A CAC Scheme for Voice/Data DS-CDMA Systems with Prioritized Services

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Abstract— **In this paper, we propose a call admission control(CAC) scheme for the mixed voice/data DS-CDMA systems and analyze the Erlang capacity under the proposed CAC scheme. Voice and data traffics require different system resources based on their Quality of Service(QoS) requirements. In the proposed CAC scheme, some system resources are reserved exclusively for handoff calls to have high priority over new calls. Additionally the queueing of both new and handoff data traffics that are not sensitive to delay is allowed. As a performance measure for the suggested CAC scheme, Erlang capacity is utilized. For the performance analysis, a four-dimensional Markov chain model is developed. Erlang capacity of a practical IS-95B type system depicts, and optimum values of system parameters such as the number of reservation channels and queue lengths are found with respect to Erlang capacity. Finally, it is observed that Erlang capacity is improved more than two times by properly selecting the system parameters with the proposed CAC scheme.**

Keywords— **Voice/Data, Call Admission Control, Erlang Capacity, DS-CDMA**

I. INTRODUCTION

Over the past decade, wireless communication networks have experienced tremendous growth. The future wireless networks will expand their services to mobile systems from voice service to the multimedia services such as voice, data, graphics, low resolution video, etc., using advanced multiple access techniques[1-2]. Direct Sequence Code Division Multiple Access(DS-CDMA) is one of major candidates for future wireless access systems due to its attractive features such as high system capacity, soft hand-off, multipath mitigation, interference suppression and low power transmission[3]. The future wireless applications will also be more bandwidth-intensive, the radio spectrum allocated to wireless communication is hardly to be extended. This implies that Call Admission Control(CAC) has become one of essential network functions of wireless networks supporting the mixed services.

Under a mixed-media DS-CDMA environment, CAC is not a trivial problem. In [4-5], CAC schemes favoring handoff calls by means of queuing and channel reservation were presented. In [6], Pavlidou proposed a mathematical model to analyze the performance of the mixed voice and data systems when a number of channels is reserved exclusively for handoff calls and only data handoff calls are queued. Further, Calin and Zeghlache suggested a scheme allowing voice handoff calls also to be queued[7]. However, all of them did not consider DS-CDMA systems. Also, it was assumed that voice and data traffics have the same Quality of Service(QoS) requirements, and require same system resources, which is not suitable for the Multimedia environment where multimedia traffics require different system resources based on their QoS requirements such as data transmission rate and the required E_b/N_o.

In this paper, we propose a CAC scheme for the mixed voice/data DS-CDMA systems supporting the different QoS requirements. In the proposed CAC scheme, some system resources are reserved exclusively for handoff calls to have high priority over new calls. Additionally, queueing is allowed for both new and handoff data traffics that are not sensitive to delay. As a typical realtime traffic that is sensitive to time delay, voice traffic is considered. On the other hand, as a typical non-realtime traffic, the data traffic is considered. In addition, voice and data calls require different system resources based on their QoS requirements such as the required BER and data transmission rate.

As a performance measure, Erlang capacity, defined as a set of the average offered traffic loads of each service group that the DS-CDMA system can carry while the QoS and GoS requirements for all service groups are being satisfied, is utilized so as to consider the performances of all service groups simultaneously. For the performance analysis, a 4-dimension Markov chain model is developed. As a practical example, an IS-95B type DS-CDMA system that supports the medium data rate by aggregating multiple codes in the reverse link is considered, and the optimum values of system parameters such as the number of reservation channels and queue size are selected with respect to the Erlang capacity.

The remainder of this paper is organized as follows: In Section II, we describes the system model. In Section III, a CAC scheme for the mixed voice/data DS-CDMA systems is proposed and analyzed, based on the multi-dimensional Markov model. In Section IV, a numerical example is taken into consideration and discussions are given. Finally conclusions are drawn in Section V.

