An Admission Control Algorithm for CDMA Networks

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Abstract - This paper proposes an admission control algorithm for CDMA networks, from which a revenue optimization problem is formulated as a mixed integer problem. The objective of the optimization problem is to maximizing total system revenue subject to capacity as well as QoS constraints. The approach for solving revenue optimization problem is Lagrangean relaxation in conjunction with a heuristic. The experiments consider total system revenue with respective to voice activity factor (VAF) and signal-to- interference (SIR) on 500 test cases which are within 9 base stations, 50 existing mobile stations, as well as 50 new mobile stations. 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.

Index Terms—admission control algorithm, CDMA networks, Lagrangean relaxation, mathematical formulation, optimization model

I. INTRODUCTION

CDMA (code division multiple access)-based broadband wireless communications networks provide a sound environment for forthcoming applications of mobile commerce. A key attribute of CDMA is that it is able to operate in single cell clusters as well as sectors while sectorization is introduced; each one uses the same carrier frequencies. Thus the system has a reuse of unity. From which, the core technique of CDMA is spread spectrum [15] [16] to accommodate more users as the system can provide. Generally, compared with FDMA (frequency division multiple access) and TDMA (time division multiple access), CDMA provides no upper limit of available channels. All of users share entire frequency spectrum instead of dividing frequency or time, therefore the system capacity is bounded by interferences. 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. Accordingly, capacity limit is depended upon the interference incurred at base station.

In CDMA systems, because of spectrum sharing, channel assignment by allocating transmission power results in interference on other mobile stations. 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) [8]. The less interference is incurred at base stations, the more capacity is provided in the system. A lot of researches have been proposed to enlarge the CDMA capacity, for example, "multi-user detection" and "smart antenna" is the usual technologies [6] [17]. Multi-user detection is capable of interference cancellation to mitigating the interference from the intracellular mobile stations [17]. To cope with the intercellular interference, advanced technique is smart antenna, for which sectorization is introduced [6] [17].

To effectively manage system capacity, call admission control (CAC) is another prevalent mechanism to allocating channel resources. The mechanism regulates the network operation with an optimal condition in such a way to promise the uninterrupted services for existing users, and meantime to accommodate as more new users' requests as possible. In the reverse-link, received signal-to-interference ratio (SIR) at the base station affects the connection quality. Thus, to preserve the whole system QoS, a number of interferences sources, including existing connections and other interferences propagated from cells, must be taken into account. Besides, mobility of new, handover, and outbound calls are should be effectively managed [18]. Most of previous researches discuss the call admission control of multimedia traffics [1] [12] [13].

In this paper, we focus on admission control to preserving whole system QoS, meanwhile, to accommodating as more users as possible. The more users are admitted, the more revenue is contributed. Previous works pay more attention to analysis of QoS in terms of different issues as follows: (1) consideration of how traffic types affect performance on delay [9] and capacity [10];(2) power control mechanism to enhance capacity [5][14] and reduce call blocking/forced termination [11]. Less research discusses revenue optimization in terms of admission control [7]; however the conclusion offers none of managerial implication or deeper experiments on solution quality.

This paper based upon previous research [7] not only proposes an admission control algorithm, but also intends to model a revenue optimization problem that highlights the managerial implication for system manipulation. We construct a mathematical model of the problem and proof the solution quality as well as revenue contribution with proposed admission control algorithm. A technique that has been prevalently applied for solving the complicated mathematical model, Lagrangean relaxation combined with subgradient- based method [2][3][4], is our solution approach.

The remainder of this paper is organized as follows. In Section II, a mathematical formulation of revenue optimization problem is proposed. Section III applies

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Lagrangean relaxation as a solution approach to the problem. For effectively solving the problem, we develop an admission control algorithm to accommodate as more users as possible. In Section IV, illustrates the computational experiments. Finally, Section V concludes this paper.

II. Problem Formulation

A. Problem Description

To evaluate system revenue in terms of optimization, problem formulation applies admission control mechanism to granting users. For simplicity of modeling and further experiments, we just focus on the new mobile stations in the problem to contribute total system revenue. Besides, in term of long-term call blocking analysis, a number of assumptions in this paper are given: (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. For the purpose of long-term revenue analysis, some complicated scenarios like re-homing, outbound, and handover calls are not dealt with. Also, the problem would not take account of mobility of both new and existing mobile stations. In other words, the new mobile stations in the model can either be homed to the controlling base station or blocked. Notations used to modeling the problem are listed in Table I.

