Real-Time Admission Control Supporting Prioritized Soft Handoff Calls in Cellular DS-CDMA Systems

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Abstract. This paper proposes a prioritized real-time admission control algorithm to support soft handoff calls with QoS assurance in both uplink and downlink signal to interference ratio (SIR) requirement. Admission control is formulated as a performance optimization model, in which the objective is to minimize handoff forced termination probability. The algorithm is based upon dynamic reserved channels (guard channels) scheme for prioritized calls, it adapts to changes in handoff traffics where associated parameters (guard channels, new and handoff call arrival rates) can be varied. To solving the optimization model, iteration-based Lagrangian relaxation approach is applied by allocating a time budget. We analyze the system performance, and computational experiments indicate that proposed dynamic guard channel approach outperforms other schemes.

1 Introduction

Demand for wireless communications and Internet applications is continuously growing. Due to the advantages in system capacity and soft handoff, direct sequence code division multiple access (DS-CDMA) provides a high-capacity mobile communications service. Capacity analysis by call admission control (CAC) has been conducted for the uplink connection, because the non-orthogonality leads to the limited capacity is in the uplink [1]. However, asymmetric Internet traffic has increased, and power allocation in a downlink is an important issue. Theoretically, capacity is unbalanced on the downlink and uplink [2]. Thus, both links analysis are required in admission control.

Soft handoff is another characteristic in DS-CDMA system. Admitting a call request with soft handoff consideration, mobile station (MS) maintains simultaneous connections with more than one base station (BS). The MS is allocated a downlink channel at each BS, and the information transmitted on each channel is the same. The MS performs diversity combining of the downlink paths, regardless of their origin. Rejection of a soft handoff request results in forced termination of an ongoing service. To reducing the blocking of handoff calls, several channel reservation researches have been conducted [3–5]. These researches focused on general cellular mobile networks but not CDMA system. For CDMA, the admission control problem has been proposed in literature [6–9], these articles are based on uplink analysis. Although [7,9] consider channel reservation for handoff calls, a fixed number of channel at each BS is reserved. Generally, these schemes give priority to handoff call over

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new call, so-called cutoff priority scheme (CPS), and do not adapt to changes in the handoff traffics. Unlike [7,9], Huang and Ho [5] proposed a dynamic guard channel approach which adapts the number of guard channels in each BS according to the estimate of the handoff calls arrival rate. In [5] non-CDMA admission control was considered.

In this paper, considering integrated voice/data traffics in CDMA system we propose a prioritized real-time admission control model for supporting soft handoff calls with QoS assurance in both uplink and downlink signal to interference ratio (SIR) requirement. For simplicity, we only focus on voice call requests to optimize the handoff call performance. To effectively manage system performance, a real-time admission control algorithm conducted by Lagrangian relaxation approach and subgradient-based method is proposed. The remainder of this paper is organized as follows. In Section 2, the background of DS-CDMA admission control is reviewed which consists of soft handoff, SIR models, as well as problem formulation. Solution approach is described in Section 3. Section 4 illustrates the computational experiments. Finally, Section 5 concludes this paper.

2 Prioritized Real-Time Admission Control

2.1 Soft Handoff

Considering the MS in soft-handoff zone, it applies maximum ratio combining (MRC) of contributions coming from the involved BSs, the addition of energy to interference (E_b/I_0) coming from involved BSs must be larger than the (E_b/I_0) target at the MS. A diversity gain has to be taken into account for those MSs in soft handoff zone. Two assumptions are possible to representing handoff gain. First one assumes the same transmission power from each involved BS, while the other considering those (E_b/I_0) contributions from involved BSs are the same [10–12]. For example, if MS *t* is in the handoff zone in which two BSs (BS 1 and 2) are involved, the first assumption denote P_{jt} the transmitted power from BS *j* to MS *t* in soft handoff situation, then $P_{1t} = P_{2t}$ is assigned by each BS. For second one, the total (E_b/I_0) calculated at MS *t* is expressed as $(E_b/I_0) = (E_b/I_0)_1 + (E_b/I_0)_2$ and $(E_b/I_0)_1 = (E_b/I_0)_2$ where $(E_b/I_0)_1$ and $(E_b/I_0)_2$ is contributed from BS 1 and 2, respectively. In this paper, both assumptions are applied. Denote Λ_t the soft handoff factor (SHOF), which is number of base stations involved in soft handoff process for mobile station *t*. With perfect power control, it is required that P_{jt} should be proportional to the interference. The transmitted power P_{jt} for MS *t* from BS *j* can be adjusted to have the same shape as the total interference. Then P_{jt} changes by power adjustment factor as interference changes with high P_{jt} for large interference.

