Interference-Based Channel Assignment for DS-CDMA Cellular Systems

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***Abstract*—Link capacity is defined as the number of channels available in a link. In direct-sequence code-division multiple-access (DS-CDMA) cellular systems, this is limited by the interference present in the link. The interference is affected by many environmental factors, and, thus, the link capacity of the systems varies with the environment. Due to the varying link capacity, static channel assignment (SCA) based on fixed link capacity is not fully using the link capacity. This paper proposes a more efficient channel assignment based on the interference received at the base station (BS). In the proposed algorithm, a channel is assigned if the corresponding interference margin is less than the allowed interference, and, thus, channels are assigned adaptively to dynamically varying link capacity. Using the proposed algorithm yields more channels than using SCA in such an environment changes with nonhomogeneous traffic load or varying radio path loss. The algorithm also improves service grade by reserving channels for handoff calls.**

***Index Terms*—Adaptive channel assignment, CDMA, link capacity.**

I. Introduction

THE CAPACITY of direct-sequence code-division multiple-access (DS-CDMA) cellular systems depends on the reverse link rather than the forward link [1], [2]. Reverse link capacity is limited by the interference received at the base station (BS). This link capacity varies with such environmental factors as traffic load in neighboring cells, radio path loss, power control, and cell coverage area [2]–[9]. However, conventional channel assignment has utilized fixed link capacity estimated under the worst case interference. Therefore, conventional channel assignment is inefficient for the systems.

Dynamic channel allocation (DCA) increases the capacity of frequency-division multiple-access (FDMA) or time-division multiple-access (TDMA) cellular systems by adapting to the varying traffic load [10], [11]. By using DCA, heavy cell traffic load can be shared with less loaded neighboring cells. In DS-CDMA cellular systems, however, it is difficult to utilize DCA due to the difficulty of sharing traffic load between cells. Instead, it seems effective to assign channels adaptively according to their varying link capacity. As an effective channel assignment, Liu proposed the call admission control (CAC) based on the signal-to-interference ratio (SIR) [12]. However, Liu's algorithm is inconsistent with the reality because SIR is assumed to change during operation. In practical systems, SIR is kept constant by the power control mechanism [2].

We here propose an adaptive channel assignment (ACA) for the power-controlled DS-CDMA cellular system. The proposed ACA is based on interference instead of SIR. In the proposed algorithm, a new channel is assigned if the interference after assigning the channel is less than the interference allowed in the link. The allowed interference is determined by the network. Utilizing the algorithm, we can significantly reduce redundant link capacity. Redundant link capacity is here defined as the difference between the actual link capacity and the fixed link capacity used in conventional static channel assignment (SCA). Besides this capability, the proposed algorithm improves service grade by reserving a few channels for handoff calls. Service grade is improved by reserving priority channels [10], [13], [14].

The remaining part of this paper is organized as follows. In Section II, the link capacity of DS-CDMA cellular systems is analyzed according to their link characteristics. Several environmental factors affecting link capacity are introduced in the link characteristics analysis. Section III presents the proposed channel control scheme for effective channel assignments in DS-CDMA cellular systems. In Section IV, the performance of the proposed algorithm is evaluated in terms of link capacity and grade of service (GOS). The results are discussed in Section V. Finally, Section VI concludes this paper.

II. Link Characteristics and Capacity

In the discussion of DS-CDMA link capacity in this paper, we model the DS-CDMA cellular system as follows.

1) The same radio frequency band is reused in every cell.
2) The reverse link is perfectly separated from the forward link. The BS receives interference only from the users, while the user receives interference only from the BS's.
3) The wanted user signal is ideally separated from the other user signals by means of a pseudonoise (PN) sequence. The user signals are uncorrelated.
4) The user chooses his home cell so that the radio path loss between the user and the home cell BS is minimized.
5) The cellular system consists of many cells of equal size and the BS is located at the center of each cell.
6) The system follows the IS-95 specifications [15].