B. Mathematical Formulation

According to the problem description in previous section, the revenue problem is formulated as a combinatorial optimization problem that the objective function is to maximize the total revenue by admitting new mobile stations into the system. Of course a number of constraints must be satisfied. Usually, a maximization problem is equivalent to minimization one by multiplying a minus sign in the equation. The following revenue maximization problem (IP) is also a revenue loss minimization problem.

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

subject to:

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

$$\sum_{t \in T'} \delta_{jt} + \sum_{t \in T''} z_{jt} \le M_j \qquad \forall j \in B \quad (2)$$

$$\sum_{j \in \{b', b_t\}} z_{jt} = 1 \qquad \forall t \in T'' \quad (3)$$

$$z_{jt} = 0 \text{ or } 1 \qquad \forall j \in B', \forall t \in T'' \quad (4)$$

$$\delta_{jt} = 0 \text{ or } 1 \qquad \forall j \in B, t \in T' \quad (5)$$

TABLE I
DESCRIPTION OF NOTATIONS

Notation	Description
B	the set of candidate locations for base stations
S	the power that a base station received from a mobile station that is homed to the base station with perfect power control
T	the set of mobile stations
E_b	the energy that BS received
N_{total}	total noise
α	voice activity factor
M_j	upper bound on the number of users that can active at the same time in base station j
τ	attenuation factor
D_{jt}	distance between base station j and mobile station t
$D_{jj'}$	distance between base station j and j'
N_0	the background noise
μ_{jt}	indicator function which is 1 if mobile station t can be served by base station j and 0 otherwise
G	the processing gain
a_t	the revenue from admitting mobile station $t \in T$ into the system
T'	the set of existing mobile stations
T''	the set of new mobile stations whose admittance into the cell is to be determined
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
R_j	upper bound of power transmission radius of base station j
r_j	transmission radius of base station j
δ_{jt}	indicator function which is 1 if mobile station t is homed to base station j and 0 otherwise
z_{jt}	decision variable which is 1 if mobile station t is served by base station j and 0 otherwise

The objective function is to minimize the total revenue loss in the process of admitting new mobile stations, where a_t is the average revenue each new mobile station contribute. Constraint (1) requires that every one mobile station is served with its homing base station in the required QoS. The left hand side of (1) is the threshold of acceptable SIR for each connection. The right hand side means the real SIR. The denominator of the right hand side is the total interference value, including white noise, the intra-cell interference as well as inter-cell interference. For simplicity, we do not consider the multi-user detection in this model. Constraint (2) is to ensure that the number of users who can be active at the same time in a base station would not exceed the base station's upper bound. Constraint (3) ensures that each mobile station can be homed to only one physical base station or rejected. Constraint (4) and (5) guarantee the integer property of decision variables and indicator functions.

III. Solution Approach

A. Lagrangean Relaxation

We apply Lagrangean relaxation combined with subgradient method as a solution approach, from which the lower bounds for minimization problems can be calculated by solving decision variables. Based on the decision variables it will hint us to getting primal solutions subject to related constraints [2] [3]. The entire procedure of Lagrangean relaxation method is as following: relax complicating constraints, multiply the relaxed constraints with corresponding Lagrangean multipliers, and add them to the primal objective function. Accordingly, the primal optimization problem can be transformed to the Lagrangean relaxation problem. Furthermore, decompose the Lagrangean relaxation problem into several independent subproblems that could be optimally solved. For the purpose of getting optimal solutions, we must iteratively adjust Lagrangean multipliers to optimally solve Lagrangean dual problem.

In this paper, we transform the primal optimization problem (IP) into the following Lagrangean relaxation problem (LR) where Constraints (1) (2) are relaxed.

$$\begin{aligned} &Z_D\left(v_j^1, v_j^2\right) = \\ &\min -\sum_{t\in T''} a_t \sum_{j\in B} z_{jt} \\ &+\sum_{j\in B} v_j^1 \left((\frac{E_b}{N_{total}})_{req} + (\frac{E_b}{N_{total}})_{req} \frac{1}{G}\alpha \frac{S}{N_0} \left(\begin{array}{c} \left(\sum_{t\in T'}\delta_{jt} + \sum_{t\in T''} z_{jt} - 1\right) \\ +\sum_{\substack{j'\in B\\ j'\neq j}} \left(\sum_{t\in T'} \left(\frac{D_{j't}}{D_{jt}}\right)^{\tau} \delta_{j't} + \sum_{t\in T''} \left(\frac{D_{j't}}{D_{jt}}\right)^{\tau} z_{j't} \right) \end{array} \right) - \frac{S}{N_0} \right) \\ &+\sum_{j\in B} v_j^2 \left(\sum_{t\in T'} \delta_{jt} + \sum_{t\in T''} z_{jt} - M_j \right) \end{aligned} \tag{LR}$$

Subject to: (3) (4) (5).

