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불균형 멀티미디어 트래픽을 갖는 CDMA/TDD 이동통신시스템을 위한 최적 타임슬롯/채널 운용체계*

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Optimal Time Slot and Channel Allocation for CDMA/TDD Systems with Unbalanced Multimedia Traffic*

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■ Abstract ■

Traffic unbalance between uplink and downlink is one of the most notable characteristics in the next generation cellular mobile systems which provide multimedia services such as voice and video telephony, high-speed Internet access, and mobile computing, etc. The CDMA/TDD system with unbalanced slot allocation between two links is a good solution for the traffic unbalance. In this paper, we formulate the time slot and channel allocation problem for the CDMA/TDD systems in general multicell environments, which is to maximize the system capacity under the given traffic unbalance, and solve that problem by simulated annealing technique. Computational experiments show that the proposed scheme yields a good performance.

Keyword : CDMA/TDD System, Time Slot Allocation, Simulated Annealing

1. Introduction

The code division multiple access (CDMA) is becoming a promising radio access technology for current and future mobile communications networks. In the current CDMA systems [1, 2],

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frequency division duplex (FDD) is used between uplink (mobile to base) and downlink (base to mobile), and both links are assigned an equal bandwidth, respectively. While the main service target of the current CDMA systems is the voice communications, the next generation networks will provide multimedia services including voice and video telephony and wireless Internet access.

In the future mobile multimedia communications environments, the traffic volume on the uplink may differ from that on the downlink. For example, let us consider Internet access, electronic newspaper, or mobile computing [11]. Since the mobile station tends to become a small and light one, the information database and the computing power for multimedia services would be located at the network side rather than at the mobile station. Thus, in the above-mentioned applications, short commands (typically, several tens of bytes) are transmitted via uplink, whereas relatively large multimedia files (typically, several tens or hundreds of kilobytes) are transmitted via downlink. In this case, the downlink requires more capacity than the uplink.

Since the current CDMA/FDD systems allocate the same bandwidth to both links, the traffic unbalance will result in the waste of bandwidth and the overall system capacity [6, 7]. For example, if the uplink traffic volume is 20% of downlink one under full load condition, 80% of uplink bandwidth (and, eventually, 40% of the overall system bandwidth) is wasted. To overcome this problem, the downlink bandwidth should be larger than the uplink. Moreover, the network operators should be able to easily establish the different bandwidths since the traffic unbalance varies from area to area and from time to time. Introducing time division duplex (TDD) makes more flexible bandwidth allocation between two links [10].

In the previous researches [3, 4, 8], power control issues and complexity reduction aspects in CDMA/TDD systems have been discussed, where uplink and downlink are assumed to have an equal number of time slots. The idea of assigning different numbers of CDMA/TDD time slots to two links is proposed in [6] for the two-cell model with unbalanced traffic. In this paper, we refine the asymmetric time slot allocation problem in the aspects of maximizing the system capacity. And we formulate the problem in general multicell environments where the traffic unbalance exists, and solve that problem by the simulated annealing technique. Computational experiments show that the proposed scheme yields a good performance.

The remainder of this paper is organized as follows. The next section provides interference analysis that describes the inherent constraints in CDMA/TDD systems. In section 3, we define the time slot and channel allocation problem as an integer programming problem. Simulated annealing is considered to obtain an approximate solution of the problem in section 4. Some results of computational experiments are discussed in section 5, and the paper is concluded in section 6.

2. System Analysis

Assume that there are N_d downlink slots and N_u uplink slots in a TDD frame ($N = N_d + N_u$). And assume that each channel supports one call, and the channels are evenly distributed over slots in each cell. We also assume that perfect power control is achieved in each cell. Since traffic demand in each cell is equally distributed for each time slot, we just consider a typical time slot for uplink and downlink, respectively.

