PAPER

Radio Resource Assignment in Multiple-Chip-Rate DS/CDMA Systems Supporting Multimedia Services

Young-Woo KIM[†], **Seung Joon LEE**[††], **Min Young CHUNG**[†], **Jeong Ho KIM**[†], ***Nonmembers***, *and* **Dan Keun SUNG**[†], ***Member***

SUMMARY This paper is concerned with radio resource allocation in multiple-chip-rate (MCR) DS/CDMA systems accommodating multimedia services with different information rates and quality requirements. Considering both power spectral density (PSD) over a radio frequency (RF) band and the effect of RF input filtering on the receiver in MCR-DS/CDMA systems, criteria for capacity estimation are presented and the characteristics of co-channel interference between subsystems are investigated. System performance in MCR-DS/CDMA systems is strongly affected by radio resource assignment. A minimum power-increment-based resource assignment scheme for an efficient resource assignment scheme is proposed herein. The performance of this scheme is compared with that of a random-based resource assignment scheme in terms of blocking probability and normalized throughput. The minimum power-increment-based resource assignment scheme yields a better performance than the random-based resource assignment scheme for multimedia services.

key words: *multiple-chip-rate DS/CDMA, capacity, radio resource assignment*

1. Introduction

Third-generation wireless systems, such as the IMT-2000 [1] and the UMTS [2], are required to accommodate a wide variety of services, including high quality voice, data, facsimile, video, and interactive applications, with information bit rates ranging from a few kb/s to 2 Mb/s [3], [4]. Code division multiple access (CDMA) is a promising technique that complies with the above requirements [5]. Direct sequence (DS)-CDMA is attractive because of its flexibility in supporting multimedia traffic, as well as low interference coexistence with other CDMA or narrow-band systems operating in the same frequency band [6].

Two approaches for accommodating multi-rate services generated from multimedia traffic in DS-CDMA systems have been proposed. One is to use either a single-code or a multi-code DS-CDMA system in a single RF channel bandwidth [7]–[9]. The other is to use a multiple-chip-rate DS/CDMA system in multiple RF channel bandwidths [4], [10]–[14]. The frequency bandwidth of an MCR-DS/CDMA system is selected according to the maximum information rate to be supported. MCR-DS/CDMA systems were proposed by the Code Division Testbed (CODIT) project [4], [10], OKI [11], [12], and ETRI [14]. In the experimental CODIT testbed, an MCR-DS/CDMA system was proposed with three different chip rates corresponding to three different RF channel bandwidths of approximately 1, 5, and 20 MHz. The three RF channel bandwidths of this system are referred to as narrow-band, medium-band, and wide-band RF channels. In this system, low-rate services (e.g., voice) can be optionally accommodated on narrow-band or on medium-band channels. The 1 MHz channel can be allocated as a standard RF channel for low-rate voice mobile phones, and 5 MHz can be used as an option for providing a higher grade-of-service (GoS). High-rate services (64 kb/s and above) require RF channels of 5 or 20 MHz. For flexible use of limited RF resources to accommodate multimedia services, MCR-DS/CDMA systems are preferable to single RF channel bandwidth systems [3], [10], [13]. However, due to the complexity of obtaining quantitative results on the performance of MCR-DS/CDMA systems, only a few results have been reported [15]–[17]. These reported results did not consider the shape of the PSD of all spread signals in the system or the effect of RF input filtering on the receiver.

In this paper, radio resource allocation schemes supporting multimedia services in MCR-DS/CDMA systems are investigated. The number of users per cell is limited by the total interference received at each base station (BS). When a system encounters congestion, admitting a new call can only cause deterioration of the link quality for some active calls and may result in dropping calls. Thus, in order to maintain acceptable connections for existing users, a system requires call admission criteria for new call requests. Gilhousen et al. [18] derived the number of accepted voice calls in order to represent the capacity of CDMA systems. Evans and Everitt [19] reported results regarding the capacity of multiple service DS-CDMA cellular networks, but they neglected background noise and considered the target signal in the interference. Lee et al. [20] proposed call admission criteria and derived the capacities of single-code and multi-code DS-CDMA systems ac-

Manuscript received March 9, 1998.
Manuscript revised July 3, 1998.
[†]The authors are with the Department of Electrical Engineering, Korea Advanced Institute of Science & Technology, 373-1, Kusong-dong, Yusong-gu, Taejon 305-701, Korea.
[††]The author is with Hyundai Electronics Industries Co., Ltd., 136-1, Ami-ri, Bubal-eub, Ichon-kun, Kyoungki-do 467-860, Korea.

commodating multi-class services. Liu and Zarki [21] proposed call admission control algorithms based on the measured signal-to-interference ratio for dynamically changing multiple cell CDMA systems where only voice calls are accommodated. Anderlind [22] proposed a distributed and adaptive radio bandwidth assignment algorithm in the case that each user's bandwidth requirements can vary substantially among users in a wireless network. Zander [23] presented a general formulation of a radio resource management problem and discussed some of the key problems of resource management in the third generation personal communications services (PCS). Chen and Rao [24] proposed a flexible resource management strategy to handle heterogeneous traffic which was dynamically adapted to a time-varying channel and user mobility. Wahlqvist et al. [25] compared the capacity of an orthogonal frequency division multiplexing (OFDM) based multiple access system for a least interfered resource allocation, a random resource allocation, and a fixed resource allocation scheme. However, these results were for single RF channel bandwidth systems and not for MCR-DS/CDMA systems.

Each call in the four narrow-band RF channels of 5 MHz in MCR-DS/CDMA systems experiences different interferences from the power level of calls in the wide-band RF channel of 20 MHz. Therefore, a different call admission control scheme is necessary, compared with conventional single RF channel bandwidth systems. This paper presents criteria for capacity estimation and derives system performance. System performance is strongly affected by a selected channel assignment strategy, and it is important to efficiently assign radio resources in MCR-DS/CDMA systems that support high capacity with a low blocking rate. A minimum power-increment-based resource assignment scheme is proposed and the performance of this scheme is compared with that of a random-based resource assignment scheme in terms of blocking probability and normalized throughput.

