An Admission Control Algorithm Considering Revenue Optimization 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 maximize total system revenue subject to system 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 respect 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 error gap less than 5.0% is with percentile 0.99. Proposed algorithm is calculated with near-optimal solution.

1 Introduction

CDMA (code division multiple access) – based broadband wireless communication networks provide a sound environment for forthcoming applications of mobile commerce. A key attribute of CDMA is that it can operate in single cell/sector clusters; each cell/sector uses the same carrier frequencies, i.e., reuse of unity [1][2]. Generally, compared with FDMA and TDMA, CDMA provides no upper limit of available channels. As all users share the entire frequency spectrum, instead of divided frequency or time, the system's capacity is bounded by interference, which may comprise inter-cellular and intra-cellular interference, and background noise.

In CDMA systems, because of spectrum sharing, channel assignment by allocating transmission power results in interference on other mobile stations. Inter-cellular interference comes from mobile stations/users (the two terms are mutually substituted hereafter) served by neighboring cells, while mobile stations in the coverage of their homing cells generate intra-cellular interference. This kind of situation requires that the interferences base station incurred must be lower than pre-defined acceptable interference threshold to ensure communication quality of service (QoS) [3]. The capacity limit depends on the interference incurred in each cell. 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” are the usual technologies. Multi-user detection is capable of interference cancellation to mitigate the interference from the intra-cellular mobile stations [4]. To cope with the inter-cellular interference, advanced technique is smart antenna, for which sectorization is introduced [5].

To effectively manage system capacity, call admission control (CAC) is another prevalent mechanism to allocate channel resources. CAC, also called connection admission control, is used in networks to administer QoS. 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 [6]. In the reverse-link, received 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. In CDMA systems, multi-access interference is a function of the number of users and is a limiting factor in ensuring QoS. The CAC mechanism relies on the “soft capacity” of the CDMA networks, as determined by the level of multi-access interference, and is often characterized by the signal-to-interference ratio (SIR). Generally speaking, the usual measures of CAC are call blocking and call dropping. Blocking means a new user is denied access to the system, while dropping means an existing user call is forcibly terminated in the handoff process.

In this paper, we focus on admission control to preserve whole system QoS, meanwhile, to accommodate as more users as possible. The more users are admitted, the more revenue is earned. 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 [7] and system capacity [8]; (2) power control mechanism to enhance capacity [9][10] and reduce call blocking/forced termination [11]. With the best of our knowledge, little research discusses revenue optimization in terms of admission control. This paper not only proposes an admission control algorithm, but also intends to model a revenue optimization problem. A mathematical model of the problem is constructed, and the solution quality of proposed algorithm and revenue contribution are analyzed. We apply Lagrangean relaxation as solution approach that combined with subgradient- based method [12].

The remainder of this paper is organized as follows. In Section 2, a mathematical formulation of revenue optimization problem is proposed. Section 3 applies 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 4, illustrates the computational experiments. Finally, Section 5 concludes this paper.

2 Problem Formulation

2.1 Problem Description

To evaluate the system revenue, the problem that is modeled as an optimization problem is to grant call requests or not. CAC prevents the system from being overloaded, and to provide uninterrupted services for existing users as well. This assumes the following conditions: (1) perfect power control; (2) the uplink is perfectly separated from the downlink; (3) fading is not considered; and (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. For simplicity of modeling and further experiments, we just focus on the new mobile stations in the problem to contribute total system revenue. Notations used to modeling the problem are listed in Table 1.

2.2 Mathematical Formulation

The revenue analysis is formulated as a combinatorial optimization problem that the objective function is to maximize the total revenue by admitting new users into the system, and a number of constraints must be satisfied. The following revenue maximization problem (IP) is also a revenue loss minimization problem, where a_t is the average revenue each new user contribute. Usually, a maximization problem is equivalent to minimization one by multiplying a minus sign in the equation.

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

subject to:

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

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

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

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

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

Table 1. 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 (VAF)
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 $\mathrm{B} \cup \{\mathrm{b'}\}$
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 meanings of associated constraints are described as follows. 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 that includes white noise, the intra-cell interference, and inter-cell interference. For simplicity, we do not consider the multi-user detection in this model. Constraint (2) ensures that the number of users who are active at the same time in a base station would not exceed the upper bound of capacity M_j. Constraint (3) ensures that each mobile station can be homed to only one physical base station or rejected. Constraints (4) and (5) guarantee the integer property of decision variables and indicator functions.

3 Solution Approach

3.1 Lagrangean Relaxation

Lagrangean relaxation (LR) is a general solution approach for solving mathematical optimization problems, and is used to decompose such problems to exploit their special structure. LR has a number of significant advantages [12]. The entire procedure of the LR method is as follows: relax complicating constraints, multiply the relaxed constraints by the corresponding Lagrangean multipliers, and then add them to the primal objective function. Accordingly, the primal optimization problem can be transformed into an LR problem that can be decomposed into several independent sub-problems. Furthermore, each sub-problem can be optimally solved by proposed algorithm. To obtain optimal solutions, we must iteratively adjust Lagrangean multipliers to optimally solve the 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.

