A Modified Model and Performance Analysis of Uplink Connection Admission Control for Cellular CDMA Networks

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Summary

This paper proposes a modified mathematical model for revenue management in terms of uplink admission control. The solution approach to the model is Lagrangean relaxation. Performance analysis is based on voice activity factor (VAF), where 9 base stations, 50 existing mobile users are given. In addition, new mobile users are generated in Poisson arrival process (λ=100) on 500 test cases. Computational results illustrate that no matter which value of VAF is given; the proposed primal algorithm outperforms other heuristics on solution optimality, blocking rate, as well as revenue contribution.

Key words:
Call admission control, CDMA, Lagrangean relaxation, mathematical formulation, Quality of service

1. Introduction

Theoretically, CDMA (code division multiple access) provides no upper limit of available channels, since all users share the entire frequency spectrum, instead of dividing frequency or time. However, as channel assignment based on the allocation of transmission power results in interference with other mobile users, the system's capacity is strictly limited by interference. The interference comprises of inter-cellular, intra-cellular interferences, and background noises. Inter-cellular interference comes from mobile users serviced by neighboring cells, while active mobile users in coverage generate intra-cellular interference. For example, in the uplink (reverse-link) connection, signal-to-interference ratio (SIR) received at a base station (BS) affects the connection quality. This kind of situation requires that interference which is incurred in a BS must be lower than a pre-defined threshold to guarantee communication quality of service (QoS) [1][2].

In terms of whole system QoS, a number of interference sources that include existing connections and other interference propagated from cells must be dealt with. In addition, mobility of new, handoff, and outbound calls should be effectively managed [3]. To manage system capacity, call admission control (CAC) plays an important role. The more users are admitted, the more revenue is contributed. The goal of uplink CAC is to prevent the system from being overloaded, and to provide uninterrupted services for existing users as well. More specifically, literature [2] [4] [5] point out that CDMA capacity is bounded on the uplink connection, and the received SIR at the BS affects the connection quality. This assumes the following conditions: (i) downlink (forward-link) is not considered; (ii) the uplink is perfectly separated from the downlink; (iii) perfect power control is assumed; and (iv) fading is not considered.

However, less research discusses revenue optimization in terms of admission control. Even though previous work [6] has been illustrated the revenue analysis, but no consideration of homing blocked mobile users into another BS. It would be a poor performance. This paper not only modifies the formulation in [6], but also proposes a solution algorithm with dropping and homing mechanisms to enhance total system revenue. In order to verify the performance of proposed algorithm, experiments that include solution quality, call blocking rate, and revenue analysis are presented.

The remainder of this paper is organized as follows. Literature review about CDMA admission control is given in Section 2. In Section 3, a modified mathematical model is proposed. We apply Lagrangean relaxation as solution approach, and a novel primal algorithm is also developed in Section 4. Section 5 illustrates the computational experiments and related analyses. Section 6 concludes this paper.

2. CDMA Admission Control

2.1 Call Admission Policies

In order to guarantee QoS, existing connections, new call requests, and other interferences propagated from adjacent

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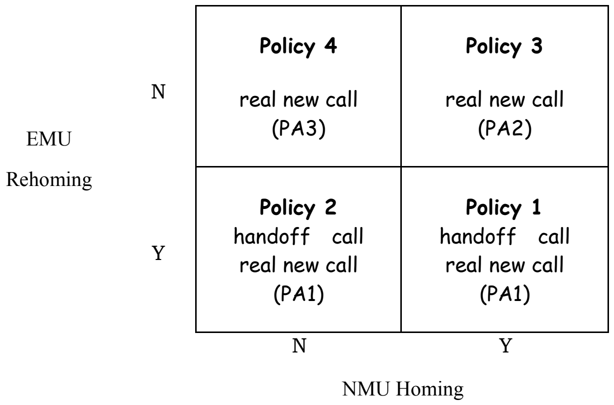
BSs must be taken into account. In addition, mobility (handoff) of new and existing call requests should be effectively managed. We summarize CAC as a user type, comprised of existing mobile users (EMUs) and new mobile users (NMUs) call requests, and call type, comprised of handoff and real new calls. For simplicity, we focus on the handoff of EMUs (re-homing policy) and call requests of NMUs (homing policy).