II. SYSTEM AND TRAFFIC MODELS

A. System Model

We consider the DS-CDMA systems supporting the voice and data services. In the case of DS-CDMA, although there is no hard limit on the number of mobile users served, there is a practical limit on the number of simultaneous users in a cell to control the interference between users having the same pilot signal. Here it is assumed that the considered system supports $\widehat{C}_{etc}$ basic channels per cell and one call attempt of data traffic is equivalent to Λ times voice call attempts, based on the QoS requirements such as data transmission rate and the required E_b/N_o. Then, a capacity limit of the maximum number of concurrent users that DS-CDMA system can support with QoS requirements can be written as follows.

$$N_v + \Lambda N_d \leq \widehat{C}_{etc} \tag{1}$$

where subscript of 'etc' denotes Equivalent Telephone(voice) Channel. Eqn.(1) will be utilized to determine the admission set for the proposed CAC scheme in Section III.

B. Traffic Model

The considered system employs a circuit switching method to deal with the data transmission for voice and data traffics. Each user shares the system resources with other users, and they compete with each traffic for the use of the system resources. Also, once a call request is accepted in the system, the call occupies a channel and transmits the information without delay throughout the call duration. In this situation, we assume that two arrivals of voice and data traffics are distributed according to independent Poisson processes with the average arrival rate λ_v and λ_d respectively. To consider the handoff, let Λ_h be the ratio of area of handoff region to area of a cell, and assume that the location of call generation is uniformly distributed all over a cell. Then, the arrival rates of new voice and handoff voice calls are given by:

$$\lambda_{nv} = (1 - \Lambda_h)\lambda_v, \qquad \lambda_{hv} = \Lambda_h \lambda_v \tag{2}$$

Similarly, the arrival rates of new data and handoff data calls are also given by:

$$\lambda_{nd} = (1 - \Lambda_h)\lambda_d, \qquad \lambda_{hd} = \Lambda_h \lambda_d \tag{3}$$

The unencumbered service time(the time for which an assigned channel would be held if no handoff is required), T_μ, is assumed to be exponentially distributed with $1/\mu$. Here, μ can be μ_v for voice calls, and μ_d for data calls. In addition to the unencumbered service time, we also need to define the residence time(the time for which a traffic that will perform handoff stays in a cell before handoff); T_n is the residence time of a new call, and T_h is the residence time of a handoff call. The channel assigned to a call will be held until either the service is completed in the cell of the assignment or the mobile station moves out of the cell before service completion. Hence, the channel holding time of a new call, T_{Hn}, and the channel holding time of a handoff call, T_{Hh}, are given as follows:

$$T_{Hn} = min(T_\mu, T_n), \; T_{Hh} = min(T_\mu, T_h) \tag{4}$$

where "min" indicates the smaller of the two random variables. Distribution functions of T_{Hn} and T_{Hh} are given by

$$F_{T_{Hn}}(t) = F_{T_\mu}(t) + F_{T_n}(t)[1 - F_{T_\mu}] \tag{5}$$
$$F_{T_{Hh}}(t) = F_{T_\mu}(t) + F_{T_h}(t)[1 - F_{T_\mu}] \tag{6}$$

Now we assume that T_n and T_h are exponentially distributed with means $\overline{T}_n$=$1/\mu_n$ and $\overline{T}_h$=$1/\mu_h$. Then, T_{Hn} and T_{Hh} are also exponentially distributed with $\mu_{Hn} = \mu + \mu_n$ and $\mu_{Hh} = \mu + \mu_h$. Here μ, μ_{Hn} and μ_{Hh} can be μ_v, μ_{vHn} and μ_{vHh} for voice calls, and μ_d, μ_{dHn} and μ_{dHh} for data calls. Hence, distribution function of the total channel holding time, T_H, in a cell is

$$F_{T_H}(t) = \frac{F_{T_{Hn}}(t)}{1+\gamma_c} + \frac{\gamma_c F_{T_{Hh}}(t)}{1+\gamma_c} \tag{7}$$

where γ_c is the ratio of the average handoff attempt rate to the average new arrival attempt rate, and is given as $\gamma_c = \Lambda_h/(1-\Lambda_h)$.

For the following analysis, the distribution of T_h can be approximated by an exponential distribution with mean $\overline{T}_H$[5]. The mean value of T_H, $\overline{T}_H$, is chosen such that the following condition is satisfied:

$$\int_0^\infty (F_{T_H}^C - e^{-\mu_H t})\, dt = 0 \tag{8}$$

where $F_{T_H}^C$ is the complementary function of F_{T_H}. Then, the mean value of T_H is given as:

$$\overline{T}_H = \frac{1}{\mu_H} = \frac{1}{1+\gamma_c}\left(\frac{1}{\mu+\mu_n} + \frac{\gamma_c}{\mu+\mu_h}\right) \tag{9}$$

Here, it should be noted that μ and T_H can be μ_v and T_{vH} for voice traffic, or μ_d and T_{dH} for data traffic.