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

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

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

Subproblem : for z_{jt}

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

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

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

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

In this paper, two kinds of users that include existing and new mobile stations are taken care. We apply indication function δ_{jt} and decision variable z_{jt} to track existing and new mobile stations, respectively. From which, δ_{jt} just indicates the homing status of existing mobile stations because of existing ones would not be blocked at all. Irrelevant to the decision variable, the second term and the third term of (SUB) are constant values which can be pre-calculated. Thus, the first term of (SUB) is what we intend to treat it. Define p_{jt} as following equation,

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

Then the first term of (SUB) can be decomposed into |*T"*| sub-problems that decide new mobile stations to be admitted or not in terms of revenue optimality. If p_{jt} is less than 0, we assign z_{jt} to 1, and 0 otherwise. According to the weak Lagrangean duality theorem, 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.

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

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

Subgradient method is then applied to solve 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 $\pi^{k+1}=\pi^k+t^kS^k$, 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 $0\leq\lambda\leq 2$.

3.2 Getting Primal Feasible Solution

After optimally solving the Lagrangean dual problem, we get a set of decision variables. However, this solution would not be feasible for primal problem because 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 the UB and the 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 *A*, shown in the following to 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 *A*]

Step 1. Check capacity constraint (2) for each one base station j. Drop the new user call requests, 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 j. Block the new call requests, 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.

4 Computational Experiments

4.1 Scenario

For experiments purpose, a few of constants used in the formulation are given as follows: they are S/N_0= 7 db, Eb/N_{total} =6 db, M_j =120, τ=4, G =156.25, a_t =10. 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; and (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 VAF, i.e. α, and 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 respect to three VAF values.

4.2 Results Analysis

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

Optimality of solution. The frequency statistic of error gaps is based on 500 test cases of new mobile stations with Poisson arrival process (λ =50). The error gap is defined by (UB-LB)/LB*100%, where UB and LB is an optimal solution of primal problem (IP) and dual one (D), respectively. We 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 2. Proposed algorithm is with an average gap in range of 0.08% to 0.44%, while the worse case is up to 12.5%.

Table 2. Worse and average cases of error gap in solving revenue optimization problem by Lagrangean relaxation approach based on 500 test cases of new users with 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

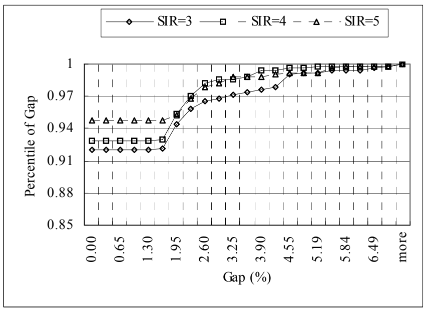
To claim the optimality, we also depict the percentile of gaps in Fig. 1, in which Fig. 1(a), Fig. 1(b), Fig. 1(c) is with VAF=0.2, 0.3, 0.4, respectively. In case of VAF=0.2, as shown in Fig. 1(a), all of three SIR values bring on the gap less than 1.95% is with percentile 0.95, while in case of VAF=0.4, 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%.

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 in 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 given, 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.

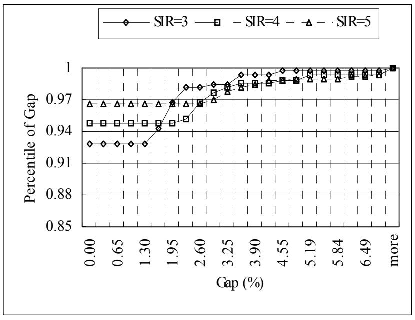
5 Conclusion

CDMA-based broadband wireless communications networks provide services on ever-growing demands for mobile commerce and mobile computing. To ensure QoS, this paper proposes an admission 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, and locations of both base stations and mobile stations are randomly generated. Number of new mobile stations is modeled as Poisson arrival process on 500 test cases. Proposed admission control algorithm is applied to maximize the system revenue.. The experiments consider total system revenue with respect to VAF and SIR. Computational results illustrate that no matter which value of VAF and SIR is combined, the 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 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%.

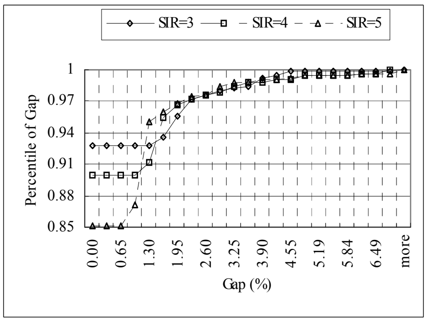
In this paper, we do not take mobility into account for admission control. If so, related issues including re-homing and handover calls must be dealt with. Thus the new mobile stations could be further classified with handover calls and real new calls. To sustaining services for non-preemptive existing 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.



