Real-time Admission Control and Revenue Optimization for Cellular DS-CDMA Networks

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Abstract. In this paper, we propose a real-time admission control mechanism in conjunction with revenue optimization for DS-CDMA network. For solving the optimization problem, iteration-based Lagrangean relaxation approach is applied by allocating a time budget. The achievement in terms of problem formulation and performance analysis is presented. Associated parameters considered are mean arrival rate, mean call holing time, and time budget. Computational experiments indicate that time budget is a key factor to affect the system loading, and small mean arrival rate is more significant than large mean arrival rate especially. Time budget and mean call holding time jointly affects the ratio of admit to existence. The analysis concludes that assigning time budget 6 seconds is proper value in real-time admission control.

1 Introduction

Due to the continuous growth on demand of wireless communications, direct sequence code division multiple access (DS-CDMA) is a promising multiple-access technique for the third generation (3G) wireless systems since its advantage in user capacity. All of users share entire frequency spectrum, theoretically this provides no upper bound limit of available channels. Since all uses communicate at the same time and same frequency, each user's transmission power is regarded as a part of other users' interference. Thus, CDMA is a kind of power-constrained or interference-limited system. The system capacity is bounded by interferences, signal to interference ratio (SIR), on uplink connection especially [1] [2]. To manage system capacity, call admission control (CAC) is a prevalent mechanism to allocating channel resources. The more users are admitted, the more revenue is contributed.

Recent CAC studies focus on supporting multimedia traffics because of asymmetric Internet applications has been increased, but they considers general performance issues such as system throughout, call blocking probability, outage probability, etc. To maximizing the overall carried traffic, CAC is fulfilled by controlling the user powers and data rates [3] that the throughout maximization problem is formulated as a classical optimization problem. For soft handoff call requests of real-time services in CDMA system, [4] proposed admission control policy to guarantee quality of service (QoS) for soft handoff calls which is given priority

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over new calls and stream-type data traffics. Another article is also considered prioritized CAC policy to admit a new call with the SIR requirements of both the existing calls and the new call are guaranteed [5]. For the sake of supporting mobile multimedia communication services, it taken into account the traffic asymmetry between uplink and downlink. The performance measures focus on the system throughput and the blocking probabilities of handoff calls and new calls. The outage probability of a call in progress is also calculated.

Related CAC studies pay more attention to performance issue, but revenue contributed by admitted users is another interested issue in terms of system provider. Preliminary works have been proposed to consider both revenue optimization and performance analysis [6] [7] [8]. However, previous CAC based revenue optimization researches provide non-realtime mechanism. In the nature of admission control, multimedia services for example, call admission must be decided in seconds.

In this paper, based on previous work [8] we propose a CAC mechanism to jointly considering revenue optimization and real-time processing. QoS analysis of SIR requirement is simplified in uplink connection. The remainder of this paper is organized as follows. In Section 2, the background of DS-CDMA admission control is reviewed. Section 3 presents real-time admission control model which consists of traffic model, performance measures, as well as problem formulation, as well as solution approach. The solution approach to the optimization problem is given in Section 4. Section 5 illustrates the computational experiments. Finally, Section 6 concludes this paper.

2 Admission Control of DS-CDMA System

2.1 Previous researches

Generally, call requests can be categorized into both real new calls that are initiated in original base station (BS), and handoff calls that are coming from adjacent BS. Three CAC works are presented to analyze voice only revenue optimization and the solution approach is Lagrangean relaxation. The first young model considers only real new mobile user (NMU) call admission [6]; they are admitted or rejected in its homing base station. The experiments analyze the effect of pre-defined QoS requirement on total system revenue with respective to voice activity factor. Computational results illustrate that the solution quality of error gap less than 5.0% is with percentile 0.99. Proposed algorithm is calculated with near-optimal solution. Second, NMU calls are also considered, but they are admitted, rehomed to adjacent cells, or rejected [7]. Experiments illustrate that no matter which value of VAF is given, proposed CAC algorithm always is with an outstanding performance on solution optimality. To clarify the CAC concept of, a framework of admission control policies is also presented. Based upon it, this article takes into count account both NMU calls and existing mobile user (EMU) calls, in which forced handoff of existing calls from its homing BS to adjacent BS can be conducted in such a way that real new calls can be optimally admitted to contribute overall revenue [8].

A number of solution heuristics have been proposed in previous researches to tackle optimization problem in terms of CAC mechanism, and also calculated with near-optimal solutions as well as an outstanding performance. In summary, the number of new call generation in three previous researches is Poisson distributed, whereas existing call generation is given with constant number. Also, they focus on long-term analysis instead of real-time scenario. In fact, real-time processing is the nature of admission control, and also meets real-world requirements [3]-[5]. We expect that admission control should be done in seconds. To do so, we try to build a real-time admission control mechanism by Lagrangean relaxation approach combined with subgradient-based method.

2.2 SIR Model

Denote B and T the set of base stations and mobile stations, respectively. In CDMA environments, since all uses communicate at the same time and same frequency, each user's transmission power is regarded as a part of other users' interference. More specifically, literatures [1] [2] point out that CDMA capacity is bounded on uplink connection. Received signal-to-interference ratio (SIR) at the base station affects the connection quality. This kind of situation requires that the interferences base station incurred must be lower than pre-defined acceptable interference threshold $(E_b/N_{total})_{req}$ to ensuring communication quality of service (QoS), where E_b and N_{total} is the energy that BS received and the total noise, respectively. The interference comprises of background noise N_0, inter-cellular (1), and intra-cellular interferences (2), where D_{jt} is the distance between base station $j \in B$ and mobile station $t \in T$, and z_{jt} is decision variable which is 1 if mobile station *t* is admitted by base station *j* and 0 otherwise. G, τ, and α is the processing gain, attenuation factor and voice activity factor, respectively.

