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Time Slot Allocation for CDMA/TDD Indoor Wireless Systems

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Abstract

Future wireless communication systems are expected to provide a broad range of multimedia services in which the asymmetry of traffic load between uplink and downlink is a significant feature. The code division multiple access system with time division duplex mode (CDMA/TDD) is a good solution to cope with the traffic asymmetry problem. However, the TDD system is subject to inter-cell interference compared to frequency division duplex (FDD) system. Since both uplink and downlink share the same frequency in TDD, uplink and downlink may interfere each other especially when neighboring cells require different rates of asymmetry. Thus, time slot allocation for cells is an important issue in TDD. In this paper, we propose a genetic algorithm based time slot allocation scheme which maximizes the residual system capacity. The proposed scheme allows that each cell employ different level of uplink/downlink asymmetry and satisfies the interference requirement.

1. Introduction

Future wireless communication systems are expected to provide a broad range of multimedia services in which the asymmetry of traffic load between uplink and downlink is a significant feature. The code division multiple access system with time division duplex mode (CDMA/TDD) is a good solution to cope with the traffic asymmetry problem.

In the Third Generation Partnership Project (3GPP), CDMA/TDD mode has been proposed as one of the standards for IMT-2000. The CDMA/TDD mode of 3GPP, named UTRA-TDD, is based on TD-CDMA technology, which is a mixture of TDMA and CDMA. More detailed review of TD-CDMA can be found in [1-2].

Despite the availability of managing uplink and downlink traffic asymmetry, the TDD system is subject to inter-cell interference compared to frequency division duplex (FDD) system. Since both uplink and downlink share the same frequency in TDD, uplink and downlink may interfere each other especially when neighboring cells require different rates of asymmetry. The interference of UTRA-TDD system is investigated in [3]. Because of the interference problem, time slot allocation for cells is an important issue in TDD.

The dynamic channel allocation of UTRA-TDD is divided to into two parts: Fast DCA and Slow DCA [4]. Slow DCA allocates channels to cells. Any timeslot within the TDD frame is available either for uplink or downlink transmission. However, an interference constraint should be satisfied when the slow DCA is employed. The slow DCA is based on a long term change of the traffic load. Thus, it need not be able to opetate in real time. On the contrary, the fast DCA allocates channels to bearer services in a cell. It requires an algorithm which runs in real time. The slow and fast DCA algorithms are independent of each other. A slow DCA algorithm is the scope of this paper. The proposed DCA algorithm can be used with any fast DCA algorithm.

Several literatures have been investigated a resource allocation of CDMA/TDD. [5-6] proposed a resource allocation scheme for single cell model. A resource utilization of CDMA/TDD for multi cell model is analyzed in [7]. However, the inter-cell interference is not considered in these works. Authors of [8] argued that timeslots allocated to uplink or downlink are preferred to be used to the same link in other cells to minimized inter-cell interference. However, the synchronization of uplink/downlink in each slot is not necessary to obtain the maximum capacity in a CDMA/TDD [9]. In [10], a DCA algorithm was proposed based on "timeslot opposing technique". However, the algorithm is triggered only when the uplink capacity of a cell is deficient. A capacity of CDMA/TDD in a two cell model is analyzed in [11]. However, a resource allocation algorithm is not provided in [11].

In this paper, we propose a genetic algorithm based time slot allocation scheme which maximizes the residual system capacity. The proposed scheme allows that each cell employ different level of uplink/downlink asymmetry and satisfies the interference requirement.

This paper is organized as follows. In Section 2, the system model and the problem is explained. The interference requirement of the system is analyzed in Section 3. The performance of the proposed resource allocation algorithm is demonstrated in Section 4, and the conclusion is presented in Section 5.

2. System Model and Problem Description

We assume a two-cell model in this paper. Although the two-cell model is a limited system for the analysis, it has a practical use in an indoor environment because it is likely that a few TDD cells in a building are isolated from the other outdoor cells. Let us denote the number of cells in the system as M and the number of slots in a frame as S. $M=2$ in this paper. The binary indicator variables u_{ij} and d_{ij} are defined as follows:

$$u_{ij} = \begin{cases} 1, & \text{if slot } j \text{ of cell } i \text{ is allocated to uplink} \\ 0, & \text{otherwise} \end{cases}$$

$$d_{ij} = \begin{cases} 1, & \text{if slot } j \text{ of cell } i \text{ is allocated to downlink} \\ 0, & \text{otherwise} \end{cases}$$

It is clear that $u_{ij} + d_{ij} = 1$ for all i, j pairs because a time slot cannot be allocated to both uplink and downlink simultaneously.

