CAPACITY ANALYSIS FOR UPLINK CONNECTION ADMISSION CONTROL IN CDMA PACKET TRANSMISSION SYSTEMS

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Abstract – In this paper, we present a capacity analysis in order to set an effective threshold for connection admission control associated to the reverse link of a multimedia wireless communication system using CDMA. The analysis has been associated to the WCDMA concept defined in UMTS, where packet transmission has been considered for both real time and non real time services. A centralized demand assignment algorithm has been considered in the packet level in order to provide QoS, in terms of lost packet and delay constraints.

I. INTRODUCTION

The connection admission control for mobile communications is one of the most important engineering issues in order to guarantee system efficiency and quality of service (QoS) to connection oriented services in a very scarce resource as radio spectrum. CAC policies protect networks from overloading by determining whether incoming connection request should be accepted or rejected. Many of the proposed CAC policies for wired and wireless system make admission decisions by comparing the resources required by an incoming connection request with the resources currently available in the network. These policies implicitly assume that network capacity remains constant over the time an admitted connection is in the system, that is, the network capacity is fixed. However, since in CDMA the capacity is not fixed and varies due to changes in the interference, the design of Connection Admission Control in a CDMA system has associated two main design problems: a) setting an effective CAC threshold in order to guarantee the QoS for a integration of various service types, and b) to achieve the maximum efficiency in the resources utilization. That is, connection admission control really operates at two different levels: the first one characterized by the "packet level" constraints such as packet loss, delay jitter or average delay and the second one that allows to share the system capacity among the various traffic types and/or to protect the handoff connections from the new connections. Note that dropping a connection is generally considered a less desirable result than blocking a connection request. Several research studies have addressed these issues by means of static and dynamic prioritization and sharing scheme, associated with static or adaptive reserve of resources. The most accurate of them consider the mobility models of users and distribution of traffic (load) both in the own and in the neighbour cells.

In order to support the evaluation of future CAC policies, the present study is focus on a capacity threshold analysis associated to a CDMA system where transmission of multimedia services is performed in packetized form. Computer simulations results obtained from packet level have been evaluated in order to infer and support the proposed design method for CAC. Specifically, the study has been associated to the Wideband Code Division Multiple Access (WCDMA) concept defined in the Universal Mobile Telecommunication System (UMTS) terrestrial radio access (UTRA).

Both transmissions of real-time and non real-time services have been considered to be performed in packetized form over the physical data channel (DPDCH). Note however that in spite of the fact that WCDMA specification currently considers transmission of real-time services in circuit mode, it could be addressed using circuit or packet switched model, being the latter the most topical for future popular services. In order to provide QoS in a multimedia scenario, a centralized demand assignment protocol has been implemented to integrate services with quality of service. Several scheduling strategies, related with the centralized protocol, have been considered and proved to perform differentiate QoS. Note that this proposal differs from packet transmission modes defined for the moment in UTRA. UTRA specifies short infrequent packet transmission on RACH and it also considers reserves to mobiles for a short number of successive frames on Common Packet Channels (CPCH) (the procedure access are described in [1]). Since transmission on CPCH needs to have a restriction on maximum duration, we have considered the mentioned alternative packet transmission over dedicated physical data channel (DPDCH) in order to transmit large or frequent data packets without content for a code. Note that not all mobiles with active connections (with a code assigned) need to have packets to transmit.

In that case, each mobile station (MS), which has packets waiting to transmit, setup a dedicated code using an initial Random Access request, wherein the type and parameters of traffic to be transmitted are specified. Then, the network evaluates the request and decides if the necessary resources can be provided to the MS in order to support its QoS. Once the dedicated channel (code) is assigned, the MS is not allowed to start the transmission, it needs to wait the base station (BS) specifies the times in which it can transmit.

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Since in CDMA the capacity varies with the interference, both transmitted powers of MS and transmission rates may be considered as controllable resources by the network. Thus, the scheduling disciplines at BS, in coordination with a minimum transmitted power criterion, are responsible for arranging transmission of packets within their specified rate requirements and delay tolerances, being channel conditions of individual users in mind. Whereas, the purpose of the minimum power control criterion is to meet the Bit Error Rate (BER) of simultaneously transmitted packets, assigning an optimum level to the transmitted power by all the MS in such a way that interference caused to other cells is minimized and so throughput is maximized. Besides, the level of interference at BS is always maintained under a threshold while output powers of MS are constrained. Note that scheduling is performed each frame (10ms).

