멀티셀 CDMA/TDD 시스템의 용량 분석
Capacity of Multicell CDMA/TDD Systems

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Abstract

The CDMA system with time division duplex mode (CDMA/TDD system) is a highly attractive solution to support the next generation cellular mobile systems providing multimedia services where the traffic unbalance between downlink and uplink exists. In this paper, the capacity of the CDMA/TDD system is analyzed in general multicell environments. For this analysis, the interference for a time slot is analyzed, and a time slot and channel allocation problem is mathematically formulated and solved using simulated annealing technique. Computational experiments provide a promising result.

1. Introduction

The code division multiple access (CDMA) is becoming a promising radio access technology for current and future mobile communications systems. While the main service target of the current CDMA systems is the voice communications, the next generation systems will provide multimedia services including voice and video telephony and wireless Internet access. IMT-2000 (International Mobile Telecommunications-2000) is one of the most important examples for such a system [3,15].

The CDMA proposals for IMT-2000 are grouped into the following three categories : DS-CDMA (direct sequence CDMA) with FDD (frequency division duplex) mode, MC-CDMA (multicarrier CDMA) with FDD mode, and DS-CDMA with TDD (time division duplex) mode [1]. Among these, DS-CDMA with TDD mode (CDMA/TDD system) has become highly attractive one to support multimedia services.

One of the most important merits of the CDMA/TDD systems over the CDMA/FDD systems is the flexibility in resource allocation. 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 [14]. 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 are transmitted via uplink, whereas relatively large multimedia files 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. 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 TDD makes more flexible bandwidth allocation between two links [13].

Many researches [1,2,5,6,8,10-13] about the CDMA/TDD systems have been performed. However, those researches assume that uplink and downlink have an equal number of time slots, and consider one-cell and two-cell models. In this paper, the capacity of the CDMA/TDD system, where the time slot allocation between two links is asymmetric, is analyzed in general multicell environments. For this analysis, the interference for a time slot is analyzed, and a time slot and channel allocation problem is mathematically formulated and solved using the simulated annealing technique. Computational experiments provide a promising result.

2. Interference Analysis

Let N denote total number of slots in a TDD frame, and let N_d and N_u respectively denote the numbers of downlink slots and uplink slots in a TDD frame ($N=N_d+N_u$). And let M_i denote the number of channels in cell i, and let R_i^d and R_i^u respectively denote the data rates of downlink and uplink in cell i. We 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.

2.1 Downlink Slot

In this subsection, we consider the case that a slot is assigned for downlink in all cells. Let P_t^i denote the transmission power of base for a channel in cell i, and let x be the distance between base and a mobile z in cell i. Then the received signal power at the mobile z is $kx^{-\upsilon}P_t^i$ where k and υ are constants respectively, and the bit energy-to-noise density ratio of the mobile z in cell i during a downlink slot, $\left(\frac{E_b}{N_o}\right)_i^d$, is as follows:

$$\left(\frac{E_b}{N_o}\right)_i^d \tag{1}$$
$$=\frac{kx^{-\upsilon}P_t^i}{\left(\left(\frac{M_i}{N_d}-1\right)kx^{-\upsilon}P_t^i+\sum_{j\in A_i}\frac{M_j}{N_d}kl_{zj}^{-\upsilon}P_t^j\right)\frac{NR_i^d}{W}},$$

where W is the given spreading bandwidth, and A_i denotes the set of adjacent cells of cell i, and l_{zj} is the distance between the mobile z of cell i and the base of cell j. Note that the first term of the denominator means the home-cell interference and the second term does the interference coming from adjacent cells. And note that we ignore the background noise and the interference coming from other cells except adjacent cells.

To simplify and generalize the analysis on the bit energy-to-noise density ratio in cell i, we assume that the transmission power of base of each adjacent cell is equal, and the number of channels allocated to each adjacent cell is equal, and the propagation path-loss slope υ is 4 since υ is equal to about 4 in mobile radio environments [7]. Then the equation (1) is simplified as follows:

$$\left(\frac{E_b}{N_o}\right)_i^d \tag{2}$$
$$=\frac{1}{\left(\left(\frac{M_i}{N_d}-1\right)+\frac{\overline{M}}{N_d}\frac{\overline{P_t}}{P_t^i}\sum_{j\in A_i}x^4l_{zj}^{-4}\right)\frac{NR_i^d}{W}},$$

where $\overline{M}=M_j$ and $\overline{P_t}=P_t^j$ for all $j\in A_i$.