The resource of CDMA/TDD consists of a code and a timeslot. The basic resource unit (RU) for channel allocation is one code / timeslot / (per frequency) [4]. A channel is considered to occupy one RU in this paper. The data rate of a channel is fixed. Multi-rate services are achieved by the use of multiple channels simultaneously if necessary.

The capacity of a cell in each uplink/downlink is defined as the number of allocated channels for a frame. Let N_{ij} be the number of channels allocated to slot j of cell i. Also, the uplink and downlink capacity of cell i is denoted as C_i^u and C_i^d, respectively. Then, C_i^u and C_i^d is expressed as

$$C_i^u = \sum_{k=1}^{s} u_{ik} N_{ik} \quad (1)$$

$$C_i^d = \sum_{k=1}^{s} d_{ik} N_{ik} \quad (2)$$

The purpose of the resource allocation is usually to maximize the capacity of the system. However, the shortage of a channel is likely to occur at the hot-spot area because the residual capacity will be the minimum in a cell which accommodates the maximum channels currently. Moreover, the number of newly generated calls in the hot-spot cell will be more than those of other cells because of the crowds of people. Thus, the objective function to maximize in this paper is the sum of residual capacities of each cell and each link weighted by the current traffic load.

Let T_i^u and T_i^d be the traffic load (number of channels) of cell i in uplink and downlink, respectively. T_i^u and T_i^d are the given system parameters which have non-negative integer values. Thus, the aggregate traffic load of the system T is given as

$$T = \sum_{i=1}^{M} T_i^u + T_i^d \quad (3)$$

Then, the objective function is as follows:

$$\text{Max } \frac{1}{T}\sum_{i=1}^{M} T_i^u (C_i^u - T_i^u) + T_i^d (C_i^d - T_i^d) \quad (4)$$

Since the CDMA is the interference limited system, the most important constraint is the E_b / N_o requirement. When we denote the E_b / N_o requirement of uplink and downlink as γ_u and γ_d respectively, the E_b / N_o of all uplink slots in all cells should exceeds γ_u. As the same, the E_b / N_o of all downlink slots in all cells must be greater than γ_d. Besides, the capacity of each cell for each link should not be less than the traffic load. The objective function and constraints are shown as follows.

$\left(\frac{E_b}{N_o}\right)_{i,j}^{u/d}$ means the uplink/downlink E_b / N_o value of slot j in cell i.

$$\text{Max } \frac{1}{T}\sum_{i=1}^{M} T_i^u (C_i^u - T_i^u) + T_i^d (C_i^d - T_i^d)$$

Subject to

$$u_{ij}\left(\frac{E_b}{N_0}\right)_{i,j}^{u} \geq u_{ij}\gamma_u \quad \text{for all } i,j \text{ pairs}$$

$$d_{ij}\left(\frac{E_b}{N_0}\right)_{i,j}^{d} \geq d_{ij}\gamma_d \quad \text{for all } i,j \text{ pairs}$$

$$u_{ij} + d_{ij} = 1 \quad \text{for all } i,j \text{ pairs}$$

$$C_i^u - T_i^u \geq 0 \quad \text{for all } i$$

$$C_i^d - T_i^d \geq 0 \quad \text{for all } i$$

u_{ij}, d_{ij}, and N_{ij} are non-negative integer values.

The genetic algorithm is used to determine the values of u_{ij}, d_{ij}, and N_{ij}. Since N_{ij} is the general integer variable, the real-coded genetic algorithm [15] is employed. The performance of the genetic algorithm will be shown in Section 4.

3. Capacity of CDMA/TDD System

In this section, we derive E_b / N_o for each slot. The derivation process of E_b / N_o is based on [10] and [11]. Since different number of timeslots does not interfere each other, E_b / N_o of each slot is independent. Thus, slot number is not considered in this section. $\left(\frac{E_b}{N_o}\right)_i^{u/d}$ denotes the E_b / N_o value of cell i for uplink/downlink. In case timeslots of two cells are allocated to different links at the same time, we call these timeslots as crossed slot.

In the crossed slot, a transmitting mobile in uplink cell may cause a significant interference to a receiving mobile in downlink cell in the worst case, i.e., two mobiles locate close to each other near to the cell boundary. To prevent the significant interference problem, the transmission of uplink mobiles in a crossed slot is restricted within the inner circle which has radius of r. See Figure 1. In the figure, solid lines and dashed lines mean the desired signal and other cell interference, respectively. The restriction of uplink mobile is proposed in [11].