This paper is organized as follows. In Sect. 2, an MCR-DS/CDMA system model and a traffic model are described. In Sect. 3, a quality-of-service (QoS) measure in an MCR-DS/CDMA system is presented and criteria for capacity estimation for multimedia services are derived. In addition, capacities (or admissible sets) in four different cases are estimated and compared. And then, the characteristics of co-channel interference between subsystems are investigated. In Sect. 4, two radio resource assignment algorithms are presented and performance measures are considered in order to evaluate the performance of each scheme. In Sect. 5, system performance is evaluated by simulation and results are discussed. Finally, conclusions are given in Sect. 6.

2. System Model

2.1 MCR-DS/CDMA System Model

In MCR-DS/CDMA systems, as in other cellular systems, a service area is divided into cells, and each cell is served by a BS. In each cell, the same RF channels can be reused. The CDMA system capacity is interference limited [18]. A separation of different user signals is achieved by means of signature sequences which are used to spread the spectrum of user information signals.

A system model is shown in Fig. 1. The system consists of several subsystems. r_{mj}^{chip} and f_{mj} denote the spreading chip rate and the RF carrier frequency of subsystem $\{m, j\}$, $m = 1, \cdots, M$ and $j = 1, \cdots, 2^{m-1}$, respectively.

Calls are classified into i different classes of bearer services, $i = 1, \cdots, I$, and the bearer services are arranged in order, according to the required QoS, spreading chip rates, and RF carrier frequencies. Table 1 shows an example of relation between three types of calls and class-i bearer service, $i = 1, \cdots, 12$.

The MCR-DS/CDMA system model and the associated assumptions used in this paper are summarized as follows:

1) A service area is divided into cells of equal size.
2) Separate frequency bands are used for forward and reverse links. Thus, mobile stations experience interference only from BSs and BSs experience interference only from mobile stations.
3) Each mobile station is power-controlled by the BS of its home cell.
4) A mobile station making a call request to the system chooses its home cell such that the radio propagation attenuation between the mobile station and the BS of its home cell is minimized.
5) Only the reverse link is considered because it is more critical to the system capacity than the forward link.

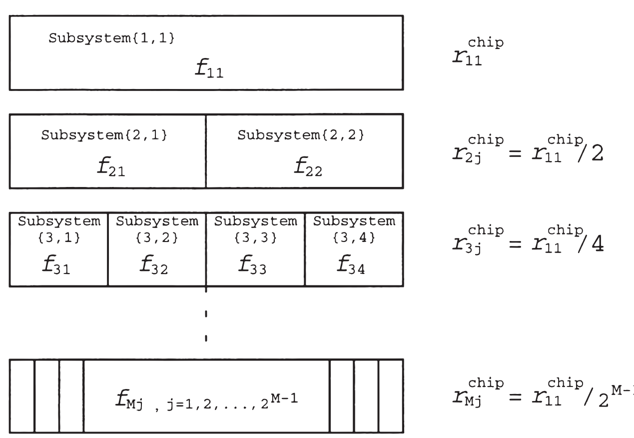


Fig. 1 Frequency assignment of an MCR-DS/CDMA system.

Table 1 Example of relation between three types of calls and class-i bearer service.

Type-t	Calls	Required $E_b/I_o, \gamma_t$	Class-i	Remarks
1	Low resolution video	γ_1	1	subsystem {1,1}, f_{11}
			2	subsystem {2,1}, f_{21}
			3	subsystem {2,2}, f_{22}
2	Facsimile	γ_2	4	subsystem {1,1}, f_{11}
			5	subsystem {2,1}, f_{21}
			6	subsystem {2,2}, f_{22}
3	Voice	γ_3	7	subsystem {2,1}, f_{21}
			8	subsystem {2,2}, f_{22}
			9	subsystem {3,1}, f_{31}
			10	subsystem {3,2}, f_{32}
			11	subsystem {3,3}, f_{33}
			12	subsystem {3,4}, f_{34}

6) There are I classes of bearer services with each information bit rate R_i and n_i bearer services of the class-i ($i = 1, \cdots, I$) are connected to the BS.
7) Given the number of accepted bearer services for each class, the received power at a BS is assumed to be equal for each bearer service in the same class through perfect power control.
8) Coherent detection and asynchronous quaternary direct-sequence spread-spectrum multiple-access systems are used in additive white Gaussian noise (AWGN) channels.
9) Inter-cell interference is assumed to be measured from the received power at the BS.

2.2 Traffic Model

Call arrivals at a BS are assumed to follow an independent Poisson process with arrival rate λ_t for type-t calls ($t = 1, \cdots, T$). The holding time of each type of call is modeled as an exponential distribution with mean service time $1/\mu_t$ ($t = 1, \cdots, T$). Handoff calls are not explicitly modeled here. The justification for this is that, with perfect power control, the need and acceptance of handoff calls should result in reducing the system-wide interference, from the interference point of view. Since a handoff is necessary only when the signal-to-interference ratio at a new cell is higher than for an original cell, handoff requires a lower transmitted power to the new cell and, thus, reduces the interference at both the new cell and the original cell.

3. Capacity Estimation

In this section, a QoS measure in an MCR-DS/CDMA system is presented and criteria for capacity estimation are derived. And then, the characteristics of co-channel interference between subsystems are investigated in order to propose an efficient radio resource assignment algorithm.

3.1 Quality-of-Service (QoS)

As a QoS measure in an MCR-DS/CDMA system supporting multi-class bearer services, the bit energy-to-interference PSD ratio for class-i bearer service, $\langle E_b/I_o\rangle_i$, is given by:

$$\langle E_b/I_o\rangle_i = \frac{S_i/R_i}{\frac{\left(\sum_{k=1}^{I} \xi_{ki} n_k S_k + I_i - S_i\right)}{(\chi R_i^{chip})} + N_o}, \qquad (1)$$