Fig. 1 illustrates the framework of CAC policies in terms of user type, including NMUs and EMUs [7]. NMUs can be homed into their controlling BS or otherwise blocked, while for EMUs they can be re-homed into an adjacent BS that has a light load in order to accommodate more users. Thus, there are two targets for CAC, namely, real new calls and handoff calls. If the system ignores the re-homing policy of EMU, the CAC will only target real new calls, irrespective of which homing policy of NMU is applied. This kind of CAC policy comprises policy 3 and policy 4. Associated policy approaches (PA) are PA2 and PA3. On the other hand, we consider EMU re-homing to accommodate as many users as possible in order to optimize system revenue. As handoff calls must be differentiated from real new calls, we propose PA1 to optimize system revenue.



EMU Rehoming	NMU Homing: N	NMU Homing: Y
N	**Policy 4** real new call (PA3)	**Policy 3** real new call (PA2)
Y	**Policy 2** handoff call real new call (PA1)	**Policy 1** handoff call real new call (PA1)

Fig. 1 Framework of admission control policies.

2.2 Interference Models

Since the capacity of CDMA systems is bounded by interference, a key issue of capacity management depends on how an interference model is defined. Several interference models are expressed as follows. Denote S as the power received at a BS from a mobile user that is homed to the BS with perfect power control, G as the processing gain, E_b as the bit energy that the BS receives, N_0 as the background noise, and N_{total} as the total noise. Three interference models are described below [7]. The SIR level in each of them should be higher than the pre-defined QoS threshold:

(i) Without EMU rehoming: Previous work [6] has used interference model (1) to manipulate CAC, in which δ_{jt} and z_{jt} are decision variables of EMUs and NMUs, respectively. Without considering EMU re-homing, δ_{jt} is always assigned to 1, while $z_{jt}=1$ if mobile user t is admitted, or 0 otherwise. The second and third terms of the denominator are the intra-cell and inter-cell interferences, respectively.

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

(ii) With EMU rehoming: In this case, we consider re-homing of EMUs and homing of NMUs jointly. For various reasons, EMUs may be either re-homed to an adjacent BS or forcibly terminated in order to grant access to more NMUs. Thus, the cost of re-homing EMUs must be taken into account. In the interference model presented in (2), one decision variable z_{jt} is sufficient.

$$(\frac{E_b}{N_{total}})_{req} \le \frac{\frac{S}{N_0}}{1+\frac{1}{G}\alpha\frac{S}{N_0}(\sum_{t\in T}z_{jt}-1)+\frac{1}{G}\alpha\frac{S}{N_0}\sum_{\substack{j'\in B\\ j'\neq j}}\sum_{t\in T}(\frac{D_{j't}}{D_{jt}})^{\tau}z_{j't}} \quad (2)$$

(iii) Multi-user detection: Although several approaches have been proposed to reduce interference, "multi-user detection" and "smart antenna" are the most popular technologies [4][5]. For example, multi-user detection can mitigate the effects of interference on intra-cellular users. If it is used, intra-cell interferences can be reduced. A concise model is shown in (3).

$$(\frac{E_b}{N_{total}})_{req} \le \frac{\frac{S}{N_0}}{1+\frac{1}{G}\alpha\frac{S}{N_0}\sum_{\substack{j'\in B\\ j'\neq j}}\left(\frac{\frac{r_{j'}}{2}}{Max(D_{jj'}-\frac{r_{j'}}{2},\varpi)}\right)^{\tau}\hat{c}_{j'}} \quad (3)$$

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

In early work [6], for simplicity of modeling admission control problem, only NMUs are considered. In addition, NMUs can either be homed to the controlling BS or blocked. However, to optimally contribute system revenue, the CAC mechanism that will home blocked mobile users to another BS is proposed. In this section, we modify the problem formulation in [6] to construct admission control model as problem (IP). Notations used for the modeling are described in Table 1.