A detailed description of protocol and scheduling disciplines (based on static and dynamic priorities related with delay tolerances) can be found in [2]. However, in order to address capacity evaluation, some assumptions about power assignment (minimum power control criterion) are review in next section.

II. ANALISYS OF THRESHOLD CAPACITY.

Three teletraffic characteristics have a significant influence on system capacity: propagation parameters, traffic distributions, and transmission rate in association with QoS requirements.

The set of requirements associated with a given mobile i located in a cell k: maximum delay and delay jitter, minimum rate r_i, and maximum bit (BER) or block (BLER) error rates, can be mapped into an equivalent $E_b/N_{oi.,k}$ constraint denoted by γ_i (1):

$$\left(\frac{E_b}{N_o}\right)_{i,k} = \frac{W}{r_{i,k}} \frac{P_{i,k} h_{i,k}}{I_{\text{int}k} + I_{ext,k} + \eta_o W} \geq \gamma_i \quad i = 1..N \tag{1}$$

with $$I_{ext,k} = \sum_{\forall k' \neq k} \sum_{\forall l} P_{l,k'} h_{l,k} \text{ and } I_{\text{int},k} = \sum_{\forall i} P_{i,k} h_{i,k}$$

$$I_{total,k} = I_{\text{int},k} + I_{ext,k} + \eta_o W$$

where E_b is the bit energy, N_o the total interference density received at the base station, η_o the thermal noise spectral density, $I_{int,k.}$ and $I_{ext,k}$ the intracell and intercell interference, $P_{i,k}$ the transmitted power associated to the mobile i located in cell k, $h_{i,k}$ the path loss between MS i and the BS k, N the number of users in the cell k and W the available bandwidth in the cell (chip rate).

It has been shown that for a bandwidth W and N transmitter users, considering that power output constraints are applied to mobile stations (MS), $0 < P_{i,k} < p_{i,k}$,max, the power control problem in a cell is feasible if and only if [3]:

$$\sum_{j=1}^{N} \frac{1}{\left(\frac{W}{r_{j,k}\gamma_j} + 1\right)} \leq \frac{1 - \eta(t)}{(1 + f(t))} = \mathrm{C}_{\max}(\mathrm{t}) \quad \text{or} \quad \sum_{\mathrm{j}=1}^{\mathrm{N}} \mathrm{C}_{\mathrm{j}} \leq \frac{1 - \eta(t)}{(1 + f(t))} \tag{2}$$

where $$\eta(t) = \frac{\eta_o W}{min_j \left[p_{j,k,max} h_{j,k}(t) \left(\frac{W}{r_{j,k}\gamma_j} + 1 \right) \right]} \tag{3}$$

and $$f(t) = \frac{I_{ext,k}(t)}{I_{\text{int},k}(t)} \qquad C_j = \frac{1}{\frac{W}{r_{j.k}\gamma_j} + 1}$$

Note that if there are no transmit power limits, the parameter η in (2) becomes equal to 0. If condition (2) is satisfied for a set of rates and E_b/N_o values, then the power can be obtained using (4):

$$\begin{gathered} P_i(t) = \frac{\eta_o W}{\hat{h}_{i,k}(t) \left(\frac{W}{r_{i,k}\gamma_i} + 1 \right) C_{res}(t)} \\ C_{res}(t) = (1 + f(t)) \left(\frac{1}{(1 + f(t))} - \sum_{j=1}^{N} \frac{1}{\frac{W}{r_{j,k}\gamma_j} + 1} \right) \end{gathered} \tag{4}$$

See that power allocation to every mobile has a common parameter, $\eta_o W/C_{res}(t)$, while the value of C_i is known by mobiles and corrections associated with h_i are controlled by the closed loop power control.

Equation (2) is a necessary and sufficient condition to guarantee E_b/N_o and rate requirements, but, in order to limit the maximum total power received at the BS $I_{total,k}$, a minimum value of parameter η equal to 0.1 is considered (thermal noise represents at least the 10% of maximum total interference level).The ratio between external and internal interference (f), and the channel condition should be known in order to achieve the minimum transmitted power criterion with accuracy in a multi-cell scenario. In this work, power control is implemented in a distributed manner. That is, BSs of individual cells manage the power levels and instants of transmission of mobile stations, MS, in base of local measurements of the interference without the need of interchange of information between different cells. The estimation ratio f is induced from the ratio measured in the previous frame.

Taking into account condition (2), we consider that in a given time instant only a limited number of users are allowed to transmit. Meanwhile, the remaining users could be in contact with the base through the Dedicated Control Channel (DPCCH), which is associated to DPDCH in order to perform closed power control. Waste of capacity associated to DPCCH must be added in (2).