A. Link Capacity in a Single Cell

Throughout this paper, we are concerned with the reverse link because the DS-CDMA link capacity is limited by the reverse link. First, the link characteristics are analyzed in order

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to estimate the DS-CDMA link capacity. Supposing that N conversing users are in a single cell, the signal received at the BS contains one desired signal of power level S and $(N-1)$ interfering signals with the identical power S. Then, the ratio of bit energy to the noise power spectral density E_b/N_0 is given by

$$E_b/N_0 = \frac{S/(R \cdot \alpha)}{N_t + (N-1) \cdot S/W} \tag{1}$$

where R, α, N_t, and W are the information data rate, voice activity, thermal noise spectral density, and transmission bandwidth, respectively. If link capacity is fully occupied, S is approximately equal to $N_t \cdot W$ [2]. Typically, α is equal to 2/5. According to the IS-95 specification [15], R and W are given by 9.6 kbps and 1.2288 MHz, respectively. The channel bit error rate (BER) depends on the E_b/N_0. This is kept constant by the power control mechanism [2]. For this system, the link capacity C is estimated as

$$C = \frac{W/(R \cdot \alpha)}{E_b/N_0}. \tag{2}$$

If the cell consists of multiple sectors, the sectorization gain G is included in (2). Thus, the link capacity C of the single sectored cell is given by

$$C = \frac{W/(R \cdot \alpha)}{E_b/N_0} \cdot \frac{G}{M} \tag{3}$$

where M is the number of sectors in the cell. G depends on the sector antenna performance. If ideal sector antennas are used, no interference is received from the other sectors and thus G is equal to M. In practical systems, however, G is less than M because the link receives interference from the other sectors. According to Qualcomm's engineering data [16], G is given by 2.55 for three-sectored cells.

B. Link Capacity in Multiple Cells

For simplicity of discussion, all cells throughout this paper are assumed to be omnicells (nonsectored cells). Gilhousen [2] proposed a model for estimating the link capacity of multiple cell systems. Supposing an inner cell surrounded by many outer cells, the inner cell BS receives the interference I_o from the outer cells. For this system, the link capacity of the inner cell is estimated by utilizing the following:

$$\Pr(\text{BER} \geq 10^{-3}) = \sum_{k=1}^{N-1} \binom{N-1}{k} \cdot \alpha^k \cdot (1-\alpha)^{N-1-k} \cdot Q\left(\frac{\delta - k - E(I_o/S)}{\sqrt{\text{Var}(I_o/S)}}\right) \tag{4}$$

where

$$Q(x) = \frac{1}{2\pi} \int_x^\infty e^{-y^2/2}\, dy$$
$$\delta = \frac{W/R}{E_b/N_0} - \frac{N_t \cdot W}{S}$$

and N is the number of channels assigned in the inner cell. Link capacity C is defined as the maximum integer N satisfying $\Pr(\text{BER} \geq 10^{-3}) \leq 0.01$ [2]. BER of 10^{-3} is accomplished when $E_b/N_0 = 7$ dB. As shown in (4), $\Pr(\text{BER} \geq 10^{-3})$ increases as the outer cell interference I_o increases. This means that C decreases as I_o increases. If I_o is fixed, C will be constant. However, I_o varies with the environment. Due to this varying I_o, the link capacity of DS-CDMA cellular systems varies with the environment.

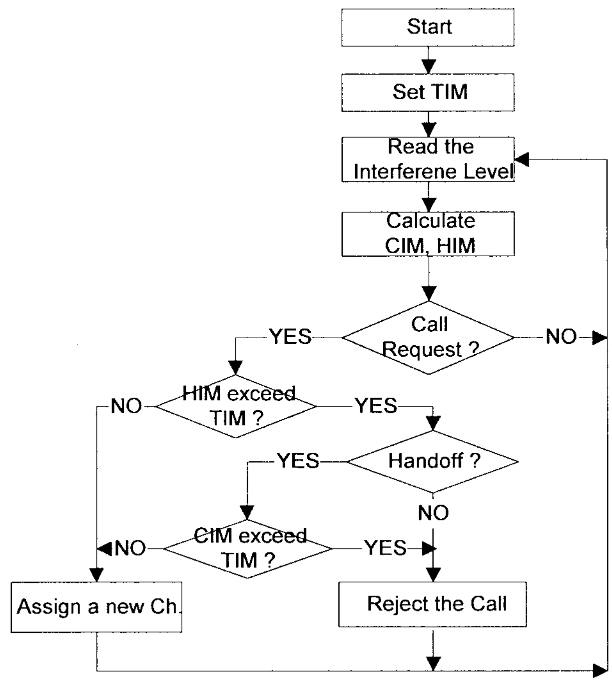

Fig. 1. The proposed BS controller channel assignment scheme.

III. Adaptive Channel Assignment

To fully utilize the link capacity, channels must be assigned according to the actual link capacity instead of fixed link capacity. Actual link capacity depends on the amount of interference allowed in the link. In DS-CDMA cellular systems, interference increases as traffic load increases. However, interference must be limited to meeting the E_b/N_0 required in the link. If more channels than the actual link capacity can accommodate are assigned to the link, the required E_b/N_0 is not satisfied. Equation (2) implies how link capacity C must be limited to ensuring the required E_b/N_0.

