Frequency Reuse Efficiency and Admission Control in Multirate Systems

Álvaro A. M. de Medeiros[1], Michel D. Yacoub[1], César K. D'Ávila[2]

[1]UNICAMP, Campinas SP / [2]CEDET, Campinas SP - Brazil

Abstract - **In this paper, we derive the Frequency Reuse Efficiency parameter for multirate systems taking into account the different services and their respective bit rates and QoS requirements. According to the service, this parameter shows a strong variation with high data rates and is nearly constant for lower data rates. An admission control algorithm is then proposed that makes use of the frequency reuse frequency parameter. Finally, the analysis carried out in this paper is exercised in an application example for WCDMA.**

I. INTRODUCTION

Frequency reuse efficiency F_k for a given user k is a dimensionless CDMA parameter that represents the relative power received from the serving cell with respect to the total received power. It is given by [1]:

$$F_k = \frac{P_k}{P_k + I_{OC}} \qquad (1)$$

where P_k is the total power received by the k-th user that is generated within the serving cell and I_{oc} is the interference generated by the other cells.

Frequency reuse efficiency is intimately related to system capacity and cell coverage. Therefore, its use has a direct impact on sensitive issues such as those already mentioned, namely capacity and coverage. Until recently, the studies on frequency reuse efficiency have concentrated on reverse link applications because, as was unanimously thought, Second Generation (2G) CDMA cellular systems were uplink limited [1-3]. Such an assumption turned out to be not unanimous any longer, and a number of reasons exist that lead to the conclusion that these systems are forward link limited [4, page 265]. Third Generation (3G) systems are unequivocally forward link limited, for the 3G data services require higher data rates in the forward link as compared to the reverse link. Again until recently, the studies on the frequency reuse efficiency have concentrated on one-service system (voice service). To be best of the authors' knowledge, there has been very little, or even inexistent, attention to the multirate case.

This paper derives the forward frequency reuse efficiency for multirate systems and analyzes its variation with respect to different services, i.e. different bit rates and Quality of Services (QoS) requirements. An admission control algorithm is also proposed that makes use of such a parameter. In the Section II, we analyze the forward link interference and the power allocation for each service based. In Section III, we explore the power allocation under the call admission perspective. In Section IV, we derive an expression for the frequency reuse efficiency, based on the power allocation presented in Section III. In Section V, an admission control algorithm is proposed that makes use of the frequency reuse efficiency parameter. Finally, in Section VI, an example of application is exercised.

II. INTERFERENCE ON FORWARD LINK AND RELATIVE POWER

To analyze the F_k parameter, we estimate the various interferences within the CDMA system. In the forward direction, the same cell interference I_{sc} is given by:

$$I_{SC} = \varepsilon_k (1-\delta_k) \frac{P_T^{(j)}}{l_o r_{jk}^{\alpha}} \qquad (2)$$

where ε_k is the orthogonalization factor (ε_k=1 signifying zero orthogonality and ε_k=0 signifying full orthogonality), $P_T^{(j)}$ is the total power for the forward link in the cell j, δ_k is the fraction of the total power $P_T^{(j)}$ allocated to the k-th user (allocated relative power), l_o is the path loss proportionality factor, α is the path loss exponent and r_j is the distance from the k-th user to its serving base station j. Hence, the total power P_k received by the target subscriber from its own cell is given by:

$$P_k = \varepsilon_k (1-\delta_k) \frac{P_T^{(j)}}{l_o r_{jk}^{\alpha}} + \delta_k \frac{P_T^{(j)}}{l_o r_{jk}^{\alpha}} \qquad (3)$$

Álvaro A. M. de Medeiros and Michel D. Yacoub are with DECOM/FEEC/UNICAMP, Campinas SP, Brazil, PO Box 6101, 13.081-970, Phone: +55 19 378-83812, FAX: +55 19 3289-1395 e:mails: {alvaro,michel}@decom.fee.unicamp.br. César K. D'Ávila is with Centro de Desenvolvimento Profissional e Tecnológico (CEDET), Rua Ângelo Vicentin, 70, 13084-640, Campinas, SP, Brazil, e-mail: cesar@cedet.com.br.

The other cells interference I_{oc} is obtained as:

$$I_{OC} = \sum_{\substack{i=1 \\ i \neq j}}^{M} \frac{P_T^{(i)}}{l_o r_{ik}^{\alpha}} \tag{4}$$

where r_i is the distance from the k-th user to the interfering base station.

