \left[\frac{P_{k,i}^{CPICH}}{\left(\frac{E_c}{N_0}\right)_{k,i}^{CPICH}} - \overline{\alpha} \cdot P_i^{on} \right] \quad (1)$$

where W is the chip rate (3.84 Mcps); $\overline{\alpha}$ is the mean downlink orthogonality factor (0.5); R_k and $\Gamma_{k,target}^{DCH}$ are the transmission data rate (12.2 kbps) and the target value of the signal energy per bit divided by noise plus interference spectral density (4.2 dB) [1] of the k^{th} user; P_i^{on} is the active transmission power of the i^{th} BS including traffic, pilot and other common channels; $P_{k,i}^{CPICH}$ is the transmission power of the Common Pilot Channel (CPICH) of the i^{th} BS, which is the same for all BSs in the cell grid; and $\left(\frac{E_c}{N_0}\right)_{k,i}^{CPICH}$ is the wideband energy per chip divided by noise plus interference spectral density [9] measured by the k^{th} user, filtered over a time window of 10ms and reported periodically to the i^{th} BS.

The CAC strategy is based on instantaneous measurements of the available BS transmission power. By doing that, the BS transmission power constraint can be guaranteed all the time throughout the dynamism of the system. Furthermore, the QoS management functionality is aware of four QoS metrics: blocking of new calls, dropping of calls due to handover failures, dropping of connections coming back from inactivity periods and FEP of ongoing calls. In order to build a flexible CAC framework able to meet all the mentioned QoS requirements, three parameters are defined:

- Θ - This parameter defines a percentage of the maximum BS transmission power that is reserved for handover calls. It has a direct impact on the dropping rate due to handover failures;
- Ψ - It represents a percentage of the amount of power required by inactive connections that is reserved for the time when they become active again. It is related to the dropping rate due to activity monitoring;
- Φ - A scale factor that controls the percentage of the estimated initial transmission power that is allocated to the user at the beginning of its connection. It performs a trade-off between blocking rate of new call attempts and the FEP perceived by the user during its connection.

With the explanation above, we are ready to show a mathematical description of the proposed CAC framework.

When the k^{th} user tries to set up a new connection to the i^{th} BS, the CAC algorithm admits or denies this attempt in accordance with Eq. 2.

$$P_i^{on} + \Phi_k \cdot P_{k,i}^{DCH} \leq (1 - \Theta_i) \cdot P_i^{max} - \Psi_i \cdot P_i^{off} \quad (2)$$

where P_i^{on} is transmission power of the i^{th} BS including active traffic, pilot and other common channels; $P_{k,i}^{DCH}$ is the initial transmission power of the i^{th} BS towards the k^{th} user estimated by the open loop power control (Eq. 1); P_i^{max} is the maximum BS transmission power; and P_i^{off} is the amount of power required by all the users connected to the i^{th} BS that are inactive at that moment.

Note from Eq. 2 that the new call attempts must be aware of the resource reservation for handover calls ($\Theta_i \cdot P_i^{max}$) and inactive connections ($\Psi_i \cdot P_i^{off}$), as well as the scale factor of their initial transmission power (Φ_k), which will impact the quality that they will perceive at the beginning of their connection.

Regarding handover calls, they are benefited by the amount of power reserved for them, but they still have to respect the reservation of resources for the inactive connections, as can be seen in Eq. 3. Note that there is not a scale factor for the transmission power of the new BS, i.e., the available power of the BS that the user is trying to move to must be sufficient to meet all the power requirement of the handover call.

$$P_i^{on} + P_{k,i}^{DCH} \leq P_i^{max} - \Psi_i \cdot P_i^{off} \quad (3)$$

Finally, when an existing user k is coming back from a voice inactivity period, the CAC algorithm evaluates this request following Eq. 4.

$$P_i^{on} + P_{k,i}^{DCH} \leq (1 - \Theta_i) \cdot P_i^{max} \quad (4)$$

Note that in this case only the reservation for handover calls should be considered and the user come back with its complete power requirement ($P_{k,i}^{DCH}$).