where R_i^{chip} denotes the chip rate of the spreading sequence of class-i bearer service, S_i the received power at the BS, R_i the information bit rate, $\frac{R_i^{chip}}{R_i} (\triangleq G_i)$ the spreading factor, E_b the information bit energy, ξ_{ki} ($0 \le \xi_{ki} \le 1$) the interference factor for the class-k bearer service signal to the class-i bearer service signal (i.e., the proportion of the class-k bearer service signal received by the BS receiver for the class-i bearer service signal), I_i the inter-cell interference received by the BS receiver for the class-i bearer service signals, and $N_o/2$ the two-sided PSD of AWGN. Here χ is the coefficient that arises in the Gaussian model. The coefficient χ depends on the chip pulses and the modulation schemes in the system [26]. For example, χ becomes 0.75 for a rectangular chip pulse in asynchronous quaternary direct-sequence spread-spectrum multiple-access systems, and 0.91 for a raised cosine chip pulse with a roll-off factor of 0.35 according to the North American cellular standard [27] in the same systems. In asynchronous binary direct-sequence spread-spectrum multiple-access systems, the coefficients 1.5 and 1.82 are obtained with a rectangular and a raised cosine chip pulse, respectively. Eq. (1) is based on the fact that the bit error rate (BER) is approximately given by BER $\approx Q(\sqrt{2\langle E_b/I_o\rangle})$, where $Q(x) = \int_x^\infty \frac{1}{\sqrt{2\pi}} e^{-\frac{y^2}{2}} dy$, when coherent detection and asynchronous transmission among multiple user terminals are used in AWGN [28], [29].

3.2 Criteria for Capacity Estimation

Criteria for capacity estimation in a multiple cell environment are now considered. When a new call of type-t attempts to access the network, the network needs to estimate the QoS after the new call is accepted, as a procedure for call admission control. This admission control is done by checking if addition of the new call simultaneously fulfills the required bit energy-to-interference PSD ratio for the new and all the existing users. Given the required bit energy-to-interference PSD ratio γ_i for the class-i bearer service, the requirement for the class-i bearer service is written as:

$$\frac{S_i/R_i}{\frac{(\sum_{k=1}^{I}\xi_{ki}n_k S_k + I_i - S_i)}{(\chi R_i^{chip})} + N_o} \geq \gamma_i \ (i = 1, \cdots, I). \quad (2)$$

Eq. (2) can be rewritten as:

$$a_i S_i \geq \sum_{k=1}^{I} \xi_{ki} n_k S_k + b_i \quad (i = 1, \cdots, I), \quad (3)$$

where

- in general case:

$$a_i = 1 + \frac{\chi}{\gamma_i} G_i \quad \text{and} \quad b_i = \chi R_i^{chip} N_o + I_i \ ,$$

- in case of using the inter-cell interference factor, f [30]:

$$a_i = 1 + \frac{\chi}{1+f}\frac{G_i}{\gamma_i} \quad \text{and} \quad b_i = \frac{\chi}{1+f} R_i^{chip} N_o \ .$$

Once perfect power control is achieved, the BS can identify the power level of each call in the cell. The BS can also measure the total received power and the background noise power. Therefore, it can obtain the inter-cell interference value by subtracting the received power of all calls served by itself and the background noise power from the total received power. ξ_{ki} is a constant depending on the class-i bearer service and a_i is determined according to the spreading bandwidth and QoS requirements of the call. However, n_i, S_i, and b_i are updated to correctly reflect the interference updated for each call arrival and release. In a single cell system (i.e., $I_i = 0$), b_i only consists of a background noise component.

If $S_i = \underline{S}_i$ is the minimum for satisfying Eq. (3), it holds that

$$a_i \underline{S}_i = \sum_{k=1}^{I} \xi_{ki} n_k \underline{S}_k + b_i \quad (i = 1, \cdots, I). \quad (4)$$

We can rewrite Eq. (4) in a matrix form,

$$\mathbf{A}\underline{\mathbf{S}} = \mathbf{b}, \quad (5)$$

where

$$\mathbf{A} \triangleq \begin{bmatrix} a_1 - n_1\xi_{11} & -n_2\xi_{21} & \cdots & -n_I\xi_{I1} \\ -n_1\xi_{12} & a_2 - n_2\xi_{22} & \cdots & -n_I\xi_{I2} \\ \vdots & \vdots & \ddots & \vdots \\ -n_1\xi_{1I} & -n_2\xi_{2I} & \cdots & a_I - n_I\xi_{II} \end{bmatrix},$$

$$\underline{\mathbf{S}} \triangleq \begin{bmatrix} \underline{S}_1 \\ \underline{S}_2 \\ \vdots \\ \underline{S}_I \end{bmatrix}, \text{and } \mathbf{b} \triangleq \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_I \end{bmatrix}.$$

Given the maximum receivable power of the class-i bearer service as $\overline{S}_i$ $(i = 1, \cdots, I)$, the admissible set of network traffic is given by

$$\{(n_1, \cdots, n_I) | \ \exists \ \underline{S}_i \ \text{ such that } 0 \leq \underline{S}_i \leq \overline{S}_i \ \text{and } \underline{S}_i \text{ satisfies (5)}\}. \quad (6)$$

Here, the maximum receivable power of the class-i bearer service means the maximum power that can be received by the BS even in the case of the largest propagation loss between the BS and the mobile station. In addition, $\underline{S}_i$ implies the minimum received power causing the least interference to other signals while maintaining an acceptable bit energy-to-interference PSD ratio, which can be obtained from Eq. (6), given existing calls.

3.3 Characteristics of Interference between Subsystems

We consider an MCR-DS/CDMA system with three chip rates and seven subsystems, as shown in Fig. 2 [31].

The power spectral densities of DS waveforms in a system configuration are shown in Fig. 3. The PSD of each spreading signal is expressed in the form of $|\{1 - \sin[\frac{4\pi(f-f_c)T_c-\pi}{2\alpha}]\}|^2$, ($T_c$: chip duration, f_c: carrier frequency, and α: roll-off factor) with a raised cosine chip pulse.

We assume that $r_{11}^{chip} = 20$ Mchips/s, $r_{2j}^{chip} = r_{11}^{chip}/2 = 10$ Mchips/s, $r_{3j}^{chip} = r_{11}^{chip}/4 = 5$ Mchips/s, $N_o = 4 \times 10^{-21}$W/Hz, $\overline{S}_i = 4 \times 10^{-10}$W, the inter-cell interference factor $f = 0.55$ [30], and the roll-off factor $\alpha = 0.35$ [27]. The arriving traffic consists of a mixture of three different calls, as shown in Table 2, where we refer to [32] for the required bit error rates.