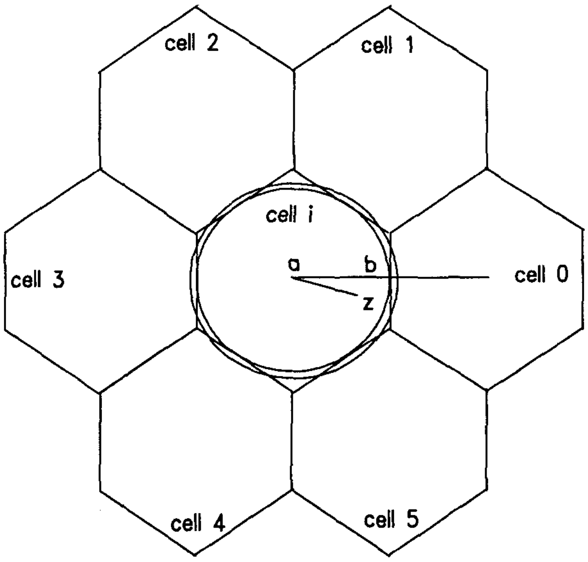

Figure 1: Multicell interference for downlink slot

We assume that the mobiles covered by cell i are located within the circle with radius r ($d\le r\le\sqrt{\frac{2\sqrt{3}}{\pi}}d$) where d is the radius of the inner circle in Figure 1, and the mobiles are located within this circle according to uniform distribution. When $r=\sqrt{\frac{2\sqrt{3}}{\pi}}d$, the area of the corresponding circle is equal to that of a hexagon. The location of the mobile z can be represented by polar coordinates (x,θ), where θ is the angle $\angle baz$. Note that $0\le\theta\le 2\pi$ and $0\le x\le r$. Since the location of base of cell j can be represented by polar coordinates $(2d, j*\pi/3)$,

$$l_{zj}=\sqrt{4d^2+x^2-4xd\cos(\theta+j*\pi/3)},$$
$$\text{for } j=0,\cdots,5.$$

Therefore,

$$\sum_{j\in A_i}x^4l_{zj}^{-4} \tag{3}$$
$$=\sum_{j=0}^{5}\frac{x^4}{(4d^2+x^2-4xd\cos(\theta+j*\pi/3))^2}.$$

Since the probability that the location of a mobile is (x,θ) is $\frac{x}{\pi r^2}$ by the assumption of uniform distribution, the expected value of (3) is 0.284148 when $r=d$ and 0.379782 when $r=\sqrt{\frac{2\sqrt{3}}{\pi}}d$. Meanwhile, the equation (3) is maximized at the location $(x,\theta)=(r,0)$, and the maximum value is 1.275384 when $r=d$ and 1.823881 when $r=\sqrt{\frac{2\sqrt{3}}{\pi}}d$. At this location, the equation (2) is minimized. This is the worst-case.

Now, using these results, the bit energy-to-noise density ratio during a downlink slot in cell i, $\left(\frac{E_b}{N_o}\right)_i^d$, is defined by

$$\left(\frac{E_b}{N_o}\right)_i^d = \frac{1}{\left(\left(\frac{M_i}{N_d}-1\right)+\sum_{j\in A_i}\delta^d\frac{M_j}{N_d}\frac{P_t^j}{P_t^i}\right)\frac{NR_i^d}{W}}, \tag{4}$$

where 0.047358 (when $r=d$) $\leq \delta^d \leq$ 0.063297 (when $r=\sqrt{\frac{2\sqrt{3}}{\pi}}d$). In general, the transmission power of a base for a channel is proportional to its data rate. That is, $P_t^i/P_t^j=R_i^d/R_j^d$. Thus the equation (4) is converted into

$$\left(\frac{E_b}{N_o}\right)_i^d = \frac{WN_d}{(M_i-N_d)NR_i^d+\sum_{j\in A_i}\delta^d NM_jR_j^d}.$$