The parameters of the CAC framework presented above (Θ, Ψ and Φ) can be dynamically adjusted in order to adapt to different system load and propagation situations, while meeting strict QoS requirements. In this contribution, we will show this potential presenting a case study where the setting of this parameters is translated into capacity gains over a basic scenario (basic CAC), where there is not any power reservation for handover and inactive connections and no control over the initial transmission power to the mobile terminals, i.e the users are admitted in the system as long as exist any power available.

IV. PERFORMANCE RESULTS

The system is assessed considering two performance metrics: Grade of Service (GoS) and Frame Erasure Probability (FEP). FEP is obtained from a mapping of the Signal-to-Interference plus Noise Ratio (SINR) averaged over a voice frame. SINR is measured in each time slot taking into account inter and intra-cellular interference and mapped into FEP throughout a link-level curve [10]. GoS is composed by a weighted function of both system blocking rate and system dropping rate (GoS $= P_{blocking}^{new} + 2 \cdot P_{dropping}^{total}$). The blocking rate is the ratio between the number of blocked users and the number of users that required a new connection to the system. Moreover, the total dropping rate is figured out considering two different factors: users requesting handover and users coming back from inactive periods ($P_{dropping}^{total} = P_{dropping}^{handover} + P_{dropping}^{activity}$).

Computer simulation results are presented here to demonstrate the performance of our CAC framework. Simulation results were obtained by gradually increasing the offered load until the GoS limit (5%) or the average FEP limit (2%) had been reached [5], [11]. The load is presented here in terms of theoretical conversational traffic load in Erlangs/Cell.

The main simulation parameters are: shadowing standard deviation (7 dB); inter-site shadowing correlation factor (0.5); user activity factor (0.5); mean activity period (1s); mean call duration (120s), mean user speed (3 km/h); maximum BS power (20 W); percentage of power for common and pilot channels (17.25%); cellular radius (0.9 km); tiers of interferer BSs (1 layer); voice radio frame (20 ms).

This section is organized in four sub-sections. Firstly, the performance results for the basic scenarios are shown. Secondly, we perform an analysis of power reservation for handover calls changing the parameter Θ. Afterwards, we analyze the procedure of traffic activity monitoring using the parameter (Ψ). Finally, the user initial quality parameter setting (parameter Φ) is examined. The values of capacity and quality metrics presented in the next graphics should not be regarded as absolute performance indicators. Indeed, the reader should focus on the relative comparisons presented.

A. Basic Scenarios Evaluations

Initially, the system performance using the proposed CAC framework is assessed analyzing the system blocking rate and the GoS for three CAC structures: basic CAC, our CAC framework without any reservation margins and our CAC framework with 100% of power reservation for inactive traffic.

From Fig. 1 it is possible to see that the performance in terms of blocking rate of the basic CAC is better than our proposal. In the basic CAC, if there exists available power at the BS, the user is allowed to access the system. Considering our framework for this case, an user is accepted in the system only if 100% of its initial power requirement is satisfied. Another fact can be observed when we reserve power resource for inactive traffic (Ψ = 100%; Θ = 0%; Φ = 100%). The blocking rate increases significantly compared to case without resource reservation (Ψ = 0%; Θ = 0%; Φ = 100%). However, the dropping rate due to activity monitoring $P_{dropping}^{activity}$ is a very sensitive QoS metric, and the fact of reserving or not 100% of the power required by the inactive connections makes a lot of difference in the value of GoS (see Fig. 2). We observed negligible variation in the $P_{dropping}^{handover}$ and the FEP level is lower than 2% for all the presented simulated loads. Thus, in this scenario, the system quality is limited by the GoS metric (5%).

In the next section, we develop a study towards the setting of power reservation for handover calls, aiming to improve the performance of our CAC framework with Ψ = 100%; Θ = 0%; Φ = 100%.