III. The Proposed Call Admission Control Scheme

Given the QoS requirements for voice and data service groups, there will be $\widehat{C}_{ETC}$ basic channels in each cell. Also, one call attempt of data traffic is quantitatively equivalent to Λ call attempts of voice traffic. In this situation, the call admission control(CAC) algorithm suggested in this paper is as follows: Among $\widehat{C}_{ETC}$ basic channels, $\widehat{C}_{ETC} - C_R$ basic channels are available for new voice, new data, handoff voice and handoff data calls, and C_R basic channels are reserved exclusively for handoff voice and handoff data calls. In addition, two respective first-in-first-out(FIFO) queue systems with the length of Q_n and Q_h are utilized for both new data and handoff data calls that are not sensitive to time delay. That is, if no channel is available in the cell, a new voice call attempt is blocked and a handoff voice call is forced into termination. On the other hand, new data and handoff data calls go into respective queues with finite length Q_n and Q_h, and wait until a channel becomes available as long as its associated terminal is in the area covered by the base station of the target cell. The waiting time in the queue for a data traffic is restricted only by the mobile residence time in the corresponding cell. Consequently, the maximum queueing time, T_q, for a queued data traffic has the same density function as the mobile residence time in a cell. Hence, T_q has a exponential distribution with $1/\mu_q$. Here, μ_q can be $\mu_{nq}(=\mu_n)$ for the queued new data or $\mu_{hq}(=\mu_h)$ for the queued handoff data call, respectively.

The proposed CAC scheme is summarized in the following pseudo code:

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Once a call is attempted:
  IF (sum of used channels after accepting the incoming call ≤ Ĉ_ETC − C_R)
    INCOMING CALL IS ACCEPTED
  ELSE /* not enough basic channels */
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IF (new call) /* incoming call is new call */
  IF (new voice call) /* new voice call */
    INCOMING CALL IS BLOCKED
  ELSE /* new data call */
    IF (number of new data calls in the queue < Q_n)
      INCOMING CALL IS INSERTED IN QUEUE
    ELSE
      INCOMING CALL IS BLOCKED
ELSE /* incoming call is handoff call */
  IF (sum of used channels after accepting the incoming call ≤ Ĉ_ETC)
    INCOMING CALL IS ACCEPTED
  ELSE /* reservation channel is not enough */
    IF (handoff voice call) /* handoff voice call */
      INCOMING CALL IS BLOCKED
    ELSE /* handoff data call */
      IF (number of handoff data calls in the queue < Q_h)
        INCOMING CALL IS INSERTED IN QUEUE
      ELSE
        INCOMING CALL IS BLOCKED
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The system performance of the proposed CAC scheme can be analyzed by the birth-death process. For the performance analysis, it is useful to define occupation state of the cell, characterized by the occupation numbers of cells, as a state in the birth-death process such that

$$\begin{aligned} &S = (i,j,m,n) \\ &i \geq 0, j \geq 0,\ i + \Lambda j \leq \widehat{C}_{ETC},\ 0 \leq m \leq Q_n \ and\ 0 \leq n \leq Q_n \end{aligned} \tag{10}$$

where the state variables i and j denote the number of voice and data users in the system, and m and n denote the number of new and handoff data users in the respective queues.