Inter-cellular interferences come from mobile stations served by neighboring cells, while active mobile stations in coverage generate intra-cellular interferences. For each of previous CAC work, three SIR interference models are classified [8] which include without EMU rehoming, with EMU rehoming, and multi-user detection. In this paper, we apply "with EMU rehoming" SIR model expressed in (3).

$$\frac{1}{G}\alpha S(\sum_{t\in T} z_{jt} - 1) \tag{1}$$

$$\frac{1}{G}\alpha S \sum_{\substack{j'\in B \\ j'\neq j}} \sum_{t\in T} (\frac{D_{j't}}{D_{jt}})^{\tau} z_{j't} \tag{2}$$

$$(\frac{E_b}{N_{total}})_{req} \le \frac{S}{N_0 + \frac{1}{G}\alpha S(\sum_{t\in T} z_{jt} - 1) + \frac{1}{G}\alpha S \sum_{\substack{j'\in B \\ j'\neq j}} \sum_{t\in T} (\frac{D_{j't}}{D_{jt}})^{\tau} z_{j't}} \tag{3}$$

The goal of uplink admission control is to preventing the system capacity from overloaded, and to provisioning uninterrupted services for existing users as well. A lot of conditions are assumed as follows, 1) perfect power control is assumed; 2) the uplink is perfectly separated from the downlink; 3) fading is not considered; 4) downlink is not considered. With uplink perfect power control, the power signal strengths received at BS from each MS are all the same. We denote this value S .

3 Real-time Admission Control

3.1 Basic Model

In this paper, we focus on new voice call admission. In overall system, the arrivals of new call requests are Poisson distributed with rate λ . The call holding time is assumed to be exponentially distributed with mean τ . For a specific time slot η , time $\Gamma-1$ and Γ is the start and stop point of the time slot as shown in Fig. 1. At time Γ, λ_Γ , α_Γ , γ_Γ , and ε_Γ is the number of arrived calls, the number of admitted calls, the number of remained calls, and total existence, respectively. Accordingly the admission control mechanism (4) is a function of λ_Γ and ε_Γ , in which $\varepsilon_\Gamma = (\alpha_\Gamma + \gamma_\Gamma)$ is sum of admitted and remained calls.

$$\alpha_\Gamma = CAC(\lambda_{\Gamma-1},\ \varepsilon_{\Gamma-1}) \tag{4}$$

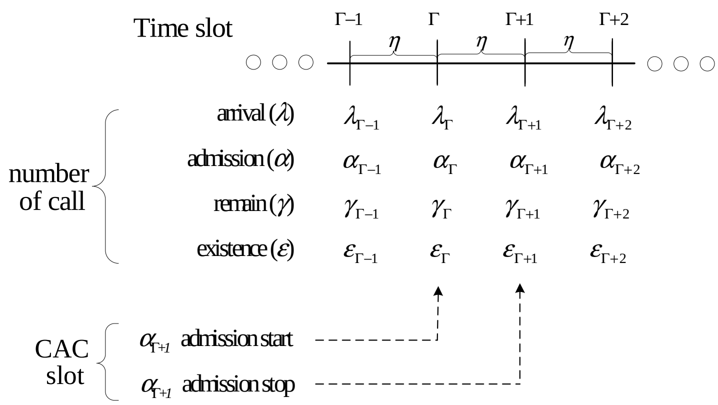

Fig. 1. The timing diagram of real-time admission control

Since the call holding time is assumed to be exponentially distributed with mean τ , $\gamma_\Gamma = \lfloor \varepsilon_{\Gamma-1} \cdot e^{-\eta/\tau} \rfloor$ represents the number of remained calls of $\varepsilon_{\Gamma-1}$ after time slot η where $\lfloor\ \rfloor$ is a floor function. The initial values are $\alpha_0 = 0,\ \gamma_0 = 0,\ \varepsilon_0 = 0$. To clarify the real-time CAC mechanism, Table 1 illustrates an example on call number calculation with $\lambda = 30$, $\tau = 90$, and $\eta = 3$ .At the end of time slot 3, for example, 39 (α_3 =39) of 45 calls arrived (λ_2 =45) at the end of time slot 2 is admitted. Also, 52 (γ_3 =52) of 54 existing calls (ε_2 =54) at the end of time slot 2 is remained after time slot η , in which $52 = \lfloor 54 \cdot e^{-3/90} \rfloor$. Thus, the total existence at end of time slot 3 is 91=39+52. The detailed formulation of *CAC* mechanism will be described in section 3.3.

Table 1. Example of call number calculation with $\lambda = 30$, $\tau = 90$, and $\eta = 3$

Time slot (*t*)	**0**	**1**	**2**	**3**	**4**	**6**	**•**	**•**
Arrival (λ_Γ)	26	34	45	28	22	31		
Admission (α_Γ)	0	25	30	39	24	19	•	•
Remain (γ_Γ)	0	0	24	52	88	108	•	•
Existence (ε_Γ)	0	25	54	91	112	127		

3.2 Performance Measures

The essence of real-time admission control is based on a series of events. First of all, total calls arrived is aggregated. Admission control taking into account both new arrived call and existing call is followed up. The existence is sum of admitted and remained calls, in which the number of remained calls is calculated by cdf of exponential distribution. Eventually, the system goes into steady state. In other words, the existence that depends upon call arrival (λ), mean of call holding time (τ), and time budget of CAC (η), will be saturated in the steady state.

To effectively analyze real-time CAC, we consider four performance measures, including system load, admit to existence call ratio, call blocking ratio, and revenue contribution. The detailed description of those measures is as follows,

1) *System load (SL)*: System load is defined as total existence, i.e. total number of existing users ε_Γ in time Γ . As we described in section 3.1, since ε_Γ in (4) is a parameter of CAC mechanism, *SL* is another considerable measures. Theoretically, the CAC performance is a decreasing function of *SL*.

2) *Admit to existence ratio (AER)*: With *SL*, number of admitted calls (α_Γ) is decided and AER= $\alpha_\Gamma / \varepsilon_\Gamma$. At end of each time slot, these two number forms a system state. AER not only provides system state analysis, but also is an indicator to justify the stability of proposed CAC mechanism. If AER has nothing to do with λ , the quality of proposed mechanism is assured.