2.2 Uplink Slot

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

$$\left(\frac{E_b}{N_o}\right)_i^u = \frac{C}{\left(\left(\frac{M_i}{N_u}-1\right)C+\sum_{j\in A_i}\delta^u\frac{M_j}{N_u}C\right)\frac{NR_i^u}{W}} = \frac{WN_u}{\left((M_i-N_u)+\sum_{j\in A_i}\delta^u M_j\right)NR_i^u},$$

where δ^u is the ratio of the interference from adjacent cell to that from cell i during a uplink slot. The value of δ^u is assumed to be equal to the value of δ^d. Note that the first term of the denominator means the home-cell interference and the second term does the interference coming from adjacent cells. And note that we ignore tne background noise and the interference coming from other cells except adjacent cells.

3. Time slot and channel allocation problem

In this section, a time slot and channel allocation problem is considered. The objective of this problem is to maximize the system capacity which is measured as the aggregated data rate (ADR), $\sum_i M_i(R_i^d+R_i^u)$. And, for adequate transmission quality, the inequalities $\left(\frac{E_b}{N_o}\right)_i^d \geq \gamma_i^d$ and $\left(\frac{E_b}{N_o}\right)_i^u \geq \gamma_i^u$ should be satisfied for each cell i. Here, γ_i^d and γ_i^u respectively are the required bit energy-to-noise density ratio for downlink traffic and uplink traffic of cell i. Then, the time slot and channel allocation problem is mathematically formulated by the above objective and constraints, and other trivial constraints ($N_d+N_u=N$; $M_i \geq \max\{N_d, N_u\}$ for all i; all variables are nonnegative integer), which is combinatorial in nature. An efficient heuristic solution of this problem can be obtained by a simulated annealing algorithm [4,9].

4. Computational Results

In the tests, a 7×7 regular hexagonal cellular mobile system is considered. The parameter values are as follows: $\gamma_i^d=\gamma_i^u=5$ (dB), $W=10$ (MHz), $N=16$ (slots). In Figure 2, the data rates for uplink and downlink are uniformly distributed around 50% of 2 kbps and the values (2, 25, 50 kbps) in the x-axis of the figure respectively, and the parameters δ^d and δ^u are set at 0.063297. In the figure, UA, OUA, and NA mean the uniform allocation strategy, the optimized uniform allocation strategy, and the nonuniform strategy using the simulated annealing algorithm, 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 NA but uniformly assigns the channels through the whole cells. It is shown that NA achieves significant improvements in terms of ADR compared to UA and OUA.

Table 1 shows the system capacity according to the parameters δ^d and δ^u. In the table, the data rates for uplink and downlink are uniformly distributed around 50% of 2 kbps and the values (2, 25, 50 kbps) in the table respectively. In the table, NA$_1$ means the strategy NA with $\delta^d=\delta^u$

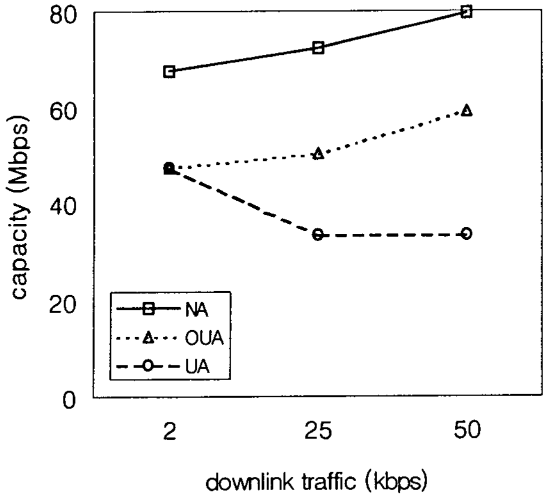

Figure 2: Capacity of CDMA/TDD system

=0.063297 and NA$_2$ does the strategy NA with $\delta^d = \delta^u$=0.047358. As expected, it is shown that the system capacity increases as the parameters δ^d and δ^u decrease.