According to the proposed CAC scheme and occupation state of the cell, a state in the birth-death process falls among the four different admission sets as follows:

$$\Omega_{non-res} \equiv \{(i,j,m,n) | i + \Lambda j \leq \widehat{C}_{ETC} - C_R\} \tag{11}$$

$$\Omega_{res} \equiv \{(i,j,m,n) | \widehat{C}_{ETC} - C_R < i + \Lambda j \leq \widehat{C}_{ETC}\} \tag{12}$$

$$\Omega_{nd-buf} \equiv \{(i,j,m,n) | \widehat{C}_{ETC} - C_R - \Lambda < i + \Lambda j \leq \widehat{C}_{ETC},\ 0 < m \leq Q_n\} \tag{13}$$

$$\Omega_{hd-buf} \equiv \{(i,j,m,n) | \widehat{C}_{ETC} - C_R < i + \Lambda j \leq \widehat{C}_{ETC}, 0 < n \leq Q_h\} \tag{14}$$

Set of all allowable states is given as

$$\Omega_{all} = \Omega_{non-res} \cup \Omega_{res} \cup \Omega_{nd-buf} \cup \Omega_{hd-buff} \tag{15}$$

Let $P_{(i,j,m,n)}$ be the probability that the four-dimensional Markov chain is in the state $S = (i,j,m,n)$. There is a flow equilibrium balance equation for each state, i.e., the total rate of flowing into a state will be equal to the total rate of flowing out from it. That is,

$$\begin{aligned} &\textbf{Rate-In} = \textbf{Rate-Out} \\ &\textbf{Rate-In} = \hat{a} \cdot P_{(i+1,j,m,n)} + \hat{b} \cdot P_{(i,j+1,m,n)} + \\ &\hat{c} \cdot P_{(i,j,m+1,n)} + \hat{d} \cdot P_{(i,j,m,n+1)} + \hat{e} \cdot P_{(i-1,j,m,n)} + \\ &\hat{f} \cdot P_{(i,j-1,m,n)} + \hat{g} \cdot P_{(i,j,m-1,n)} + \hat{h} \cdot P_{(i,j,m,n-1)} \\ &\textbf{Rate-Out} = (\hat{i} + \hat{j} + \hat{k} + \hat{l} + \hat{m} + \hat{n} + \hat{o} + \hat{p}) \cdot P_{(i,j,m,n)} \end{aligned} \tag{16}$$

where the state transitions involved in the Eqn.(16) are derived in [10].

If the total number of all allowable states is n_s, there are $n_s - 1$ linearly independent flow equilibrium balance equations. Based on these $n_s - 1$ flow equilibrium balance equations and the normalized equation, $\sum_{(i,j,m,n) \in \Omega_{all}} P_{(i,j,m,n)} = 1$, a set of linear equations of the Markov chain in the form of $\pi \mathbf{Q} = \mathbf{P}$ can be formed, where π is a vector of all states, $\mathbf{Q}$ is coefficient matrix of the linear equations, and $\mathbf{P} = [0, ..., 1]$. The dimension of π, $\mathbf{Q}$ and $\mathbf{P}$ are $1 \times n_s$, $n_s \times n_s$, $n_s \times 1$ respectively where n_s is total number of all states. By solving $\pi = \mathbf{PQ^{-1}}$, we obtain all steady-state probabilities.

The call attempts of new and handoff voice calls are blocked if there is no channel available. Hence, the blocking probabilities for new voice and handoff voice calls are given as follows:

$$P_{(B,nv)} = \sum_{s \in \Omega_{(B,nv)}} P_{(i,j,m,n)} \tag{17}$$

$$P_{(B,hv)} = \sum_{s \in \Omega_{(B,hv)}} P_{(i,j,m,n)} \tag{18}$$

where

$\Omega_{(B,nv)} = \{(i,j,m,n) | \widehat{C}_{ETC} - C_R < i + \Lambda j \leq \widehat{C}_{ETC}\}$

$\Omega_{(B,hv)} = \{(i,j,m,n) | i + \Lambda j = \widehat{C}_{ETC}\}$

On the other hand, a new and handoff data calls are blocked if there is no channel available and the respective queue is also full. That is, if all channels are busy but there is at least one place unoccupied in the queue, then new and handoff calls are inserted into the respective queues to wait for service. However, if the waiting time exceeds the maximum queueing time before they get a channel, they will be blocked.