The allocated relative power δ_k can be estimated using the signal-to-interference ratio $(E_b/I_t)_k$ for the k-th user, such that:

$$\left(\frac{E_b}{I_t}\right)_k = \left(\frac{W}{R_k}\right) \frac{\delta_k \left(P_T^{(j)} / l_o r_{jk}^{\alpha}\right)}{I_{OC} + I_{SC}} \tag{5}$$

where W is the spreading bandwidth and R_k is the data rate for the k-th user. Manipulating equations (2), (4) and (5), the allocated relative power is obtained as:

$$\delta_k = \frac{L_k + \varepsilon_k}{\varepsilon_k + \chi_k} \tag{6}$$

where

$$L_k = \sum_{\substack{i=1 \\ i \neq j}}^{M} \frac{P_T^{(i)}}{P_T^{(j)}} \left(\frac{r_j}{r_i}\right)^{\alpha} \quad . \tag{7}$$

The parameter χ_k is the jamming margin, defined as the ratio between processing gain and the signal-to-interference ratio, i.e.

$$\chi_k = \frac{W/R_k}{E_B/I_t} \quad . \tag{8}$$

It can be noticed that the L_k parameter depends exclusively on how the network is planned, i.e. on the network topology, on the total power emitted from the base stations, on and the propagation environment. Figure 1 shows the values of normalized L_k at a central cell for a network with four tiers and all base stations with the same total power ($P_T^{(i)}/P_T^{(j)}=1$ for all i). For α=4, L_k has a mean value of 0.291 and if we take the worst case (L_{kmax}), i.e. the cell border, L_k is approximately 2.073. For α=3, these values are respectively, 0.549 and 2.542, and for α=2, 1.551 and 4.284.

Figure 2 shows the variation of L_k in a four-tier network central cell with α=4. Figure 3 shows the mean values of L_k and the values of L_{kmax} (in parenthesis) for each cell in the same four-tier network where α=4.

Equation (6) shows that higher bit rates demand a higher fraction of the forward link total power. It also shows that, depending on the users' power allocation and on their location, a new subscriber may not have access to all services, as long as it may demand a higher fraction of base station's total power.

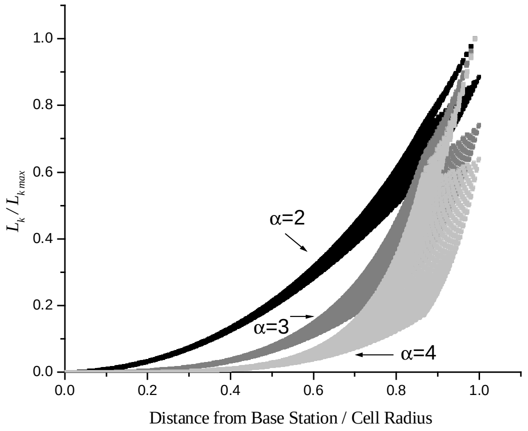

Figure 1: Normalized L_k parameter as a function of the normalized distance from the base station

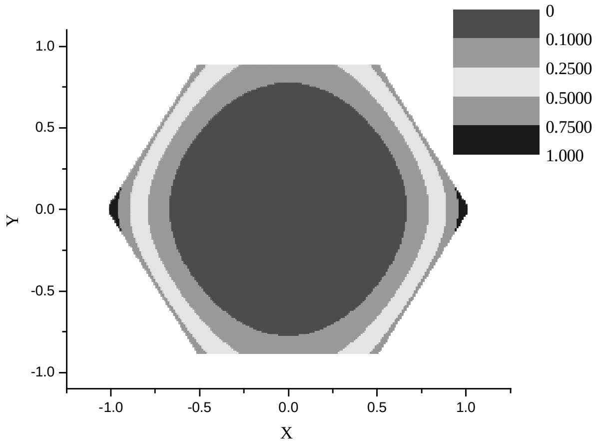

Figure 2: Variation of L_k for the central cell in a four-tier network cell (α=4)