First, we consider the case that a slot is assigned for downlink in all cells. Let P_t^i denote the transmission power of a base i for a channel. Then the received signal power at a mobile is $kd^{-v}P_t^i$ where d is distance between base and mobile and k and v are constants respectively, and the bit energy-to-noise density ratio in cell i during a downlink slot, $(E_b/N_o)_i^d$, is as follows :

$$\left(\frac{E_b}{N_o}\right)_i^d = \frac{kd^{-v}P_t^i}{\left(\left(\frac{M_i}{N_d}-1\right)kd^{-v}P_t^i + \sum_{j\neq i}\frac{M_j}{N_d}\delta_{ij}^d kd^{-v}P_t^i\right)\frac{NR_i^d}{W}}, \tag{1}$$

where W is the given spreading bandwidth, and M_i is the number of channels allocated to cell i, and R_i^d is the transmission rate for downlink in cell i, and δ_{ij}^d is the ratio of the interference from downlink slot of cell j to that from downlink slot of cell i. Note that the first term of the denominator means the home-cell interference and the second term does the interference coming from other cells. And note that we ignored the background noise.

In general, the transmission power of a base for a channel is proportional to its data rate [6, 7]. In this case,

$$P_t^i / P_t^j = R_i^d / R_j^d. \tag{2}$$

Substituting (2) to (1), we have

$$\left(\frac{E_b}{N_o}\right)_i^d = \frac{wN_d}{(M_i - N_d)NR_i^d + \sum_{j\neq i} M_j \delta_{ij}^d NR_j^d}.$$

Now, we consider the case that a slot is assigned for uplink in all cells. Let C be the received signal power at base from the farthest mobile. Then, the bit energy-to-noise density ratio in cell i during a uplink slot, $(E_b/N_o)_i^u$, is as follows :

$$\left(\frac{E_b}{N_o}\right)_i^u = \frac{C}{\left(\left(\frac{M_i}{N_u}-1\right)C + \sum_{j\neq i}\frac{M_j}{N_u}\delta_{ij}^u C\right)\frac{NR_i^u}{W}}$$

$$= \frac{WN_u}{\left((M_i - N_u) + \sum_{j\neq i} M_j \delta_{ij}^u\right)NR_i^u},$$

where R_i^u is the transmission rate for uplink in cell i, and δ_{ij}^u is the ratio of the interference from uplink slot of cell j to that from uplink slot of cell i. Note that the first term of the denominator means the home-cell interference and the second term does the interference coming from other cells. And note that we ignored the background noise.

3. Time Slot and Channel Allocation Problem

The capacity of a cellular system is usually defined by the number of simultaneous active users in a cell, who can enjoy an acceptable level of transmission quality. However, the number of users can be a meaningful measure only when all users generate the same characteristics of traffic. Unfortunately, this is not the case under multimedia environments. Thus, we take the aggregated data rate (ADR) as a measure for capacity estimation. The ADR for the whole system is calculated as $\sum_i M_i(R_i^d + R_i^u)$.

For adequate transmission quality, the following inequalities should be satisfied.

$$\left(\frac{E_b}{N_o}\right)_i^d \geq \gamma_i^d, \forall i, \tag{3}$$

and

$$\left(\frac{E_b}{N_o}\right)_i^u \geq \gamma_i^u, \forall i, \tag{4}$$

where γ_i^d and γ_i^u are the required bit energy-to-noise density ratio for downlink traffic and uplink traffic, respectively, of cell i. The inequalities (3) and (4) are converted into the following inequalities.

$$\sum_j \frac{\delta_{ij}^d}{\alpha_i} \frac{R_j^d}{R_i^d} M_j \leq N_d, \forall i, \tag{5}$$

and

$$\sum_j \frac{\delta_{ij}^u}{\beta_i} M_j \leq N_u, \forall i, \tag{6}$$

where $\alpha_i = 1 + \frac{W}{\gamma_i^d R_i^d N}$ and $\beta_i = 1 + \frac{W}{\gamma_i^u R_i^u N}$.

Now, the time slot and channel allocation problem is mathematically formulated as follows :

(TSP)

$$\begin{aligned}
&\text{Max } \sum_i M_i (R_i^d + R_i^u) \\
&\quad s.t. \quad (5) \text{ and } (6) \\
&\qquad N_d + N_u = N \\
&\qquad M_i \geq N_d, \forall i \\
&\qquad M_i \geq N_u, \forall i \\
&\qquad N_d; N_u; M_i, \forall i: \text{ positive integers.}
\end{aligned}$$

Note that the problem TSP with fixed N_d and N_u is a multiconstraint integer knapsack problem, which is combinatorial in nature.