We consider $C_{max}(t)$ is the maximum available capacity in the cell, $C_{res}(t)$ is the residual capacity after assigning all permits to transmit in a given frame, C_i the consumed capacity by a MS and $\eta(t)$ is the reserved capacity needed to guaranty the power constraints to MS's in a frame. Mobiles that need a high value of η are delayed in order to provide permits to more users [2].
Note that in a certain frame:

$$C_{max}(t) - \sum_{i=1}^{Nsch} C_i = \frac{C_{res}(t)}{1+f(t)} - \frac{\eta(t)}{1+f(t)} \geq 0 \qquad (5)$$

where N_{sch} is the number of users scheduled in that frame.

Once we have described theoretical expressions for capacity, we will develop an effective CAC threshold in order to guarantee the QoS for an integration of various service types. Threshold has been derived from the evaluation of link level simulation results obtained for the MAC protocol described previously.

The problem of setting CAC threshold and evaluating the erlang capacity has been addressed before in quite a lot of works [4][5][6]. Reference [4] presents useful expressions in evaluation of system capacity. However, since the erlang capacity is calculated based on only blocking rate, the communication quality is not guaranteed and its relation with erlang capacity is left unclear. In that case ([4]), it has been shown that the values of SIR and f can vary significantly due to changes in propagation parameters, power control inaccuracy and traffic distributions. Distribution function of interference is determined in order to evaluate blocking probability. [4] shows that the mean and variance of other-cell interference can be approximated by the intracell interference multiplied by a constant coefficient f. In [5] expressions of the QoS (packet loss) and GoS (grade of service) as functions of traffic intensity and CAC thresholds have been derived. Only a type of service is considered and probability density function (pdf) of intercell interference is derived by computer simulations in a same way that in [4]. In [6], a multimedia scenario is considered. In this case an effective capacity (rate), taking into account the stochastic nature of traffic and delay requirements, is used to characterize the resources required by multimedia services. System capacity has been derived using SIR threshold criterion, calculated based on the effective capacity. The proposed method, though useful in a multimedia scenario, has been shown to be conservative.

In any of previous references, no specific MAC protocol has been developed in order to provided differentiate QoS. We have introduced this specific factor.

Note that, in our case, unlike [4][5][6], the scheduler limits the number of mobiles transmitting in a frame, thus, a priori, every mobile having permit to transmit must reach its Eb/No constraints (condition (2) is satisfied). So, only imperfections in the estimation of ratio f could prevent it, given that almost perfect channel estimation could be assumed thanks to DPCCH. Thus, the only QoS constraints that users can not satistied are those related to delay constraints. Real time services drop packets that exceed delay constraints, so a specific drop probability constraint is imposed as QoS criterion.
On the other hand, in order to derive system capacity thresholds in terms of number of users, both stochastic distributions of traffic and of initial capacity must be taken into account.

In our case, simulation results, some of them will be present in section IV, show also that initial capacity $C_{max}(t)$ maintains the same statistical distribution, which has been seen to correspond to a gamma distribution, with the same mean an variance independently of the number of active users in the system, being only dependent of the propagation parameters, closed power control inaccuracy and the spatial distribution of mobiles within the cell.
However, in order to perform connection admission, we use an alternative measure of the capacity (6) more dependent of current users actives in the system that provide a more accurate bound.

$$C_{ini}(t) = 1 - \eta(t) - f(t)\sum_{i=1}^{Nsch} C_i(t) \qquad (6)$$

Simulations show that $C_{ini}(t)$ can be characterized by a F-distribution, given that the product of f(t) and $\sum_{i=1}^{Nsch} C_i(t)$ can be modeled as a product of Gamma distributions.

This distribution is maintained considering either one type of traffic and integration of real time and non real time services. However, in order to simplify the analysis, we will consider only real time services, and only one type of traffic. Further studies considering interaction with non real time services are being carried out.

Note that if there are N_i MSs admitted in a cell, the probability of k_i active users may be expressed as a binomial distribution (7).

$$P_{u,i}(k) = \binom{N_i}{k_i} \rho_i^{\,k_i} (1-\rho_i)^{N_i-k_i} \qquad (7)$$

where ρ_i is the activity factor associated to class i mobiles.

Remember that when the number of active users is high and the activity factor is small, this distribution of probability can be approached by a gaussian distribution with independence of the individual statistical distribution of the sources.

Note also that distribution of active users is not the same as distribution of scheduled users. However, while N_i is below $N_{max,i}$ CAC threshold, they could be considered equal. (This simplifies parameters of F-distribution of C_{ini} derivation).