3) Call blocking ratio (*CBR*): *CBR* is calculated with $(\lambda_{\Gamma-1} - \alpha_\Gamma)/\lambda_{\Gamma-1}$, which is a simplified expression on call blocking analysis. Even though, it is still the most

important measure in evaluation of CAC mechanism. We try to examine the effect of time slot η on CBR and to choose a proper value for forthcoming analysis accordingly.

4) Revenue contribution: The objective of this paper is to maximizing system revenue by using proposed CAC mechanism. The basic CAC model is described in section 3.1. The more users are admitted, the more revenue is contributed. In other words, the system revenue is a function of number of admitted users. To achieving this goal, a revenue optimization model is formulated in the following section.

3.3 Problem Formulation

In this section, an admission control model supporting revenue optimization is applied from [8], it considers only uplink signal to interference ratio (SIR) analysis. The objective function (IP) is to maximize the total revenue by admitting new mobile users into the system where a_t is the revenue from admitting mobile station $t \in T''$ into the system, a_t is given 10. On the other hand, maximum revenue is equivalent to minimum revenue loss.

Objective function:

$$\begin{aligned} Z_{IP} &= \max\Big(\sum_{t\in T''} a_t \sum_{j\in B} z_{jt} - \sum_{t\in T'} f_t \sum_{j'\in B-\{b_t\}} z_{j't}\Big) \\ &= \min\Big(-\Big(\sum_{t\in T''} a_t \sum_{j\in B} z_{jt} - \sum_{t\in T'} f_t \sum_{j'\in B-\{b_t\}} z_{j't}\Big)\Big) \end{aligned} \qquad \text{(IP)}$$

s.t.

$$\Big(\frac{E_b}{N_{total}}\Big)_{req} \le \frac{\frac{S}{N_0}}{1+\frac{1}{G}\alpha\frac{S}{N_0}\Big(\sum_{t\in T} z_{jt}-1\Big)+\frac{1}{G}\alpha\frac{S}{N_0}\sum_{\substack{j'\in B\\ j'\ne j}}\sum_{t\in T}\Big(\frac{D_{j't}}{D_{jt}}\Big)^{\tau} z_{j't}} \qquad \forall j\in B \; (5)$$

$$\sum_{t\in T} z_{jt} \le M_j \qquad \forall j\in B \; (6)$$

$$D_{jt} z_{jt} \le R_j \mu_{jt} \qquad \forall j\in B, t\in T \; (7)$$

$$z_{jt} \le \mu_{jt} \qquad \forall j\in B, t\in T \; (8)$$

$$\sum_{j\in B'} z_{jt} = 1 \qquad \forall\, t \in T'' \; (9)$$

$$\sum_{j\in B} z_{jt} = 1 \qquad \forall\, t \in T' \; (10)$$

$$\frac{\sum_{t\in T'} f_t \sum_{j'\in B-\{b_t\}} z_{j't}}{\sum_{t\in T''} a_t \sum_{j\in B} z_{jt}} \le U \qquad \forall j\in B, t\in T \; (11)$$

$$z_{jt} = 0 \text{ or } 1 \qquad \forall j\in B, t\in T \; (12)$$

SIR constraint of the uplink connection is shown in (5). Capacity constraint is given in (6), for each base station the total number of admitted users is limited on the pre-defined threshold M_j. Constraint (7) ensures that any new user to be admitted by a base station must be in the coverage of power transmission, where R_j is the power radius. We denote μ_{jt} the indicator which is 1 if mobile station t can be served by base station j and 0 otherwise. If $D_{jt} > R_j$, set μ_{jt} =0 . With μ_{jt}, the admission decision variable z_{jt} is constrained by (8). Constraint (9) guarantees new user $t \in T'$, T' is the set of new users, can be admitted to only one physical base station or rejected. Besides, B' is the set of $B \cup \{b'\}$, and *b'* is the artificial base station to carry the rejected call when admission control function decides to reject the call. For each existing user $t \in T''$, it always is admitted by constraint (10) since the uninterrupted connection is required, where T'' is the set of existing users. Cost threshold of rehoming existing user is given in constraint(11) in which U is the predefined threshold of the ratio of the handoff cost to the total revenue contributed by admitted new user, and f_t is handoff cost of mobile station t from currently assigned base station to another base station, where f_t =2, respectively. b_t is the controlling base station of mobile station *t*. Constraint (12) assures the integer property of decision variable.

4 Solution Approach

4.1 Lagrangean Relaxation

The approach to solving the problem (IP) is Lagrangean relaxation [9], which including the procedures that relax complicating constraints, multiple the relaxed constraints by corresponding Lagrangean multipliers, and add them to the primal objective function. Based on above procedures, we transform the primal optimization problem (IP) into the following Lagrangean relaxation problem (LR) where constraints (5), (6), (7), and (11) are relaxed. Furthermore, LR is tackled by subproblem 1.

$$Z_{D3}\left(v_j^1, v_j^2, v_{jt}^3, v^4\right) =$$

$$\min -\left(\sum_{t\in T''} a_t \sum_{j\in B} z_{jt} - \sum_{t\in T'} f_t \sum_{j'\in B-\{b_t\}} z_{j't}\right)$$

$$+\sum_{j\in B} v_j^1 \left((\frac{E_b}{N_{total}})_{req} + (\frac{E_b}{N_{total}})_{req} \frac{1}{G} \alpha \frac{S}{N_0} \left((\sum_{t\in T} z_{jt} - 1) + \sum_{\substack{j'\in B \\ j'\neq j}} \sum_{t\in T} (\frac{D_{j't}}{D_{jt}})^{\tau} z_{j't} \right) - \frac{S}{N_0} \right)$$

$$+\sum_{j\in B} v_j^2 \left(\sum_{t\in T} z_{jt} - M_j \right) + \sum_{t\in T}\sum_{j\in B} v_{jt}^3 \left(D_{jt} z_{jt} - R_j \mu_{jt} \right)$$

$$+v^4 \left(\sum_{t\in T'} f_t \sum_{j'\in B-\{b_t\}} z_{j't} - U \sum_{t\in T''} a_t \sum_{j\in B} z_{jt} \right) \quad \text{(LR)}$$

subject to:(8), (9), (10), and (12).