III. RELATIVE POWER AND CALL ADMISSION CONTROL

For call admission control purposes, the L_k parameter must be evaluated after the admission of k-th user's. Defining $L_k(t)$ as the value of L_k at instant t and $L_k(t+1)$ the value of L_k in instant $t+1$ after the k-th user's admission, and considering that the user's position and the total power for the forward link in the others cells ($P_T^{(i)}$) will not vary significantly, then

$$L_k(t) = \sum_{\substack{i=1 \\ i \neq j}}^{M} \frac{P_T^{(i)}}{(P_T^{(j)})_t} \left(\frac{r_{jk}}{r_{ik}}\right)^{\alpha} \tag{9}$$

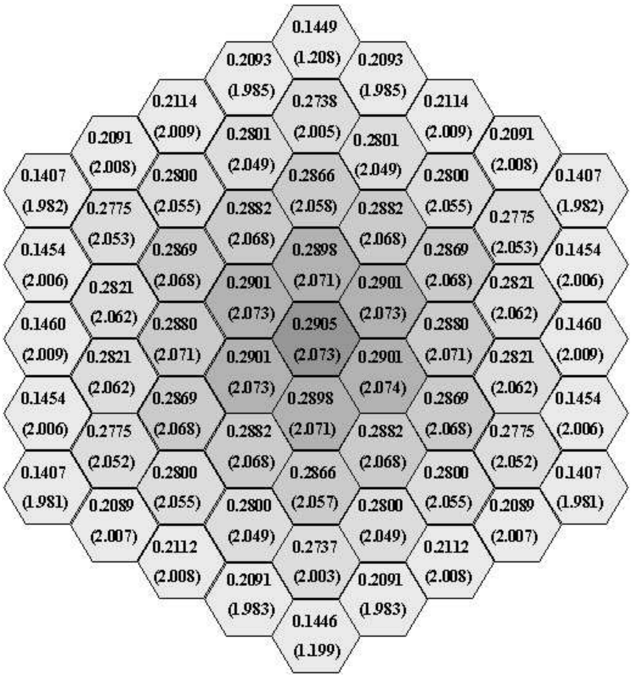

Figure 3: Mean values of L_k and values of $L_{k\ max}$ (in parenthesis) in a four-tier network (with α=4).

and

$$L_k(t+1) = \sum_{\substack{i=1 \\ i \neq j}}^{M} \frac{P_T^{(i)}}{(P_T^{(j)})_{t+1}} \left(\frac{r_{jk}}{r_{ik}} \right)^{\alpha} . \tag{10}$$

For admission purposes the following holds

$$(P_T^{(j)})_{t+1} = (P_T^{(j)})_t + \delta_k (P_T^{(j)})_{t+1} \tag{11}$$

Consequently, from (9), (10), and (11)

$$L_k(t+1) = L_k(t) \cdot (1 - \delta_k) \tag{12}$$

for $(P_T^{(j)})_{t+1} \leq P_{T\max}$. From (6), the allocated relative power δ_k at instant t+1 can now be written as:

$$\delta_k = \frac{L_k(t) + \varepsilon_k}{\varepsilon_k + \chi_k + L_k(t)} \quad . \tag{13}$$

IV. FREQUENCY REUSE EFFICIENCY ON THE CALL ADMISSION CONTROL

Using equations (1), (3) and (4), and considering all base stations transmitting the same total power ($P_T^{(i)} = P_T^{(j)}$ for all i), the following is obtained:

$$F_k = \frac{\delta_k (1 - \varepsilon_k) + \varepsilon_k}{\delta_k (1 - \varepsilon_k) + \varepsilon_k + L_k} \tag{14}$$

Combining equations (13) and (14) the reuse efficiency after the subscriber's admittance into the system can be written as:

$$F_k = \frac{L_k(t) + \varepsilon_k + \varepsilon_k \chi_k}{L_k(t) + \varepsilon_k + \varepsilon_k \chi_k + L_k(t) \chi_k} \tag{15}$$

Table I shows some cases for the jamming margin in a 3G WCDMA system (W=3.84 Mc/s) [5]. The values of E_b/N_t take into account the soft-handoff combining gain and the average power increment caused by fast power control [6]. With the parameters defined in Table 1, equation (15) can be used to obtain F_k as a function of χ_k, as presented in Figures 4, 5 and 6 (α=2, 3 and 4 respectively) for an orthogonality factor ε_k = 0.5 [8] and for several values of L_k=$L_k(t)$ before admission.

