Determination of a Time-Slot Switching-Point Considering Asymmetrical Traffic Features in TD-CDMA/TDD Systems

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ABSTRACT

We propose a mathematical model to analyze the performance of TD-CDMA/TDD systems in terms of call blocking probability and then find the optimum time-slot switching-point at the smallest call blocking probability considering asymmetrical traffic load distribution for various kinds of service applications.

I Introduction

Multimedia services including voice, data, image, video telephony, mobile computing and various kinds of downloads through Internet accesses characterize uplink and downlink traffic loads as an asymmetry; downlink traffic may be heavier or lighter than uplink traffic TDD (Time Division Duplex) transmission is a potential option for the efficient management of the radio resource in asymmetrical traffic conditions TDD systems use the same frequency band for both uplinks and downlinks but alternate the transmission direction in time The asymmetrical traffic problem can be solved by controlling the number of time-slots assigned to each direction in response to the amount of traffic load

The hybrid TD-CDMA/TDD multiple access scheme has been extensively researched[1]-[4] as a candidate for IMT-2000 The results have shown that the CD-TDMA/TDD scheme can adaptively cope with asymmetrical traffic conditions compared with the CDMA-FDD (Frequency Division Duplex) scheme In addition, since the TD-CDMA/TDD scheme manages radio resource in two dimensional space, time and code, the flexibility of resource assignment is very high. on the other hand, however, determining the optimum assignment solution is very complex and difficult

Single-cell and multi-cell systems have been analyzed to show the performance improvement gained by using appropriately adaptive time-slot assignments[1],[5] In general, the traffic load distribution varies cell by cell. If the time-slot assignment scheme is managed differently in each cell, a crossed-slot may occur, a problem wherein an uplink is assigned in a cell while there is a downlink in another cell The crossed-slot problem can induce severe quality degradation of the communication channel due to the inter-direction interference, especially around cell boundaries Although developing a method to manage an optimum assignment scheme so as not to conflict with assignments of neighboring cell si a pressing issue, we should obtain the optimum assignment solution first considering the traffic characteristics in each cell Location the switching point which separates downlink time-slots and uplink time-slots at the optimum positions is a key to the solution.

In this paper, we propose a mathematical model to analyze the performance of TD-CDMA/TDD systems in terms of call blocking probability and then find the optimum time-slot switching-point at the smallest call blocking probability considering asymmetrical traffic load distribution for various kinds of service applications As an alternate method, we use a rough estimation by simply calculating the ratio of traffic loads on the uplink and downlink We compare our proposed framework with the estimation method and show

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that the proposed method is superior to the approximated estimation, which may generate errors when applied to real systems.

The remainder of this paper is organized as follows. The following section describes the channel architecture and channel assignment scheme of TD-CDMA/TDD systems. In Section III, we propose a mathematical model to obtain the call blocking probability of TD-CDMA/TDD systems. In Section IV, we show numerical results from the mathematical model and compare them with those from a simple estimation method. Finally, in Section V, we present our conclusions.

II. System Description

Fig. 1 shows the channel architecture of the TD-CDMA/TDD system considered in this paper. The two-dimensional channel configuration is comprised of time slots and cedes. A channel unit composed of one time-slot and one code is defined by a minimum element to carry user traffic. Multiple channel units are assigned to a call according to the traffic load. For example, a call with heavier load on the downlink than on the uplink requires a larger number of channel units on the downlink than on the uplink.

It is assumed that idle channel units are randomly assigned with no sequence. Implementation complexity is not considered here. Any idle channel unit can be assigned at any time. The number of time-slots within a frame is denoted by $S_{\max}$. The frame is divided into up- and down-subframes by a switching point. If the switching point is located between S_{sw}-th and S_{sw+1}-th time-slots, the sequential time-slots from 1 to S_{sw} are assigned on the uplink and the sequence from S_{sw+1} to $S_{\max}$ are assigned on the downlink. The number of codes is denoted by $C_{\max}$. Hence the total number of channel unit is $C_{\max}\times S_{\max}$ among which $C_{\max}\times(S_{\max}-S_{sw})$ and $C_{\max}\times S_{sw}$ channel units are used to carry downlink and uplink traffic, respectively.