2.2 SIR Model

In CDMA environment, since all users communicate at the same time and same frequency, each user's transmission power is regarded as a part of other users' interference. CDMA is a kind of power-constrained or interference-limited system. With perfect power control and the interference-dominated system, we ignore background noise. The signal to interference ratio (SIR) to be considered is uplink (*UL*) and downlink (*DL*) interference, as shown in Fig. 1, which is coming from MS to BS and from BS to MS, respectively.

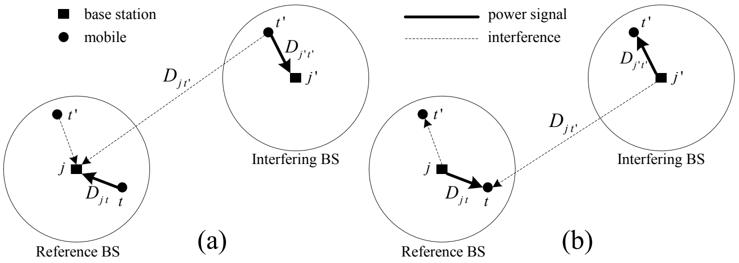

Fig. 1. The interference scenario: (a) uplink interference; (b) downlink interference

Let W^{UL} (W^{DL}) and d^{UL} (d^{DL}) be the system bandwidth and the traffic data rate for uplink (downlink), respectively. Given z_{jt}^{N} and z_{jt}^{H} ($z_{jt} = z_{jt}^{N} + z_{jt}^{H}$) is decision variable of new and handoff calls, respectively, which is 1 if mobile station *t* is admitted by base station *j* and 0 otherwise. We assume that the uplink power is perfectly controlled, it assures the received power at the BS *j*, $\forall j \in B$ where B is the BS set, is the same (constant value) for all MSs in the same traffic class-*c*. Denote $S_{c(t)}^{UL}$ the received uplink power signal at BS from MS *t* with traffic class *c(t)*, $\forall t \in T$ where T is the MS set. And denote D_{jt} the distance from MS *t* to BS *j*. The received SIR $SIR_{j,c(t)}^{UL}$ in uplink is given by (1), where θ^{UL} is the uplink orthogonality factor and $\alpha_{c(t)}^{UL}$ is uplink activity factor of traffic class-c(t), and attenuation factor τ =4. The uplink processing gain is given $G^{UL} = W^{UL} / d^{UL}$. The first and second term of denominator is intra-cell and inter-cell interference, respectively. A very large constant value *V* in numerator is to satisfying constraint requirement if MS *t* is rejected (z_{jt} =0).

$$SIR_{j,c(t)}^{UL} = \frac{W^{UL}}{d_{c(t)}^{UL}} \frac{S_{c(t)}^{UL} + (1 - z_{jt})V}{(1-\theta^{UL})\left(\sum_{\substack{t'\in T\\ t'\neq t}} \alpha_{c(t')}^{UL} S_{c(t')}^{UL} z_{jt'}\right) + \left[\sum_{\substack{j'\in B\\ j'\neq j}} \sum_{\substack{t'\in T\\ t'\neq t}} \alpha_{c(t')}^{UL} S_{c(t')}^{UL} \left(\frac{D_{j't'}}{D_{jt'}}\right)^{\tau} z_{j't'}\right]} \tag{1}$$