TABLE I
EXAMPLES OF SERVICES AND RESPECTIVE JAMMING MARGINS FOR A WCDMA SYSTEM

Service	R_k	$(E_b/I_t)_k$	χ_k
Voice	8 kbps	7 dB	95.77
Video	144 kbps	7 dB	5.32
Packet Data	384 kbps	10 dB	1

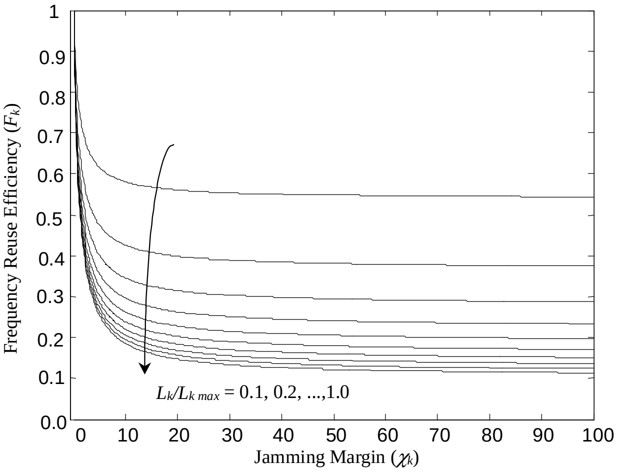

Figure 4: F_k versus χ_k for ε_k =0.5, α=2 and different values of normalized L_k.

It can be observed that the frequency reuse efficiency varies rapidly with the jamming margin for small values of jamming margins (high bit rates or high E_b/I_t requirements). Indeed, if a subscriber requires a higher bit rate for the respective service, a fast degradation of system capacity or coverage may be observed. It can also be observed that for high jamming margins (low bit rates or low E_b/I_t requirements) the necessary reuse efficiency bears almost no variation with the jamming margin.

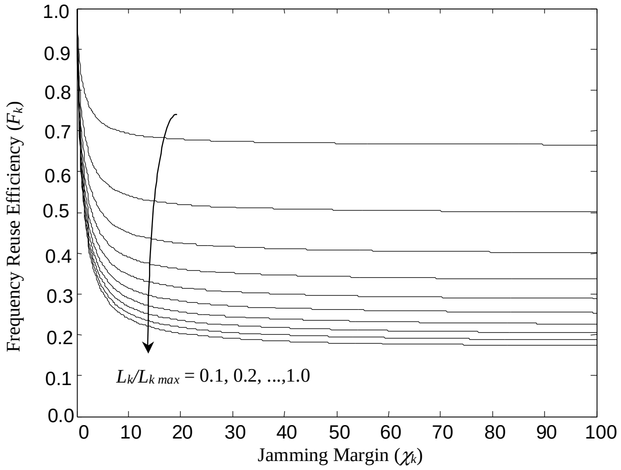

Figure 5: F_k versus χ_k for ε_k =0.5, α=3 and different values of normalized L_k.

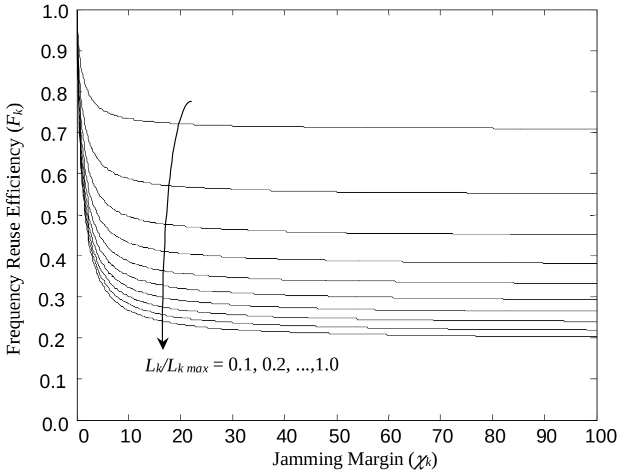

Figure 6: F_k versus χ_k for ε_k =0.5, α=4 and different values of normalized L_k.

V. ADMISSION CONTROL USING THE L_K AND χ_K PARAMETERS

A straightforward application of the F_k analysis concerns admission control algorithms for multiple-service systems. With that aim, we first calculate L_k for a given subscriber's position according to the propagation environment and network topology and emitted power before the k-th user's can be admitted into the system. Then the jamming margin χ_k, for the required service (required bi rate R_k and E_b/I_t (QoS parameter) is also evaluated. Finally, the reuse efficiency is obtained and in the capacity equation [2] as follows:

$$\rho = \sum_{k=1}^{N} \rho_k \tag{16}$$

whith

$$\rho_k = \frac{\upsilon_k}{\chi_k}\left[\varepsilon_k + \frac{1-F_k}{F_k}\right] \tag{17}$$

where ρ is the system load factor, ρ_k is the contribution of the k-th user on the load factor, υ_k is the activity factor of the k-th user and N is the number of users within the cell.