Subproblem 1: for z_{jt}

$$\min - \sum_{t\in T''} a_t \sum_{j\in B} z_{jt} + \sum_{t\in T'} f_t \sum_{j'\in B-\{b_t\}} z_{j't}$$

$$+\sum_{j\in B} v_j^1 \left((\frac{E_b}{N_{total}})_{req} + (\frac{E_b}{N_{total}})_{req} \frac{1}{G} \alpha \frac{S}{N_0} \left((\sum_{t\in T} z_{jt} - 1) + \sum_{\substack{j'\in B \\ j'\neq j}} \sum_{t\in T} (\frac{D_{j't}}{D_{jt}})^{\tau} z_{j't} \right) - \frac{S}{N_0} \right)$$

$$+\sum_{j\in B} v_j^2 \left(\sum_{t\in T} z_{jt} - M_j \right) + \sum_{t\in T}\sum_{j\in B} v_{jt}^3 \left(D_{jt} z_{jt} - R_j \mu_{jt} \right)$$

$$+v^4 \left(\sum_{t\in T'} f_t \sum_{j'\in B-\{b_t\}} z_{j't} - U \sum_{t\in T''} a_t \sum_{j\in B} z_{jt} \right) \quad \text{(SUB 1)}$$

subject to: (8), (9), (10), and (12).

(SUB 1) can be rewritten to the following form,

$$\sum_{t\in T''} \left(\sum_{j\in B} \left(\begin{array}{l} z_{jt} \left(-a_t + (\frac{E_b}{N_{total}})_{req} \frac{1}{G} \alpha \frac{S}{N_0} \left(v_j^1 + \sum_{\substack{j'\in B \\ j'\neq j}} v_{j'}^1 (\frac{D_{jt}}{D_{j't}})^{\tau} \right) + v_j^2 + v_{jt}^3 D_{jt} - U v^4 a_t \right) \\ -v_{jt}^3 R_j \mu_{jt} \end{array} \right) \right)$$

$$+\sum_{t\in T'} \left(\sum_{j\in B} \left(\begin{array}{l} z_{jt} \left(f_t \left(1+v^4\right) + (\frac{E_b}{N_{total}})_{req} \frac{1}{G} \alpha \frac{S}{N_0} \left(v_j^1 + \sum_{\substack{j'\in B \\ j'\neq j}} v_{j'}^1 (\frac{D_{jt}}{D_{j't}})^{\tau} \right) + v_j^2 + v_{jt}^3 D_{jt} \right) \\ -v_{jt}^3 R_j \mu_{jt} \end{array} \right) \right)$$

$$+\sum_{j\in B} \left(v_j^1 \left((\frac{E_b}{N_{total}})_{req} - \frac{S}{N_0} - (\frac{E_b}{N_{total}})_{req} \frac{1}{G} \alpha \frac{S}{N_0} \right) - v_j^2 M_j \right)$$

In the model, the existing mobile users could be rehomed to another base station that can serve it. Therefore, new mobile users may be admitted into the system even if it was originally blocked by the system. In (SUB 1), the first and second term can be further decomposed into |*T*| sub-problems. For new mobile user, let h_{jt} be (13), if h_{jt} is equal to or less than 0, we assign z_{jt} to 1 or 0 otherwise. For existing mobile user, let k_{jt} be (14), if k_{jt} is equal or less than 0, we assign $z_{j't}$ to 1 where $j' \neq j$ or 0 otherwise. There is a point to be paid attention, since existing mobile users can not be blocked, z_{jt} can not assign to 0. Thus, if k_{jt} is greater than 0, the rehoming cost f_t is reset to 0.

$$-a_t + (\frac{E_b}{N_{total}})_{req} \frac{1}{G} \alpha \frac{S}{N_0} \left(v_j^1 + \sum_{\substack{j' \in B \\ j' \neq j}} v_{j'}^1 (\frac{D_{jt}}{D_{j't}})^{\tau} \right) + v_j^2 + v_{jt}^3 D_{jt} - Uv^4 a_t - v_{jt}^3 R_j \mu_{jt} \qquad (13)$$

$$f_t \left(1 + v^4\right) + (\frac{E_b}{N_{total}})_{req} \frac{1}{G} \alpha \frac{S}{N_0} \left(v_j^1 + \sum_{\substack{j' \in B \\ j' \neq j}} v_{j'}^1 (\frac{D_{jt}}{D_{j't}})^{\tau} \right) + v_j^2 + v_{jt}^3 D_{jt} - v_{jt}^3 R_j \mu_{jt} \qquad (14)$$

According to the weak Lagrangean duality theorem [9], for any $v_j^1, v_j^2, v_{jt}^3, v^4 \geq 0$, the objective value of $Z_D\left(v_j^1, v_j^2, v_{jt}^3, v^4 \right)$ is a lower bound on Z_{IP}. Based on Problem (LR), the dual problem $Z_D = \max Z_D(v_j^1, v_j^2)$ subject to $v_j^1, v_j^2, v_{jt}^3, v^4 \geq 0$ is constructed to calculate the tightest lower bound. Subgradient method [10] is applied to solving the dual problem. Let the vector S is a subgradient of $Z_D\left(v_j^1, v_j^2, v_{jt}^3, v^4 \right)$ at $\left(v_j^1, v_j^2, v_{jt}^3, v^4 \right)$. In iteration k of subgradient optimization procedure, the multiplier vector π is updated by $\pi^{k+1} = \pi^k + t^k S^k$, in which t^k is a step size determined by $t^k = \lambda\left(Z_{IP}^* - Z_D(\pi^k) \right) / \left\| S^k \right\|^2$, where Z_{IP}^* is an upper bound on the primal objective function value after iteration k, and α is a scalar where $0 \leq \alpha \leq 2$.We then apply subgradient method to calculate tightest lower bound. Generally speaking, the better primal feasible solution is an upper bound (UB) of the problem (IP) while Lagrangean dual problem solution guarantees the lower bound (LB) of problem (IP). Iteratively, both solving Lagrangean dual problem and getting primal feasible solution, we get the LB and UB, respectively.