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

subject to:

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

$$\forall j \in B \quad (4)$$

$$\sum_{t\in T'}\delta_{jt} + \sum_{t\in T''} z_{jt} \le M_j \qquad \forall j \in B \quad (5)$$

$$D_{jt} z_{jt} \le R_j \mu_{jt} \qquad \forall j \in B, \forall t \in T'' \quad (6)$$

$$z_{jt} \le \mu_{jt} \qquad \forall j \in B, \forall t \in T'' \quad (7)$$

$$\sum_{j\in\{b',b_t\}} z_{jt} = 1 \qquad \forall t \in T'' \quad (8)$$

$$z_{jt} = 0 \text{ or } 1 \qquad \forall j \in B', \forall t \in T'' \quad (9)$$

$$\delta_{jt} = 0 \text{ or } 1 \qquad \forall j \in B, \forall t \in T' \quad (10)$$

The objective function of revenue maximization problem (IP) is also a revenue loss minimization problem, where a_t is the mean revenue by each new user. Associated constraints are described as follows. Constraint (4) requires that every one mobile user is serviced by its homing BS with the required QoS. The left hand side of (4) is the threshold of acceptable SIR for each call connection. The right hand side means the real SIR. The denominator of the right hand side is the total interference value; they are white noise, the intra-cell interference, and inter-cell interference. Constraint (5) ensures that the number of mobile users who can be active at the same time in a BS would not exceed the BS's upper bound. Constraint (6) ensures that a BS can only serve the mobile users inside its coverage of effective transmission power radius, where R_j is an upper bound of power transmission radius of BS j. Constraint (7) guarantees that if a BS does not serve to a mobile user, and then the decision variable z_{jt} must be equal to 0. Constraint (8) ensures that each mobile user can be homed to only one physical BS or rejected. Constraint (9) and (10) guarantee the integer property of decision variables and indicator functions.

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
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
R_j	upper bound of power 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

4. Lagrangean Relaxation Approach

The solution approach applied to solving admission control problem is Lagrangean relaxation that is originally designed to solve large-scale linear as well as integer programming problems [8]. The modified revenue optimization problem (IP) is transformed into the following Lagrangean relaxation problem (LR) where Constraints (4), (5), and (6) are relaxed.

$$Z_D\left(v_j^1, v_j^2, v_{jt}^3\right) = \min - \sum_{t\in T''} a_t \sum_{j\in B} z_{jt}$$

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

$$+\sum_{j\in B} v_j^2 \left(\sum_{t\in T'} \delta_{jt} + \sum_{t\in T''} z_{jt} - M_j \right) + \sum_{t\in T''} \sum_{j\in B} v_{jt}^3 \left(D_{jt} z_{jt} - R_j \mu_{jt} \right) \tag{LR}$$

subject to: (7), (8), (9), and (10).

(LR) can further be decomposed into a subproblem that could be optimally solved with respect to decision variables. To get primal optimal solutions, we iteratively adjust Lagrangean multipliers by subgradient method to optimally solve Lagrangean dual problem. Here, we express (LR) into subproblem (SUB) related to decision variables z_{jt}.

Subproblem: for z_{jt}

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

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

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

subject to: (7), (8), (9), and (10).

In (SUB), indication function δ_{jt} and decision variable z_{jt} are used to track EMUs and NMUs, respectively. By which, δ_{jt} indicate the homing status of EMUs since they would not be blocked at all. The second and the third term of (SUB) are constant, because all variables in both terms are constant. Finally, the first term of (SUB) is what we intent to treat it. Let q_{jt} as follows, the first term of (SUB) can be decomposed into |*T"*| sub-problems, each of them decides NMUs to be admitted or not in terms of revenue optimization. If q_{jt} is less than 0, we assign z_{jt} to 1, or 0 otherwise.

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

According to the weak Lagrangean duality theorem, for any $(v_j^1, v_j^2, v_{jt}^3) \geq 0$, the objective value of $Z_D\left(v_j^1, v_j^2, v_{jt}^3\right)$ is a lower bound (LB) of Z_{IP}. Based on problem (LR), the following dual problem (D) is constructed to calculate the tightest lower bound.

$$Z_D = \max Z_D\left(v_j^1, v_j^2, v_{jt}^3\right) \tag{D}$$

subject to: $(v_j^1, v_j^2, v_{jt}^3) \geq 0$.

Then, subgradient method is applied to solving the dual problem. Let the vector S is a subgradient of $Z_D\left(v_j^1, v_j^2, v_{jt}^3\right)$ at (v_j^1, v_j^2, v_{jt}^3). In iteration k of subgradient optimization procedure, the multiplier vector π is updated by $\pi^{k+1} = \pi^k + t^k S^k$, where t^k is a step size determined by $t^k = \delta\left(Z_{IP}^* - Z_D(\pi^k)\right) / \|S^k\|^2$, where Z_{IP}^* is an upper bound (UB) on the objective function value after iteration k, and δ is a constant where $0 \leq \delta \leq 2$.