Thus, from equation (15) and (17) the following is obtained:

$$\rho_k = \frac{\upsilon_k}{\chi_k}\left[\varepsilon_k + \frac{\chi_k L_k}{L_k + \varepsilon_k + \varepsilon_k \chi_k}\right]. \tag{18}$$

The admission control algorithm must evaluate the subscriber's contribution ρ_k in the total load factor before the required service is granted. If $\rho \le \rho_{\max}$ ($\rho_{\max}$ is a system parameter, typically 0.5) the service is accepted by the system, otherwise rejected or a negotiation for a new service can be started. Figure 7, 8 and 9 shows the contribution ρ_k for one user of the WCDMA services shown on Table I, with an orthogonality factor ε_k = 0.5 [8]. The curves are obtained for several values of υ_k, and for the central cell in a four-tier network, with α=2, 3 and 4, respectively.

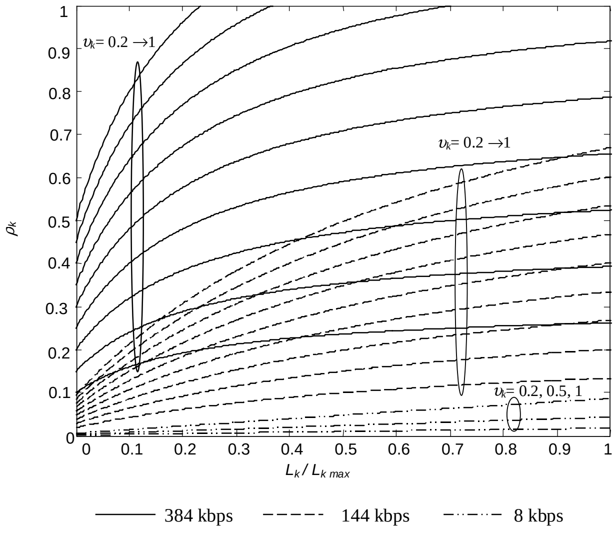

Figure 7: Contribution in the load factor from the k-th user (ρ_k) as a function of the normalized L_k ($L_{k\,max}$=4.284) for the central cell in a four-tier network (α=2 and ε_k = 0.5).

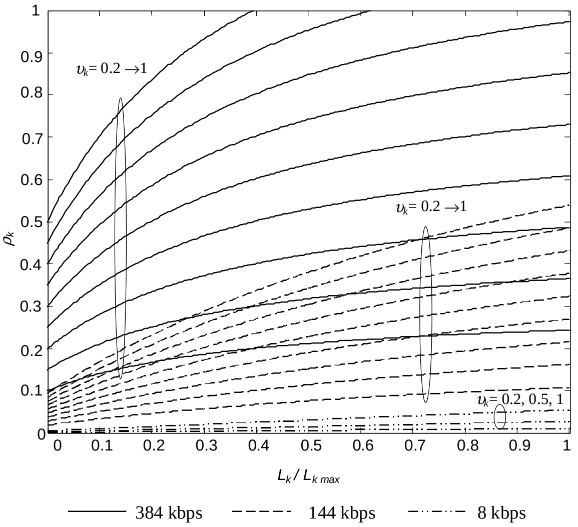

Figure 8: Contribution in the load factor from the k-th user (ρ_k) as a function of the normalized L_k ($L_{k\,max}$=4.284) for the central cell in a four-tier network (α=3 and ε_k = 0.5).