Let P_R be the received signal power at a base station (BS) for a channel in uplink. Also, Q_R is denoted as the received signal power at a mobile for a channel in downlink. The perfect power control is assumed in this paper. Thus, P_R at a BS is same for all uplink users and Q_R are same for all downlink users.

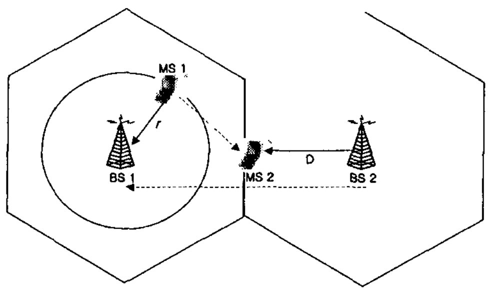

Fig. 1 Two Cell Model

Let us denote P_T and Q_T as the transmission power of MS1 and BS2, respectively in Figure 1. Since path loss exponent is about 4 at the indoor environment [12],

$$P_R = r^{-4} P_T \quad (5)$$

$$Q_R = D^{-4} Q_T \quad (6)$$

Fading effects are ignored in the above equations.

Now, the E_b / N_o is derived for the following three cases: crossed slot, both uplink slots, both downlink slots.

CASE 1: Crossed Slot

We assume cell 1 is used for uplink and cell 2 is for downlink without loss of generality. Then, for a slot, N_1 and N_2 denote the number of channels for uplink and downlink, respectively. Let W be the spreading bandwidth and R be the data rate of one channel. Then, the E_b / N_o of uplink cell in crossed slot is expressed as

$$\frac{E_b}{N_o}{}_1^{u} = \frac{W}{SR} \frac{P_R}{(N_1 - 1)P_R + (2D)^{-4} Q_T N_2} \quad (7)$$

In equation (7), the left term and right term of denominator mean home cell interference and other cell interference, respectively. Since the condition $\frac{E_b}{N_{o\,1}}^{u} \geq \gamma^u$ should be satisfied, we have the following inequality. δ means that the ratio of the radius of the inner circle to that of the cell ($\delta = \frac{r}{D}$).

$$N_1 + \frac{\delta^4 Q_T}{16 P_T} N_2 \leq \frac{W}{SR\gamma_u} + 1 \quad (8)$$

A similar equation with (7) can be derived in the downlink. The main difference between the uplink and the downlink is that the synchronous transmission among users is applied in the downlink. The synchronous transmission enables the use of the orthogonal codes for each user. Thus, the home cell interference can be diminished in the downlink. However, the multi-path propagation violates the orthogonality at the receiving mobile in the real field. In [13], the orthogonality factor α is defined. α has higher value when signals are more corrupted by the multi-path propagation. $\alpha = 1$ means that the orthogonality is not maintained any more. In the indoor environment which is subject to severe multi-path propagation, α reaches 0.8 [13].

Let Q be the total received signal power at a mobile. Q consists of the pilot signal and user signals.

$$Q = Q_{pilot} + N_2 Q_R \quad (9)$$

A factor ψ is defined as the fraction of the user signals to the total received power [14]. ψ=0.8 is used in [15]. When we approximate $N_2 Q_R$ as $(N_2 - 1)Q_R$, E_b / N_o of the downlink in the crossed slot is as follows:

$$\frac{E_b}{N_{o\,2}}^{d} = \frac{W}{SR} \frac{Q_R}{\frac{\alpha(N_2 - 1)Q_R}{\psi} + I_1^u}$$

$$= \frac{W}{SR} \frac{Q_R}{(N_2 - 1)Q_R + I_1^u} \quad (10)$$

I_1^u denotes other cell interferences generated from uplink mobiles in cell 1. We consider MS2 in the Figure 2. In other words, the receiving mobile in the worst case is considered. In the uplink cell (cell 1), the mobiles are expected to locate uniformly within the circle. Thus, we assume that mobiles are concentrated a center of a cell with the transmission power of P_T as an approximation. Then, I_1^u becomes $D^{-4} P_T N_1$. Thus we have

$$N_2 + \frac{P_T}{Q_T} N_1 \leq \frac{W}{SR\gamma_d} + 1 \quad (11)$$

CASE 2: Both Uplink Slots

Mobiles in each cell are expected to be uniformly located. Let ζ be the ratio of the interference from other cell to that form the home cell [11]. Then, the following equation holds.

$$\frac{E_b}{N_{o\,1}}^{u} = \frac{W}{SR} \frac{R_R}{(N_1 - 1)R_R + \zeta P_R N_2} \quad (12)$$

From (12), we get

$$N_1 + \zeta N_2 \leq \frac{W}{SR\gamma_u} + 1 \quad (13)$$

A similar inequality holds for cell 2.