Here, we express (LR) into subproblem 1 related to decision variable z_{jt}.

Subproblem 1: for z_{jt}

$$\begin{aligned} &= \sum_{t\in T''} \left(\sum_{j\in B} z_{jt} \left(-a_t + (\frac{E_b}{N_{total}})_{req} \frac{1}{G}\alpha \frac{S}{N_0} \left(v_j^1 + \sum_{\substack{j'\in B\\ j'\neq j}} v_j^1 (\frac{D_{jt}}{D_{j't}})^{\tau} \right) + v_j^2 \right) \right) \\ &+ \sum_{t\in T'} \left(\sum_{j\in B} \delta_{jt} \left((\frac{E_b}{N_{total}})_{req} \frac{1}{G}\alpha \frac{S}{N_0} \left(v_j^1 + \sum_{\substack{j'\in B\\ j'\neq j}} v_j^1 (\frac{D_{jt}}{D_{j't}})^{\tau} \right) + v_j^2 \right) \right) \\ &+ \sum_{j\in B} \left(v_j^1 \left((\frac{E_b}{N_{total}})_{req} - \frac{S}{N_0} - (\frac{E_b}{N_{total}})_{req} \frac{1}{G}\alpha \frac{S}{N_0} \right) - v_j^2 M_j \right) \end{aligned} \tag{SUB}$$

subject to: (3) (4) (5).

In this paper, two kinds of users including existing and new mobile stations are taken care. We apply indication function δ_{jt} and decision variable z_{jt} to tracking existing and new mobile stations, respectively. From which, δ_{jt} just indicates the homing status of existing mobile stations since existing ones would not be blocked at all. No surprisingly, the second term of (SUB) is a constant. The third term is obvious also a constant. Finally, the first term of (SUB) is what we intend to treat it.

Let

$$p_{jt} = -a_t + (\frac{E_b}{N_{total}})_{req} \frac{1}{G}\alpha \frac{S}{N_0} \left(v_j^1 + \sum_{\substack{j'\in B\\ j'\neq j}} v_j^1 (\frac{D_{jt}}{D_{j't}})^{\tau} \right) + v_j^2$$

Then the first term can be decomposed into $|T''|$ subproblems for treatment of new mobile stations whether to be admitted or not in terms of revenue optimality. If p_{jt} is less than 0, assign z_{jt} to 1 or 0 otherwise.

According to the weak Lagrangean duality theorem [2], for any $(v_j^1, v_j^2) \geq 0$, the objective value of $Z_D(v_j^1, v_j^2)$ is a lower bound of Z_{IP}. Based on Problem (LR), the following dual problem (D) is constructed to calculate the tightest lower bound.

$$Z_D = \max Z_D(v_j^1, v_j^2) \tag{D}$$

subject to: $(v_j^1, v_j^2) \geq 0$.

Then, subgradient method [4] is applied to solving the dual problem. Let the vector S is a subgradient of $Z_D(v_j^1, v_j^2)$ at (v_j^1, v_j^2). 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 $t^k = \lambda\left(Z_{IP}^* - Z_D(\pi^k)\right) / \|S^k\|^2$, where Z_{IP}^* is an upper bound on the primal objective function value after iteration k, and λ is a constant where $0 \leq \lambda \leq 2$.

B. Getting Primal Feasible Solutions

After optimally solving the Lagrangean dual problem, we get a set of decision variables. However, this solution would not be a feasible one for primal problem since some of constraints are not satisfied. Thus, minor modification on decision variables must be taken to getting primal feasible solution of problem (IP). 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. So, the gap between UB and LB, computed by (UB-LB)/LB*100%, illustrates the optimality of problem solution. The smaller gap is computed, the better optimality is solved.

Here we propose a heuristic, denoted Heuristic *C*, shown in the following for getting primal feasible solution in this paper. There is only one decision variable, i.e. z_{jt} used in the problem solving to checking new mobile station.

[Heuristic *C*]

Step 1. Check capacity constraint (2) for each one base station. Drop the new mobile station, i.e. set z_{jt}=0, which is currently farthest one away from its homing base station, if violates the constraint, or go to Step 2 otherwise.