In downlink case, notations used are similar to uplink model. Applying soft handoff factor (SHOF) $\Lambda_t = \sum_{j\in B} \delta_{jt}^{H}$ and downlink perfect power control is assumed, the received SIR $SIR_{j,c(t)}^{UL}$ in uplink is given by (2).

$$SIR_{j,c(t)}^{DL} = \frac{W^{DL}}{d_{c(t)}^{DL}} \frac{\Lambda_t S_{c(t)}^{DL} + (1 - z_{jt})V}{(1-\theta^{DL}) \sum_{\substack{t'\in T\\ t'\neq t}} \alpha_{c(t')}^{DL} S_{c(t')}^{DL} \left(\frac{D_{jt'}}{D_{jt}}\right)^{\tau} z_{jt'} + \sum_{\substack{j'\in B\\ j'\neq j}} \sum_{\substack{t'\in T\\ t'\neq t}} \alpha_{c(t')}^{DL} S_{c(t')}^{DL} \left(\frac{D_{j't'}}{D_{j't}}\right)^{\tau} z_{j't'}} \tag{2}$$

2.3 Traffic Model and Performance Measure

In this paper, we focus on voice traffic which consists of new and handoff call type. For each BS *j*, denote $\lambda_j = \lambda_j^N + \lambda_j^H$ total arrivals, where the arrivals of new and hand-off calls are Poisson distributed with rates λ_j^N and λ_j^H, respectively. The call holding time of both types is assumed to be exponentially distributed with mean μ. Location of MSs is generated in uniform distribution. Thus, the traffic intensity (in Erlangs) of new and handoff call is given $\varphi_j^N = \lambda_j^N \times \mu$ and $\varphi_j^H = \lambda_j^H \times \mu$, respectively. To investigating the effect of traffic intensity on performance analysis, denote ξ_j the ratio of φ_j^N to φ_j^H in BS *j*. Admission control is based on SIR measurement. Providing guaranteed QoS for ongoing calls is more important than admitting new call requests. Due to the soft handoff advantage in CDMA system, we would like to focus on minimization of handoff/ongoing call forced termination (blocking) probability subject to given new call blocking probability. For each admission control architecture in Fig. 2, admission control applying dynamic guard channel (DGC) approach is useful since it gives priority to handoff requests. The proposed approach dynamically reserves channels for prioritized handoff calls, it not only reserves different number of guard channels for each BS in terms of BS scenario (heterogeneous handoff arrival rate), but also provides runtime channel reservation. The reserved channels C_j^g (=$\lceil C_j \cdot f_j \rceil$, a ceiling function) among available channels C_j in BS *j* are referred to as the guard channels, where f_j is a reserved fraction of C_j and it is be determined. The remaining C_j^o (=C_j - C_j^g) channels, called the ordinary channels, are shared by both call types. When a new call attempt is generated in BS *j*, it is blocked if the number of free channels is less than or equal to C_j^g. Then the blocking probabilities of new and handoff calls in the BS *j* are given by $BN_j(g_j^N, g_j^H, C_j^o, C_j^g)$ and $BH_j(g_j^N, g_j^H, C_j^o, C_j^g)$ [3,4], respectively, where $\mu\sum_{t\in T} z_{jt}^N = g_j^N$ and $\mu\sum_{t\in T} z_{jt}^H = g_j^H$, and $g_j = g_j^N + g_j^H$.

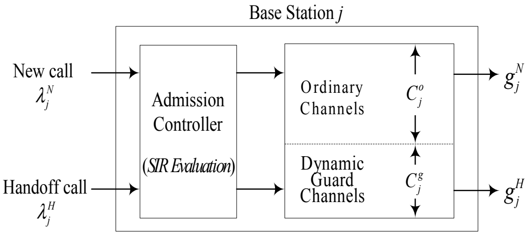

Fig. 2. Admission control architecture

2.4 Problem Formulation

In this section, we propose a prioritized real-time admission control algorithm to support soft handoff calls with QoS assurance in both uplink and downlink signal to interference ratio (SIR) requirement. The objective function (IP) is to minimize the weighted handoff call blocking probability, where the weighted probability is given by $w_j = g_j^H \Big/ \sum_{j\in B} g_j^H$.