We here propose an efficient channel assignment algorithm based on interference measurements. We include a power strength measurer in front of correlators. The measured power strength is approximately equal to the current interference. This is periodically reported to the BS controller. To ensure the proper operation of the proposed algorithm, the report period needs to be less than the call arrival interval. According to [15], the call arrival interval is more than 1.25 ms. Therefore, we here assume that the report period is 1.25 ms.

Fig. 1 shows the channel assignment scheme of the BS controller. The required E_b/N_0 is satisfied by the power control mechanism keeping the E_b/N_0 at 7 dB. However, if the number of assigned channels is the same as the actual link capacity, no new channel need be assigned in order to meet the required E_b/N_0. The required E_b/N_0 is also ensured by limiting the interference allowed in the link. This allowed link interference is specified as the total interference margin (TIM) in Fig. 1. TIM is determined by the network so that the E_b/N_0 required in the link is ensured.

The BS controller reads the current interference I_c from the power strength measurer. It calculates the current interference margin (CIM) and handoff interference margin (HIM). CIM represents the interference after assigning one more channel. HIM is used to reserve channels for handoff calls. The Appendix shows that if channels are assigned keeping HIM at less than TIM, R channels are reserved in the link. From (19) and (22) in the Appendix

$$\mathrm{CIM} = I_c \cdot \frac{65 - N}{64 - N} \tag{5}$$

$$\mathrm{HIM} = I_c \cdot \frac{65 - N}{64 - N - R} \tag{6}$$

where N is the number of channels currently occupied in the link. A handoff call is here assumed to require the same power as a new call. A new call or a handoff call is accepted if HIM is less than TIM. However, if HIM is more than TIM, only handoff calls can be accepted. If a handoff call is requested and CIM is less than TIM, then this handoff call is accepted. If CIM is more than TIM, this means that the link is fully occupied in accordance with the actual link capacity and thus the requested call is rejected. Hence, the interference after the channel assignment is kept at less than the determined TIM. Since current interference is reflected in channel assignments, the proposed algorithm is adaptable to varying interference.

The current interference I_c may be more than TIM because of the sudden increase in interference from outer cells. I_c must be kept at less than TIM. Otherwise, due to the link's unsatisfied BER's, the occupied channels may be cut off during conversation by the power control mechanism [16]. HIM also needs to be kept at less than TIM in order to reliably reserve R channels. In order to keep I_c and HIM at less than TIM, we can utilize soft capacity. DS-CDMA link capacity is soft in the sense that the link capacity varies with the BER supported by the link [16]. Since I_c is less than HIM, it is enough to keep only HIM at less than TIM in order to ensure the reliable operation of the algorithm. In this paper, HIM is assumed to be kept at less than TIM.

From (20) in the Appendix, we can regard TIM as the link capacity allocated to a cell. TIM is utilized in limiting the maximum interference. Inserting the IS-95 specification data in (2), the link capacity of the single omnicell is 64. From (15) in the Appendix, the channel signal power in worst case interference is the same as $N_t \cdot W$. This is estimated as -110 dBm [16]. Including thermal noise, maximum -91.87 dBm ($=-110$ dBm $\times$ 65) can be allowed to a link. For multiple cell systems, if the cell TIM allocated is -91.87 dBm and no interference comes from outer cells, 64 channels can be assigned in the inner cell. However, if the cell TIM allocated is less than -91.87 dBm, the number of inner cell assignable channels decreases. We recommend that a cell TIM be determined after considering its effect on neighboring cells. For example, if TIM allocated to outer cells is high, interference from the outer cell may increase. This decreases the actual link capacity of the inner cell. In order to ensure the large link capacity for the inner cell, TIM's allocated to outer cells must be low. In this paper, a TIM of -91.87 dBm is assumed to be allocated to all cells.

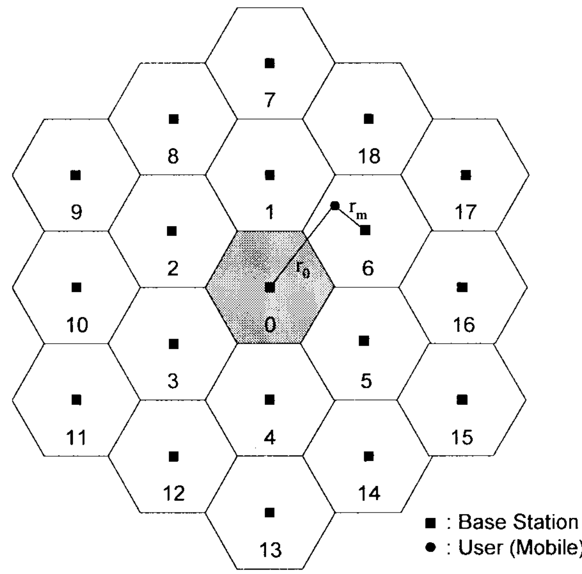

Fig. 2. Cell configuration used in simulations.