For these three calls, Tables 3 and 4 show parameters a_i and b_i, and interference factor ξ_{ki}.

Considering both PSD over an RF band and the

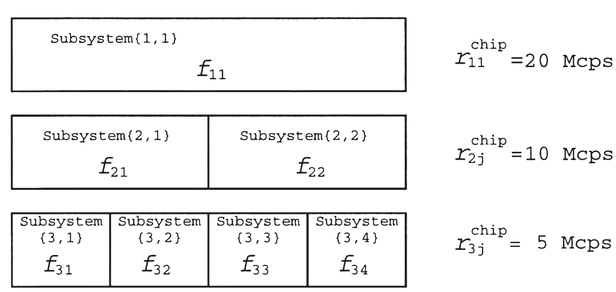


Fig. 2 MCR-DS/CDMA system model for simulation.

Table 2 Required performance for different calls.

Type-t	Calls	Information bit rate	Required BER	Required $E_b/I_o, \gamma_t$
1	Low resolution video	128 kb/s	10^{-5}	9.095 (=9.6 dB)
2	Facsimile	64 kb/s	10^{-4}	6.916 (=8.4 dB)
3	Voice	32 kb/s	10^{-3}	4.775 (=6.8 dB)

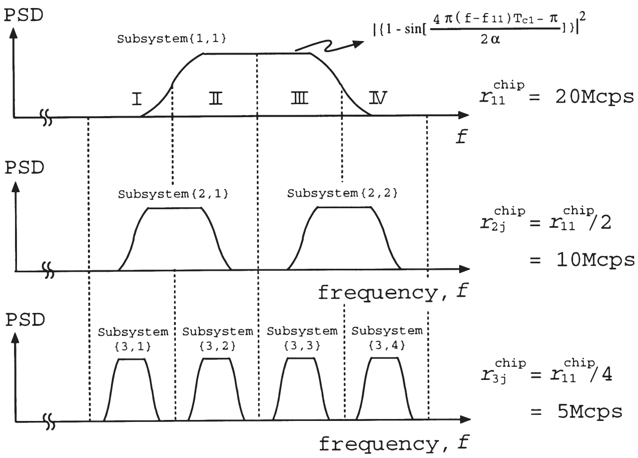


Fig. 3 PSD of DS waveforms in a system configuration.

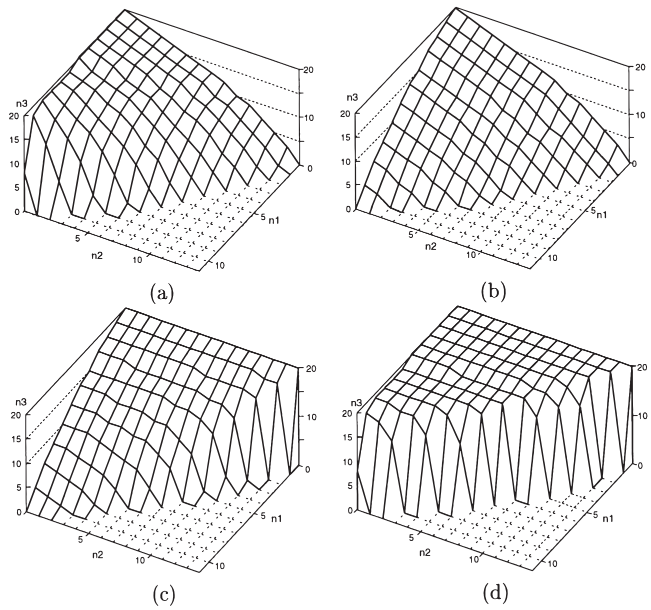


Fig. 4 Admissible sets: (a) case-1, (b) case-2, (c) case-3, (d) case-4.

Table 3 Parameters.

Class-i	Services	a_i	b_i
1	Video	11.086	4.697×10^{-14}
2	Facsimile	14.264	2.348×10^{-14}
3	Voice	20.211	1.174×10^{-14}

Table 4 The interference factors.

ξ_{ki}	Case-1	Case-2	Case-3	Case-4
ξ_{11}	1	1	1	1
ξ_{12}	0.5	0.5	0.5	0.5
ξ_{13}	0.011	0.489	0.489	0.011
ξ_{21}	1	1	1	1
ξ_{22}	1	1	1	1
ξ_{23}	0.5	0.5	0	0
ξ_{31}	1	1	1	1
ξ_{32}	1	1	0	0
ξ_{33}	1	1	1	1

Table 5 Admissible set.

Items	Case-1	Case-2	Case-3	Case-4
Number of admissible points	1448	1072	1595	2245
Proportion $(= \frac{\text{number}}{\text{max. number}})$	0.6450	0.4775	0.7105	1

effect of RF input filtering on the receiver, admissible sets in the following four cases are estimated and the characteristics of co-channel interference between subsystems are investigated:

- Case-1: Using subsystem {1,1}, subsystems {2,1} and {3,1},
- Case-2: Using subsystem {1,1}, subsystems {2,1} and {3,2},
- Case-3: Using subsystem {1,1}, subsystems {2,1} and {3,3},
- Case-4: Using subsystem {1,1}, subsystems {2,1} and {3,4}.

For simplicity, we assume that lower-rate calls are only accommodated on narrow-band channels and higher-rate calls require the use of wide-band channels. Therefore, 5 MHz bandwidth channels can be allocated for RF channels for voice calls, 10 MHz bandwidth channels for facsimile calls, and a 20 MHz bandwidth channel for video calls. Hence, we assume that $R_1^{chip} = r_{11}^{chip}$ = 20 Mchips/s, $R_2^{chip} = r_{21}^{chip}$ = 10 Mchips/s, and R_3^{chip} = r_{3j}^{chip} = 5 Mchips/s. R_i^{chip} denotes the chip rate of the spreading sequence of the class-i bearer service and r_{mj}^{chip} denotes the chip rate of the spreading sequence in subsystem $\{m, j\}$.

Figure 4 and Table 5 show the admissible sets in case-1, case-2, case-3, and case-4.

