Revenue Optimization for Uplink Connection Admission Control in Cellular CDMA Networks

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Abstract: Previous call admission control (CAC) studies for CDMA networks focused on call blocking and call dropping. In this paper, a revenue optimization model is proposed to accommodating as more users as possible, meanwhile to preserving whole system quality of service (QoS) in terms of admission control policy. To clarify the concept of CAC, we construct a framework of admission control policies. Based upon it, associated interference models are also identified. For efficiently solving complicated integer programming problem, a powerful Lagrangean relaxation approach is applied. The experiments consider revenue contribution and service rate with respect to traffic loading of both existing and new users. Computational results illustrate that the more new user is loaded, the more service rate is improved. The more new traffic is loaded and the more existing user exists, the more revenue is contributed. Compared with previous researches, the admission policy proposed in this research is calculated with distinguished results.
Key Words: Admission control policies, CDMA networks, Lagrangean relaxation, Mathematical programming, Revenue optimization.

1. Introduction

Wireless and mobile communications have been highly improved, thus the diffusion and demand of mobile communication services are growing rapidly. To fulfill ever-growing user demands, CDMA based on direct sequence technique (DS-CDMA) provides no upper limit of available channels. All of users share entire frequency spectrum instead of divide frequency or time, therefore the system capacity is bounded by interferences [1] [2]. Furthermore, the system capacity of CDMA systems is bounded on uplink connection [2] [3] [4]. Obviously, it is a tradeoff between the system capacity and the level of communication quality. This kind of situation requires that the interferences base station incurred must be lower than pre-defined acceptable interference threshold to ensuring communication quality of service [1]. The less interference incurred at base stations, the more capacity provided in the system. Thus, interference model is a key component for CDMA capacity management. Received signal-to-interference ratio (SIR) at the base station affects the connection quality.

Even though a lot of researches have been proposed to enlarge the CDMA capacity, e.g. “multi-user detection” and ”smart antenna”, call admission control (CAC) is an essential approach to effectively manage system capacity. The mechanism of CAC regulates the network operation with an optimal condition in such a way to promise the uninterrupted services for existing users, and meanwhile to accommodate as more new users’ requests as possible.

Generally speaking, the usual measures for admission control are call blocking and call dropping. Blocking means a new user is denied access to the system, while dropping stands for a call of an existing user is forced terminated in handoff process. CAC policy is crucial to guarantee both a grade of service (GoS), i.e. call blocking probability, forced termination probability of exiting users, and a quality of service (QoS), i.e. SIR. For example, traffic types affect performance on delay [5], power control mechanism to reduce call blocking, forced termination [6].

This research focuses on both revenue contribution and service rate instead of the typical performance measures to preserving whole system QoS, meanwhile, to accommodating as more users as possible. Although previous researches [7][8] have been proposed an optimization model in terms of admission control mechanism, it tackle only simple cases of admission policies without considering rehoming of existing.

To clarify the concept of CAC, we construct a framework of admission control policies. Based upon it, associated interference models are also identified. This paper models revenue optimization problem as a mathematical formulation. Be more realistic, we jointly consider both rehoming and homing for existing and new users, respectively. It tries to enlarge system capacity. To efficiently solve complicated integer programming problem, a powerful approach, say Lagrangean relaxation, is applied.

The remainder of this paper is organized as follows. In Section 2, we discuss the admission control problem of CDMA networks. Section 3 models the revenue optimization problem in terms of admission control mechanism. A solution approach is also proposed here. In Section 4, illustrates the computational experiments. Finally, Section 5 concludes this paper.

2. Admission Control Problem of CDMA Networks

2.1 Background

Theoretically, CDMA provides no upper limit of available channels since all of users share entire frequency spectrum instead of dividing frequency or time. However, channel assignment by allocating transmission power results in interference on other mobile users, the system capacity is strictly interference limited. The interferences comprise of inter-cellular, intra-cellular interferences, and background noises. Inter-cellular interferences come from mobile stations served by neighboring cells, while active mobile stations in coverage generate intra-cellular interferences. This kind of situation requires that the interferences base station incurred must be lower than pre-defined acceptable interference threshold to ensuring communication quality of service (QoS) [1][2]. More specifically, literatures [2] [3] [4] point out that CDMA capacity is bounded on uplink connection. Received signal-to-interference ratio (SIR) at the base station affects the connection quality.