Let $P_{(full,nd)}$ and $P_{(full,hd)}$ denote the probability that new and handoff data calls find the respective queues full, respectively. Then, $P_{(full,nd)}$ and $P_{(full,hd)}$ are given as follows:

$$P_{(full,nd)} = \sum_{s \in \Omega_{(full,nd)}} P_{(i,j,m,n)} \tag{19}$$

$$P_{(full,hd)} = \sum_{s \in \Omega_{(full,hd)}} P_{(i,j,m,n)} \tag{20}$$

where

$\Omega_{(full,nd)} =$
$\{(i,j,m,n) | \widehat{C}_{ETC} - C_R - \Lambda < i + \Lambda j \leq \widehat{C}_{ETC},\ m = Q_n,\ 0 \leq n \leq Q_h\}$

$\Omega_{(full,hd)} =$
$\{(i,j,m,n) | \widehat{C}_{ETC} - \Lambda < i + \Lambda j \leq \widehat{C}_{ETC},\ 0 \leq m \leq Q_n,\ n = Q_h\}$

Also, the handoff failure probabilities for the new and handoff data calls due to their time-out are provided by the following equations.

$$P_{(F,nd)} = \frac{\sum_{s\in\Omega_{(nd-buf)}} k\mu_{qn}P_{(i,j,k,l)}}{\lambda_{nd}(1-P_{(full,nd)})} \quad (21)$$

$$P_{(F,hd)} = \frac{\sum_{s\in\Omega_{(hd-buf)}} l\mu_{qh}P_{(i,j,k,l)}}{\lambda_{hd}(1-P_{(full,hd)})} \quad (22)$$

Then, the total blocking probabilities for a new and handoff data traffics are:

$$P_{(B,nd)} = P_{(F,nd)}(1-P_{(full,nd)}) + P_{(full,nd)} \quad (23)$$

$$P_{(B,hd)} = P_{(F,hd)}(1-P_{(full,hd)}) + P_{(full,hd)} \quad (24)$$

As a performance measure for the proposed CAC scheme, we utilize Erlang capacity, defined as a set of the average traffic loads of voice and data traffics that can be supported with a given quality and with availability of service. In this case, Erlang capacity is given as:

$$C_{erlang} \equiv \{(\hat{\rho_v}, \hat{\rho_d})\} = \{(\rho_v,\rho_d)|P_{(B,nv)} \le P_{(B,nv)_{req}}, P_{(B,hv)} \le P_{(B,hv)_{req}}, P_{(B,nd)} \le P_{(B,nd)_{req}} \, and \, P_{(B,hd)} \le P_{(B,hd)_{req}}\} \quad (25)$$

where $\rho_v = \lambda_v/\mu_{vH}$, $\rho_d = \lambda_d/\mu_{dH}$, λ_v and λ_d are the call arrival rates of voice and date calls per cell, respectively, and $1/\mu_{vH}$ and $1/\mu_{dH}$ are the average total channel holding times of voice and data calls respectively, and $P_{(B,nv)_{req}}$, $P_{(B,nd)_{req}}$, $P_{(B,hv)_{req}}$ and $P_{(B,hd)_{req}}$ are the required call blocking probabilities of new voice, new data, handoff voice and handoff data calls, respectively.

The system Erlang capacity is the set of values $\{(\hat{\rho_v}, \hat{\rho_d})\}$ that keep the call blocking probability experimented by each traffic less than the required call blocking probability of each traffic call. In this situation, the Erlang capacity with respect to each traffic can be calculated as a function of offered traffic loads of voice and data traffics, by contouring the call blocking probability experimented by each traffic at the required call blocking probability. Furthermore, the total system Erlang capacity is determined by the overlapped region of Erlang capacity with respect to each traffic.

A general goal of the proposed CAC scheme is to carry the largest Erlang capacity for a given amount of spectrum, and further to find the optimum values of system parameters such as the number of reservation channel and queue size with respect to the Erlang capacity.

IV. NUMERICAL EXAMPLE

As a numerical example, we assume that Λ and $\widehat{C}_{ETC}$ are given as 4 and 29, respectively. It means that there are 29 basic channels, and one call attempt of data traffic is quantitatively equivalent to 4 call attempts of voice traffic. Also, we assume that all Mobile Stations stay in a cell for 1800 sec, the average unencumbered service time is 200 sec for both services, maximum queueing times of new and handoff data calls are 1800 sec, respectively and the ratio of area of handoff region to area of a cell, Λ_h, is 0.2. The average call arrival rates of voice and data, λ_v and λ_d are variable. Since Λ_h is given as 0.2, the average