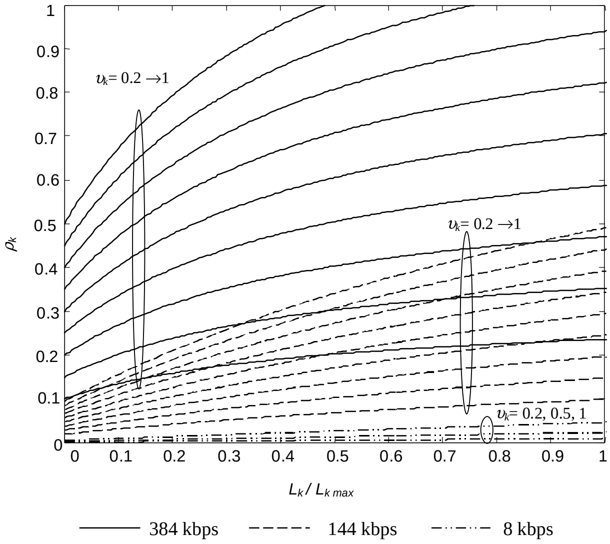

Figure 9: Contribution in the load factor from the k-th user (ρ_k) as a function of the normalized L_k ($L_{k\,max}$=4.284) for the central cell in a four-tier network (α=4 and ε_k = 0.5).

VI. AN APPLICATION EXAMPLE

Consider an urban scenario (α=4), $\rho_{\max}$=0.5, a packet data user (R_k=384 kbps and $(E_b/I_t)_k$=10 dB as shown in Table I), and supposing υ_k=1). From Figure 7, the contribution of such a user to the load factor equals ρ_k = 0.5 for the normalized L_k value near zero. From Figure 1, for such a value of the normalized L_k,, we observe that the user can only be admitted into the system if no other user is present within the system. In such a case, this user must be confined within a maximum distance $d_{max} \leq 0.3 r_{cell}$, where r_{cell} is the cell radius.

The same procedure can be used in other examples. For instance, in Table II we show 40 voice users (R_k=8 kbps and $(E_b/I_t)_k$=7 dB as shown in Table I, and assuming υ_k=0.5), distributed around the base station. Departing from this condition, Table III shows some possible admission scenarios (S1, S2, …, S5), having as target the admission of video users (R_k=144 kbps and $(E_b/I_t)_k$=7 dB as shown in Table I, and assuming υ_k=1). More specifically:

- S1 - 1 user in a distance $0.8r_{cell} \leq d_{max} \leq 0.9r_{cell}$ or
- S2 - 1 user where $0.6r_{cell} \leq d_{max} \leq 0.8r_{cell}$ and 1 user where $d_{max} \leq 0.2r_{cell}$ or
- S3 - 1 user in a distance $0.4r_{cell} \leq d_{max} \leq 0.6r_{cell}$, 1 user $0.2r_{cell} \leq d_{max} \leq 0.4r_{cell}$ and 1 user in a distance $d_{max} \leq 0.2r_{cell}$ or
- S4 - 3 users in a distance $0.2r_{cell} \leq d_{max} \leq 0.4r_{cell}$ or
- S5 - 1 user in a distance $d_{max} \leq 0.2r_{cell}$.

TABLE II
EXAMPLE OF CALL ADMISSION SCENARIO BEFORE ADMISSION

d_{max}/R_{cell}	0.2	0.4	0.6	0.8	0.9
Existing voice users	10	10	10	5	5

TABLE III
POSSIBLE ADMISSION SCENARIO HAVING TABLE II SCENARIO BEFORE ADMISSION

d_{max}/R_{cell}	Possible combinations of new video users				
	S1	S2	S3	S4	S5
0.2	-	1	1	-	3
0.4	-	-	1	3	-
0.6	-	-	1	-	-
0.8	-	1	-	-	-
0.9	1	-	-	-	-
Total users	1	2	3	3	3

VII. CONCLUSION

Frequency reuse efficiency is a parameter that must be calculated locally, as a means to obtain an accurate estimation of the cell capacity in order to admit or reject an incoming service demand. We have shown that for lower values of jamming margin, i.e. for higher bit rates or higher demands of signal-to-interference ratio, the required frequency reuse efficiency has a considerable variation. Thus, if a new subscriber is accepted that requires a high data rate, a fast degradation of system capacity or coverage can be observed. For lower bit rates or lower requirements of signal-to-interference ratio, the value of frequency reuse efficiency is almost independent on the variation of jamming margin. Note that the reuse efficiency expression is strongly dependent on the network topology, which plays an important role in the determination of which services and where within the cell these services and respective QoSs are guaranteed. An admission control algorithm must consider the value of the reuse efficiency according to subscriber's location and requested service. We proposed an admission control algorithm based on the capacity equation. Finally, we presented an example of admission control for WCDMA services using this algorithm.

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