Objective function:

$$Z_{IP} = \min \sum\nolimits_{j\in B} w_j BH_j(g_j^N, g_j^H, C_j^o, C_j^g) \tag{IP}$$

s.t.

$$\left(\frac{E_b}{I_0}\right)_{c(t)}^{UL} \le SIR_{j,c(t)}^{UL} \qquad \forall j\in B, t\in T \tag{3}$$

$$\left(\frac{E_b}{I_0}\right)_{c(t)}^{DL} \le SIR_{j,c(t)}^{DL} \qquad \forall j\in B, t\in T \tag{4}$$

$$\mu \sum\nolimits_{t\in T} z_{jt}^N = g_j^N \qquad \forall j\in B \tag{5}$$

$$\mu \sum\nolimits_{t\in T} z_{jt}^H = g_j^H \qquad \forall j\in B \tag{6}$$

$$z_{jt}^N D_{jt} \le \delta_{jt}^N R_j \qquad \forall j\in B, t\in T \tag{7}$$

$$z_{jt}^H D_{jt} \le \delta_{jt}^H R_j \qquad \forall j\in B, t\in T \tag{8}$$

$$z_{jt}^N + z_{jt}^H \le 1 \qquad \forall j\in B, t\in T \tag{9}$$

$$z_{jt}^N \le (1-\delta_{jt'}^H) + z_{jt'}^H \qquad \forall j\in B, t, t'\in T, t\ne t' \tag{10}$$

$$BN_j(g_j^N, g_j^H, C_j^o, C_j^g) \le \beta_j \qquad \forall j\in B \tag{11}$$

$$\Omega_j \le \frac{\sum\limits_{t\in T} z_j^N}{\sum\limits_{t\in T} \delta_j^N} \qquad \forall j\in B \tag{12}$$

$$\Phi_j \le \frac{\sum\limits_{t\in T} z_j^H}{\sum\limits_{t\in T} \delta_j^H} \qquad \forall j\in B \tag{13}$$

$$C_j^o + C_j^g \le C_j \qquad \forall j\in B \tag{14}$$

$$f_j \in F \qquad \forall j\in B \tag{15}$$

$$z_{jt}^N = 0 \text{ or } 1 \qquad \forall j\in B, t\in T \tag{16}$$

$$z_{jt}^H = 0 \text{ or } 1 \qquad \forall j\in B, t\in T \tag{17}$$

In CDMA system, each traffic demand is served with base station in the required QoS in both uplink and downlink connections. For uplink connection with perfect power control, the SIR value $SIR_{j,c(t)}^{UL}$ of each call class-*c* in its homing BS *j* must be greater than the pre-defined threshold $(E_b/I_0)_c^{UL}$, as shown in constraint (3). Again perfect power control is assumed in downlink, for each call request *t* in BS *j* QoS is required with threshold $(E_b/I_0)_{c(t)}^{DL}$ in (4). Constraint (5) and (6) check aggregate flow (in Erlangs) of new and handoff calls for BS *j*, which is based upon all granting mobile stations. Constraint (7) and (8) require that the MS would be in the coverage (power transmission radius R_j) area of a base station it is to be served by that base station. For each call request z_{jt} in BS *j*, in constraint (9), it must belong to only one of call types, either new (z_{jt}^N) or handoff call (z_{jt}^H). Constraint (10) guarantees the prioritized handoff calls. For each BS *j*, any new call z_{jt}^N can be granted only if all handoff calls $z^{H}_{jt'}$ are admitted if it initiates (δ^{H}_{jt} =1 which is indicator function if MS *t* initiates a call request to BS *j*), or z^{N}_{jt} is admitted directly if there is no more handoff call initiates (δ^{H}_{jt} =0). Constraint (11) requires that any base station can serve its slave MS under pre-defined new call blocking probability β_j . Constraint (12) and (13) require that the service rate for new and handoff calls is fulfilled in BS *j*. For channel reservation, total available channel is bounded by (14), and decision variable f_j is applied which belongs to the set *F* in (15). Constraint (16) and (17) are to enforce the integer property of the decision variables.