IV. Performance Analysis

A. DS-CDMA Link Capacity

Considering a system with an inner cell i, K outer cells, and n_j users in cell j, total interference I_t received at the inner cell BS is given by

$$I_t = \sum_{h=1}^{n_i - 1} I_u(h, i) + \sum_{k=1}^{K} \sum_{h=1}^{n_k} I_u(h, k) \tag{7}$$

where $I_u(h, j)$ is the interference from user h of cell j. As mentioned in Section II, $I_u(h, i)$ is kept constant, S in (1), by the power control mechanism. For this system, the link capacity of the inner cell is easily calculated if $E(I_o/S)$ and $\mathrm{Var}(I_o/S)$ are given in (4).

To estimate $E(I_o/S)$ and $\mathrm{Var}(I_o/S)$, we need to discuss the radio propagation loss. This is generally modeled as the product of the γth power of distance and a lognormal component representing shadowing losses. For a user transmitting power A at distance r from a BS, the signal power S received at the BS is expressed as

$$S = A \cdot r^{-\gamma} \cdot 10^{-\xi/10} \tag{8}$$

where ξ is the dB attenuation due to shadowing with mean zero and standard deviation σ. The typical values of σ and γ in cellular environments are 8 dB and 2.7–5.0, respectively [2], [12].

The hexagonal cell shape of Fig. 2 is assumed for its advantages over other cell shapes [17]. If a user h is located at distance r_o from the inner cell BS (cell 0) and distance

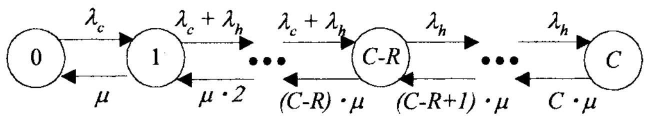

Fig. 3. State transition diagram for the proposed ACA.

r_m from the outer cell (cell k) BS, this user produces the interference $I_u(h,k)$ to the inner cell

$$\frac{I_u(h,k)}{S} = \left(\frac{r_m}{r_o}\right)^{\gamma} \cdot 10^{(\xi_m - \xi_o)/10} \tag{9}$$

where ξ_m and ξ_o are lognormal shadowing factors of the corresponding propagation losses. Hence, $E(I_o/S)$ and $\mathrm{Var}(I_o/S)$ are calculated by

$$E(I_o/S) = \sum_{k=1}^{K} \sum_{h=1}^{n_k} E(I_u(h,k)/S) \tag{10}$$

$$\mathrm{Var}(I_o/S) = \frac{1}{N} \cdot \sum_{k=1}^{K} \sum_{h=1}^{n_k} \left(\frac{I_u(h,k)}{S} - E(I_o/S)\right)^2 \tag{11}$$

where N is the number of all the outer cell users and $E(I_u(h,k)/S)$ is the expected interference from an outer cell user to an inner cell user's signal power. $I_u(h,k)/S$ is less than one because a user determines his cell by choosing the strongest one among all the received pilot signals. Users are assumed to be uniformly distributed in 18 outer cells of Fig. 2. The interference from the other cells beyond the 18 outer cells is negligible. $E(I_o/S)$ and $\mathrm{Var}(I_o/S)$ in this paper are estimated utilizing computer simulations.

B. Grade of Service

According to the digital European cordless telecommunication (DECT) specifications [18], GOS is defined as

$$\mathrm{GOS} = P(\textit{call block}) + \textit{weight} \cdot P(\textit{handoff failure}) \tag{12}$$

where $P(a)$ is the probability of the event a. $P(\textit{call block})$ and $P(\textit{handoff failure})$ can be calculated by utilizing the birth–death model. In this model, the equation of "rate up $=$ rate down" is applied. The rate up (arrival rate) consists of the new call attempt rate λ_c and the handoff call attempt rate λ_h. λ_c depends on the expected number of subscribers per cell. λ_h depends on such system parameters as traffic load, user velocity, and cell coverage area [14]. The rate down (service rate) is the channel release rate. This is the product of the release rate per channel and the number of channels occupied in the link. A channel is released by call completion or handoff to a neighboring cell. In this paper, the release rate per channel is assumed to be the same rate μ. The state transition diagrams is given in Fig. 3. In this figure, state j denotes the state where j channels are occupied. C and R represent the link capacity and the number of reserved priority channels, respectively. $P(\textit{call block})$ is the probability of the state where all channels available for new calls are occupied and thus no more new call is accepted. $P(\textit{handoff failure})$ is the probability of the state where link capacity is fully occupied and thus a handoff call is rejected.

