Connection Admission Control in WCDMA-based UMTS Using the Effective Bandwidth

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Abstract— **In this paper, we study Call Admission Control (CAC) in UMTS, a key mechanism to offering QoS in forthcoming next generation mobile communications networks. We consider both uplink and downlink and develop CAC algorithms for the two mostly used receivers : conventional matched filter and MMSE. In addition to power constraints, our CAC algorithm takes into account the effects of mobility, coverage as well as the wired capacity beyond the B Node, in the UTRAN, for the uplink and the maximal transmission power of the B Node for the downlink.**

I. INTRODUCTION

Universal Mobile Telecommunication System (UMTS) holds the promise to provide multimedia services, including voice and video telephony, high-speed Internet access and mobile computing. UMTS is based on Wideband-CDMA (WCDMA), a resource sharing scheme based on code-division rather than time-division in TDMA or frequency-division in FDMA. In such a context, Connection Admission Control (CAC) plays a major role in ensuring Quality of Service (QoS).

Most commonly, CAC algorithms are based on a pre-determined number of users in the system ([5] and [6]). This approach is not adequate in a CDMA-based system because the system is interference limited, and multimedia calls can have variable bit rates. Other algorithms are more CDMA-oriented and consider the Signal-to-Interference Ratio (SIR) as the determinant parameter in accepting or not a new call ; the idea being mainly that each call should be granted a minimal SIR ([6], [7], [8],[9]).

The effective bandwidth, a notion that originated in CAC algorithms for ATM-based B-ISDN based on the large deviations theory, is making its ways to the context of UMTS. In [10], ATM's effective bandwidth was directly applied for different classes in CDMA ; at the expense of a high complexity. Several CAC algorithms have been developed in UMTS. In our work, we base our view on the model developed in [1] and retain the Signal-to-Interference Ratio SIR as the major criterion of QoS. This choice is based on the fact that the mutual information achieved for each user under an independent Gaussian input distribution is : $1/2 \log(1 + SIR)$ bits per symbol time. Meeting a target SIR is hence equivalent to meeting a target rate. We consider both uplink and downlink CAC.

In [1] however, only power constraints limit the number of users in a cell. Other constraints are equally important and shall be considered in our CAC decision. These are mainly mobility and coverage as well as wired capacity of the UMTS Terrestrial Radio Access Network (UTRAN), beyond the B Node. Indeed, air and wired resources are complementary ; the former is preponderant in large cells, used in rural environments where we have a small load factor and the system is coverage-limited, while the wired capacity is more significant in urban environments where small cells with high load are used and the system is capacity-limited.

The study has been achieved for different receivers. The choice of the receiver affects the SIR in the system, because different receivers lead to different interference schemes.

The remainder of this paper is organized as follows. In Section II, we focus on the CAC for the uplink. We first study the effective bandwidth for the case of the conventional matched filter receiver and develop a CAC algorithm based on mobility, coverage and wired capacity, in addition to power constraints. The same work is then carried out for the case of Minimum Mean Square Error (MMSE) receivers. The downlink is considered in Section III. In Section IV, we present some numerical examples to show the influence of both air and wired capacities on the CAC decision. Finally, Section V concludes the paper and gives perspectives for future work.

II. CAC ALGORITHM FOR UPLINK

A. *The effective bandwidth for different receivers*

A.1 The conventional / matched filter receiver

In a spread spectrum system, the received signal is given by

$$\overrightarrow{Y} = \sum_{i=1}^{K} X_i \overrightarrow{s_i} + \overrightarrow{w} \tag{1}$$

where $\overrightarrow{s_i}$ is the vector of the spreading sequence of user i, X_i is the transmitted symbol, and $\overrightarrow{w}$ is $N(0, \sigma^2 I)$, the background Gaussian noise. $\overrightarrow{Y}$ and $\overrightarrow{s_i}$ are of length N. We assume the X_i are independent and that $E[X_i] = 0$ and $E[X_i^2] = P_i$, where P_i is the received power of user i . There are K users in the system and N is the length of the spreading code.