Intuitively we know that the S_{sw} should be

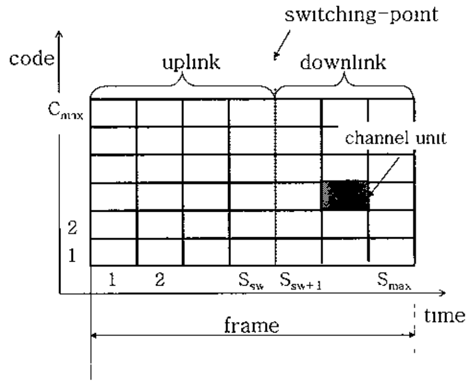

Fig. 1. Channel Architecture

determined so that the ratio of traffic load on uplink to downlink is as close as possible to $S_{sw}/(S_{\max}-S_{sw})$. Numerical examples in Section IV will show that the approximation, although somewhat acceptable, is not exact. We need an exact solution to obtain the optimum switching-point.

III. Mathematical Model

WCDMA, the European standard for IMT-2000, manages three kinds of physical channels: dedicated, shared, and common. We only consider dedicated-type channels, which are exclusively assigned to users and are operated in circuit-mode. We employ some useful assumptions as follows:

- The user calls arrive according to a Poisson process with a rate of λ.
- The call service time is exponentially distributed with a mean of $1/\mu$.

In asymmetrical traffic environments, a user's up- and down-traffic must be modeled separately. The traffic load of user i is then expressed in a vector as

$$\overrightarrow{T_i}=(t_{u_i}, t_{d_i}), \tag{1}$$

where t_{u_i} and t_{d_i} are up- and down-traffic load of user i, respectively. The traffic load is normalized by one-channel-unit capable load. Hence, t_{u_i} and t_{d_i} have an integer value representing the number of channel units required

We let the state S_u be the number of active users in a cell. On the condition of $S_u = k$, the system is overloaded when the total traffic load from k users exceeds the channel capacity either on uplink or on downlink. Hence the overload probability at state k, is given by

$$P_{overload|k} = 1 - \text{Prob(not overload on uplink)} \times \text{Prob(not overload on downlink)} = 1 - \Pr\left(\sum_{i=1}^{k} t_{u_i} \le M_{up}\right) \times \Pr\left(\sum_{i=1}^{k} t_{d_i} \le M_{down}\right) \quad (2)$$

where M_{up} and M_{down} denote uplink and downlink channel capacities, respectively, and are given by

$$M_{up} = S_{sw} \times C_{max},$$
$$M_{down} = (S_{max} - S_{sw}) \times C_{max}$$

If we define two random variables to represent the sum of traffic loads from k users as

$$T_u^{(k)} = \sum_{i=1}^{k} t_{u_i},$$
$$T_d^{(k)} = \sum_{i=1}^{k} t_{d_i},$$

then Eq (2) is more simply represented by

$$P_{overload|k} = 1 - F_{T_u^{(k)}}(M_{up}) \times F_{T_d^{(k)}}(M_{down}), \quad (3)$$

where $F_X(x)$ represents a distribution function of random variable X We assume that both random variables of t_{u_i} and t_{d_i} have independent identical distribution, therefore simply denoted by t_u and t_d Then,

$$\begin{aligned} F_{T_u^{(k)}}(x) &= \int_0^x f_{t_u}(\tilde{x}) \cdot F_{T_u^{(k-1)}}(x-\tilde{x})d\tilde{x} \\ &= f_{t_u}(x) * F_{T_u^{(k-1)}}(x) \\ &= f_{t_u}(x) * f_{t_u}(x) * F_{T_u^{(k-2)}}(x) \\ &= \overbrace{f_{t_u}(x) * f_{t_u}(x) * \bullet\bullet\bullet f_{t_u}(x)}^{\text{(k-1) times}} * F_{t_u}(x) \\ &\equiv G_{t_u}^{(k)}(x) \end{aligned}$$

Therefore, the Eq. (3) is newly represented by

$$P_{overload|k} = 1 - G_{t_u}^{(k)}(M_{up}) \cdot G_{t_d}^{(k)}(M_{down}). \quad (4)$$

The system considered here is a finite-state system However, we cannot determine the maximum state as a fixed value because the total system load is determined by the sum of loads from heterogeneous-traffic users rather than by the number of active users In other words, the overload condition may occur at any state except for the zero-state Using the probability law, the probability that the system is in overload state is obtained by

$$P_{overload} = \sum_{k=1}^{\infty} P_{k\_\inf} \cdot P_{overload\ |k} \quad (5)$$

where P_{k_∞} is the steady-state probability at $S_u = k$ in a infinite-state system and is given by $\frac{(\lambda/\mu)^k}{k!}\exp(-\lambda/\mu)$. We let P_k be the steady-state probability at $S_u = k$ in the finite-state system. Then using the property[6] of

$$\frac{P_k}{P_{k\_\inf}} = \alpha(\text{constant}) \qquad (k = 0,1,2\Lambda\ , \text{max. of } S_u)$$

we can obtain a normalized P_k from P_{k_∞} so that the probability sum on not-overloaded states becomes 1

$$\begin{aligned} \sum_{k=0}^{\max\_of\ S_u} P_k &= \alpha \sum_{k=0}^{\max\_of\ S_u} P_{k_\infty} \\ &= \alpha \cdot \Pr ob(\underline{/}\ overloaded) \\ &= \alpha \cdot (1 - P_{overload}) = 1. \end{aligned}$$