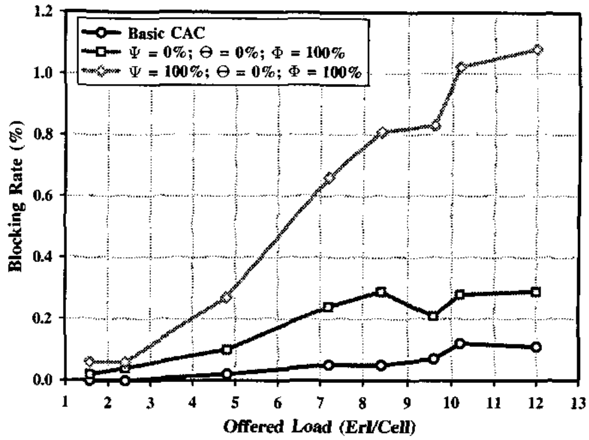

Fig. 1: System blocking rate considering basic scenarios evaluation.

B. Power Reservation for Handover Calls (Parameter Θ)

This section investigates the influence of the parameter Θ on the system performance. Note from Eqs. 2 and 4 that the higher the value of Θ_i the lower the available power for new connections and connections coming back from inactivity. In spite of a negligible increase of the blocking rate, the dropping rate due to handover requests declines significantly, as showed in Fig. 3. Thus, in this specific case, there is an offered load gain of 14.5 Erl and a spectral efficiency gain of 2.09 Erl/Mhz/Cell after reserving 5% of the total BS power for handover calls (see Fig. 4). The system QoS continues to be limited by the GoS metric, i.e., FEP is lower than the allowed value.

Until now, we assessed the system behavior based on system blocking and dropping rate, i.e., the GoS. However, it is important to show a BS power utilization study. Fig. 5 depicts the Cumulative Distribution Functions (CDF) of the BS power utilization for the active traffic channels and the total BS

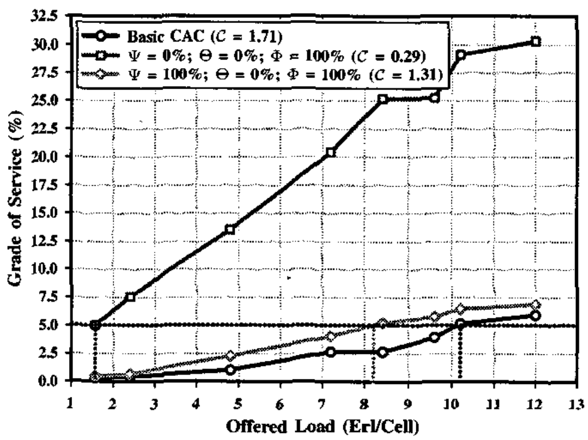

Fig. 2: System GoS considering basic scenarios evaluation. C is the spectral efficiency in Erl/Mhz/Cell.

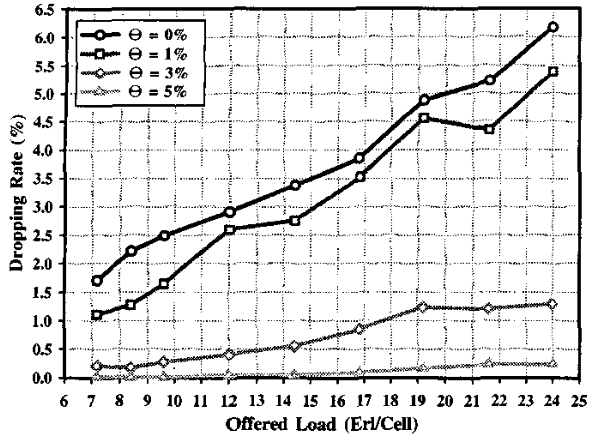

Fig. 3: System dropping rate due to handover failures considering power reservation for handover calls.