The state probability is derived from Fig. 3 as

$$\begin{aligned} P_j &= \frac{\lambda_c + \lambda_h}{j \cdot \mu} P_{j-1}, \quad \text{for } j = 1, 2, \cdots, C-R \\ &= \frac{\lambda_h}{j \cdot \mu} P_{j-1}, \quad \text{for } j = C-R+1, \cdots, C \end{aligned} \tag{13}$$

where P_j is the probability of state j. Utilizing (13) recursively with $\sum_{j=0}^{C} P_j = 1$ yields P_j as

$$\begin{aligned} P_j &= \frac{(\lambda_c + \lambda_h)^j}{j! \cdot \mu^j} P_0, \quad \text{for } j = 1, 2, \cdots, C-R \\ &= \frac{(\lambda_c + \lambda_h)^{C-R} \cdot \lambda_h^{j-(C-R)}}{j! \cdot \mu^j} P_0, \\ &\qquad \text{for } j = C-R+1, \cdots, C \end{aligned} \tag{14}$$

where

$$P_0 = \left\{ \sum_{k=0}^{C-R} \frac{(\lambda_c + \lambda_h)^k}{k! \cdot \mu^k} + \sum_{k=C-R+1}^{C} \frac{(\lambda_c + \lambda_h)^{C-R} \cdot \lambda_h^{k-(C-R)}}{k! \cdot \mu^k} \right\}^{-1}.$$

$P(\textit{call block})$ and $P(\textit{handoff failure})$ are given by $\sum_{j=C-R}^{C} P_j$ and P_c, respectively. Inserting these probabilities in (12) yields the GOS of the algorithm in a given link capacity C.

V. Results and Discussion

A. Link Capacity Comparison

The link capacity of the proposed ACA is compared with that of SCA. First, the environmental factors affecting the DS-CDMA link capacity are discussed. In this paper, link capacity is estimated according to traffic load in outer cells, power index of distance γ, and standard deviation of the lognormal shadowing factor σ. We are concerned with the inner cell because other cells may have the same environment as the inner cell. The ideal power control is assumed. The data used in the evaluation are based on the IS-95 specification [15] and Qualcomm's engineering data [16].

Figs. 4 and 5 show the actual link capacity of the inner cell to varying environmental factors. We can observe that more channels can be assigned by utilizing the proposed ACA than by using SCA. For example, in Fig. 4, link capacity increases as the number of outer cell users decreases. If we assume that γ and σ are given by 3 and 8 dB, respectively, all BS's utilizing SCA can assign 21 channels. However, if the number of actually occupied channels is 15 per outer cell, 3 more channels from 21 to 24 can be assigned to the inner cell by utilizing the proposed algorithm. If 20 channels per outer cell are occupied and γ varies from 3 to 4 due to such environment changes as heavy rain, user movement, or new buildings, the effect is more significant and 31 channels can be assigned to the inner cell, compared with the 21 channels of SCA.

From Figs. 4 and 5, the performance of the proposed ACA is summarized as follows. First, in normal operations, the proposed ACA can assign more channels than the conventional SCA. By utilizing the proposed ACA, redundant link capacity is significantly reduced and more channels can be assigned in the link. Second, redundant link capacity increases as

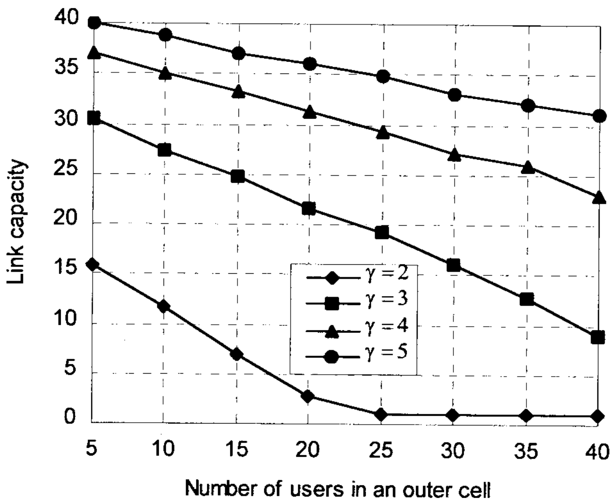

Fig. 4. The DS-CDMA reverse link capacity of varying the traffic load of outer cells and power index of distance λ. Standard deviation of lognormal shadowing $\sigma = 8$ dB.