For the matched filter receiver, the SIR is given by the formula ([1]) :

$$\beta_i = \frac{P_i}{\sigma^2 + \frac{1}{N}\sum_{j=1}^{J} \alpha_j P_j} \tag{2}$$

where J is the number of classes of users in the system. $\alpha_j = k_j/N$, k_j and β_j are respectively the number and the SIR of class j users. (2) shows that P_j/β_j is constant and independent of the class j. Then (2) leads to :

$$P_j = \frac{\beta_j \sigma^2}{1 - \sum_{i=1}^{J} \alpha_i \beta_i} \tag{3}$$

Equation (3) can be used to introduce an effective bandwidth for each class of users in the case of the conventional receiver : $e(\beta_j) = \beta_j$.

A.2 The MMSE receiver

The conventional receiver simply matches the vector $\overrightarrow{Y}$ to $\overrightarrow{s_1}$ in Eqn. (1) to obtain X_1. This would be optimal if the interference was white, but this interference has a large well known component $(\overrightarrow{s_2}, ..., \overrightarrow{s_k})$, and one can think to use this well known structure in maximizing the SIR. The MMSE receiver exploits this structure and gives the demodulator $\overrightarrow{c_1}$ maximizing the SIR :

$$\beta_1 = \frac{(\overrightarrow{c_1}^t \overrightarrow{s_1})^2 P_1}{(\overrightarrow{c_1}^t \overrightarrow{c_1})\sigma^2 + \sum_{i=2}^{k} (\overrightarrow{c_1}^t \overrightarrow{s_i})^2 P_i}$$

Further calculations lead to ([1]) :

$$\beta_1 = \frac{P_1}{\sigma^2 + \frac{1}{N}\sum_{i=2}^{k} I(P_i, P_1, \beta_1)} \tag{4}$$

where

$$I(P_i, P_1, \beta_1) = \frac{P_i P_1}{P_1 + P_i \beta_1}$$

This result is obtained for a large system where $k \to \infty$ and $N \to \infty$. The quantity $\frac{1}{N} I(P_i, P_1, \beta_1)$ is the interference due to user i on user 1. This interference depends not only on the power P_i of user i, but also on the power P_1 of user 1 and his SIR β_1, which in turn is a function of the entire system.

In the case of J classes of calls, Eqn. (4) leads to

$$\beta_i = \frac{P_i}{\sigma^2 + \sum_{i=2}^{k} \alpha_j I(P_j, P_i, \beta_i)}, i = 1, ..., J$$

Using the fact that $\frac{\beta_j}{P_j}$ is constant, we obtain :

$$P_i = \frac{\beta_i \sigma^2}{1 - \sum_{j=1}^{J} \alpha_j \frac{\beta_j}{1+\beta_j}}, i = 1, ..., J \tag{5}$$

Again, we obtain a notion of the effective bandwidth for users of class j given by $e(\beta_j) = \frac{\beta_j}{1+\beta_j}$.

Let us note that, in this study, we assume that the system is symbol synchronous. This is not the case for the uplink which is asynchronous. The downlink however is synchronous but due to multipath issues it may be considered as asynchronous. Nevertheless, it was shown in [12] that the effective bandwidth and SIR expressions are the same for synchronous and asynchronous systems for matched filter receiver. The synchronous case is a limiting case for the asynchronous system for the MMSE receiver. hence, in all cases, expressions in subsections A.1 and A.2 hold.

B. *Effect of the mobility and coverage*

Let consider $P_{i,max}$ the maximal power allowed for a class i user at the base station :

$$P_i \leq P_{i,max}, i = 1, J \tag{6}$$

Then (3) and (5) lead to

$$\sum_{j=1}^{J} \alpha_j e(\beta_j) \leq min_{1 \leq i \leq J}[1 - \frac{\beta_i \sigma^2}{P_{i,max}}] \tag{7}$$

However, it's wise to notice that the power received by the antenna is different from the power emitted $P_{i,e} = PL_i P_i$, PL_i is the path loss ratio given by [2] [3] $PL_i = r^4 10^{\frac{\xi_i}{10}} A^{-2}$, r is the distance from the base station and ξ_i a random variable due to shadowing (a zero mean log-normal random variable with standard deviation of 6-8 dB in a simulation context). A is the fading random variable, which is Rayleigh-distributed.