In order to guarantee QoS, call admission control thus plays an important role. The goal of uplink admission control is to preventing the system capacity from overloaded, and to provisioning uninterrupted services for existing users as well. Accordingly, in this paper, we assume a lot of conditions as follows: (1) perfect power control is assumed; (2) the reverse link is perfectly separated from the forward link; (3) fading is not considered; (4) forward link is not considered.

2.2 Call Admission Policies

To preserve the whole system QoS, for each base station, a number of interferences sources that including existing connections and new call requests come from both controlling base station and other interferences propagated from adjacent cells, must be taken into account. Besides, mobility (handoff) of new and existing calls should be effectively managed [9]. Accordingly, we summarize admission control with both user type that consists of exiting user and new user call requests, and call type that consists of handoff and real new calls. For the purpose of simplicity, we focus on handoff of new (homing policy) and existing calls (rehoming policy). Figure 1 illustrates a framework of call admission control policies in terms of user type that including new mobile users (NMU) and existing mobile users (EMU). For new user, it can be homed into their controlling base station or blocked otherwise, while for existing user it can be rehomed into adjacent cell which is light loading to accommodate more users. Thus, there are two targets of admission control, say real new call and handoff call, in which associated research is listed by.

If the system ignores rehoming policy of EMU, admission control target will only be real new call, no matter which homing policy of NMU is applied. This kind of admission control policy comprises of Policy 3 and Policy 4 in Figure 1, and associated policy approach (PA) researches are PA2 [8] and PA3 [7], respectively. On the other hand, we take EMU rehoming into account to granting as many users as it optimize system revenue. Handoff call must be differentiated from real new call. That is why this paper proposes PA1 to optimize the system revenue.

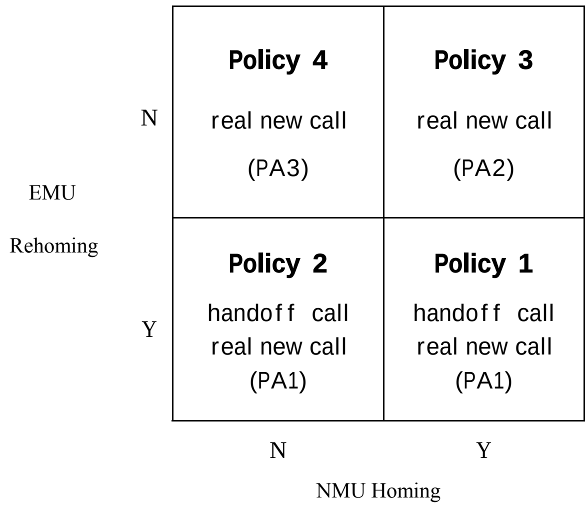


Figure 1 Framework of admission control policies

2.3 Interference Models

Since the capacity of CDMA systems is bounded on uplink interference incurred in base station, a key issue of capacity management depended upon how interference model is defined. Several interference models are expressed as follows.

1) Without EMU Rehoming: Previous researches [7] [8] use interference model (IM1) to manipulate admission control, in which δ_{jt} and z_{jt} are decision variables of existing and real new users, respectively. Without considering EMU rehoming, δ_{jt} always is assigned to 1, while z_{jt} is assigned according to admission control. The second and third term of denominator is intra-cell and inter-cell interferences, respectively. (IM1) is a generic model.

$$(\frac{E_b}{N_{total}})_{req} \le \frac{\frac{S}{N_0}}{1+\frac{1}{G}\alpha\frac{S}{N_0}\left(\sum_{t\in T'}\delta_{jt}+\sum_{t\in T''}z_{jt}-1\right)+\frac{1}{G}\alpha\frac{S}{N_0}\sum_{\substack{j'\in B\\ j'\neq j}}\left(\sum_{t\in T'}(\frac{D_{j't}}{D_{jt}})^{\tau}\delta_{j't}+\sum_{t\in T''}(\frac{D_{j't}}{D_{jt}})^{\tau}z_{j't}\right)} \quad \text{(IM1)}$$