3 Solution Approach

3.1 Lagrangian Relaxation

The approach to solving problem (IP) is Lagrangian relaxation [13], which including the procedure that relax complicating constraints, multiple the relaxed constraints by corresponding Lagrangian multipliers, and add them to the primal objective function. Based on above procedure, the primal optimization problem (IP) can be transferred to Lagrangian relaxation problem (LR) where constraints (3)-(6), (10) are relaxed. LR can be further decomposed into two independent subproblems. All of them can be optimally solved by proposed algorithms. In summary, problem (IP) is transferred to be a dual problem (D) by multiplying the relaxed constraints with corresponding Lagrangian multipliers v^1_{jt} , v^2_{jt} , v^3_j , v^4_j , $v^5_{jtt'}$ and add them to the primal objective function. According to the weak Lagrangian duality theorem, for any v^1_{jt} , v^2_{jt} , v^3_j , v^4_j , $v^5_{jtt'} \geq 0$, the objective value of Z_D (v^1_{jt} , v^2_{jt} , v^3_j , v^4_j , $v^5_{jtt'}$) is a lower bound of Z_{IP}. Thus, the following dual problem (D) is constructed to calculate the tightest lower bound by adjusting multipliers.

$$Z_D = \max Z_D(\, v^1_{jt}, v^2_{jt}, v^3_j, v^4_j, v^5_{jtt'}) \tag{D}$$

subject to: v^1_{jt} , v^2_{jt} , v^3_j , v^4_j , $v^5_{jtt'} \geq 0$.

Then, subgradient method is applied to solving the dual problem. Let the vector *S* is a subgradient of Z_D (v^1_{jt} , v^2_{jt} , v^3_j , v^4_j , $v^5_{jtt'}$) at v^1_{jt} , v^2_{jt} , v^3_j , v^4_j , $v^5_{jtt'} \geq 0$. In iteration k of subgradient optimization procedure, the multiplier vector π is updated by $\pi^{k+1} = \pi^k + \zeta^k S^k$, the step size ζ^k is determined by $\varepsilon\left(Z^*_{IP} - Z_D(\pi^k)\right) / \left\|S^k\right\|^2$, where Z^*_{IP} is an upper bound on the primal objective function value after iteration k, and ε is a constant where $0 \leq \varepsilon \leq 2$. Solutions calculated in dual problems need to be checked if solutions satisfy all constraints relaxed in (LR). A heuristic for getting primal feasible solutions is also developed† .

3.2 Real-Time Admission Control Algorithm

Based upon Lagrangian relaxation approach, a predefined time budget η, 5 seconds is given to solving Lagrangian dual problem and getting primal feasible solutions

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† Associated algorithms to solving the subproblems and to getting primal feasible solutions are omitted due to the length limitation of the paper. A complete version of the paper is available upon request.

iteratively. Number of call request admitted is depended on the time budget, as illustrated in Fig. 3. Assuming existing calls (in Erlangs) are still held after time Γ_n, at the same time call admission control starts when both calls arrived ($\lambda_j^N + \lambda_j^H$). After time budget η is used up, admission control is also well done, i.e. z_{jt}^N and z_{jt}^H are decided. On the other hand, initial value of Lagrangian multipliers and upper bound affects the solution quality on algorithm convergence. If we appropriately assign initial values, algorithm will be speeded up to converge in stead of more iterations are required. Fortunately, Lagrangian multipliers associated with users left can also be reused in next time interval. Besides, updating ε in the iteration process is carefully controlled by the error gap in previous iteration. The tighter gap is calculated, the smaller ε is assigned. For each real-time processing is on behalf of changing the number of both users arrived and users left in next time period. Overall procedure of real-time admission control is shown in Fig. 4.