The real limitation is in the maximal power that can be emitted by the mobile $P_{i,e,max}$. So, $P_{i,max} = \frac{P_{i,e,max}}{PL_i}$ where $P_{i,max}$ is then calculated at each new arrival, and reported in Eqn. (7), which becomes :

$$\sum_{i=1}^{J} \alpha_i e(\beta_i) \leq \min_{1 \leq j \leq J} (\min_{1 \leq l \leq K_j} [1 - \frac{\beta_j \sigma^2 PL_l}{P_{j,e,max}}]) \tag{8}$$

Let us discuss this equation. Let $f(j,l) = 1 - \frac{e(\beta_j)\sigma^2 PL_l}{P_{j,e,max}}$. Each element of the set

$$S = \{f(j,l), j = 1..J, l = 1..K_j\}$$

corresponds to a user in the system. The condition $\sum_{i=1}^{J} \alpha_i e(\beta_i) \leq f(j,l)$ insures, if verified, that the call of user (j,l) will not be dropped if a new call is accepted. Condition (8) corresponds then to a zero-dropping CAC, but with the price of a possibly large blocking rate for new calls. This policy is, in general, preferable because premature termination of connected calls is more undesirable than rejection of a new call request.

C. *Effect of the UTRAN's wired capacity*

While studying the network capacity, we cannot neglect the fact that the wired bandwidth is not infinite, and that this resource must be considered when a CAC decision is taken. Curves are usually drawn to represent the relationship between the noise rise and the throughput [4]. The noise rise is defined as the ratio of the total received wideband power to the noise power : noise rise $\lambda = I_{total}/\sigma^2 = f(D)$ where D is the throughput and f is a continuous, strictly increasing function.

The condition on the throughput is $D \leq D_{max}$, where D_{max} is the wired capacity. Then $\lambda \leq \lambda_{max} = f(D_{max})$.

$$\frac{I_{total}}{\sigma^2} = \frac{\sum_{i=1}^{N} P_i + \sigma^2}{\sigma^2} \leq \lambda_{max} \tag{9}$$

Then, using Eqns. (3) and (5) we obtain

$$\sum_{j=1}^{J} \alpha_j (\beta_j + \frac{W}{N\sigma^2} e(\beta_j)) \leq \frac{W}{N\sigma^2} \tag{10}$$

where $W = \lambda_{max}\sigma^2 - \sigma^2$. And the CAC equation, based on both air as well as wired capacity, in terms of the effective bandwidth e_j of class j users, is then found from Eqns. (8) and (10).

III. CAC ALGORITHM FOR DOWNLINK

In the downlink, the problem is different. For user i, the signal emitted by the base station arrives

Top

with the path loss PL_i, common to all users' signals. As the design of mobile station is limited by size and cost, multiuser detection is very difficult and orthogonal codes are used to eliminate the Multiple Access Interference (MAI). The latter is then caused entirely by the multipath propagation channel which reduces the orthogonality. MMSE equalization can then be used to restore the orthogonality distorted by the multipath propagation. However, this does not affect our CAC algorithm ; in fact, this is a chip equalization aiming to restore the spread signal $\overrightarrow{Y}$ defined in Eqn. (1) and distorted by multipath propagation [11]. As our work focuses on extracting the signal $\overrightarrow{X}$ from the sum $\overrightarrow{Y}$, we are not interested in this equalization and can apply our matched filter receiver at the output of the equalizer.

To obtain the SIR equation, one must take into account the orthogonality factor $\epsilon \in [0,1]$ that creates the MAI in the downlink. This factor is equal to 1 in a perfectly orthogonal context and tends to 0 in a complete multipath channel. The interference at mobile j is then equivalent to that generated at the input of the matched filter by users having powers $(1-\epsilon)P_i^{(j)}$ - $P_i^{(j)}$ being the power received at mobile j for user i. The equation of the SIR is then given by

$$\beta_j = \frac{P_j^{(j)}}{\sigma^2 + \frac{1-\epsilon}{N}\sum_{i=1}^{K} P_i^{(j)}} \tag{11}$$

If $P_i^{(B)}$ is the signal emitted by the base station (B Node) for user i, we have, at mobile j

$$P_i^{(B)} = PL_j P_i^{(j)}$$

and Eqn. (11) becomes :

$$\beta_j = \frac{P_j^{(B)}}{\sigma^2 PL_j + \frac{1-\epsilon}{N}\sum_{i=1}^{K} P_i^{(B)}}, j = 1, K$$