4. Simulated Annealing

Simulated annealing is a general approach to obtain an approximate solution of combinatorial optimization problems. It has been applied in such diverse areas as computer aided design of integrated circuits, code design, etc. [5, 9].

Generally, a combinatorial optimization problem consists of a solution set Z and a cost function C which determines the cost $C(z)$ for each $z \in Z$. Simulated annealing can be considered as a generalization of the iterative improvement scheme (local search). For performing a local search one needs to know the neighbors z' of z.

For local search, starting from an arbitrary solution z, in each step of iterative improvement a neighbor z' of z is proposed at random. The solution z is replaced by z' only if cost does not rise, i.e., $C(z') \leq C(z)$. Obviously, this procedure terminates in a local minimum, i.e., in a solution whose neighbors do not offer any improvement in cost. Unfortunately, such a local minimum may have a substantially higher cost than the global one. To avoid this trapping in poor local optima, simulated annealing occasionally allows solutions of higher cost according to an acceptance rule. We use the acceptance rule used in the literature [5, 9], in which the probability of accepting a move to a neighbor producing a variation in the cost function is given by the following function :

$$\begin{cases} e^{-(C(z') - C(z))/T} & \text{if } C(z') - C(z) > 0 \\ 1 & \text{if } C(z') - C(z) \leq 0 \end{cases}$$

Parameter T called temperature is initially set to a relatively large value so that the transition from z to z' occurs more frequently, and then it is gradually decreased as the search proceeds. When T becomes sufficiently small and the solution does not change for many iterations, it is concluded to be *frozen*, and the best solution available by then is output as the computed approximate solution.

Simulated Annealing Algorithm

Step 0 : Set a feasible solution $z^0 \in Z$, an initial temperature T_0, $0 < \gamma < 1$, L, $\varepsilon > 0$, and $k = l = 0$.

Step 1 : Generate a solution z' from z^l. If $(C(z') - C(z^l)) \leq 0$, then set $z^{l+1} = z'$, otherwise, set $z^{l+1} = z'$ with probability $q(= e^{-(C(z') - C(z^l))/T_k})$. and set $z^{l+1} = z^l$ with probability $1 - q$.

Step 2 : If $l \geq L$, then go to Step 3, otherwise, go to Step 1 with replacing $l+1$ to l.

Step 3 : If $T_k \leq \varepsilon$, then terminate, otherwise set $T_{k+1} = \gamma T_k$ and go to Step 1 with replacing $k+1$ to k.

In the algorithm, $z = (M, N_d, N_u)$ and $C(z) = -\sum_i M_i(R_i^d + R_i^u)$. In Step 0, the initial solution $z^0 = (M^0, N_d^0, N_u^0)$ is set at a solution of the problem TSP where all M_i's are equal. In Step 2, if it is concluded that a sufficient number of trials have been made with the current T_k (i.e., in *equilibrium*), then the temperature T_k is updated. In Step 3. if the current T_k is concluded to be sufficiently small (i.e., *frozen*), then the algorithm terminates with the current best feasible solution. In Step 1, given a solution z^l, a next solution z' is generated by the following procedure :

Step 0 : Set $S_1 = \{all\ cells\}$. Compute $\varDelta_i =$

$$\frac{R_i^d + R_i^u}{\sum_j \frac{\delta_{ij}^d}{\alpha_i} \frac{R_j^d}{R_i^d} / N_d^l + \sum_j \frac{\delta_{ij}^u}{\beta_i} / N_u^l}.$$

Step 1 : Set $z' = z^l$ and $S_2 = \{all\ cells\} - \{k \mid M_k' = N_d' \text{ or } M_k' = N_u'\}$. If the set S_1 is empty, then go to Substep 2.1.

Substep 1.1 : Select a cell $i^+ \in S_1$ in proportion to $\varDelta_i / \sum_i \varDelta_i$. Set $M_{i^+}' = M_{i^+}' + 1$ and $S_1 = S_1 - \{i^+\}$. If z' is a feasible solution, then terminate.

Substep 1.2 : If $N_u' > 1$ and $(M', N_d' + 1, N_u' - 1)$ is a feasible solution, or if $N_d' > 1$ and $(M', N_d' - 1, N_u' + 1)$ is a feasible solution, then terminate.