Step 2. Assure QoS constraint (1) in each base station. Block the new mobile station, i.e. again set z_{jt}=0, that is currently farthest one away from its homing base station, if violates the constraint, or go to Step 2 otherwise.

Step 3. End heuristic.

IV. Computational Experiments

A. Scenario

For experiments purpose, a few of constants used in the formulation are listed in Table II, and the number of base station ($|B|$), existing mobile stations ($|T'|$) are given to 9, and 50, respectively. Concerning about the number of new mobile stations, it is generated in Poisson arrival process with λ=50. A description about the Poisson distribution is as follows; (1) min = 28; (2) max = 74; (3) μ= 49.95; (4) median = 50; (5) mode = 51; (6) σ = 7.01; (7) σ^2 = 49.13; (8) range = 64; (9) skewness = -0.057; (10) kurtosis = 0.078. More generically, all locations of base stations, existing as well as new mobile stations are randomized, even thought a few of number of new mobile stations generated in Poisson process may be the same.

Besides, a combination of voice activity factor (VAF), i.e. α, and signal-to-interference ratio (SIR) is also applied to see how these parameters affect the total system revenue. For the convenience of comparison, we analyze the contribution of optimal revenue from three SIR values with respective to three VAF values.

B. Results analysis

The analysis comprises of results about optimality of proposed admission control algorithm solved with Lagrangean relation approach, and revenue contribution based on the algorithm.

1)Optimality of solution: Table III summaries the frequency statistics of error gaps in solving revenue optimization problem on 500 test cases of new mobile stations with Poisson arrival process (λ=50). The error gap

TABLE II
Given Parameter for Experiments

Notation	Value
S/N_0	7 db
Eb/N_{total}	6 db
M_j	120
τ	4
G	156.25
a_t	10

is defined by *(UB-LB)/LB*100%,* where UB and LB is an optimal solution of primal problem (IP) and dual one (D), respectively, in Lagrangean relaxation process. As we can see that the gap 0.00% is with number of range from 426 to 483 among nine experiments on 500 test cases, this implies proposed algorithm guarantees optimality from 85.2% to 96.6%. On the other hand, solutions also inevitably incur a few of gaps. For more information about these gaps, a comparison of worse and average case on the gaps is illustrated in Table IV. Proposed algorithm is with an average gap in range of 0.08% to 0.44%, while the worse case is up to 12.5%.

To claim the optimality, we also depict the percentile of gap in Fig. 1, in which Fig. 1(a), Fig. 1(b), Fig. 1(c) is with VAF=0.2, 0.3, 0.4, respectively. In case of VAF=0.2, as shown in Fig. 1(a), all of three SIR values bring on the gap less than 1.95% is with percentile 0.95, while in case of VAF=0.4, as shown in Fig. 1(c), if we tolerant the gap on 3.25%, 98% (0.98 percentile) of 500 test cases can be efficiently solved. No matter which value of SIR and VAF is combined, the gap less than 5.0% is with percentile 0.99. The other findings are as follows: (1) both case VAF=0.2 and VAF=0.3 has with a similar percentile; (2) there is a stable solution quality in case of SIR=3; (3) the solution quality of SIR=5 is varied much more than the other two SIR values in the range of percentile from 0.85 to 0.96 when the gap is 0.65%.

2) Revenue contribution: The revenue contribution is a managerial implication for system operation in terms of admission control policy. Thus, Fig. 2 also illustrates the analysis of experiment results on revenue optimization for Fig. 2(a), Fig. 2(b), Fig. 2(c) with VAF=0.2, 0.3, 0.4, respectively. Obviously, all of three results gain a similar revenue distribution on 500 test cases. In case of VAF=0.2, no matter what SIR value is applied, the revenue contribution is almost the same. Besides, SIR=3 is a very stable parameter assigned in experiments. Another interesting finding is that revenue contribution of SIR=4 and SIR=5 is similar, but behaves in different VAF values of 0.3 and 0.4.