2) With EMU Rehoming: In this case, we jointly consider rehoming of existing users and homing of real new users. For some reasons, existing users may be either rehomed to adjacent cell or forced terminated to granting more new users. Therefore, cost for rehoming existing users must be taken into account. Thus, only one decision variable z_{jt} is enough. The interference model is presented in (IM2).

$$(\frac{E_b}{N_{total}})_{req} \le \frac{\frac{S}{N_0}}{1+\frac{1}{G}\alpha\frac{S}{N_0}(\sum_{t\in T}z_{jt}-1)+\frac{1}{G}\alpha\frac{S}{N_0}\sum_{\substack{j'\in B\\ j'\neq j}}\sum_{t\in T}(\frac{D_{j't}}{D_{jt}})^{\tau}z_{j't}} \quad \text{(IM2)}$$

3) Multi-user Detection: Actually, a lot of researches have been proposed to reducing interference, for example, “multi-user detection” and ”smart antenna” is the usual technologies [3] [4]. Multi-user detection is capable of interference cancellation to mitigating the interference from the intracellular mobile users. To cope with the intercellular interference, advanced technique is smart antenna, for which sectorization is introduced. If multi-user detection is exerted, intra-cell interferences can be eliminated, a concise model is shown in (IM3).

$$(\frac{E_b}{N_{total}})_{req} \le \frac{\frac{S}{N_0}}{1+\frac{1}{G}\alpha\frac{S}{N_0}\sum_{\substack{j'\in B\\ j'\neq j}}\left(\frac{\frac{r_{j'}}{2}}{Max(D_{jj'}-\frac{r_{j'}}{2},\varpi)}\right)^{\tau}\hat{c}_{j'}} \qquad \text{(IM3)}$$

3. The Model of Revenue Optimization based on Uplink Admission Control

3.1 Problem Formulation

The revenue problem is formulated as a combinatorial optimization problem that the objective function is to maximize the total revenue by admitting new mobile users into the system, and the rehoming of existing users is considered as well. The optimization problem (IP) is expressed by revenue loss instead of revenue contribution. Notations used to modeling the problem are listed in Table 1.

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

subject to:

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

$$\sum_{t\in T} z_{jt} \le M_j \qquad \forall j\in B \; (2)$$

$$D_{jt} z_{jt} \le R_j \mu_{jt} \qquad \forall j\in B, t\in T \; (3)$$

$$z_{jt} \le \mu_{jt} \qquad \forall j\in B, t\in T \; (4)$$

$$\sum_{j\in B'} z_{jt} = 1 \qquad \forall t\in T'' \; (5)$$

$$\sum_{j\in B} z_{jt} = 1 \qquad \forall t\in T \; (6)$$

$$\frac{\sum_{t\in T'} f_t \sum_{j'\in B-\{b_t\}} z_{j't}}{\sum_{t\in T''} a_t \sum_{j\in B} z_{jt}} \le U \qquad (7)$$

$$z_{jt} = 0 \text{ or } 1 \qquad \forall j\in B,\; t\in T \; (8)$$

Constraint (1) is adopted from (IM2) to guarantee QoS. To be more generic, we do not consider the multi-user detection in this model. Capacity constraint is given in (2). Constraints (3) and (4) ensure that user can only be serviced in the coverage of base station. Constraint (5) requires new user can be homed to only one physical base station or rejected. For existing user, constraint (6), it always is admitted. Cost threshold of rehoming existing user is given in constraint (7). Constraint (8) assures the integer property of decision variable.

Table 1. Description of Notations.