Step 2 : Set $S_2 = S_2 - \{i^+\} - \{k \mid \delta_{i^+k}^d = 0 \text{ and } \delta_{i^+k}^u = 0\}$

Substep 2.1 : If the set S_2 is empty, then go to Step 1. Select a cell $i^- \in S_2$ in proportion to $(1/\varDelta_i)/(\sum_i 1/\varDelta_i)$. Set $M_{i^-}' = M_{i^-}' - 1$ and $S_2 = S_2 - \{i^-\}$. If z' is a feasible solution, then terminate.

Substep 2.2 : If $N_u' > 1$ and $(M', N_d' + 1, N_u' - 1)$ is a feasible solution, or if $N_d' > 1$ and $(M', N_d' - 1, N_u' + 1)$ is a feasible solution, then terminate, otherwise go to Substep 2.1.

5. Computational Experiments

We consider a 7×7 regular hexagonal cellular mobile system. Input parameters are assigned values that are often used in earlier CDMA researches [6, 10]. In the tests, $\gamma^{d_i}=\gamma^{u_i}=5$ (dB), $W=10$ (MHz), $N=16$ (slots), and $\delta^{d}_{ij}=\delta^{u}_{ij}=0.05$ (between adjacent cells), 0.01 (between cells in the same cluster) or 0 (elsewhere). In the simulated annealing algorithm, we use $T_0=10$, $\gamma=0.5$, $\varepsilon=10^{-10}$, and $L=100$.

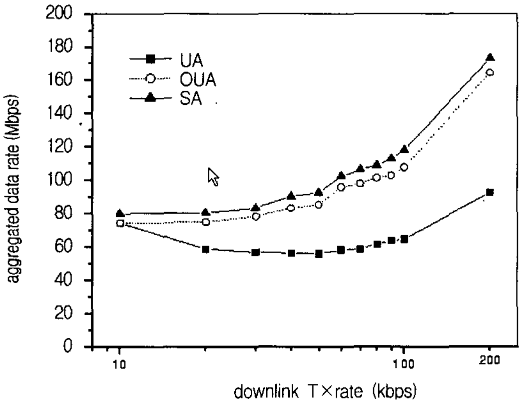
The test results are summarized in [Figure 1]~[Figure 3] and <Table 1>. The transmission rate for uplink is uniformly distributed around p% ($p=0$, 20, 40) of 10 kbps, and the transmission rate for downlink is uniformly distributed around p% of the values (10~200 kbps) in X-axes of [Figure 1]~[Figure 3]. In [Figure 1]~[Figure 3], $p=0$, 20, 40, respectively. In the figures, UA, OUA, and SA mean the uniform allocation strategy, the optimized uniform allocation strategy, and the proposed strategy using simulated annealing technique, respectively. In UA, $N_d=N_u=8$, and the channels are uniformly allocated through the whole cells. The strategy OUA, which is reported as a reference, uses the same time slot allocation given by SA but uniformly assigns the channels through the whole cells. The figures show that SA achieves significant improvements in terms of ADR compared to UA, and the performance gap between the strategy UA and other two strategies SA and OUA increases as the transmission rate for downlink increases. The figures also show that the performance gap between SA and OUA increases as the value of p increases (i.e., as the variance among