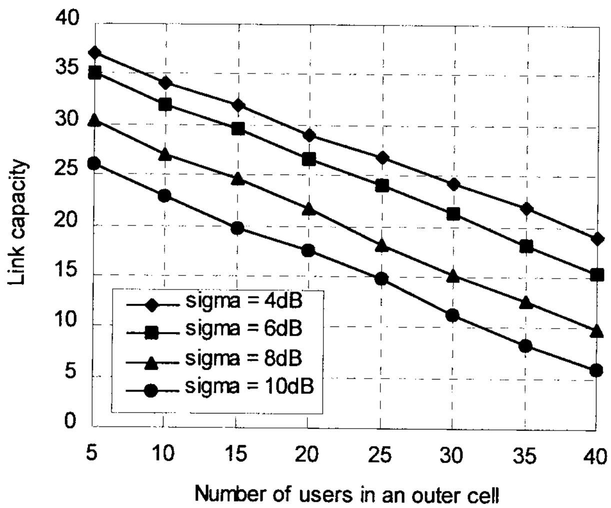

Fig. 5. The DS-CDMA reverse link capacity of varying the traffic load of outer cells and standard deviation of lognormal shadowing *sigma*(σ). Power index of distance $\gamma = 3$.

environment variation grows. Therefore, the proposed ACA demonstrates better performance in areas of large environment variation than in areas of small environment variation. The environment varies with the traffic load of neighboring cells and radio path losses. The radio path loss varies with user movement, new buildings, cell coverage area and so on.

Poor power control performance also causes DS-CDMA link capacity to seriously decrease. In SCA, since the worst power control is assumed, link capacity may significantly decrease. This problem can be alleviated by utilizing the proposed ACA because the actual power control performance is reflected in channel assignments.

B. GOS Comparison

The effect of priority channels reservation on GOS is evaluated. First, the factors affecting GOS are discussed. GOS is generally evaluated according to link capacity C, new call

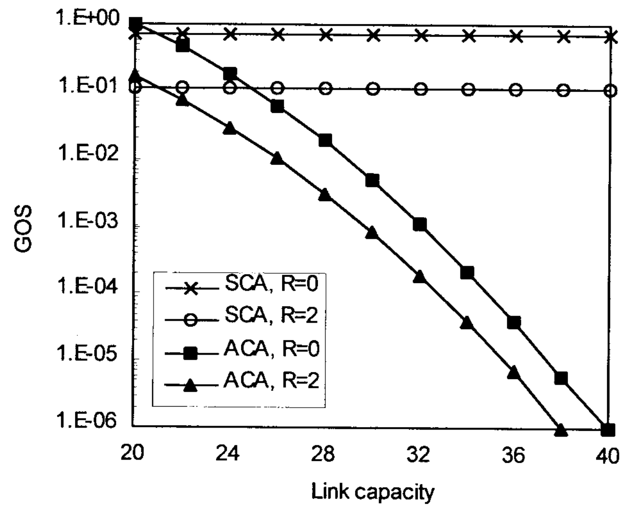

Fig. 6. The GOS of varying the link capacity and channel assignment scheme. $\lambda_c = 1/3$, $\lambda_h = 1/6$, $\mu = 1/30$, and *weight* $= 10$.

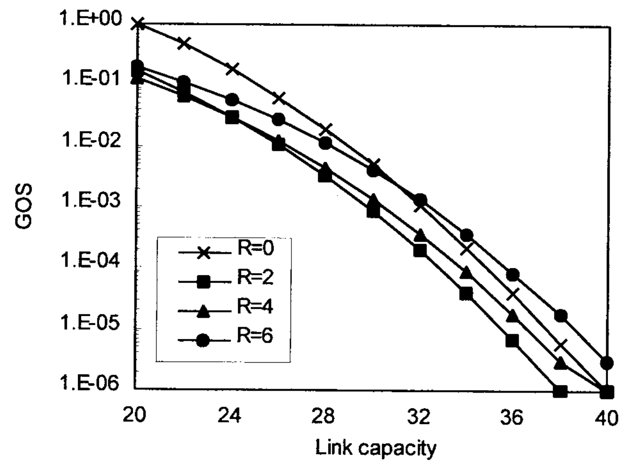

Fig. 7. The GOS of varying the link capacity and the number of reserved priority channels R. $\lambda_c = 1/3$, $\lambda_h = 1/6$, $\mu = 1/30$, and *weight* $= 10$.

attempt rate λ_c, handoff call attempt rate λ_h, and number of reserved priority channels R. Since the GOS of varying λ_c and λ_h has already been evaluated in [10], [13], and [14], we in this paper evaluate the GOS of varying C and R. The typical parameter values used are as follows: $R = 2$, $\lambda_c = 1/3$, $\lambda_h = 1/6$, $\mu = 1/30$, and *weight* $= 10$. When the effect of one parameter on GOS is analyzed, the other parameters remain the same as the above values.