To get primal feasible solutions, based on decision variables solved in Lagrangean dual problem (D), we must adjust them for getting primal feasible solutions of problem (IP). Actually, the primal feasible solution is an UB of (IP), while the solution of Lagrangean dual problem guarantees the LB of (IP). Iteratively, both solving Lagrangean dual problem and getting primal feasible solutions, we get the LB and UB, respectively. The gap between UB and LB, expressed by (UB-LB)/LB*100%, illustrates the optimality of problem.

In order to develop a good primal algorithm, we define two mechanisms, namely call dropping and call homing, described as follows: 1) call dropping mechanism (*CDM*): No surprisingly, some of new users would be dropped due to capacity and QoS constraints. However, selection of dropped users has something to do with the homing mechanism. If system properly chooses a NMU to be dropped, then it can be homed (added back) into another BS (system) later. For each mobile user, the more number of users is covered by BSs, the more possibility that it can be homed into another BS in the homing stage. This implies total system revenue is enhanced. In this paper, we propose *CDM* with number it is covered by BSs (*CDM-NCBS*), from which the system will pick up the user in the descending number that it is covered by BSs; 2) call homing mechanism (*CHM*): the system tries to home each dropped NMU to another/candidate BS. Selection of candidate BS is also a key issue. Here we propose *CHM* with randomly selected candidates (*CHM-RSC*). Combining *CDM-NCBS* to *CHM-RSC*, an algorithm denoted primal algorithm *AA*, shown in the following is our solution for problem (IP).

[*Primal Algorithm AA*]

Step 1. Based on decision variables z_{jt} solved in Lagrangean dual problem (D), we check capacity constraint (5) for each BS $j \in B$. Drop a NMU, i.e. set z_{jt} =0 by *CDM-NCBS*, if violates the constraint (5), or go to Step 2 otherwise.

Step 2. Make sure QoS constraint (4) for each BS j is satisfied. Drop the NMU, i.e. set z_{jt} =0 by *CDM-NCBS*, if violates the constraint (4), or go to Step 3 otherwise.

Step 3. Try re-add back all NMUs dropped in Step 1 & 2 into the system.

3-1) sequentially picks up a dropped NMU.

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

Step 4. End primal algorithm AA.

5. Experiments

5.1 Other Primal Heuristics

As mentioned in previous section, selection of candidate BS is a key issue. For the purpose of comparison, other primal heuristic by another homing mechanism, denoted algorithm *AB*, is proposed that is *CHM* with rank of interference incurred at BS (*CHM -RII*). For *CHM-RII*, let SIR_j equals to the right side of constraint (4), based on SIR_j in terms of ascending interference load, a candidate is selected. Algorithm *AB* is following up *CDM-NCBS* with *CHM -RII*, the system will re-add dropped users into the candidate BS, i.e. set z_{jt}=1, if it does not violate constraints. Additional heuristic denoted *AC*, which is originally denoted A in [6], is also implemented for performance analysis.

5.2 Parameters

A few of parameters are used in the experiments. They include S/N_0, E_b/N_{total}, M_j, τ, G, and a_t are the same as in [6]. BS number ($|B|$), EMU number ($|T'|$) are given to 9 and 50, respectively. NMU number is generated in Poisson arrival process with λ=100. More generically, all locations of MS, EMU, and NMU are randomized, even thought a few of number of NMU generated in Poisson process may be the same. For the purpose of statistic analysis, 500 test cases with Poisson arrival are generated. Three algorithms, say *AA*, *AB*, *and AC*, conjunction with voice activity factor (VAF) are analyzed.

5.3 Performance Analysis

(i) Solution quality : Table 2 summaries a statistics of error gaps on best and average cases for three algorithms. Because the problem is with a strong integrality property, no matter which algorithm applied, the more traffic is penetrated in the system (heavy VAF), the loose gaps the solutions are incurred. Even though the proposed algorithm *AA* calculates average gap up to 14.57%, it still is a best solution among three algorithms in all four VAF cases.