<Table 1> Results for the nonuniform channel allocation, an example

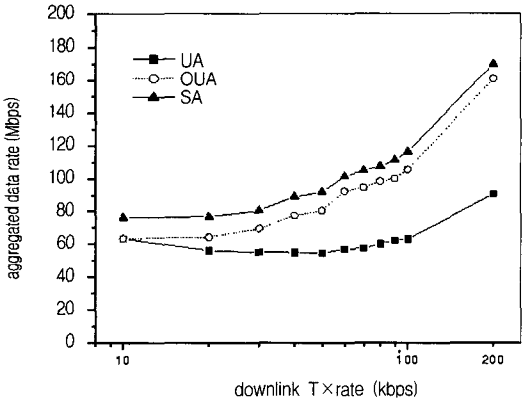
cell(i)	R^u_i	R^d_i	M_i	cell(i)	R^u_i	R^d_i	M_i
1	6.03	60.84	30	26	8.67	83.60	22
2	6.33	105.15	23	27	9.24	88.41	22
3	10.84	96.08	23	28	9.87	96.64	24
4	8.12	129.50	21	29	13.60	116.03	21
5	10.65	90.14	24	30	9.41	77.55	22
6	9.28	60.13	28	31	11.37	69.71	22
7	11.89	132.43	23	32	6.02	109.87	20
8	6.27	86.81	25	33	7.92	92.69	21
9	12.52	73.21	23	34	7.58	75.37	23
10	10.80	112.93	20	35	8.03	107.76	23
11	9.38	74.38	22	36	9.55	81.98	24
12	8.24	108.28	21	37	12.72	136.21	19
13	6.59	65.58	25	38	9.93	97.99	21
14	10.25	96.90	24	39	8.15	122.98	20
15	7.74	88.46	23	40	6.43	93.12	21
16	12.11	114.24	20	41	7.99	76.93	23
17	11.76	103.93	20	42	11.61	69.17	26
18	7.31	115.58	20	43	11.59	68.72	30
19	12.44	73.65	22	44	12.49	133.86	21
20	13.80	80.34	21	45	8.76	105.14	22
21	7.04	62.82	28	46	9.09	96.88	22
22	7.57	102.96	22	47	13.87	99.53	22
23	13.68	126.21	20	48	13.11	120.65	21
24	9.25	69.12	22	49	13.09	111.94	23
25	11.16	103.06	20		$N_d=13$	$N_u=3$	

cells in the transmission rate increases). There is a trade-off between system performance and system complexity. That is, compared to OUA, SA increases system performance and also increases system complexity. However, the increase in system performance is sufficiently large while the increase in system complexity is slight and sufficiently tolerable. <Table 1> shows the results obtained by SA. Here, the basic uplink and downlink traffic rates are 10 kbps and 100 kbps, respectively, and the value of p is 40. The table shows that SA allocates the channels differently between cells according to the traffic condition.

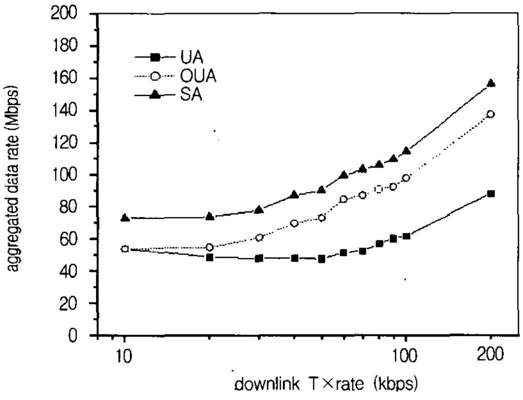
Finally, in order to analyze the solution quality and computational complexity of simulated annealing technique, we solved the problem *TSP* using a commercial solver. When the transmission rates for downlink and uplink are uniformly distributed around 40% of 10 kbps, the solver finds an optimal solution in about 43 million iterations and about 23 hours on an IBM PC. For this problem, during about 30 thousand iterations, SA finds a near optimal solution whose objective value is about 99.9999137% of the optimal objective value. Meanwhile, as th number of cells and the number of channels available increase, commercial solver will require much more iterations and runtime. These results show that simulated annealing technique is a promising tool for solving the problem *TSP*. That is, simulated annealing technique obtains a near optimal solution and requires much less iterations and runtime, compared to commercial solver. This is very important because in the CDMA/TDD system, the numbers of downlink and uplink slots and the number of channels allocated to each cell are periodically (per several tens of seconds or several hundreds of seconds) updated according to traffic conditions.



[Figure 1] Test results for p=0



[Figure 2] Test results for p=20



[Figure 3] Test results for p=40

6. Conclusions

In this paper, we formulate the time slot and channel allocation problem for the CDMA/TDD systems in general multicell environments, which is to maximize the system capacity under the given traffic unbalance, and solve that problem by simulated annealing technique. Computational experiments show that the final allocation obtained from the proposed strategy (SA) achieves significant improvements in terms of ADR compared to the ordinary uniform allocation (UA), and the performance gap between SA and the optimized uniform allocation (OUA) increases as the variance among cells in the transmission rate increases. Computational experiments also show that the proposed strategy SA is a promising tool for solving the proposed time slot and channel allocation problem. However, this does not guarantee that the strategy SA is the best tool. Thus a further research to develop another heuristic algorithms and perform a comparative analysis is required.

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