4.2 Real-time Admission Control Algorithm

1) Real-time rationale of Lagrangean relaxation: Based upon Lagrangean relaxation approach, a predefined time budget η, e.g. 3 seconds of time period for real-time requirement, is given to solving Lagrangean dual problem and getting primal feasible solutions iteratively. Actually the time budget is equivalent to the time slot. In a specific time slot, real-time admission control is fulfilled at end of time slot. Hereafter, the term "time slot" and "time budget" is exchangeable. Number of call requests admitted is depended on the time budget. Applying Lagrangean relaxation approach to proposed admission model described in section 3.1, real-time CAC is fulfilled. On the other hand, initial value of Lagrangean multipliers affects solution quality. If we appropriately assign initial values, algorithm is probably speeded up to converge in stead of more iterations are required. Fortunately, Lagrangean multipliers associated with users remained can be reused in next time slot.

2) Algorithm: Overall procedure of Lagrangean relaxation based real-time admission control algorithm is illustrated in Fig. 2. Associated input parameters are λ (*new call arrival rate*), τ (*average time of call holding*), η (*time budget for admission control*), whereas outputs measures are *System load (SL), Admit to existence ratio (AER),* Z_{IP} (revenue) and *call blocking ratio (CBR)*. The detailed algorithm of each process in the procedure chart is described as follows.

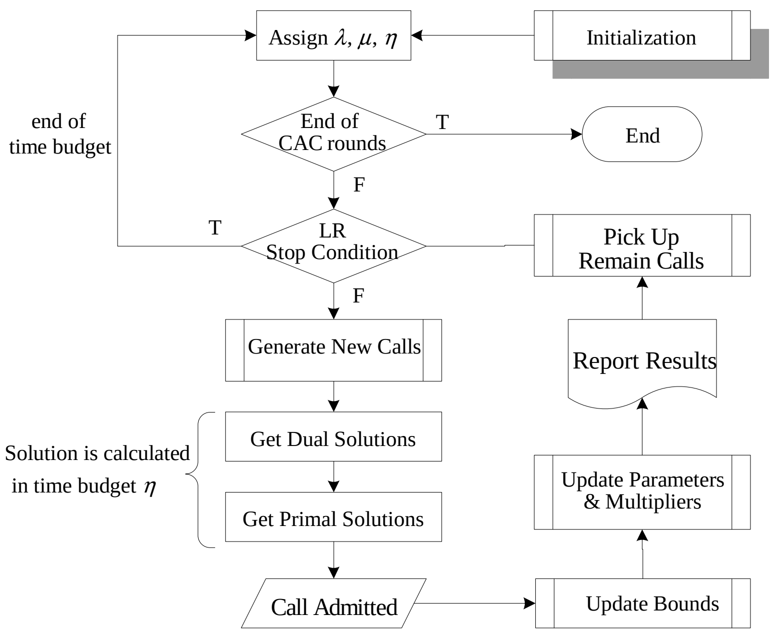

Fig. 2. Procedure of Lagrangean relaxation based real-time admission control

algorithm Initialization:

a) Given base station locations (set *B*);
b) Uniformly generate users (set *T*);
c) Calculate the distance D_{jt};
d) Set $UB^* = 0$, $LB^* = -\infty$;
e) Set initial Lagrangean Multipliers $\pi^0 = 0$, where π is multiplier vector;
f) Set iteration counter *k=0*, improvement counter *m= 0*, scalar of step size $\alpha_0 = 2$;
g) Set the number of CAC rounds (*T*)

algorithm Generate New Calls:

```
a) Generate the number of new calls (λ_t, t ≤ T);
b) Set NewCallCount=0;
c) do
 {
  Randomly select a user;
  If (isNewCallFlag=0 && isRemainCallFlag=0)
      {Set isNewCallFlag=1;}
  NewCallCount= NewCallCount+1;
 }Until NewCallCount=λ_t;
```

algorithm Generate Dual Solutions:

a) $k = k+1$, $m = m+1$;

b) Get dual decision variables to calculate LB^k on Z_{IP}

algorithm Generate Primal Feasible Solutions:

a) Get Primal feasible solutions (decision variables) to calculate UB^k on Z_{IP} subject to constraints

algorithm Update Bounds:

a) Check *LB*

If $LB^k > LB^*$ then $LB^* = LB^k$;

b) Check *UB*

If $UB^k < UB^*$ then $UB^* = UB^k$;

algorithm Pick UP RemainCalls:

```
a) Calculate the number of terminated calls
   (TerminatedCalls);
b) do
 {
  Randomly select a user;
  If (isRemainCallFlag=1) {Set isRemainCallFlag
 =0;}
  TerminatedCount= TerminatedCount +1;
 }Until TerminatedCount = TerminatedCalls;
```

algorithm Update Parameters & Multipliers:

a) If (*m* = update_counter_limit) { $\alpha_k = \alpha_k / 2$; *m* = 0;}

$$\pi^{k+1} = \max\left\{0,\ \pi^k + t^k \cdot S^k\right\};$$

4.3 Getting Primal Feasible Solutions

To solving the admission control problem, this section develops a heuristic for getting primal feasible solutions in the process of iteratively solving dual problem. Solutions calculated in dual problems need to be checked if solutions satisfy all constraints relaxed in (LR)

[*Heuristic H*]

Step 1. Check capacity constraint (6), for each base station. Drop the new mobile user, i.e. set z_{jt} =0, if violates the constraint (6), or go to Step 2 otherwise.

Step 2. Make sure QoS constraint (5) is satisfied for each base station. Drop the new mobile user, i.e. set z_{jt} =0, if violates the constraint (5), or go to Step 3 otherwise.