In Fig. 4, n_1, n_2, and n_3 are the admissible numbers for video, facsimile, and voice call, respectively. The admissible set in each case is given by simulations. Each admissible point (n_1, n_2, n_3) within the admissible set, in which the relative rewards are reflected, means the admissible number of each type of calls that the system can support at a specified level of QoS. The number of admissible points in case-2 is approximately 52% less than in case-4, and the capacity boundary in case-2 is more similar to that in the single RF channel bandwidth systems [19], than the capacity boundary in any other case. This is because mutual-interference in case-2 is the largest. Furthermore, it can be observed that subsystem $\{3,2\}$ (or $\{3,3\}$) suffers more interference from subsystem $\{1,1\}$ than does subsystem $\{3,1\}$ (or $\{3,4\}$). However, in the case that the PSD of all spread signals is flat for all frequencies, it can be observed that all the subsystems $\{3,j\}$, $j=1,\cdots,4$, suffer the same interference from subsystem $\{1,1\}$.

In addition, subsystems $\{2,j\}$, $(j=1,2)$ (or $\{3,j\}$, $(j=1,\cdots,4)$) interfere with each other by way of subsystem $\{1,1\}$, which yields a change in the number of admitted users in subsystems 1, 2, and 3. From these observations, it is noted that adjusting the allocation of the number of calls to subsystems can reduce the blocking probability in MCR-DS/CDMA systems.

4. Radio Resource Assignment

4.1 Algorithm

As described above, subsystems $\{3,j\}$, $(j=1,\cdots,4)$ experience different interferences from subsystem $\{1,1\}$. Therefore, it is critical to efficiently assign radio resources in MCR-DS/CDMA systems that support high capacity and a low blocking rate. A minimum power-increment-based resource assignment scheme for an efficient resource assignment scheme is proposed. Minimum power-increment here means that a new call is accepted in such a way that subsystem with $\min[P(n+1)-P(n)]$ is chosen for the new call, where $\min[X]$ denotes the minimum value of X, $P(n)$ the total received power at a BS, and $P(n+1)$ the total received power in case of adding the new call. In order to effectively evaluate the performance of the minimum power-increment-based resource assignment algorithm, a random-based radio resource assignment algorithm is also presented.

Both algorithms allocate a subsystem to a new user on a first-come first-served (FCFS) basis. The QoS requirements in Sect. 3 are used in the criteria for call admission.

- Algorithm I (Random resource assignment algorithm)
  1) When the network receives a call request from user l, it assigns an unassigned spreading code to the new user in a randomly chosen subsystem among the candidate subsystems determined according to the bandwidth requirement of the requested call.
  2) The new call is accepted if addition of the new call satisfies the criteria for call admission. Otherwise, it is blocked.

  This scheme is commonly adopted in selecting a channel among equally probable candidate channels. The feature of this scheme is simple to implement the algorithm.

- Algorithm II (Minimum power-increment-based resource assignment algorithm)
  1) When a BS receives a call request from user l, it first checks if there are any subsystems that satisfy the criteria for call admission.
  2) If several subsystems meet the requirements, the BS chooses a subsystem with the minimum increment of total received power and assigns an unassigned spreading code to the new user. If no subsystem satisfies the requirements, the call is blocked.
  3) When a user terminates a call, the serving BS makes a list of the minimum received power for the existing users.

In the algorithm, the minimum received power for the existing users is instantaneously available for each incoming call request and call-release in the process of checking the QoS requirements. This scheme, based on the minimum power-increment, is used for radio resource assignment to reduce the blocking of incoming calls.

4.2 Performance Measures

Performance is evaluated in terms of the blocking probability and normalized throughput. The blocking probability P_{bt} is defined in the model as:

$$P_{bt} = \frac{\text{number of the type-}t\text{ calls blocked}}{\text{number of the type-}t\text{ calls arrived}}, \quad t=1,\cdots,T. \tag{7}$$

The normalized throughput S is defined as the degree of utilization of system capacity:

$$S = \left\{ \sum_{t=1}^{T} \eta_t \frac{\lambda_t}{\mu_t}(1-P_{bt}) \right\} / \{C\}, \tag{8}$$

where λ_t denotes the arrival rate, μ_t the mean service rate, η_t the relative reward of type-t call $(t=1,\cdots,T)$, and C the system capacity (e.g., $\eta_t \cdot a_i \cdot 2^{m-1}$ for class-i bearer service, i.e., type-t call using subsystem $\{m,j\}$ with a chip rate of r_{mj}^{chip}). The maximum (admissible) number of class-i bearer service admissible in the total bandwidth of an MCR-DS/CDMA system is $\lfloor a_i \cdot 2^{m-1} \rfloor$, where $\lfloor X \rfloor$ denotes the greatest integer less than or equal to X, a_i the parameter for class-i bearer service, and 2^{m-1} the number of subsystems $\{m,j\}$ with a chip rate of r_{mj}^{chip}. From these values, the relative reward η_t of type-t call, which is defined as the proportion of the maximum admissible number of reference calls to that of type-t calls, can be derived. The reference call, which is defined as a call with a basic rate to be supported, is chosen among each type of call in the system. $\frac{\lambda_t}{\mu_t}$ is the traffic load for type-t call.

Table 6 Parameters and relative rewards.

Type-t	Calls	Class-i	a_i	b_i	η_t
1	Low resolution video	1	11.086	4.697×10^{-14}	6.67
		2	6.043	2.348×10^{-14}	
		3	6.043	2.348×10^{-14}	
2	Facsimile	4	27.528	4.697×10^{-14}	2.86
		5	14.264	2.348×10^{-14}	
		6	14.264	2.348×10^{-14}	
3	Voice	7	39.422	2.348×10^{-14}	1
		8	39.422	2.348×10^{-14}	
		9	20.211	1.174×10^{-14}	
		10	20.211	1.174×10^{-14}	
		11	20.211	1.174×10^{-14}	
		12	20.211	1.174×10^{-14}	

Table 7 The interference factors, ξ_{ki}.