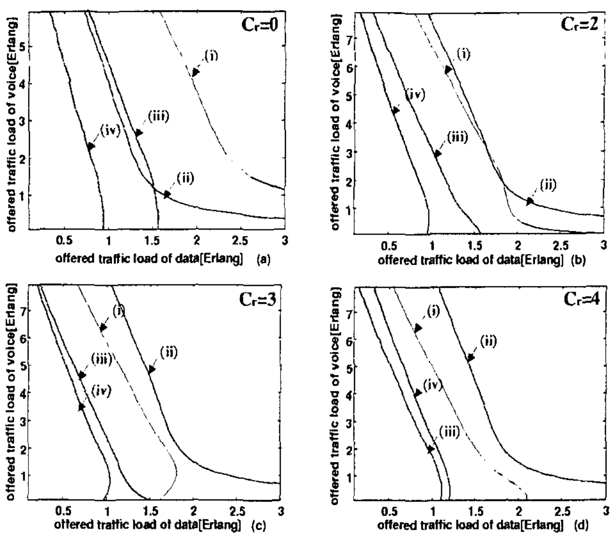

Fig. 1. Erlang capacity according to the number of reservation channels for voice and data handoff calls when Q_n=0 and Q_h=0; (a) C_r=1, (b) C_r=2, (c) C_r=3 and (d) C_r=4. For each case, the curve represented by (i) is the Erlang capacity limited by the required call blocking probability of new voice call(1%), the curve represented by (ii) is the Erlang capacity limited by the required call blocking probability of handoff voice call(0.1%), the curve represented by (iii) is the Erlang capacity limited by the required call blocking probability of new data call(1%) and the curve represented by (iv) is the Erlang capacity limited by the required call blocking probability of handoff data call(0.1%)

arrival rates of new voice, handoff voice, new data and handoff data are $0.8\lambda_v$, $0.2\lambda_v$, $0.8\lambda_v$ and $0.2\lambda_v$, respectively. Fig.1(a) shows Erlang capacity region that the system can support with 1% call blocking probability for new calls and 0.1% for handoff calls, when C_r=0, Q_n=0 and Q_h=0. In this case, any control schemes such as reservation and queue are not considered. It is conceptually correspondent to complete sharing scheme. From Fig.1(a), the two main observations are made: The first is that data traffic has more impact on Erlang capacity than voice traffic since the effective bandwidth required by one data user is more larger than that of one voice user. The other observation is that the total system Erlang capacity region is determined by the Erlang capacity limited by the required call blocking probability of handoff data call since the system should satisfy the required call blocking probabilities of all traffic groups, simultaneously. Hence, it is required to get a proper tradeoff between Erlang capacities limited by the required call blocking probability of all traffic groups so as to enhance the total system Erlang capacity. This observation leads us to the way how to operate the proposed CAC scheme.

Fig.1 shows the effect of the number of reservation channels, C_R, on the Erlang capacity. In this case, some channels are exclusively reserved for voice and data handoff calls, which is very useful especially when both voice and data traffics are real-time traffics that are sensitive to delay. As we see in Fig.1, Erlang capacity regions that are limited by the required call blocking probabilities of handoff voice and data calls increase respectively, as the number of reservation channels for handoff calls increases(see (ii) and (iv) in Fig.1). On the other hand, Erlang capacity regions that are limited by the required call blocking probabilities of new voice and data calls decrease respectively.