Step 3. Try re-adding back all dropped new users in Step 1 & 2 into system.

3-1) sequentially picks up a dropped new user.

3-2) home to another base station, i.e. set z_{jt} =1 again, if this setting satisfies constraint (5) as well as capacity constraint (6) for each base station, or go to Step 4 otherwise.

Step 4. Rehoming existing user into adjacent base stations in order to granting more new users.

4-1) sequentially selects existing users which are covered by more than one base station.

4-2) rehome the selected users into adjacent base station if constraint (5), (6), and (11) are all satisfied for each base station, or go to Step 5 otherwise.

4-3) admit new users which is still blocked into the system, i.e. set z_{jt}=1 again, if this setting satisfies constraint (5) and (6) for each base station, or go to Step 5 otherwise.

Step 5. End heuristic.

5 Computational Experiments

5.1 Environment and Parameters

All locations of base stations, existing as well as new mobile users are generated in uniform distribution. For each real-time processing is on behalf of changing the number of both users admitted and users remained in next time slot. For the purpose of statistic analysis, 500 consecutive 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. Associated parameters are also given in Table 2. We considered a cellular system which consists of 10 base stations arranged as a two-dimensional array.

All experiments are coded in C++ and running on INTEL™ P4-1.6GHZ CPU with 256 MB RAM.

We would like to examine the effect of three factors on the performance measures. First of all, real-time admission control is fulfilled subject to time budget η, where 3, 6, 9, and 12 seconds are selected. Theoretically, the more time used in admission control, the better performance is calculated. Second, average call holding time is another key factor which directly affects the number of remained calls, for which we choose 60, 70, 80, and 90 seconds. Third, the number of call arrivals (λ) is considerable on performance analysis. Assuming that the number of admitted users is proportional to the call arrivals, if the more users are arrived, the more users are admitted and remained. Arrivals not only provide as a parameter, but also is an indicator to justify the stability of proposed CAC mechanism. If the ratio of admit to existence is nothing to do with λ , the quality of proposed admission control mechanism is assured. From overall system viewpoint, three cases of λ=100, 150, 200 are examined to see how arrivals affect admission performance.

5.2 Performance Analysis

1) *Mean System load (μ_{SL})*: In Fig. 3, no matter what value of mean call holding time (τ) and mean arrival rate (λ) is examined, the mean system load μ_{SL} is the decreasing function of time budget (η). Since the call holding time is assumed to be exponentially distributed, the number of remained calls (γ_Γ) decreases when time budget increases, in which γ_Γ affects the number of existing calls (ε_Γ). In case of λ=100, Fig. 3 (a), μ_{SL} is in range of 2000 to 2800 with η=3, while it is near 750 with η=12. In case of λ=150, Fig. 3 (b), μ_{SL} is near 3000 and near 1000 with η=3 and 12, respectively. In case of λ=200, Fig. 3 (c), the decreases in μ_{SL} is 50% (from 2800 to near 1400). *Time budget is a key factor to affect the system loading, and small mean arrival rate is more significant than large mean arrival rate especially*.

Table 2. Given parameter for experiment

Notation	Value
S/N_0	10 db
Eb/N_{total}	1 db
M_j	120
R_j	4 km
τ	4
α	0.3
G	156.25
a_t	10

2) *Mean Admit to existence ratio (* μ_{AER} *)*: μ_{AER} is a stable measure in all cases analysis. Mean AER is a monotonically increasing function of time budget (η), Fig. 4. Even three cases of mean arrival rate (λ) are taken into account, as shown in Fig. 4 (a)-(c), each of them shows almost equivalent for all mean call holding time (τ). This result justifies that based upon proposed real-time admission control mechanism, eventually the system is in the steady state. Another interesting finding is that the difference of μ_{AER} for four values τ is varied from η=3 to η=12. With η=3, μ_{AER} difference is in the range from 0.03 to 0.05, while it is in the range from 0.11 to 0.15 in case of η=12. *Time budget and mean call holding time jointly affects the ratio of admit to existence. Time budget is more significant factor than mean call holding time since the difference is more distinguishable with larger value* η.

3) *Mean revenue contribution (* $\mu_{Z_{IP}}$ *):* Revenue contribution is calculated by problem (IP). The mean revenue contribution for three mean arrival rates is illustrated in Fig. 5. Obviously, the more time budget is given, the more revenue is calculated. With η=3, $\mu_{Z_{IP}}$ is varied for different mean call holding time in all λ. Increasing η to 6, $\mu_{Z_{IP}}$ converges to 1000, 1500, and 1900 in case of λ=100, 150, and 200, respectively. With η=9 and 12, the optimal revenue is calculated except case λ=100, as shown in Fig. 5(b) and Fig. 5(c). To justify the optimality of proposed admission control mechanism, standard deviation ($\sigma_{Z_{IP}}$) of Z_{IP} is also analyzed. Fig. 6(b) and Fig. 6(c) shows that $\sigma_{Z_{IP}}$ is almost the same in all mean call holding time (τ). Although η=9 and 12 calculates with optimal revenue, if there exists a smaller value is an alternative, it achieves the essence of real-time processing. *The analysis concludes that* η *=6 is proper value in real-time admission control.*

4) *Mean call blocking ratio (* μ_{CBR} *)*: In all cases, Fig. 7, μ_{CBR} is a decreasing function of time budget (η). Unavoidably, the larger λ is given, the larger μ_{CBR} is calculated. Following up the suggestion value of η=6, we observe that μ_{CBR} is in the range from 0.00 to 0.08 in Fig. 7(a), while it is in the range from 0.00 to 0.10 in Fig. 7(b), and in the range from 0.05 to 0.28 in Fig. 7(c). All these μ_{CBR} values are acceptable. *The analysis of mean call blocking ratio conforms to the result of mean revenue contribution.*

5) *Error gap*: Table 3 summaries the statistic of error gaps in solving revenue optimization problem. The error gap is defined by (UB-LB)/LB*100%. In Table 3 (a), all gaps are 0.00% except 3.04% in average on η=3, τ=90. In Table 3 (b), all gaps are 0.00% except case η=3, in which maximum gap is 32.42 in average case while maximum gap is 2.21 in best case. Unfortunately, in Table 3 (c), these exists a maximum gap 54.37% in average on η=3, τ=90. Again, if we choose previous suggestion value η=6, maximum gap 54.37% is reduced to 10.89%. To a certain extent, proposed solution optimality is also justified.