CASE 3: Both Downlink Slots

When we consider the worst case mobile,

Table. 1 Parameters

Parameters	Values
W	5MHz
S	15
R	4Kbps
Q_T	4.8W
P_T	$0.4016 \times \delta^4$ W
ζ	0.06
γ_u, γ_d	5dB

$$\frac{E_b}{N_o}{}^{d}_{1} = \frac{W}{SR} \frac{Q_R}{(N_1 - 1)Q_R + Q_R N_2} \quad (14)$$

Thus,

$$N_1 + N_2 \leq \frac{W}{SR\gamma_d} + 1 \quad (15)$$

4. Computational Results.

The performance of the time slot allocation scheme with the genetic algorithm is shown in this Section. The proposed algorithm is compared to the single slot allocation (SA) scheme in which crossed slot is not used. The optimal number of uplink and downlink slots in SA scheme is also investigated with the genetic algorithm. Parameters that are used in the experiments are shown in Table 1. ς, Q_T, and P_T follow the values used in [11].

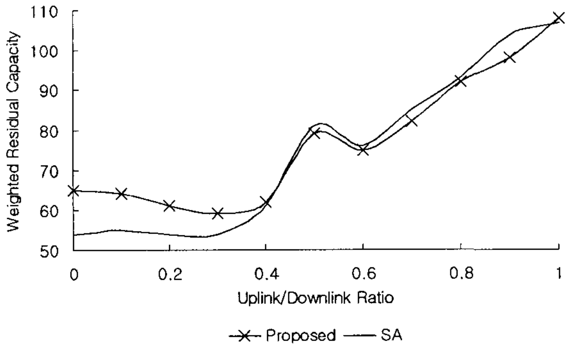

Figure. 2 Weighted Residual Capacity

The traffic load in cell 1 is fixed in a synchronous manner (uplink 50 and downlink 50) and the up/down ratio of traffic load in cell 2 are changed from 0 to 1 with same amount of traffic load (uplink + downlink = 100). Figure 2 illustrates the weighted residual capacities of the proposed algorithm and SA algorithm.

As the fraction of uplink traffic load increases, the weighted residual capacity increases in both algorithms. It is due to the fact that the capacity of uplink slot is larger than that of downlink slot according to inequalities (13) and (14). When the downlink traffic load is greater than the uplink traffic load, the proposed algorithm outperforms the SA algorithm. On the contrary, when the uplink traffic load exceeds the downlink traffic load, the difference of two algorithms is slight. It means that the proposed algorithm is fitted to the situation that the downlink

Table 2. Timeslot usage of the proposed algorithm

Uplink Load	0	10	20	30	40	50	60	70	80	90	100
Downlink Load	100	90	80	70	60	50	40	30	20	10	0
Uplink Slot	0	0	1	3	8	9	10	8	10	10	10
Downlink Slot	6	3	3	2	4	2	3	2	1	1	5
Crossed Slot	9	12	11	10	3	4	2	5	4	4	0

traffic load is larger than the uplink traffic. When the uplink traffic is more than the downlink traffic, it seems that the SA is sufficient. However, it is generally considered that the bandwidth requirement of the multimedia applications is downlink biased. Thus, the proposed algorithm will give a good performance in most real situations.

The timeslot usage of the proposed algorithm is shown in Table 2. When the uplink load increases, the number of uplink slot also increases. However, when the downlink load increases, the number of crossed slot increases instead of that of downlink slot. From the table it is shown that the crossed slot enhances the capacity of the system when the downlink traffic load is larger than the uplink traffic load.

5. Conclusion

A slow dynamic channel allocation (DCA) algorithm is proposed in this paper. The proposed algorithm is based on a genetic algorithm and investigated in two cell model. The objective of the proposed algorithm is to maximize the weighted residual capacity of the system. The interference requirement of the system is analyzed because it is a significant constraint of the algorithm.

The proposed algorithm is compared with the same slot allocation (SA) algorithm. Computational result shows that the proposed algorithm outperforms SA algorithm when the downlink traffic load is larger than the uplink traffic load.

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