Notation	Description
B	the set of candidate locations for base stations
b'	the artificial base station to carry the rejected call when admission control function decides to reject the call
B'	the set of $B\cup\{b'\}$
b_t	the controlling base station of mobile station t
T	the set of mobile stations
T'	the set of existing mobile stations
T''	the set of new mobile stations whose admittance into the cell is to be determined
G	the processing gain
S	the power that a base station received from a mobile station that is homed to the base station with perfect power control
E_b	the energy that BS received
N_{total}	total noise
N_0	the background noise
α	voice activity factor
τ	attenuation factor
U	the predefined threshold of the ratio of the handoff cost to the total revenue of admittance of new mobile terminal
D_{jt}	distance between base station j and mobile station t
M_j	upper bound on the number of users that can active at the same time in base station j
μ_{jt}	indicator function which is 1 if mobile station t can be served by base station j and 0 otherwise
a_t	the revenue from admitting mobile station $t\in T''$ into the system), where a_t =10.
R_j	upper bound of power transmission radius of base station j
f_t	handoff cost of mobile station t from currently assigned base station to another base station, where f_t =2;
z_{jt}	decision variable which is 1 if mobile station t is served by base station j and 0 otherwise

3.2 Solution Approach

The solution approach applied as previous researches [19] [20] is Lagrangean relaxation combined with subgradient. Based upon it, we relax constraints (1) (2) (3) (7), the primal optimization problem (IP) is transferred into the following Lagrangean relaxation problem $Z_D\left(v_j^1,v_j^2,v_{jt}^3,v^4\right)$ subject to (4) (5) (6) (8). Furthermore, only one subproblem that related to decision variable z_{jt} can be optimally solved is to be tackled[1]. According to the weak Lagrangean duality theorem, for any $v_j^1,v_j^2,v_{jt}^3,v^4\ge 0$, $Z_D\left(v_j^1,v_j^2,v_{jt}^3,v^4\right)$ is a lower bound on Z_{IP}. We then apply subgradient method [10] 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. Here we modify algorithm AA in [10], denoted algorithm *GPFS*

[1] Detailed procedure is omitted due to the length limitation of the paper. A complete version of the paper is available upon request.

(getting primal feasible solutions) for getting primal feasible solution in this paper.

[Algorithm *GPFS*]

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

Step 2. Make sure QoS constraint (1) is satisfied for each base station. Drop the new mobile user, i.e. set z_{jt} =0, if violates the constraint (1), 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 (1) as well as capacity constraint (2) 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 (1), (2), and (7) are all satisfied for each base station, or go to Step 5 otherwise.

4-2) admit new users which is still blocked into the system, i.e. set z_{jt}=1 again, if this setting satisfies constraint (1) and (2) for each base station, or go to Step 5 otherwise.

Step 5. End algorithm *GPFS*.

4. Computational Experiments

4.1 Environment

A few of input parameters used for problem (IP) is the same as in [9] [10]. However, we fix voice activity factor (α) with 0.3 under suggestion from previous researches. The number of base station ($|B|$) is given 16. In order to analyze how existing users affect new users on admission behavior, we consider three cases of existing mobile users (EMU= $|T'|$) with 50, 60 and 70. Concerning about the number of new mobile users (NMU), it is generated in Poisson arrival process with three cases, λ=100, 150, and 200, to see how traffic demands affect revenue contribution. For each λ case, 500 tests are experimented. More generically, all locations of base stations, existing as well as new mobile users are uniform distributed, even thought a few of number of new mobile ones generated in Poisson process may be the same. Experiments run on a PC with INTEL™ P4-1.6GHZ CPU and 256 MB RAM.

4.2 Output Measures and Analysis Results

1) Solution gap: We apply Lagrangean relaxation as our solution approach to solve complicated integer optimization problem. Inevitably, there exists solution gap between upper

Table 2. Statistics of Error Gaps+ in Percentage (%) based on 500 Tests with respect to λ, EMU, and PA.

λ		100			150			200		
Algorithm		PA1	PA2	PA3	PA1	PA2	PA3	PA1	PA2	PA3
W*	50	0.00	0.00	0.00	1.34	2.48	11.18	7.08	14.29	31.98
	60	0.00	0.00	0.00	1.86	4.26	16.49	8.37	16.96	38.64
	70	0.74	1.48	9.63	2.01	11.36	25.76	8.77	29.83	39.04
A*	50	0.00	0.00	0.00	0.01	0.02	0.08	0.30	0.88	3.24
	60	0.00	0.00	0.00	0.02	0.08	0.31	0.46	1.44	5.00
	70	0.00	0.00	0.02	0.03	0.15	0.63	0.70	2.34	7.65
B*	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

+ The exact error gap is less than 0.001%. For simplicity of expression, only two decimal places are reported.