$k \setminus i$	1	2	3	4	5	6	7	8	9	10	11	12
1	1	0.5	0.5	1	0.5	0.5	0.5	0.5	0.011	0.489	0.489	0.011
2	1	1	0	1	1	0	1	0	0.5	0.5	0	0
3	1	0	1	1	0	1	0	1	0	0	0.5	0.5
4	1	0.5	0.5	1	0.5	0.5	0.5	0.5	0.011	0.489	0.489	0.011
5	1	1	0	1	1	0	1	0	0.5	0.5	0	0
6	1	0	1	1	0	1	0	1	0	0	0.5	0.5
7	1	1	0	1	1	0	1	0	0.5	0.5	0	0
8	1	0	1	1	0	1	0	1	0	0	0.5	0.5
9	1	1	0	1	1	0	1	0	1	0	0	0
10	1	1	0	0	1	0	1	0	0	1	0	0
11	1	0	1	1	0	1	0	1	0	0	1	0
12	1	0	1	1	0	1	0	1	0	0	0	1

5. Simulation

The performance of both algorithms is evaluated for varying the call arrival rate by simulations. The MCR-DS/CDMA system model shown in Fig. 2 is used in the simulation. For the example described in Sect. 3, the simulation is performed in an AWGN environment. We consider that 5 MHz bandwidth channels can be allocated for RF channels for voice calls, 10 MHz bandwidth channels for voice, facsimile, and video calls, and a 20 MHz bandwidth channel for facsimile and video calls. Therefore, we assume that $R_1^{chip} = R_4^{chip} = r_{11}^{chip}$ = 20 Mchips/s, $R_2^{chip} = R_3^{chip} = R_5^{chip} = R_6^{chip} = R_7^{chip}$ = $R_8^{chip} = r_{21}^{chip} = r_{22}^{chip}$ = 10 Mchips/s, and $R_9^{chip} = R_{10}^{chip} = R_{11}^{chip} = R_{12}^{chip} = r_{31}^{chip} = r_{32}^{chip} = r_{33}^{chip} = r_{34}^{chip}$ = 5 Mchips/s. We can obtain the parameters a_i and b_i and relative rewards η_t in Table 6, and the interference factors ξ_{ki} in Table 7.

As the future mixture ratio of calls is not well known (neither for fixed nor for mobile networks), the relative mixture ratio is not important. One of the key issues in future wireless communication will be how to handle different mixtures of traffic, with different performance requirements and in different environments [25]. In the simulation, therefore, the relative call arrival rate of video and facsimile to voice is varied from 10% to 125%. Poisson call arrivals are uniformly distributed over the service area with an arrival rate of λ_1 for video calls (i.e., type-1 calls), λ_2 for facsimile calls (i.e., type-2 calls), and λ_3 for voice calls (i.e., type-3 calls) as the parameter for load variation. Call duration is assumed to be exponentially distributed with $1/\mu_1 = 90$ seconds for video calls, $1/\mu_2 = 60$ seconds for facsimile calls, and $1/\mu_3 = 90$ seconds for voice calls. Users are assumed to be stationary during the whole active session.

Figures 5–7 compare the blocking probabilities for Algorithms I and II. The blocking probability is plotted with a confidence interval of 95% for each type of call as a function of traffic load in terms of incoming arrival rate for video, facsimile, and voice calls. From Figures 5–7, the incoming call arrival rate for each type of call can be obtained under a blocking probability of 1% [33], which is summarized in Table 8. The following observations can be made from these results:

- The blocking probabilities of Algorithm II can be significantly reduced for all traffic types, compared with those of Algorithm I. At a given traffic load, there is a big difference between the blocking probabilities of each type of call in both schemes.
- At an acceptable level of blocking probability (P_b = 1%), Algorithm II supports at least 51%, 230%, and 73% higher traffic than Algorithm I for video, facsimile, and voice calls, respectively, as shown in Table 8.
- The highest blocking probability for calls under the given traffic occurs for video calls with the largest bandwidth and the highest QoS requirements. If a higher blocking probability for video calls can

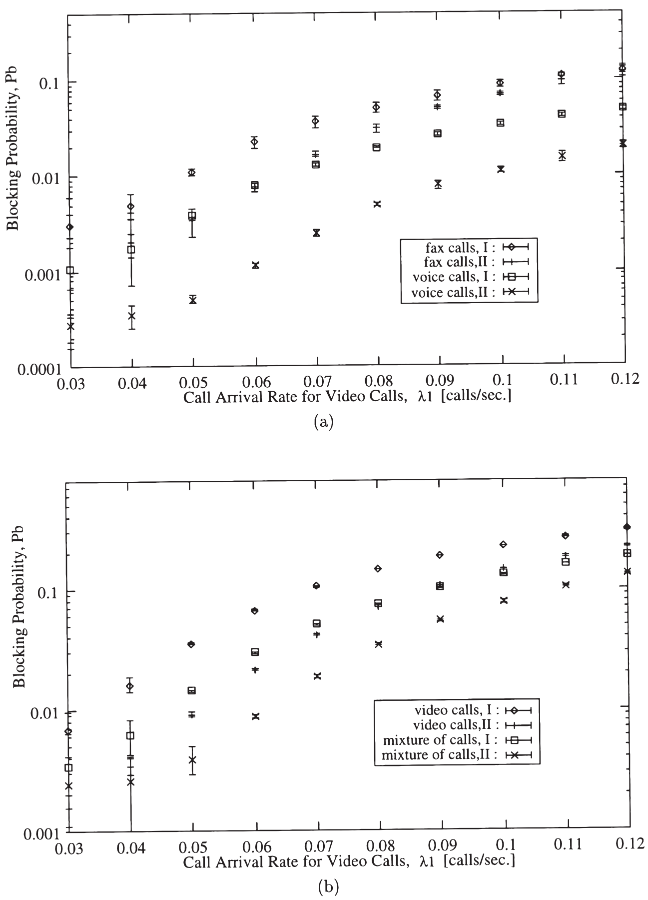


Fig. 5 Blocking probability versus incoming call arrival rate for video calls ($\lambda_2 = 0.005$ and $\lambda_3 = 0.1$), confidence interval of 95%: (a) facsimile calls and voice calls, (b) video calls and mixture of three different calls.