(a) VAF = 0.2

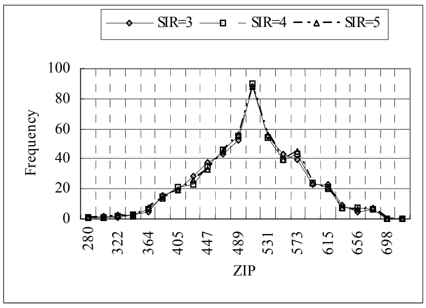


(b) VAF = 0.3

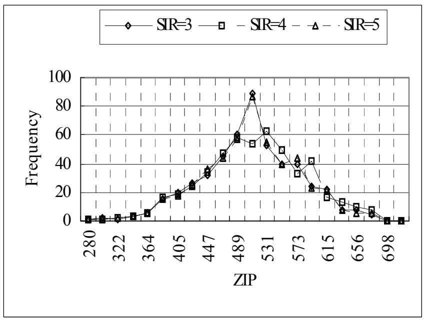


(c) VAF = 0.4

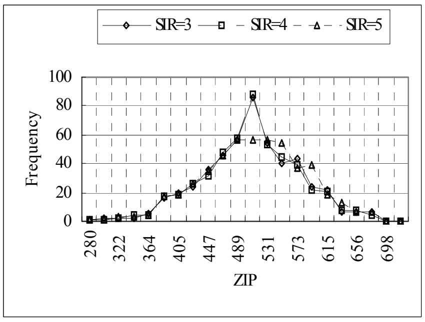
Fig. 1. Percentile of error gap in solving revenue optimization problem by Lagrangean relaxation approach, that 500 test cases of new users are generated in Poisson arrival process (λ =50). The analysis is based on combination of two parameters SIR and VAF



(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 VAF

References

[1] F. Adachi, M. Sawahashi, and H. Suda, "Wideband DS-CDMA for next-generation mobile communications systems," *IEEE Communications Magazine*, vol. 36, no. 9, pp. 56-69, Sept. 1998.

[2] M. Frodigh, S. Parkvall, C. Roobol, P. Johansson, and P. Larsson, "Future-generation wireless networks," *IEEE Personal Communications*, vol. 8, no. 5, pp. 10-17, Oct. 2001.

[3] K. Kim and Y. Han, "A call admission control with thresholds for multi-rate traffic in CDMA systems," in *Proc. IEEE 51st VTC-Spring*, pp. 830–834, vol. 2, Tokyo, Japan, 2000.

[4] D. Dahlhaus and Z. Cheng," Smart antenna concepts with interference cancellation for joint demodulation in the WCDMA UTRA uplink", *Spread Spectrum Techniques and Applications*, vol. 1, pp. 244-248, 2000.

[5] M.A. Hernandez, G.J.M. Janssen, and R. Prasad,"Uplink performance enhancement for WCDMA systems through adaptive antenna and multi-user detection," in Proc. IEEE 51st VTC-Spring, vol. 1, pp. 571-575, Tokyo, Japan , 2000.

[6] N. Dimitriou, G. Sfikas, and R. Tafazolli, "Call admission policies for UMTS," in *Proc. IEEE 51st VTC-Spring*, vol. 2, pp. 1420-1424, Tokyo, Japan , 2000.

[7] K. S. Park and D. H. Cho, "An advanced channel access scheme for integrated multimedia services with various bit rates in CDMA networks," *IEEE Communications Letters*, vol. 3, pp. 91–93, April 1999.

[8] S. K. Kwon, H. G. Jeon, and H. Lee, "A Channel Assignment Scheme for Integrated Services in DS-CDMA Cellular Systems," in *Proc. IEEE 6th ICUPC*, vol. 2, pp. 642 – 645, San Diego, California, 1997.

[9] S. M. Shin and D. K. Sung, "DS-CDMA Reverse Link Channel Assignment Based on Interference Measurements," *Electronics Letters*, vol. 31, pp. 1897-1899, Oct. 1995.

[10] S. M. Shin, C. -H. Cho, and D. K. Sung, "Interference-based Channel Assignment for DS-CDMA Cellular Systems," *IEEE Trans. Veh. Technol.*, vol. 48, pp. 233-239, Jan. 1999.

[11] D. M. Lee, D. C. Son, and H. S. Seong, "Queuing Priority Channel Assignment Scheme for Handoff in CDMA Cellular System," in *Proc. IEEE 1st ICICS*, pp. 1766-1770, Singapore, 1997.

[12] M. L. Fisher, "The Lagrangian relaxation method for solving integer programming problems", *Management Science*, vol. 27, pp. 1-18, 1981.

Biography

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