* (W, A, B) denote cases of (worse, average, best), respectively.

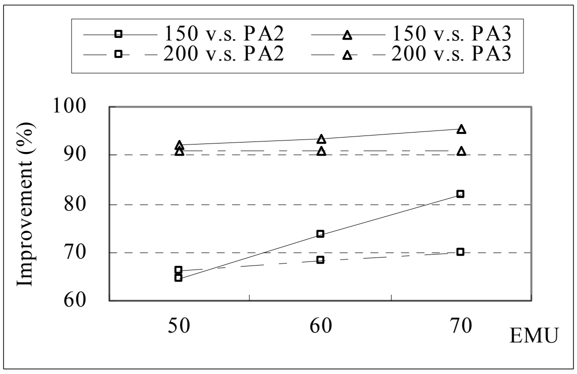


Figure 2. Solution gap improvement of PA1 in average case with respect to (λ v.s. PA) and EMU.

bound (UB, for primal solution) and lower bound (LB, for dual solution). The gap, defined by (UB-LB)/LB*100%, illustrates the optimality of problem solution. Table 2 summaries the statistics of solution gap on worse, average, and best cases of 500 tests with respective to λ, EMU, and PA (policy approach described in section 2.2). The admission control policy approach (PA1) proposed in this paper calculates with better solution optimality than PA2, PA3, it ranges from 0.00% to 2.34% in average case, while the worse case is up to 8.77%. To claim the superiority of PA1, analysis of improvement on previous two approaches PA2, PA3 is also depicted in Figure 2. The most improvement is 96% on the case of 150 vs. PA3 of EMU=70.

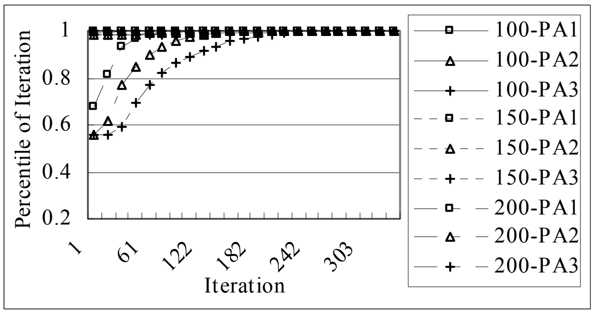
2) Number of iteration: Usually, both number of iteration and improvement count are pre-defined for Lagrangean relaxation approach. Accordingly, to see what extent of solution gap is converged, and how much the time is consumed. Conversely, in this paper, a time budget of 30 seconds is given, and then experiments iteratively solve the problem as many iterations as possible. The less iteration of experiment is calculated, the more efficient of algorithm is proved. Figure 3 illustrates the percentile of iteration calculated. No matter which λ and EMU are experimented, PA1 is with percentile 0.95 in less than 50 iterations. Number of iteration is increasing for both PA2 and PA3 when λ and EMU are increasing, and extent of the increasing of PA3 is more significant than of PA2. We also find that even though λ and EMU are increasing, iteration number of PA1 is small enough in stable state.

3) Service rate: Service rate is defined by ratio of total admitted users (both admitted new users and all existing users) to total users (including existing and new users) in the system. Table 3 summaries the statistics of service rate on worse, average, and best cases of 500 tests with respective to λ, EMU, and PA. Fortunately, there are all 1.0 service rates in best case. Thus, we further compare service rate in average and worse cases shown in Figure 4. For worse case, no matter which PA is applied, λ is a more significant impact factor than EMU. For PA3, service rate is decreased from 1.0 to 0.71, 1.0 to 0.67, and 0.94 to 0.57 for EMU=50, 60, and 70, respectively. Improvement analysis is also depicted in Figure 5. The more new user is loaded, the more service rate is improved.