5. Conclusions

In this paper, for the CDMA/TDD systems in general multicell environments, the interference for a time slot is analyzed, and the time slot and channel allocation problem is mathematically formulated, which is to maximize the system capacity under the given traffic unbalance. This combinatorial problem is solved by simulated annealing technique. Computational experiments show that the final allocation obtained from the proposed strategy (NA) achieves significant improvements in terms of ADR, compared to the ordinary uniform allocation (UA) and the optimized uniform allocation (OUA).

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Table 1: Capacity according to δ^d and δ^u

downlink Tx (kbps)	5	25	50
NA$_1$ (Mbps)	67.40 (8,8)*	72.41 (12,4)	79.76 (14,2)
NA$_2$ (Mbps)	71.69 (8,8)	76.79 (12,4)	84.60 (14,2)

* time slot allocation (N_d , N_u)

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그림 6은 부하에 대해 시뮬레이션 안을 생성하는 화면이다.

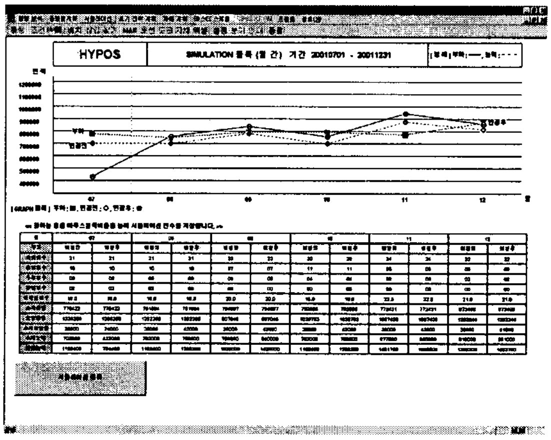

그림 6 시뮬레이션 안 생성

그림 7, 그림8은 자동계획 실행 결과화면이다.

수행 PC 사양이 RAM(128M), CPU(933MHz)인 펜티엄 Ⅲ에서 6개월 기간의 계획을 수립한 결과 소요시간은 13분 내외였다. 실행 시간 측면에서 상당히 만족 할만한 결과라고 생각된다.

5. 결론

본 연구에서는 선박생산 주 공정상의 대표적인 애로공정인 블록 도장공정을 대상으로 6개월간의 계획 기간에 대한 효율적인 운영 방안 수립 절차를 제시하였으며, 이를 위한 시스템을 개발하였다.

시스템 개발은 분석, 설계, 구현, 테스트 및 보완 등의 과정을 통하여 진행되었다. 시뮬레이션 안에 대한 실행 가능성 검증을 한 자동계획 알고리즘은 일별 블록 할당 알고리즘, 작업장별 블록 할당 알고리즘, 블록 배치 알고리즘으로 구성되었다. 블록 배치 알고리즘은 기존의 연구를 응용하여 적용하였다.

개발된 시스템을 도장 공장의 운영과 관련된 각종 업무에 실제로 적용함으로써 수작업으로 수립하기 어려운 장기 계획 운영 방안을 15분 내외의 비교적 빠른 시간에 수립할 수 있었다. 향후 과제로는 시뮬레이션변수의 세분화와 블록 이동 간섭을 고려한 공간배치에 대한 연구, 3차원 형상정보를 이용한 공간배치에 관한 연구이다.

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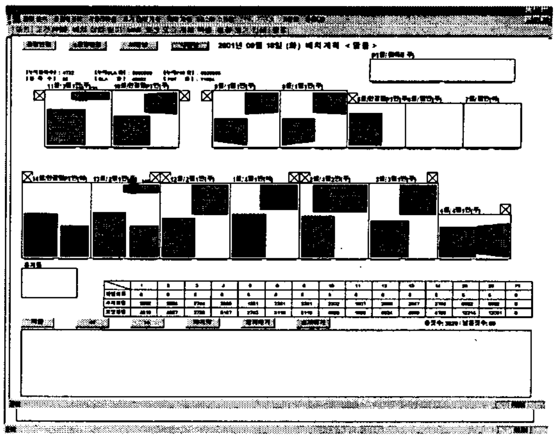

그림 8 도장 작업장 자동배치 결과