(ii) Blocking rate : Based on the solution the total call blocking rate is also analyzed. The rate is defined by ratio of blocked users (NMUs only) to total users (including EMUs and NMUs) in the system. Fig. 2 illustrates the experiment results on blocking rate with respect to four VAF values. Inevitably, the bigger VAF is applied, the more blocking rate is incurred. The proposed algorithm *AA* outperforms other algorithms.

Table 2: Summary of error gaps percentage (%) for three algorithms based on 500 test cases of NMUs with Poisson arrival process (λ=100) with respect to VAF.

VAF	0.3			0.325		
Algorithm	AA	AB	AC	AA	AB	AC
Best	0.00	0.00	0.00	0.00	0.00	0.00
Average	1.60	1.65	2.12	4.27	4.43	5.48
VAF	0.35			0.375		
Algorithm	AA	AB	AC	AA	AB	AC
Best	0.00	0.00	0.00	0.00	0.00	0.00
Average	8.50	8.78	10.52	14.57	14.98	17.59

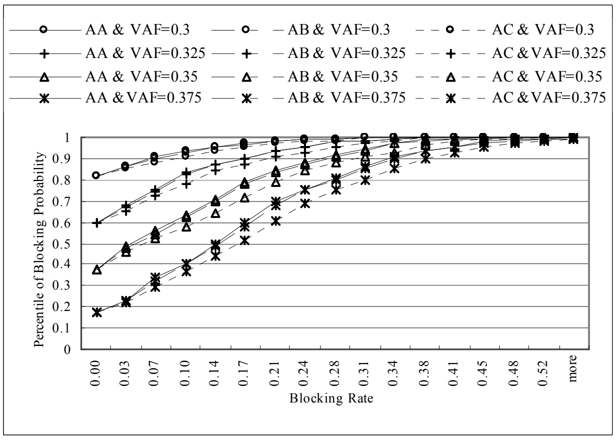


Fig. 2 Percentile of blocking rate for three algorithms based on 500 test cases of NMUs with Poisson arrival process (λ=100) with respect to VAF.

Table 3: Revenue aggregation and improvement on 500 test cases of new mobile users with Poisson arrival process (λ=100) with respect to VAF.

VAF	0.3		
Algorithm	AA	AB	AC
Revenue Aggregation	490960	490680	488270
Improvement on AC	0.55 %	0.49 %	N/A
VAF	0.325		
Algorithm	AA	AB	AC
Aggregate Revenue	476370	475560	470220
Improvement on AC	1.31 %	1.14 %	N/A
VAF	0.35		
Algorithm	AA	AB	AC
Aggregate Revenue	453580	452170	443640
Improvement on AC	2.24 %	1.92 %	N/A
VAF	0.375		
Algorithm	AA	AB	AC
Aggregate Revenue	421780	419830	407080
Improvement on AC	3.61 %	3.13 %	N/A

(iii) Revenue analysis: Table 3 summaries the aggregate revenue of the problem (IP) on 500 test cases. In addition, improvement on algorithm *AC* is also shown. The proposed algorithm *AA* always contributes better revenue. This result is consistent with our assumption that *CHM* is an important issue for revenue optimization in terms of admission control. Another interesting finding is that the revenue improvement is monotonically increasing from 0.55% to 3.60% and from 0.49% to 3.13% for algorithm *AA* and *AB*, respectively, when VAF is increasing from 0.3 to 0.375. Especially, the more VAF is applied, the more improvement is calculated.

6. Conclusion

This paper analyzes the performance of three admission control algorithms for CDMA networks. First of all, a modified admission control problem is formulated as a mathematical revenue optimization problem and solution algorithm is proposed. The algorithm is based on call dropping mechanism (*CDM*) and call homing mechanism (*CHM*). We propose the algorithm AA that integrates CDM with number it is covered by BSs (*CDM-NCBS*) and CHM with randomly selected candidate (*CHM-RSC*) to handle mobile users. To investigate the effectiveness of the proposed algorithm, other primal heuristics are implemented. Three algorithms are jointly considered. The analysis includes solution quality, call blocking rate, and total system revenue with respective to voice activity factor (VAF). Computational results illustrate that no matter which value of VAF is given; proposed algorithm *AA* always outperforms others on solution optimality, blocking rate, as well as revenue contribution.

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