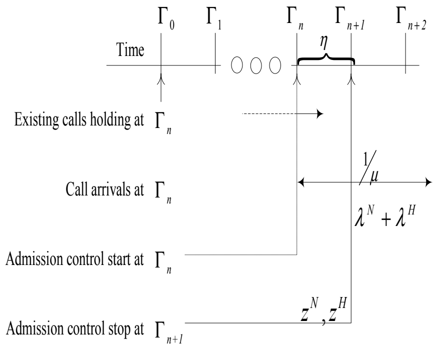

Fig. 3. The timing diagram of real-time admission control

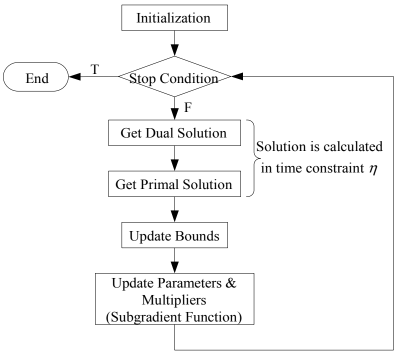

Fig. 4. Procedure of Lagrangian relaxation based real-time admission control

4 Experiment Analysis

For simplicity, we consider a cellular consisting of 9 BSs arranged as a two-dimensional array, and the voice call requests are analyzed. For statistic analysis, 500 time slots are experimented. After first 100 of them, the system is expected in the steady state. Final analysis report is based upon last 400 time slots. All experiments are coded in C. Given λ_j=12 per η, the analysis is to examine the effect of traffic load ξ_j on handoff call blocking probability (Z_{IP}) with respect to several channel reservation schemes.

The system bandwidth allocated to both uplink (W^{UL}) and downlink (W^{DL}) is 6 MHZ, and the voice activity (α^{UL}, α^{DL}) and orthogonality (θ^{UL}, θ^{DL}) for both link is (0.3, 0.3) and (0.7, 1), respectively. It assumes ($S_{c(t)}^{UL}$, $S_{c(t)}^{DL}$) = (7dB, 10dB), available channel C_j=120, as well as R_j=5km. The required bit energy-to-noise density E_b/I_0 for both links is 5 dB. The bit rate of both links is 9.6KHZ. The requirements of service rate Φ_j and Ω_j are given 0.3. For comparison purpose, traditional complete sharing scheme (CSS) [9] and cutoff priority scheme (CPS) with fixed number of guard channels are implemented.

The effects of traffic load on handoff call blocking probability with β_j=0.01, 0.02, and 0.03 are shown in Fig. 5, 6, and 7, respectively. They all illustrate that the number of reserved channel significantly affects the performance with respect to predefined threshold β_j. Theoretically, the more channels are reserved, the less blocking Z_{IP} is calculated. However, the minimization of Z_{IP} is constrained by β_j. As we can see, if we apply CPS with fixed number of reserved channels, the fraction (f_j) of reserved channel is up to 0.2, 0.3, and 0.4 in case of β_j=0.01, 0.02, and 0.03, respectively. In summary, proposed dynamic guard channel (DGC) approach outperforms other schemes. For the analysis of performance improvement, under constraint of β_j=0.01, DGC is compared to CSS and CPS with f_j=0.4. Fig. 8 shows the reduction of blocking probability is up to 20% with CPS in ξ_j=1/3, and up to 90% with CSS in the case of ξ_j=3/1.

Applying Lagrangian relaxation and subgradient method to solve the problem (IP), the better primal feasible solution is an upper bound (UB) of the problem (IP) while Lagrangian dual problem solution guarantees the lower bound (LB). Iteratively, both solving Lagrangian dual problem and getting primal feasible solution, we get the LB and UB, respectively. The error gap is defined by (UB-LB)/LB*100%. Concerning about the solution quality of Lagrangian relaxation approach, we list the statistic of error gap in Table 1. All gaps are less than 10%. Actually, we also calculated the solution quality without applying multipliers technique as described in section 3.2, in most cases the gaps are larger than 80%. Experiments show that the proposed admission control scheme jointly considers real-time processing and dynamic channel reservation is valuable for further associated investigation.