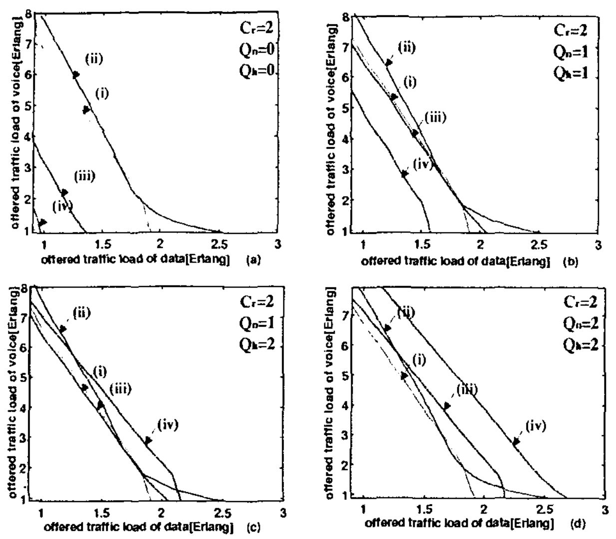

Fig. 2. Erlang capacity according to length of queue for new and handoff data calls when C_r=2; (a) Q_n=0 and Q_h=0 (b) Q_n=1 and Q_h=1, (c) Q_n=1 and Q_h=2 and (d) Q_n=2 and Q_h=2. For each case, the curve represented by (i) is the Erlang capacity limited by the required call blocking probability of new voice call(1%), the curve represented by (ii) is the Erlang capacity limited by the required call blocking probability of handoff voice call(0.1%), the curve represented by (iii) is the Erlang capacity limited by the required call blocking probability of new data call(1%) and the curve represented by (iv) is the Erlang capacity limited by the required call blocking probability of handoff data call(0.1%)

Especially, total system Erlang capacity is determined by Erlang capacity limited by the required blocking probability of handoff data calls until 3 basic channels are reserved for handoff calls. After this, it is determined by Erlang capacity limited by the required call blocking probability of new data calls. However, we can observe that the total system Erlang capacity is more increased through reserving 4 basic channels for handoff calls, by comparing Fig.1(a) and Fig.1(d). Also, we observe that it is inefficient to reserve more than 4 basic channels for handoff calls by which Erlang capacity limited by the required call blocking probability of new data calls will be more restricted. Hence, in the case where reservation scheme is only considered, the optimum value of number of reservation channels for handoff calls is 4. In the proposed CAC scheme, two respective queues with the finite queue length of Q_n and Q_h are utilized for new and handoff data traffics, respectively. Fig.2 shows the effect of the length of respective queues for new and handoff data calls on the Erlang capacity. As we see in Fig.2, Erlang capacity regions that are limited by the required call blocking probabilities of new and handoff data calls increase as the length of queues for new and handoff calls is larger(see (iii) and (iv) in Fig.2). On the other hand, Erlang capacity regions that are limited by the required call blocking probabilities of new and handoff voice calls are not changed(see (i) and (ii) in Fig.2). Here, we consider the case where the number of reservation channels for handoff traffics is 2. The reason is as following: When C_r=2, the Erlang capacity region that is overlapped by Erlang capacities limited by the required call blocking probabilities of new and handoff voice calls, is maximized(see (i) and (ii) in Fig.1(b)). Also, Erlang capacities that are limited by the required call blocking probability of new and handoff data calls can be adjusted through the queue length. Finally, Fig.2 shows that the total system Erlang capacity is maximized when C_r=2, Q_n=2 and Q_h=2. Furthermore, we can observe that the total Erlang capacity under the proposed CAC is increased more than 2 times, comparing Fig.2(d) with Fig.1(a). However, note that, even if the length of respective queues is increased more than 2, total system Erlang capacity is not increased since the Erlang capacity limited by the required call blocking probability of new voice is a dominant factor which determines the total system Erlang capacity. Also, queueing time delay is introduced due to queue. The larger is queue length, the more will be queueing time delay. Hence, the optimum values of the length of respective queues for new and handoff calls, and number of reservation channels are 2, 2, and 2, respectively, with respect to both Erlang capacity and queueing time delay.

V. Conclusion

In this paper, we have proposed and analyzed a CAC scheme for a mixed voice/data DS-CDMA system so as to accommodate the more system Erlang capacity. For the performance analysis, a four-dimensional Markov chain model is developed. Through a numerical example of an IS-95B type system, we observe that the data users have more impact on the Erlang capacity than the voice users because the effective bandwidth of one data is more larger than that of one voice. Also, it is required that the Erlang capacities with respect to all traffic groups should be balanced to enhance the total system Erlang capacity. There are optimal values of reservation channels and queue lengths in order to maximize the total Erlang capacity. In the case where only reservation scheme is considered, the optimum value of the number of reservation channels is 4 with respect to Erlang capacity. On the other hand, for the case in which queue and reservation schemes are combined, the optimum values of the number of reservation channels and length of respective queues for new and handoff data calls are 2, 2, and 2, respectively, thereby the Erlang capacity is improved more than two times.

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