6 Conclusion

This paper proposes a real-time admission control mechanism in conjunction with revenue optimization for DS-CDMA network. For solving the optimization problem, iteration-based Lagrangean relaxation approach is applied. The achievement in terms of problem formulation and performance analysis is presented. On evaluating solution optimality of Lagrangean relaxation approach, error gap is calculated. By properly adjusting Lagrangean multipliers, the error gap can be tightly bound. It is an important issue to achieving solution optimality. To effectively utilizing associated multipliers, we expect to construct a novel mechanism. On the other hand, data call requests as well as multimedia traffics must be considered in the future research.

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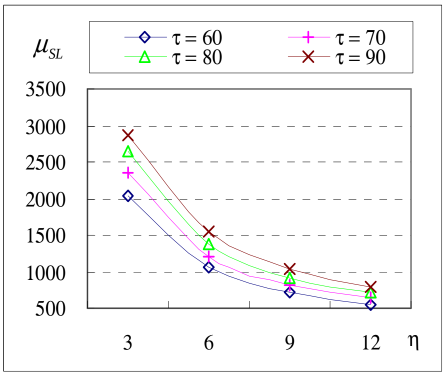
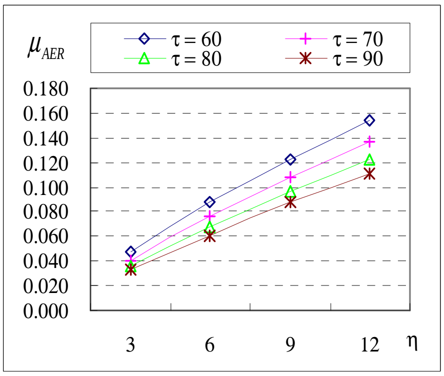


(a) λ =100



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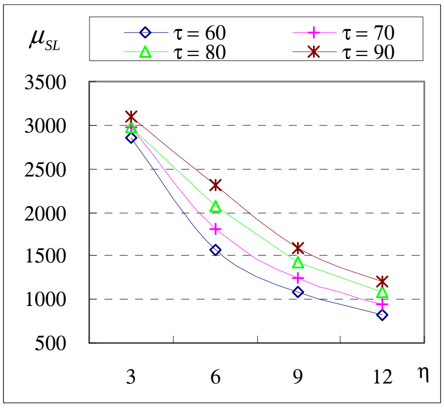

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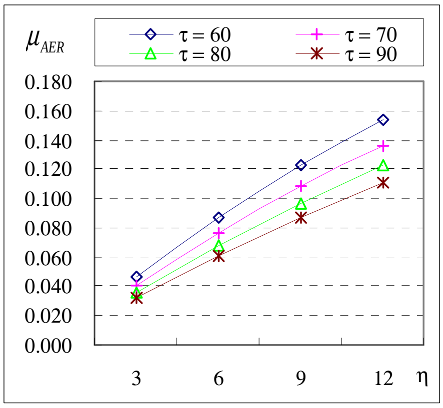

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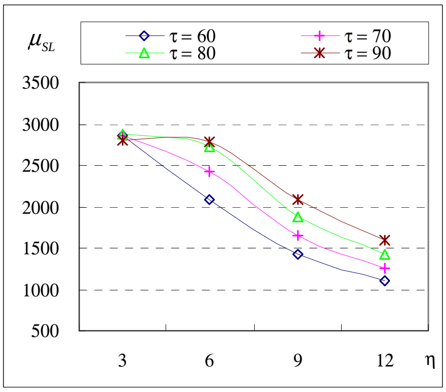
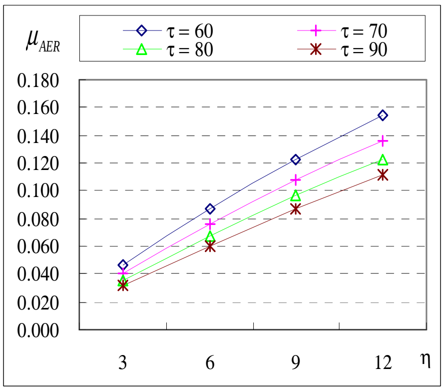


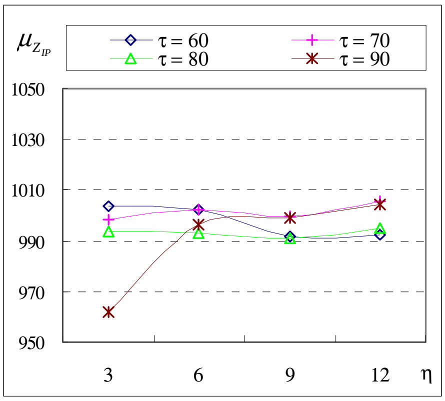
(c) λ =200



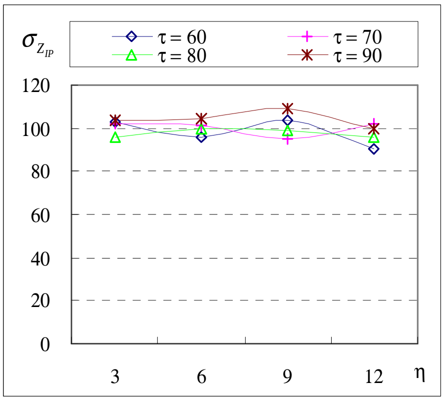
(c) λ =200

Fig. 3 Effect of time budget (η) on mean system load (μ_{SL}) with respect to average call holding time (τ)