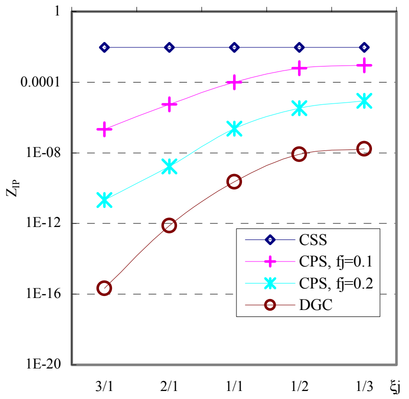

Fig. 5. Effect of traffic loads on handoff call blocking probability with β_j=0.01

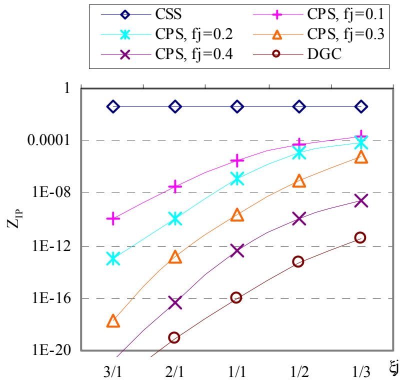

Fig. 7. Effect of traffic loads on handoff call blocking probability with β_j=0.05

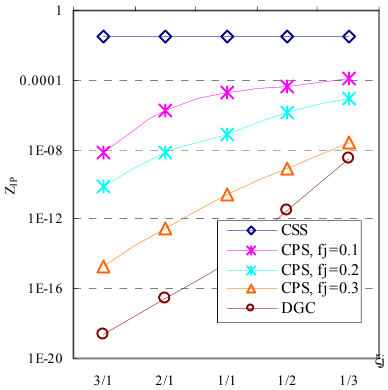

Fig.6. Effect of traffic loads on handoff call blocking probability with β_j=0.03

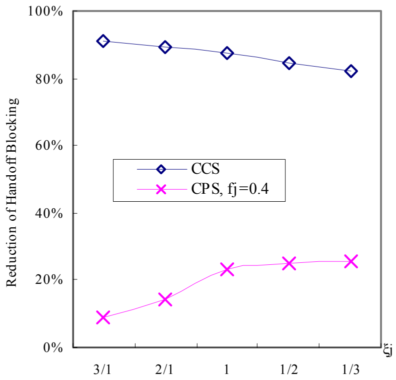

Fig. 8. Reduction of handoff blocking probability compared with two schemes in β_j=0.01

Table 1. Statistic of error gap with different traffic loads in β_j=0.01

Scheme	ξ_j				
	3/1	**2/1**	**1/1**	**1/2**	**1/3**
CSS	7.81%	8.50%	8.05%	7.70%	7.76%
CPS, f_j=0.1	8.73%	9.48%	7.78%	7.67%	9.12%
CPS, f_j=0.2	9.54%	9.97%	8.32%	9.27%	6.70%
CPS, f_j=0.3	8.59%	7.94%	7.98%	8.85%	7.05%
CPS, f_j=0.4	8.79%	9.47%	9.42%	6.99%	8.26%
DGC	8.82%	9.65%	8.19%	8.14%	8.86%

5 Conclusion

This paper proposes a prioritized real-time admission control model for DS-CDMA system. We jointly consider uplink/downlink, new/handoff calls. The algorithm is based upon dynamic reserved channels (guard channels) scheme for prioritized calls, it adapts to changes in handoff traffics where associated parameters (guard channels, new and handoff call arrival rates) can be varied. We express our achievements in terms of formulation and performance. Experiment analyzes the performance of admission control algorithm in terms of real-time manner. Computational results illustrate that proposed algorithm is calculated with better solution quality. To fitting real world scenario, jointly analysis of voice/data traffic and sectorization are considerable. They will be investigated in the future research.

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