V. Conclusions

No surprisingly, CDMA-based broadband wireless communications networks will provide services on ever-growing demands for mobile commerce and mobile computing. To ensure QoS, this paper proposes an admission

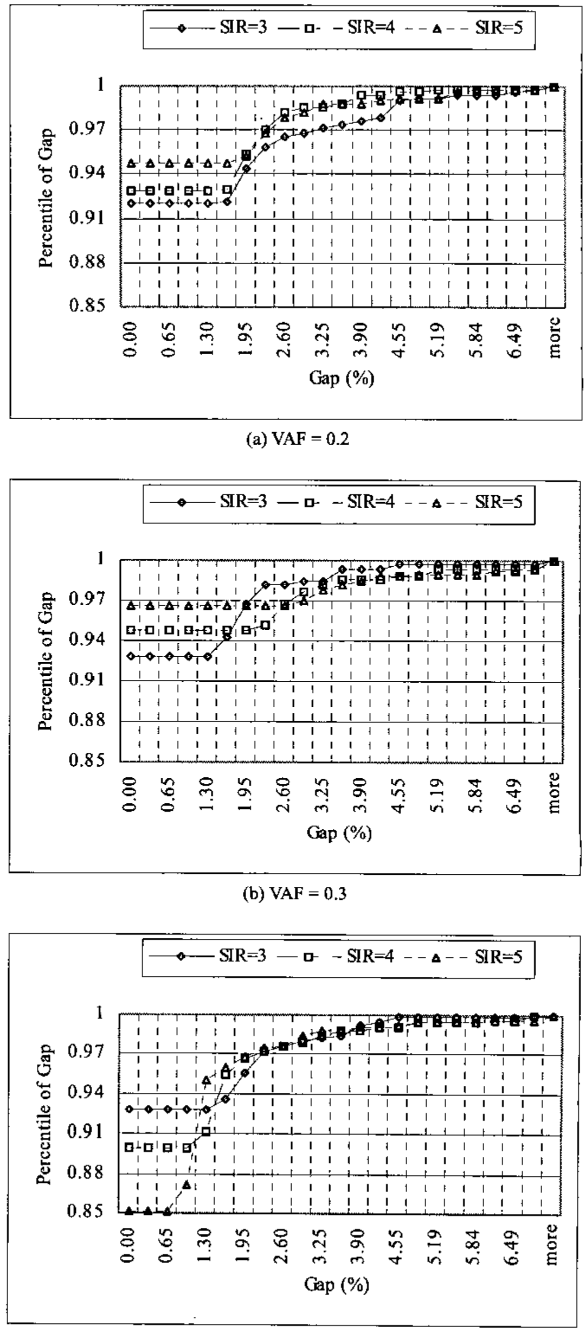
TABLE III
FREQUENCY STATISTICS OF ERROR GAPS IN SOLVING REVENUE OPTIMIZATION PROBLEM BY LAGRANGEAN RELAXATION APPROACH BASED ON 500 TEST CASES OF NEW USERS FROM POISSON ARRIVAL PROCESS (λ=50)

VAF		0.2			0.3			0.4		
SIR		3	4	5	3	4	5	3	4	5
Gap (%)	0.00	460	464	474	464	474	483	464	450	426
	0.32	0	0	0	0	0	0	0	0	0
	0.65	0	0	0	0	0	0	0	0	0
	0.97	0	0	0	0	0	0	0	0	10
	1.30	0	0	0	0	0	0	0	0	39
	1.62	1	1	0	7	0	0	4	6	5
	1.95	11	12	2	13	0	0	10	21	4
	2.27	7	8	8	7	2	0	8	6	3
	2.60	4	6	5	0	8	0	2	3	1
	2.92	1	2	2	1	4	2	2	2	4
	3.25	2	0	3	0	3	4	1	1	2
	3.57	1	1	0	5	2	2	1	3	0
	3.90	1	3	0	0	0	1	4	2	1
	4.22	1	0	1	0	0	2	1	0	0
	4.55	6	1	1	2	1	0	2	1	1
	4.87	1	0	0	0	0	1	0	0	1
	5.19	0	1	0	0	3	0	0	2	0
	5.52	1	0	2	0	0	0	0	0	0
	5.84	0	0	1	0	0	0	0	0	0
	6.17	0	0	0	0	0	1	0	0	1
	6.49	1	0	0	0	0	0	0	1	0
	6.82	1	0	0	0	0	1	0	0	0
	more	1	1	1	1	3	3	1	2	2

TABLE IV
WORSE AND AVERAGE CASE OF ERROR GAPS IN SOLVING REVENUE OPTIMIZATION PROBLEM BY LAGRANGEAN RELAXATION APPROACH BASED ON 500 TEST CASES OF NEW USERS FROM POISSON ARRIVAL PROCESS (λ=50)