Taking into account a packetized transmission, dropping probability can be calculated as the fraction of all users that can not transmit due to the absence of capacity available in a specific frame.

$$P_{drop} = \frac{\sum_{k_i=0}^{N_i} P_{u,i}(k_i)\left(\sum_{j=0}^{k_i}\left(\int_0^{jC_i} p_{Cini}(m)dm\right)\right)}{\sum_{k_i=0}^{N_i} k_i P_{u.i}(k_i)} \qquad (8)$$

Tolerance to delay is not included in (8), so P_{drop} represents a conservative bound of the admission region. In fact, P_{drop} is the probability that a packet has been delayed. Instead of $C_{i,}$ an effective capacity (introducing delay) must be derived in order to provide a more accurate result. Results presented here just provide a suitable initial capacity characterization in order to take into account interference from adjacent cells. Remember that, in order to accept a new connection, we need to ensure that Pdrop requirements are met.

III. SYSTEM AND TRAFFIC MODEL

We propose a cellular system model composed by 19 hexagonal cells. In the interference analysis only interference form the first-tier of adjacent cells is taken into consideration, The geometry of each cell is modeled by the radius of the cell (D=2Km.). Macro cell propagation model proposed in [7] is adopted for path loss. Log-normally distributed shadowing with standard deviation of $\sigma = 8dB$ is added according with the model proposed in [8]. Additionally a multi-path fading environment proposed in [9] is considered. 11dB antenna gain and thermal noise power of –103dBm are assumed [7]. MSs have a maximum output power of 27 dBm, [9], and moves with a speed between 25 to 50Km/h. Initial localization is selected randomly (uniform distribution).

Two kind of traffic sources: Real Time Services (Class I- Data services with delay constraints of 300 ms) 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, 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.

Non-real time traffic sources are based on the model presented in [10]. Two types are considered: 8kbps and 32Kbps data rate services. Normal Pareto distribution with mean 480 bytes is considered for the data packet size, while an inter arrival time between packets of 500ms is assumed for the 8Kbps and 125ms for the 32Kbps, being 25 the average number of packets within a packet call in both of them. Average time between the last packet of a packet call and the next packet call is 4s. Packets are segmented in PDU contained in transport blocks of 360 bits when 32Kbps is considered and in transport blocks of 168 bits when 8Kbps is assumed.

IV. SIMULATION RESULTS.

We present some results in order to assess the performance. These results consider a full channel model where shadow and fast fading has been considered. Equivalent results have been obtained when only shadow fading is considered.

First, we consider a scenario where only class I mobiles are present. Figure 1 shows C_{max} for 56, 64, 72 and 80 users in the cell. Variations in statistics are only due to changes in the distributions for mobiles in the cell (distribution of interference received from each of the adjacent cell has been evaluated although is not present here). Gamma distribution with the same mean and variance as C_{max} provides a very good approach. (Steps of pdf distribution are 0.005)

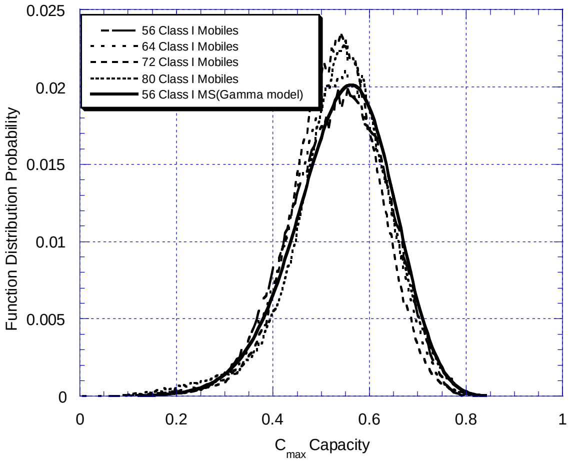

Figure 1

Figure 2 shows C_{ini} for 56 and 76 mobiles in the cell. As it can be seen, F-Distribution is very closed to simulation

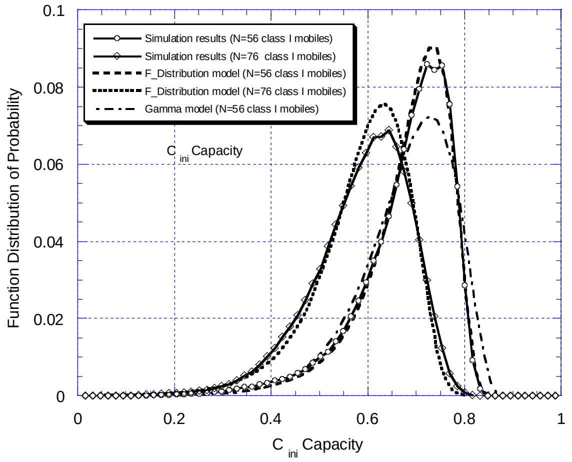

Figure 2

results. We have also modeled C_{ini} with a gamma distribution with the same mean and variance. However, results show that it is much less suitable. (Steps of pdf distribution are 1/63.74)