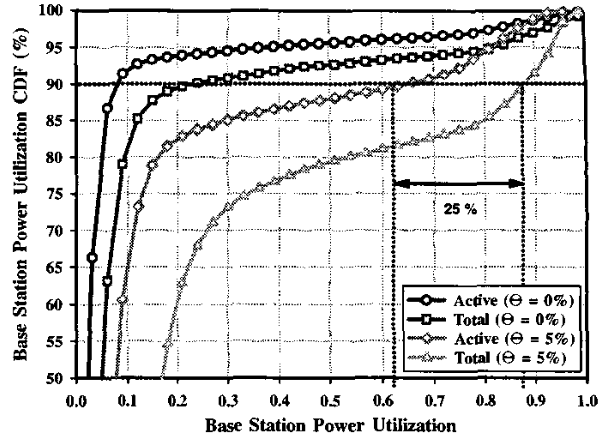

Fig. 5: Base station power utilization of active (P_i^{on}/P_i^{max}) and both active and inactive ($(P_i^{on}+P_i^{off})/P_i^{max}$) traffic channels considering power reservation for handover calls.

power concerning both the active and inactive traffic channels. We can notice a room of approximately 25% of the BS transmission power utilization in 90% of time due to power reservation for inactive traffic. This behavior is caused by the ON-OFF traffic over the dedicated transport channels modeled in the simulations. Thus, the next investigation step tries to take advantage of this characteristic, aiming an efficient power consumption with satisfactory guarantee of the QoS metrics.

C. Traffic Activity Monitoring (Parameter Ψ)

According to Eq. 4, one can observe that decreasing the parameter Ψ increases the system power availability (blocking rate is lower). However, as mentioned in section IV-A, $P_{dropping}^{activity}$ is a sensitive QoS metric. Values of Ψ lower than 100% caused significant increase in $P_{dropping}^{activity}$. The final result of the parameter Ψ variation can be seen in Fig. 6. We can conclude that the increase in $P_{dropping}^{activity}$ overcomes the benefits from resource releasing provided by the flexibility of parameter Ψ.

D. Initial Power Allocation Flexibility (Parameter Φ)

Since the dropping rate was controlled by the proper setting of parameters Θ (section IV-B) and Ψ (section IV-C), the setting of a suitable value for the parameter Φ focuses on the minimization of the blocking probability with guarantee of acceptable QoS (average FEP) during the connection, even if the user is not granted with all the required initial transmission power. This is possible due to the dynamism of the system, and particularly to the fast closed loop power control, which is able to compensate a poor link quality rapidly.

Fig. 7 depicts the GoS behavior for different offered loads and distinct values of the parameter Φ. As expected, the lower the value of Φ the lower the blocking probability of new calls. The interesting fact is that the dropping rate did not increase

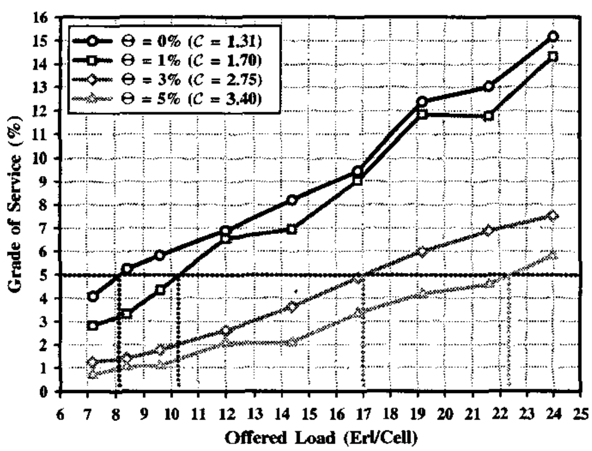

Fig. 4: System GoS considering power reservation for handover calls. C is the spectral efficiency in Erl/Mhz/Cell.

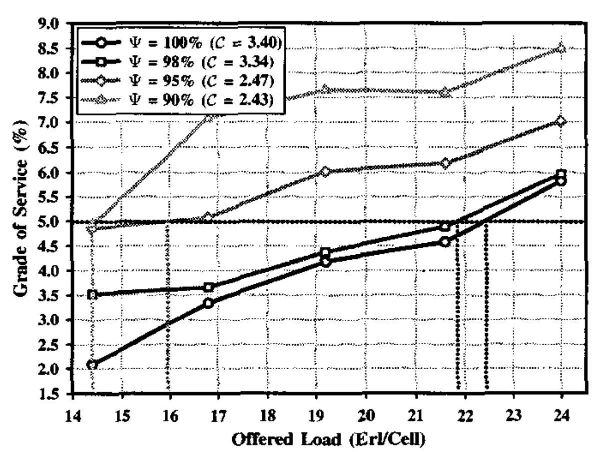

Fig. 6: GoS considering power reservation for inactive traffic. C is the spectral efficiency in Erl/Mhz/Cell.