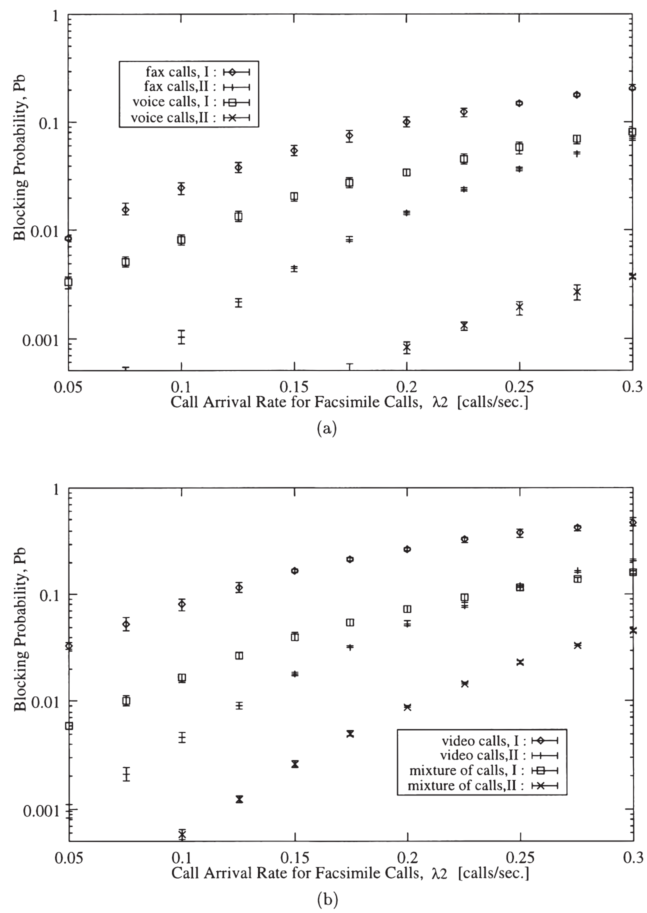


Fig. 6 Blocking probability versus incoming call arrival rate for facsimile calls ($\lambda_1 = 0.02$ and $\lambda_3 = 0.25$), confidence interval of 95%: (a) facsimile calls and voice calls, (b) video calls and mixture of three different calls.

be tolerated, a lower video call arrival rate can be chosen, more calls will be admitted, and the total blocking probability will be decreased.

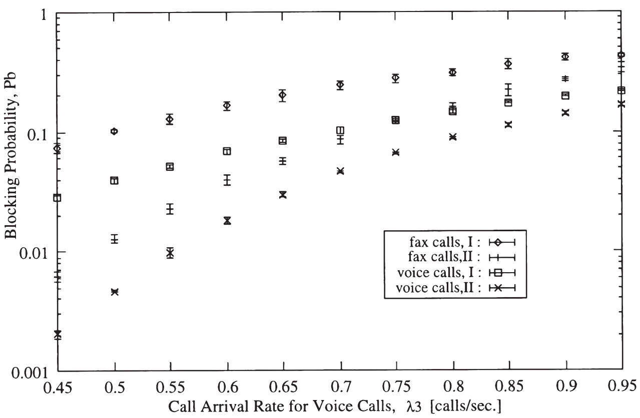
In addition, the larger the mean service time of type-t call is, the larger the traffic load $\frac{\lambda_t}{\mu_t}$ is. It is expected that blocking probability with a larger service time for a given arrival rate increases.

Figures 8–10 show normalized throughput versus the incoming call arrival rate for video, facsimile, and voice calls, respectively. In all cases, the normalized throughput of Algorithm II is better than for Algorithm I. Improvement of the throughput is especially significant with a higher call arrival rate. This is because normalized throughput is closely related to the carried load and the relative reward. The carried load is inversely related to the blocking probability. A difference between the blocking probabilities of both schemes increases with a higher arrival rate in the light and medium load region, while the blocking probabilities of both schemes tend to saturate in the heavy load region. In addition, the relative reward is related to the requested bandwidth and QoS requirement of the call. Therefore, higher QoS calls with a larger bandwidth result in more improvement of the throughput than lower QoS calls with a smaller bandwidth .

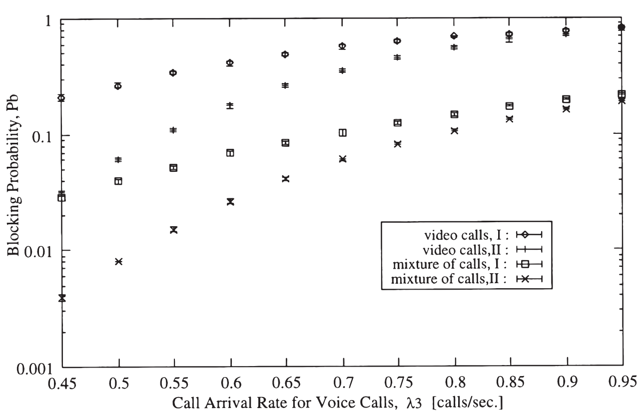
Based on these observations, the performance of Algorithm II is better than the performance of Algorithm I, in terms of both blocking probability and normalized throughput. However, low blocking and high throughput performance requires a longer processing time and more complexity for Algorithm II. Since the minimum average interarrival time (one second here) between calls in this study is longer than the processing time (several hundred of μ-seconds here) of Algorithm II, the longer processing time of Algorithm II is not a critical problem. In addition, it is expected that the performance of Algorithm I is almost the same irrespective of the shape of PSD. However, the performance of Algorithm II in the case of considering the shape of PSD is better than for the case that the PSD of all spread signals is flat for all frequencies and a difference between the performance of both cases is very large in the light and medium load region.

Table 8 Comparison of incoming call arrival rate [calls/sec.], $P_{bt} = 1\%$.

Type-t	Calls	Algorithm I	Algorithm II	Proportion($= \frac{\text{A.II}}{\text{A.I}}$)
1	Low resolution video	0.0334	0.0506	1.5149
2	Facsimile	0.0549	0.1818	3.3114
3	Voice	0.3180	0.5515	1.7343



(a)



(b)

Fig. 7 Blocking probability versus incoming call arrival rate for voice calls ($\lambda_1 = 0.03$ and $\lambda_2 = 0.02$), confidence interval of 95%: (a) facsimile calls and voice calls, (b) video calls and mixture of three different calls.