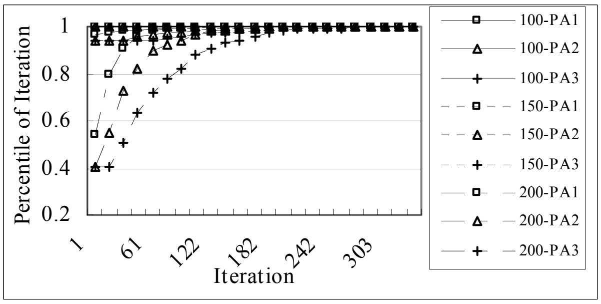
4) Revenue contribution: In order to analyze the managerial performance of admission control policy, revenue contribution is discussed instead of typical criteria such as call blocking probability, forced terminated probability, outage probability. Revenue aggregation is shown in Table 4. For the detailed comparison, we also list revenue improvements of PA1 on PA2 and PA3 with respect to λ, as shown in Figure 6. For the case of λ=200, the improvement is up to 8% on PA3 in EMU=70. It concludes that both the more new traffic is loaded and the more EMU exists, the more revenue is contributed. PA1 is calculated with distinguished results.

5. Conclusions

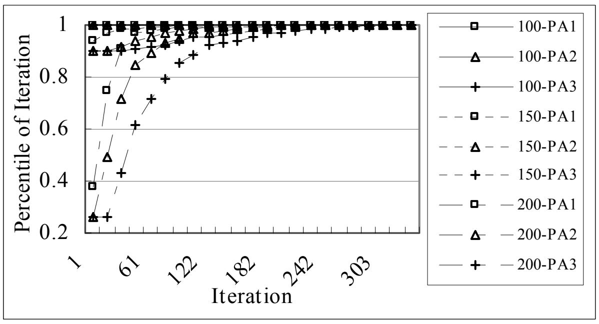
To increasing system capacity is an important issue for cellular CDMA systems. This paper proposes a revenue optimization model in terms of admission control policy to accommodate as many users as possible. We jointly consider both existing and new users, for them the admission control policies of rehoming and homing are taken into account, respectively. For simplicity of modeling revenue optimization problem, the model focuses on new users to be admitted into the system. Computational results show that the admission control policy proposed in this paper is with outstanding performance than approaches in previous researches. In this paper, the performance measure is iteration number instead of CPU time by pre-defining time budget. This hints that real-time admission control is considerable by Lagrangean relaxation approach. It will be taken into account in the future research.



(a) EMU = 50



(b) EMU = 60



(c) EMU = 70

Figure 3. Percentile of iteration calculated of (λ v.s. PA) subject to time budget (30 sec) with respect to EMU.

Table 3. Statistics of Service Rate based on 500 Tests with respect to λ, EMU, and PA.

λ		100			150			200		
Algorithm		PA1	PA2	PA3	PA1	PA2	PA3	PA1	PA2	PA3
W*	50	1.00	1.00	1.00	0.98	0.93	0.92	0.77	0.72	0.61
	60	1.00	1.00	1.00	0.97	0.92	0.85	0.72	0.69	0.67
	70	0.99	0.99	0.94	0.81	0.77	0.78	0.80	0.63	0.57
A*	50	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.96
	60	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.98	0.94
	70	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.97	0.92
B*	50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	60	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

* (W, A, B) denote cases of (worse, average, best), respectively.

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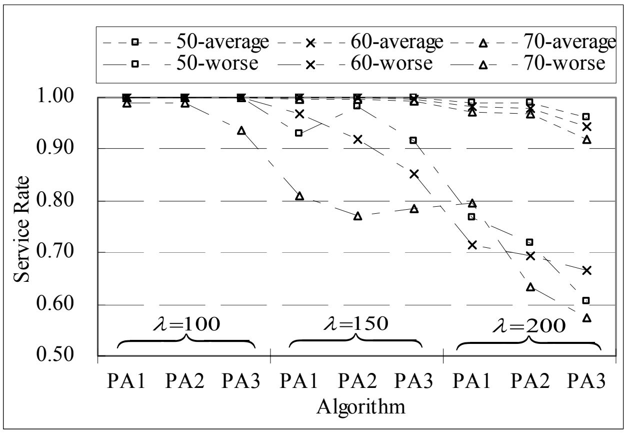


Figure 4. Comparison of service rate for both λ and PA with respect to (EMU v.s. average/worse) case.