VAF		0.2			0.3			0.4		
SIR		3	4	5	3	4	5	3	4	5
Gap (%)	Worse	7.14	6.98	6.06	7.90	5.56	4.00	7.84	7.69	12.5
	Average	0.25	0.18	0.13	0.19	0.14	0.08	0.20	0.27	0.44

control algorithm for CDMA networks. We take account of existing and new mobile stations, but focus on new ones to be admitted into the system. Be generic, location of including base stations and mobile stations are randomized generated, furthermore number of new mobile stations is modeled as Poisson arrival process on 500 test cases. For the purpose of managerial implication, the admission control algorithm is applied to modeling a revenue optimization problem in mathematical formulation. To solving this combinatorial optimization problem, a popular approach Lagrangean relaxation is used. The experiments consider total system revenue with respective to voice activity factor (VAF) and signal-to-interference (SIR). Computational results illustrate that no matter which value of VAF and SIR is combined, the solution quality of error gap less than 5.0% is with percentile 0.99. Besides, SIR=3 is with a stable solution quality as well as revenue contribution. In case of VAF=0.2, no matter what



(a) VAF = 0.2

(b) VAF = 0.3

(c) VAF = 0.4

Fig. 1. Percentile of error gap in solving revenue optimization problem by Lagrangean relaxation approach, that 500 test cases of new users are generated in Poisson arrival process (λ=50). The analysis is based on combination of two parameters SIR and VAF.

SIR value is applied, the revenue contribution is almost the same. In summary, the combination of VAF=0.2 and SIR=3 would be a near-optimal solution in experiments, and proposed algorithm has an average error gap in range of 0.08% to 0.44%, while the worse case is up to 12.5%.

In this paper, we do not take mobility into account for admission control. If so, related issues including re-homing and handover calls must be dealt with. Thus the new mobile stations could be further classified with handover calls and real new calls. To sustaining services for non-preemptive existing connections, assign the handover calls with higher priority than the real new calls would be a reasonable manner. They will be treated in the forthcoming works.

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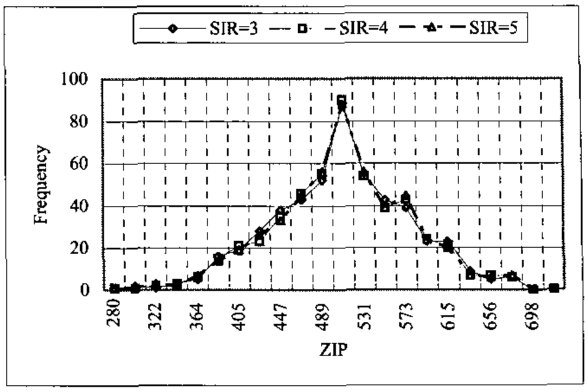
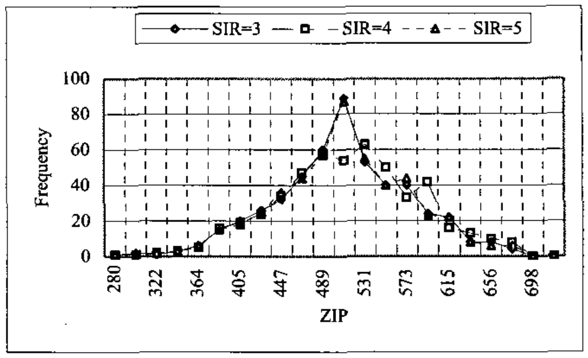
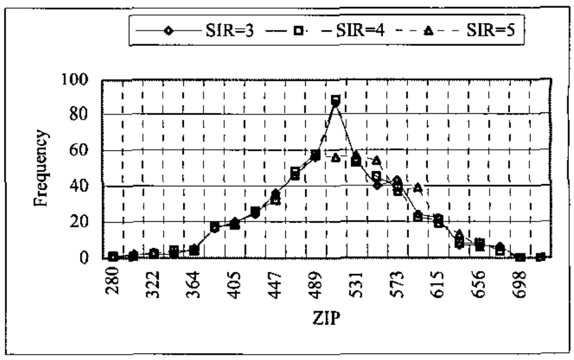


(a) VAF = 0.2



(b) VAF = 0.3



(c) VAF = 0.4

Fig. 2. Frequency as a function of optimal revenue of problem Z_{IP}, for which Z_{IP} is calculated by Lagrangean relaxation approach, that 500 test cases of new users are generated in Poisson arrival process (λ=50). The analysis is based on combination of two parameters SIR and voice activity factor VAF.