Fig. 6 shows GOS to vary the actual link capacity and channel assignment scheme. The link capacity used in SCA is assumed to be 21. According to [18], GOS is required to be less than 0.01. In Fig. 6, both GOS's of SCA are greater than 0.01 and the DECT requirement is not satisfied. To improve GOS, in this paper, we consider two methods: link capacity increase and priority channel reservation. First, Fig. 6 shows that GOS is improved by increasing link capacity. As mentioned in Section V-A, link capacity can be increased by utilizing the proposed ACA. Second, Fig. 6 shows that GOS is improved by reserving priority channels. For example, to meet the GOS requirement, the ACA with priority channels reservation needs the link capacity of 26 channels while the ACA without priority channel reservation needs 29 channels. On the same link capacity, priority channels reservation provides better GOS. The number of reserved priority channels R chosen, however, needs to be optimal; refer to Fig. 7. We recommend that R be chosen optimally considering such parameters as new call attempt rate, handoff call attempt rate, and release rate per channel.

VI. Conclusion

In this paper, an ACA is proposed for DS-CDMA cellular systems. We realized that SCA based on fixed link capacity is not fully utilizing the capacity of the systems because of varying link capacity due to environmental factors. Therefore, we here proposed an efficient algorithm to assign channels adaptively in accordance with the varying link capacity. In the proposed algorithm, channels are assigned according to the current interference margin instead of the fixed link capacity. More channels can be assigned by using the proposed algorithm thus significantly reducing redundant link capacity.

GOS is also improved by reserving priority channels. Priority channels can be reserved by limiting the interference allowable for new calls. If we assign channels keeping HIM at less than TIM, we can reserve priority channels in the link. The number of reserved priority channels is controlled by HIM. The number of reserved priority channels, however, must be chosen optimally considering such traffic loads as the new call attempt rate and the handoff call attempt rate. In the proposed algorithm, priority channels are reserved with high confidence even in a varying environment. This ensures the reliable performance of the proposed ACA.

Besides these capabilities, the proposed algorithm has a number of other distinctive features: ease of implementation, no need of information about environmental factors, channel reservation for other priority services, and so on. For efficient use of the proposed algorithm, further study on TIM management is required.

Appendix
Interference Margin Calculation

Rearranging the terms of (1), we can express the signal power S_N when N channels are occupied in the cell, as follows:

$$S_N = \frac{N_t \cdot W}{\frac{W/(R\cdot\alpha)}{E_b/N_0} - (N-1)}. \tag{15}$$

Inserting the IS-95 specification data in $\frac{W/(R\cdot\alpha)}{E_b/N_0}$ yields 64. Hence, if N channels are occupied in the cell, the power strength P_N received at the cell BS is simply given by

$$\begin{aligned} P_N &= N_t \cdot W + N \cdot S_N \\ &= \frac{65}{65-N} \cdot (N_t \cdot W). \end{aligned} \tag{16}$$

In multiple cell systems, however, the inner cell BS receives outer cell interference I_o as well as thermal noise. Therefore, in multiple cell systems, (16) is changed into

$$P_N = \frac{65}{65-N} \cdot (N_t \cdot W + I_o). \tag{17}$$

From (17), $N_t \cdot W + I_o$ is given by

$$N_t \cdot W + I_o = P_N \cdot \frac{65-N}{65}. \tag{18}$$

Hence, P_{N+1} under a given $N_t \cdot W + I_o$ is

$$\begin{aligned} P_{N+1} &= \frac{65}{65-(N+1)} \cdot (N_t \cdot W + I_o) \\ &= \frac{65-N}{64-N} \cdot P_N. \end{aligned} \tag{19}$$

Therefore, if P_{N+1} is less than the allowed interference TIM, a channel can be assigned. (19) yields CIM.