So,

$$\alpha = \frac{1}{1 - P_{overload}}.$$

Therefore, we obtain

$$P_k = \frac{P_{k_\infty}}{1 - P_{overload}} \quad (6)$$

From the P_k, we now derive the blocking probability. A new call is blocked when the additional traffic generated by the new call arrival makes the total up- or down-traffic load exceed the channel capacity. The probability that a new call is blocked at state k is given by

$$\begin{aligned} P_{block|k} &= \Pr\left(\sum_{i=1}^{k} t_{u_i} < M_{up}\right) \cdot \Pr\left(\sum_{i=1}^{k} t_{d_i} < M_{down}\right) \\ &- \Pr\left(\sum_{i=1}^{k+1} t_{u_i} < M_{up}\right) \cdot \Pr\left(\sum_{i=1}^{k+1} t_{d_i} < M_{down}\right) \\ &= G_{t_u}^{(k)}(M_{up}) \cdot G_{t_d}^{(k)}(M_{down}) \\ &- G_{t_u}^{(k+1)}(M_{up}) \cdot G_{t_d}^{(k+1)}(M_{down}). \end{aligned}$$

Since the system state can be larger than neither M_{up} nor M_{down}, the blocking probability is finally given by

$$P_{block} = \sum_{k=1}^{\min[M_{up}, M_{down}]} P_k \cdot P_{block|k} \qquad (7)$$

where

$$\min[M_{up}, M_{down}] = \begin{cases} M_{up}, & M_{up} \le M_{down} \\ M_{down} & M_{up} > M_{down} \end{cases}.$$

Table 1. Default parameter values

parameter	value
C_{max}	7
S_{max}	10
λ	1
$\max(t_u)$, $\max(t_d)$	10

Ⅳ. Numerical Results

Asymmetric features of user traffic on up/down links are considered by making the traffic load distributions different for each direction. The amount of traffic load required for user application services is expressed by the number of channel units; a channel unit is composed of one time slot and one code. Hence the traffic load density function has a mass on a discrete value. The default values of parameters used in this numerical analysis are summarized in Table 1.

We obtained numerical results for the traffic load distributions listed in Table 2. Cases 1, 2, and 3 have a few kinds of traffic loads on both the uplink and downlink. Any combination of up and down traffic load can be considered as a service application. Examples of service applications for traffic load values are shown in Fig. 2.

Table 2. Traffic load distributions in each case

Case 1					
Up	Load	1	3	5	
	Mass	0.7	0.2	0.1	
Down	Load	1	5	10	
	Mass	0.2	0.5	0.3	
Case 2					
Up	Load	1	4	10	
	Mass	0.5	0.3	0.2	
Down	Load	1	3	7	10
	Mass	0.3	0.2	0.1	0.4
Case 3					
Up	Load	1	5		
	Mass	0.8	0.2		
Down	Load	1	5	8	
	Mass	0.2	0.3	0.5	

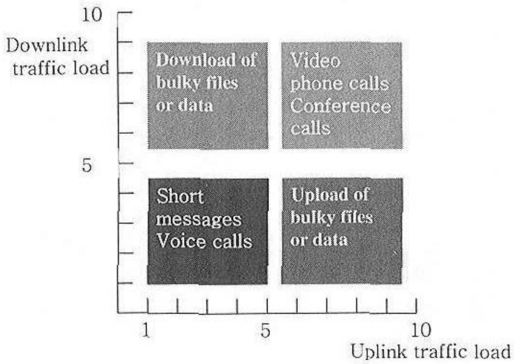

Fig. 2 Service applications for traffic load values

Fig. 3 shows the blocking probability of Case 1 versus the variable S_{sw} the value of which denotes the switching-point as illustrated in Fig. 1. As presented in Table 2, Case 1 includes heavier traffic loads on downlinks than on uplinks. Hence larger capacity on the downlink is required, which means a switching-point value that is smaller than middle 5 $(=S_{max}/2)$ is desirable. In this case, the optimum switching-point value is 3 for various service rates