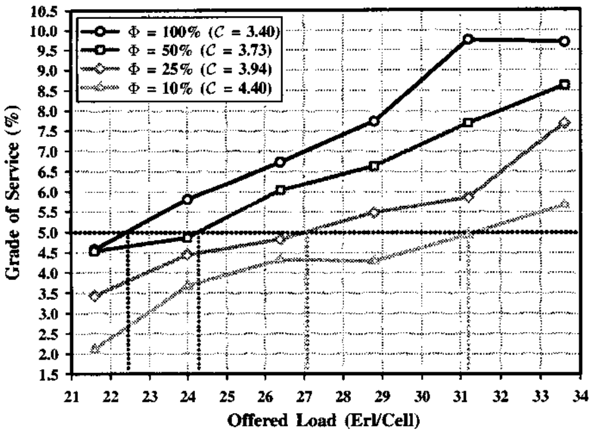

Fig. 7: GoS considering flexibility of initial power allocation. C is the spectral efficiency in Erl/Mhz/Cell.

so much. Thus, we can see capacity gain in terms of offered load and spectral efficiency.

Since the setting of this parameter provides a trade-off between capacity and quality, we must observe the average FEP of the connections that were finished normally. Observing Fig. 8, one can note that the use of the proposed CAC framework provided the possibility to have capacity gains while both QoS requirements (GoS and FEP) limits were reached at the same time. In this way, the system is able to manage their radio resources efficiently.

V. Conclusions

It can be concluded that the proposed CAC framework can be flexible regarding resource reservation to deal with the system dynamism. Mobility and traffic activity are taken into account in the definition of QoS metrics (dropping rate due to handover failures and unavailability of power for connections coming back from inactive periods). Moreover, initial power allocation is assessed jointly with the power control algorithm in order to decrease the system blocking rate.

It was shown that the parameters of the CAC framework presented (Θ, Ψ and Φ) can be dynamically adjusted in order to adapt to different system load and propagation situations, while meeting strict QoS requirements.

The optimization steps presented in sections IV-A, IV-B, IV-C and IV-D provided capacity gains of 158% in spectral efficiency over the scenario using the basic CAC algorithm (see Figs. 2 and 8).

This study can be extended towards application on mixed services scenario (conversational an interactive users). The management of non-controllable (real time services and handover calls) and controllable (non-real time services) load is a hot research topic and it is scheduled to be studied using the CAC algorithm presented in this contribution.

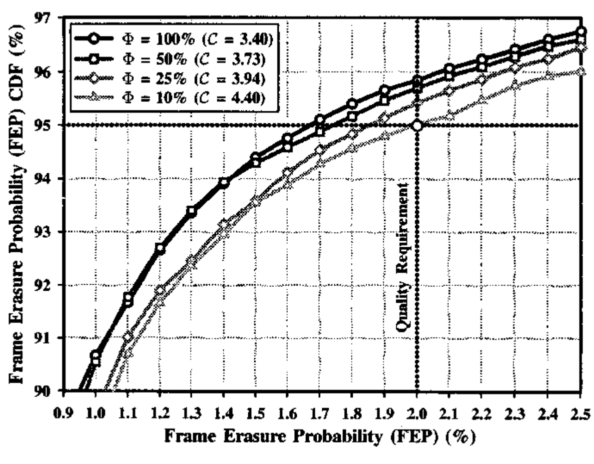

Fig. 8: FEP considering flexibility of initial power allocation. C is the spectral efficiency in Erl/Mhz/Cell.

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