The link capacity C under a given $N_t \cdot + I_o$ can be calculated using (17). If a cell TIM allocated is $65 \cdot (N_t \cdot W)$, then

$$\frac{65}{65-N} \cdot (N_t \cdot W + I_o) \leq 65 \cdot (N_t \cdot W). \tag{20}$$

C is defined as the maximum integer N satisfying (20). Hence, from (20), C is given by

$$C = \left\lfloor 65 - \frac{N_t \cdot W + I_o}{N_t \cdot W} \right\rfloor \tag{21}$$

where $\lfloor X \rfloor$ is the maximum integer less than or equal to X.

If we want to reserve R channels for priority services (e.g., handoff calls), we must assign only $C - R$ channels for new calls. If P_{N+1+R} is expected to be less than TIM, R channels can be reserved under a given $N_0 \cdot W + I_o$. Inserting (18) in (20) yields

$$\frac{65-N}{65-(N+1+R)} \cdot P_N \leq \text{TIM}. \tag{22}$$

Therefore, if channels are assigned keeping $\frac{65-N}{64-(N+R)} \cdot P_N$ at less than TIM, then R channels can be reserved. In this paper, $\frac{65-N}{64-(N+R)} \cdot P_N$ is defined as HIM.

References

[1] K. S. Gilhousen, I. M. Jacobs, R. Padovani, and L. A. Weaver, Jr., "Increased capacity using CDMA for mobile satellite communication," *IEEE J. Select. Areas Commun.*, vol. 8, pp. 503–514, May 1990.

[2] K. S. Gilhousen, I. M. Jacobs, R. Padovani, A. J. Viterbi, L. A. Weaver, Jr., and C. E. Wheatley III, "On the capacity of a cellular CDMA system," *IEEE Trans. Veh. Technol.*, vol. 40, no. 2, pp. 303–312, 1991.

[3] R. Ganesh, K. Joseph, and N. Wilson, "Traffic capacity of cellular packet CDMA for varying cell size and propagation scenarios," in *Proc. ICC*, New Orleans, LA, May 1994, pp. 805–810.

[4] D. E. Everitt, "Traffic engineering of the radio interface for cellular mobile networks," *Proc. IEEE.*, vol. 82, pp. 1371–1382, Sept. 1994.

[5] A. Jalali, "On the bandwidth efficiency of CDMA for mobile systems," in *Proc. ICC*, New Orleans, LA, May 1994, pp. 515–519.

[6] F. Behbabani and H. Hasheni, "Performance and capacity evaluation of CDMA mobile radio systems reverse link analysis," in *Proc. VTC*, Stockholm, Sweden, June 1994, pp. 65–69.

[7] B. Lavery and P. Newson, "On the teletraffic characteristics of cellular CDMA systems," in *Proc. VTC*, Secaucus, NJ, May 1993, pp. 416–419.

[8] M. R. Heath and P. Newson, "On the capacity of spread-spectrum CDMA for mobile radio," in *Proc. VTC*, Denver, CO, May 1992, pp. 985–988.

[9] R. Cameron and B. D. Woerner, "An analysis of CDMA with imperfect power control," in *Proc. VTC*, Denver, CO, May 1992, pp. 977–980.

[10] L. Bonzano and V. Palestini, "DECT performance in the wireless application," in *Proc. ICC*, Geneva, Switzerland, May 1993, pp. 1269–1273.

[11] H. Panzer and R. Beck, "Adaptive resource allocation in metropolitan area cellular mobile radio systems," in *Proc. VTC*, Orlando, FL, May 1990, pp. 638–645.
[12] Z. Liu and M. E. Zarki, "SIR-based call admission control for DS-CDMA cellular systems," *IEEE J. Select. Areas Commun.*, vol. 12, no. 4, pp. 638–644, 1994.
[13] D. Hong and S. S. Rappaport, "Traffic model and performance analysis for cellular mobile radio telephone systems with prioritized and non-prioritized handoff procedure," *IEEE Trans. Veh. Technol.*, vol. 35, pp. 77–92, Aug. 1986.
[14] R. A. Guerin, "Channel occupancy time distribution in a cellular radio system," *IEEE Trans. Veh. Technol.*, vol. 35, pp. 89–99, Aug. 1987.
[15] *Mobile Station—Base Station Compatibility Standards for Dual-Mode Wideband Spread Spectrum Cellular Systems*, TIA/EIA Interim Standard (IS-95), July 1993.
[16] *The CDMA Network Engineering Handbook*, Qualcomm, Mar. 1993.
[17] V. H. MacDonald, "Advanced mobile phone service: The cellular concept," *Bell Syst. Tech. J.*, vol. 58, pp. 15–41, Jan. 1979.
[18] ETSI/RES3, "A Guide to DECT feature," *RES3(92)21*, Feb. 1992.

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