μ, as shown in Fig. 3. We can roughly estimate the optimum switching-point using a simple calculation. The average traffic loads on both uplink and downlink are 1.8 (=1×0 7+3×0 2+5×0 1) and 5.7 (=1×0.2+5×0 5+10×0 3), respectively Hence the reasonable switching-point, x is calculated by

$$\frac{Avg.\ up\ traffic}{Avg.\ up\ traffic + Avg.\ down\ trffic} = \frac{1.8}{1.8+5.7} = \frac{x}{S_{max}}.$$

In this example, x is 2.4, which, however, is not an integer Hence we must choose an integer, either 2 or 3, in order to apply the value in a real system Although the estimation by a simple calculation is meaningful, error always exists in mapping the estimated value to the optimum integer value

Fig. 4 shows the blocking probability of Case 2, where the average traffic loads on both links are 3.7 for uplink and 5 6 for downlink. Using the same method as Case 1, the estimated switching-point x is obtained by 3 98 (=10×3 7/(3 7+5.6)). As shown in Fig. 4, the optimum switching-point should be either 4 or 5 according to the service rate μ, which determines the offered traffic load. For $\mu=0.3$ and 0 4 the optimum switching-point of 4 is the nearest integer value of the estimated value of 3.98. However, for $\mu=0.5$ and 0 6, the optimum switching-point is 5 neither 4 nor 3. Hence the simple mapping of an estimated value to the nearest integer value does not always give the optimum solution In other words, the division of a time-frame into up/down-direction slots proportional to the up/down-traffic load ratio can cause a loss of capacity in terms of the blocking probability

Case 3 has the same total traffic loads of 1 8 and 5 7 on both up- and downlink as Case 1, however, different load distributions. Fig 5 compares the blocking probabilities of Cases 1 and 3 We find a little bit of disagreement which shows that the call blocking probability depends on traffic load distribution as well as total traffic load amount, although the difference of results between Cases 1 and 3 is not so large. The optimum switching-point is 3 as Case 1.

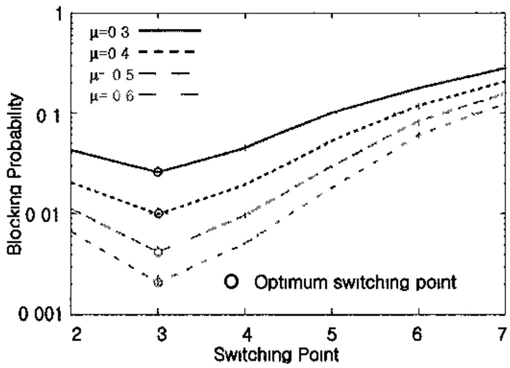

Fig 3 The call blocking probability of Case 1

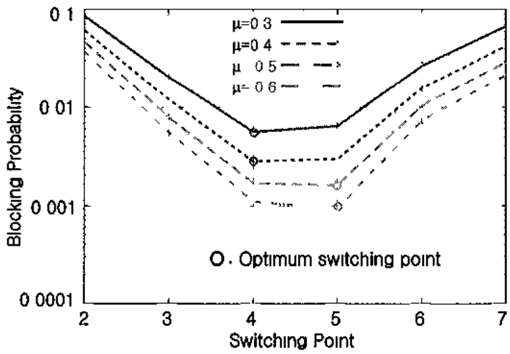

Fig 4 The call blocking probability of Case 2

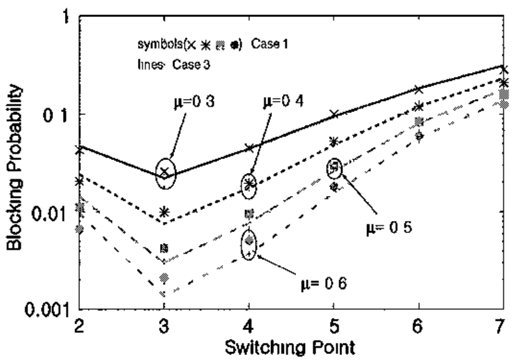

Fig 5 The call blocking probability of Case 3

V. Conclusions

We have proposed a mathematical model to obtain the call blocking probability of a

TD-CDMA/TDD system. Then, using the numerical results from the model, we found the optimum switching-point at the smallest call blocking probability to efficiently manage channel resource in asymmetrical traffic environments. Our framework to find the optimum switching-point is more applicable to real systems than a load-ration method, which may generate a wrong solution with a quantization error.

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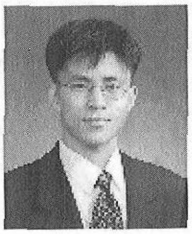

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