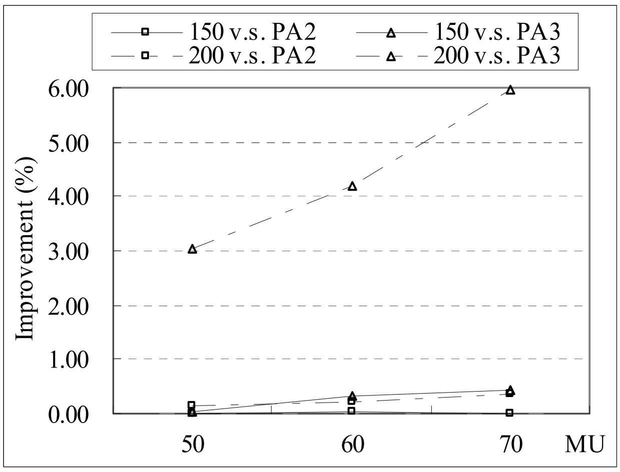
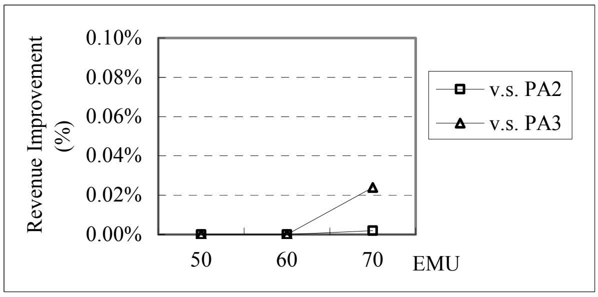


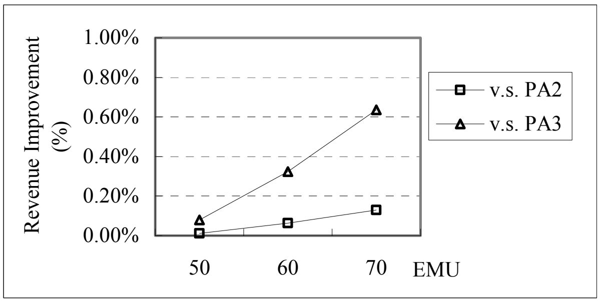
Figure 5. Service rate improvement of PA1 in average case with respect to (λ v.s. PA) and EMU.

Table 4. Revenue aggregation for three PA with respect to λ and EMU.

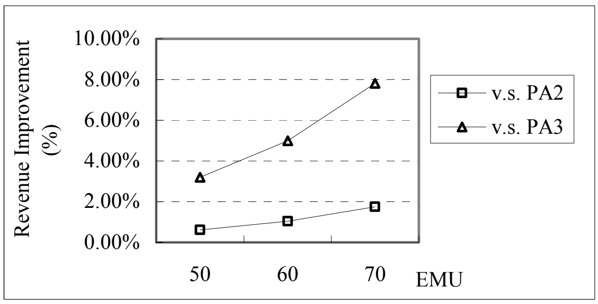
λ		100		
Algorithm		PA1	PA2	PA3
MU	50	502350	502350	502350
	60	502350	502350	502350
	70	502340	502330	502220
λ		150		
Algorithm		PA1	PA2	PA3
MU	50	749940	749850	749350
	60	749820	749350	747400
	70	749770	748800	745030
λ		200		
Algorithm		PA1	PA2	PA3
MU	50	999540	993400	968620
	60	997780	987510	950330
	70	995260	978190	923200



(a) λ = 100



(b) λ = 150



(c) λ = 200

Figure 6. Revenue improvement of PA1 on PA2 and PA3 for different λ with respect to EMU.