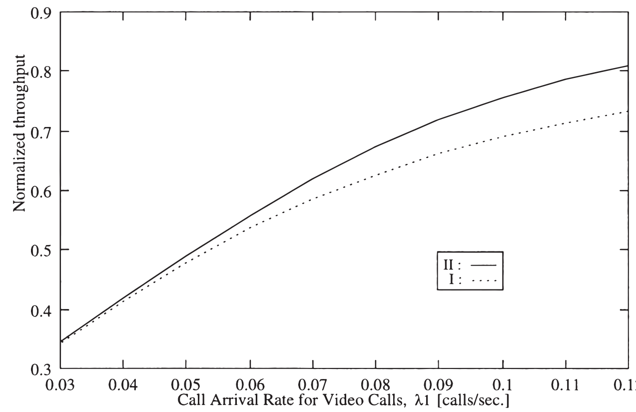


Fig. 8 Normalized throughput versus incoming call arrival rate for video calls ($\lambda_2 = 0.005$ and $\lambda_3 = 0.1$).

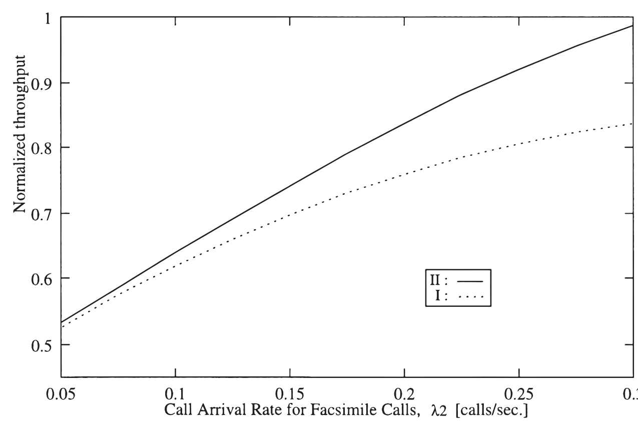


Fig. 9 Normalized throughput versus incoming call arrival rate for facsimile calls ($\lambda_1 = 0.02$ and $\lambda_3 = 0.25$).

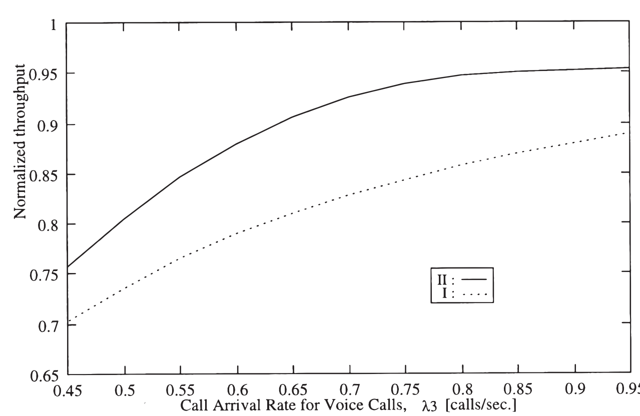


Fig. 10 Normalized throughput versus incoming call arrival rate for voice calls ($\lambda_1 = 0.03$ and $\lambda_2 = 0.02$).

6. Conclusions

The feasibility of the proposed minimum power-increment-based resource assignment scheme in MCR-DS/CDMA systems accommodating multimedia services was studied. Efficient radio resource assignment algorithms are needed in an MCR-DS/CDMA system to improve system performance according to traffic variations. Algorithm II does not degrade system performance under either overloading or underloading conditions, compared with Algorithm I. For a given blocking probability, more gain can be obtained by reallocating subsystems assigned for accepted users. Rejecting some low-bandwidth calls is another way to reduce the blocking probability of large-bandwidth calls.

Acknowledgments

This study was supported in part by the Korea Science and Engineering Foundation.

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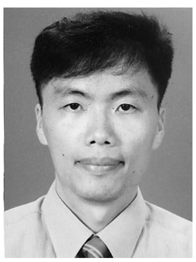
Young-Woo Kim received the B.S. degree in electronic engineering from Korea Aviation College in 1977 and the M.S. degree in electronic engineering from Seoul National University in 1983. He is working towards the Ph.D. degree in electrical engineering at Korea Advanced Institute of Science and Technology (KAIST) since 1994. From Dec. 1978 to Feb. 1985, he was a development engineer with Oriental Precision Company, Korea, where he had been engaged in research and development of military communication systems. Since March 1985, he has been with Hyundai Electronics Industries Company, Korea. His research interests include radio resource management and call admission control in IMT-2000. He is a member of KICS.



Seung Joon Lee received the B.S., M.S., and Ph.D. degrees in electrical engineering from KAIST, in 1991, 1993, and 1998, respectively. He has been with Hyundai Electronics Industries Company, Korea since Nov. 1994. His research interests include handoff schemes in wireless ATM and support of multimedia in CDMA systems. He is a member of IEEE and KICS.

Min Young Chung received the B.S. and M.S. degrees in electrical engineering from KAIST, in 1990 and 1994, respectively. Currently he is working towards the Ph.D. degree in electrical engineering at KAIST. His research interests include the performance evaluation of switching systems and intelligent networks. He is a student member of IEEE and KICS.

Jeong Ho Kim received the B.S. and M.S. degrees in electrical engineering from KAIST, in 1991 and 1993, respectively. Currently he is working towards the Ph.D. degree in electrical engineering at KAIST. He has been with LG Electronics Inc., Korea since Feb. 1993. His research interests include system analysis, power control, and multimedia multiple access protocol in CDMA systems. He is a student member of IEEE and KICS.

Dan Keun Sung received the B.S. degree in electronic engineering from Seoul National University in 1975, the M.S. and Ph.D. degrees in electrical and computer engineering from University of Texas at Austin, in 1982 and 1986, respectively. From May 1977 to July 1980, he was a research engineer with the Electronics and Telecommunications Research Institute, where he had been engaged in research on the development of electronic switching systems. In 1986, he joined the faculty of the Korea Institute of Technology and is currently a Professor of Dept. of Electrical Engineering at KAIST. His research interests include ISDN switching systems, ATM switching systems, wireless networks, and performance and reliability of systems. He is a member of IEEE, KITE, KICS and KISS.