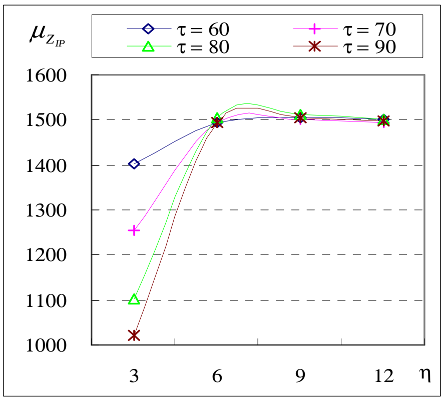
Fig. 4 Effect of time budget (η) on mean AER (μ_{AER}) with respect to average call holding time (τ)



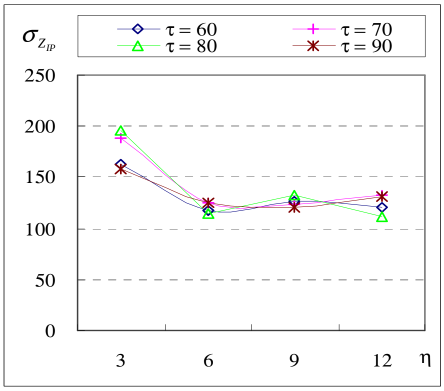
(a) λ =100



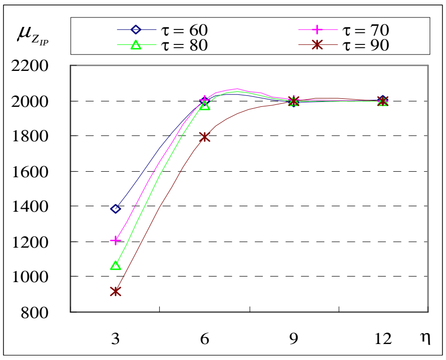
(a) λ =100



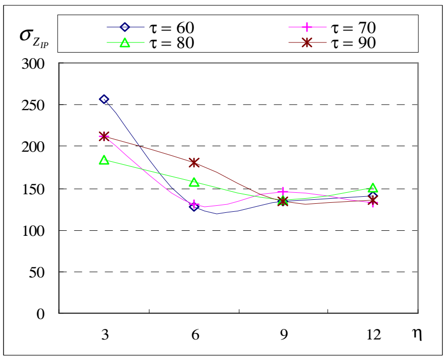
(b) λ =150



(b) λ =150



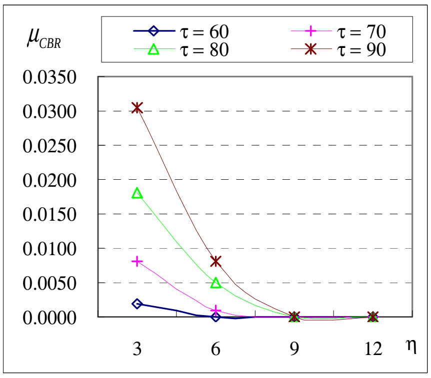
(c) λ =200



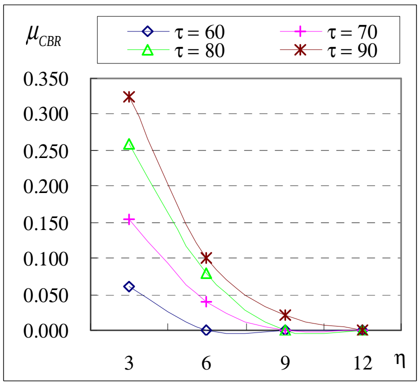
(c) λ =200

Fig. 5 Effect of time budget (η) on mean Z_{IP} ($\mu_{Z_{IP}}$) with respect to average call holding time (τ)

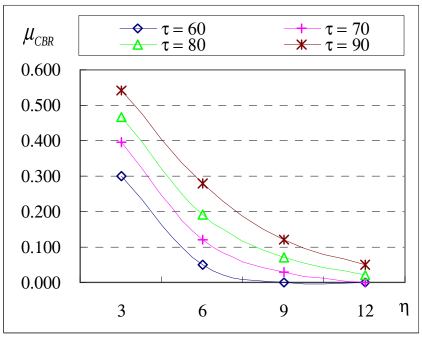
Fig. 6 Effect of time budget (η) on standard deviation of Z_{IP} ($\sigma_{Z_{IP}}$) with respect to average call holding time (τ)



(a) λ =100



(b) λ =150



(c) λ =200

Fig. 7. Effect of time budget (η) on mean call blocking ratio (μ_{CBR}) with respect to average call holding time (τ)

Table 3. Best (B) and average (A) case of error gaps in solving revenue optimization problem by real-time admission control

(a) λ =100

%		τ			
η		60	70	80	90
3	B	0.00	0.00	0.00	0.00
	A	0.06	0.00	0.00	3.04
6	B	0.00	0.00	0.00	0.00
	A	0.00	0.00	0.00	0.00
9	B	0.00	0.00	0.00	0.00
	A	0.00	0.00	0.00	0.00
12	B	0.00	0.00	0.00	0.00
	A	0.00	0.00	0.00	0.00

(b) λ =150

%		τ			
η		60	70	80	90
3	B	0.00	0.00	0.00	2.21
	A	6.14	15.33	25.79	32.42
6	B	0.00	0.00	0.00	0.00
	A	0.00	0.00	0.00	0.00
9	B	0.00	0.00	0.00	0.00
	A	0.00	0.00	0.00	0.00
12	B	0.00	0.00	0.00	0.00
	A	0.00	0.00	0.00	0.00

(c) λ =200

%		τ			
η		60	70	80	90
3	B	0.00	0.00	0.00	18.03
	A	32.02	39.42	46.64	54.37
6	B	0.00	0.00	0.00	0.00
	A	0.00	0.00	1.35	10.89
9	B	0.00	0.00	0.00	0.00
	A	0.00	0.00	0.00	0.00
12	B	0.00	0.00	0.00	0.00
	A	0.00	0.00	0.00	0.00