Figures 3 and 4 show C_{max} and C_{ini} respectively, in a scenario where there are 30 class I mobiles and a variable number class II.1 and class II.2 mobiles. In this case, gamma and F-distribution models look also to be good approaches.

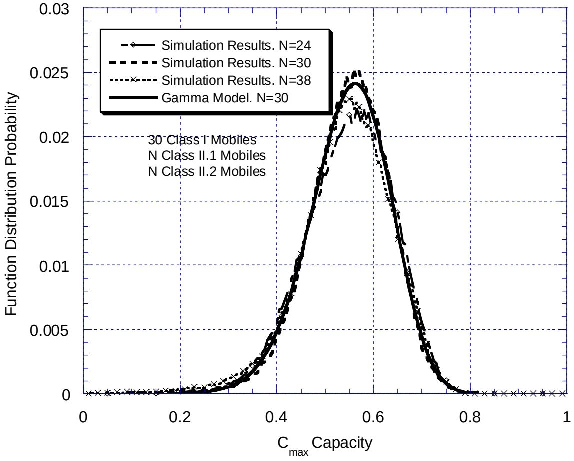

Figure 3

For the configuration of figure 3 and 4, we have obtained a dropping probability about 1% when we have 38 class II.1 plus 38 class II.2 in addition with the 30 class I mobiles.

Figure 5 compares the delay probability computed with the model and simulations results when only class I mobiles are considered. Note that delay probability is far from dropping probability. However, it is necessary to consider that delay tolerance will improve the threshold capacity. Additional analysis is been to carry out in order to incorporate delay tolerance to Pdrop expression.

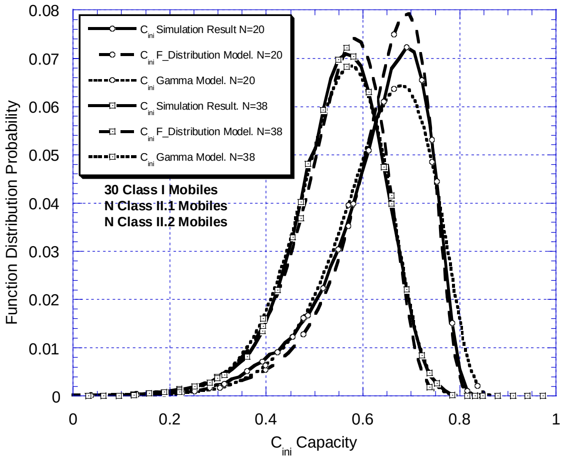

Figure 4

V. CONCLUSIONS

A capacity analysis in order to set thresholds for connection admission control has been developed. Analysis has been associated to reverse link of the WCDMA, where packet transmission has been considered for both real time and non real time services. A centralized demand assignment algorithm has been implemented in the packet level in order to provide QoS, in terms of lost packet and delay constraints. Performance in time variant wireless channel conditions has been evaluated considering channel-stated scheduling algorithms [2].

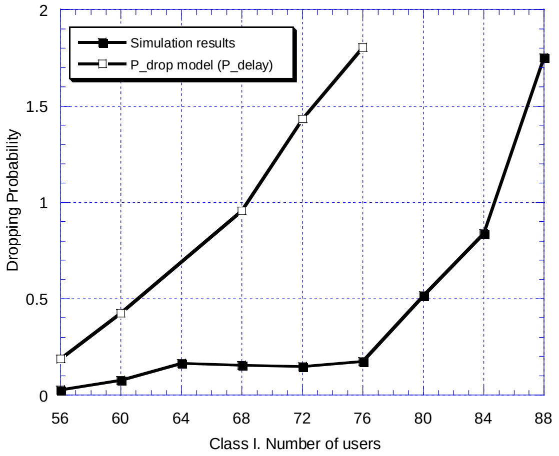

Figure 5

Results obtained from packet level provide useful information in order to induce capacity bound. Extensions of this work will include the delay constraints associated to individual traffic classes (especially real time services) in order to set a more accurate threshold of CAC in a multiservice system.

VI. ACKNOWLEDGMENT

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