This leads to

$$\sum_{i=1}^{K} P_i^{(B)} = \frac{\sigma^2 \sum_{j=1}^{K} \beta_j PL_j}{1 - \frac{1-\epsilon}{N}\sum_{j=1}^{K} \beta_j} \tag{12}$$

The downlink is limited by the maximum power W_B that could be emitted by the base station, i.e.,

$$\sum_{i=1}^{K} P_i^{(B)} \leq W_B \tag{13}$$

Eqns. (12) and (13) lead to the following CAC equation for the downlink :

$$\sum_{i=1}^{K} \beta_i \left(PL_i + \frac{(1-\epsilon)W_B}{N\sigma^2}\right) \leq \frac{W_B}{\sigma^2} \tag{14}$$

This equation introduces in the CAC decision both the effects of coverage (included in the path losses PL_i) and capacity (in terms of W_B, the maximum transmission power of the B Node).

IV. Numerical Application

A. *CAC algorithm function of air and wired resources*

Let us illustrate the influence of both air resources and wired ones on the CAC decision in UMTS. Without loss of generality, we consider the case of conventional receivers, at the uplink. We suppose for instance that we have one class of users, and that the number of users is K.

A.1 Effect of the mobility and coverage

In the case of perfect power control, all users are received by the base station with power P. As in [1], we suppose that all users require a SIR of 10 dB, and that $\frac{P_{max}}{\sigma^2} = 20\,dB$. In this case, Eqn (7) for power-only CAC yields $1 - \frac{\beta\sigma^2}{P} = 0.9$.

We consider user i, at say 70 meters distance from the base station, with a shadowing $\xi_i = 0$. If the emitted power is limited to $P_{i,e,max} = 0,125\,W$, and the noise power is $\sigma^2 = -100.2\,dBm$ (see [4]), then, Eqn. (8) for the CAC yields $1 - \frac{\beta\sigma^2 PL_i}{P_{i,e,max}} = 0.804$. This tells us that CAC threshold is determined here by the mobility conditions (expressed by the path loss), and not by the power constraint on the base station.

Top

A.2 Effect of the wired capacity

In case all users are received by the base station with power P, the CAC equation becomes :

$$K\beta \leq \min[1 - \frac{\beta\sigma^2}{P}, \frac{\lambda_{max} - 1}{\lambda_{max} - 1 + N}]$$

And as before, the first component of this equation is the power-constrained CAC and yields $1 - \frac{\beta\sigma^2}{P} = 0.9$.

Using the equations cited in [4] page 161 :

$$\eta_{UL} = \sum_{j=1}^{K} \frac{1}{1 + \frac{C}{(E_b/N_0)_j R_j \nu_j}}$$

where η_{UL} is the uplink load factor defined by : $\eta_{UL} = 1 - \frac{1}{\lambda}$, C is the chip rate (3.84 Mcps), R_j is the bit rate of user j and ν_j his activity factor (0.67 for speech, assuming 50% voice activity and DPCCH overhead during DTX).

For a despread bit energy to interference density ratio $E_b/N_0 = 5.0\,dB$ and a bit rate $R = 12.2\,Kbps$, the noise rise λ is equal to $\frac{1}{1-0.00668K}$.

Regarding the maximum noise rise allowed, for a maximum throughput of $1.8\,Mbps$ corresponding to 148 voice users, $\lambda_{max} = 88$ and for N=64, the fixed capacity component of the CAC decision gives $\frac{\lambda_{max}-1}{\lambda_{max}-1+N} = 0.576$.

We can note that in such a case, the wired capacity behind the base station is the limiting factor and must thus be considered in the CAC algorithm.

V. CONCLUSION

In this article, we studied a CAC algorithm for UMTS, based on a notion of effective bandwidth. Formulas has been obtained for two kinds of receivers : the matched filter receiver and the MMSE receiver. These equations introduce the effect of the mobility and coverage, preponderant in large cells used in rural environments, and the effect of the wired capacity, which is important in small, highly loaded cells used in urban environments . Downlink CAC is also studied, introducing the effect of the maximal transmission power of the base station.

In the future, we shall consider measurement-based CAC, a useful way to assign priorities between different classes of users as well as between new and handoff calls.

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Top