Modeling Asymmetric Slot Allocation for Mobile Multimedia Services in Microcell TDD Employing FDD Uplink as Macrocell

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Abstract. This paper introduces an analytical approach which is provided to calculate the downlink and uplink capacities of the time division duplex (TDD) system utilizing the underused frequency division duplex (FDD) uplink which shares the same frequency band. Then the ratio of downlink and uplink slots in one frame is adjusted, so as to prevent the radio resource waste due to asymmetric traffic characteristic in mobile multimedia services. The computer simulation shows that the resource waste problem can be considerably solved through the asymmetric slot allocation. Thus, this paper can be useful as a guideline in the course of planning a two-layer hierarchical cell structure (HCS) employing the TDD system as a microcell and FDD system as a macrocell as well as a mean to increase the performance of such a system.

1 Introduction

The next wireless communication systems will provide multimedia services including the voice of IP (VoIP) and video streaming, Internet access, and broadcast service [1]. Unlike the VoIP service, asymmetric characteristics of many services (e.g., Internet access and broadcast service) bring about serious radio resource wastes. Thus, as the traffic unbalance between two links may incur an unacceptable resource waste, problems related to it have been studied [2] [3] [4]. The time division duplex (TDD) scheme has been proposed to accommodate asymmetric communications between uplink and downlink. In a TDD communication system, since the uplink has unused surplus channels due to an asymmetric traffic characteristic, it is necessary to adjust the ratio of slots between uplink and downlink in one frame so as to obtain a minimum resource waste. Consequently, such a slot allocation can play an important role in wireless multimedia communication services which require the optimum radio resource utilization.

In this paper, it is assumed that both the frequency division duplex (FDD) and TDD systems can be combined in a single hierarchical structure. The aforementioned systems may be divided into two cases. In one case, they have different frequency bands, and in the other case, they have the same frequency band. This paper deals with the latter case when they share the same frequency band, and further considers a two-layer environment with the microcell employing the TDD system and the macrocell employing the FDD system [5]. The uplink and downlink capacities of the TDD system by considering the interferences in both links in the microcell TDD and an uplink in the macrocell FDD are calculated. Recently, the 3rd generation partnership project (3GPP) has generated necessary information about the 2.6 GHz FDD system, as detailed below [7]:

• 2500 $\sim$ 2570 MHz: Uplink (UE transmit, Node B receive)
• 2620 $\sim$ 2690 MHz: Downlink (base station (BS) transmit, mobile station (MS) receive)
• The co-existence with IMT2000 technology within 2500 $\sim$ 2690 MHz shall be considered.
• Assigned blocks shall be in multiple of 5.0 MHz.

As a reference, the FDD system is based on the wideband code division multiple access (W-CDMA) system parameters as specified in the 3GPP [6]. This paper is organized as follows. In Section 2, the system model is introduced. In Section 3, the TDD system capacity is analyzed. Section 4 shows that the traffic unbalance problem is evaluated and solved by adjusting the number of slots between uplink and downlink in the TDD cell as a microcell for the cases of sharing the FDD uplink band as a macrocell. The conclusion is given in Section 5.

2 System Model

In general, three different duplexing schemes are used in the wireless communication system design: frequency division duplex (FDD), time division duplex (TDD), and space division duplex (SDD). The FDD is one of the most common duplex schemes in the cellular system. In a TDD system, uplink and downlink transmissions occur at different times and usually share the same frequency. In a FDD system, uplink and downlink channels are located on separate frequencies and occur at the same time. There is a notable savings in power from the TDD architecture which is a direct result of turning the receiver off while in transmission mode and vice versa. However, a disadvantage exists. There is a reduction of the global capacity since there can be no transmission of data while in receiving mode unlike the FDD system. In essence, the TDD system must handle fewer users in a given area than in the FDD system.

All cases which can be considered in a two-layer hierarchical cell structure (HCS) employing the TDD as a microcell and the FDD as a macrocell can be categorized into four different cases in terms of sharing frequency bands and applied direction of links as follows. In the case of a TDD system utilizing an underused FDD uplink, both forward and reverse links have to be taken into account assuming an ideal power control. Case 1: The interference between the FDD uplink as a macrocell and the TDD uplink as a microcell. Case 2: The

Table 1. All cases in a two-layer HCS employing the TDD as a microcell and the FDD as a macrocell

	FDD	TDD
case 1	Uplink	Uplink
case 2	Uplink	Downlink
case 3	downlink	Uplink
case 4	downlink	Downlink

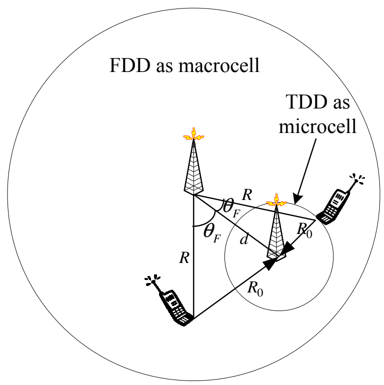

Fig. 1. The interference between the FDD uplink as a macrocell and the TDD uplink as a microcell (case 1)

interference between the FDD uplink as a macrocell and the TDD downlink as a microcell. Furthermore, in the case of a TDD system utilizing an underused FDD downlink, the following two cases need to be considered. Case 3: The interference between the FDD downlink as a macrocell and the TDD uplink as a microcell. Case 4: The interference between the FDD downlink as a macrocell and the TDD downlink as a microcell.

For all four different cases, the calculation of the other-cell interference and the same-cell interference are calulated as follows. Interferences of case 1 are pictured as in Fig. 1. The other-cell interference which all MSs in the FDD have influence on a BS in the TDD can be calculated. Also, the same-cell interference that other MSs except its own MS in a TDD have an effect on a BS in the TDD system can be calculated. Interferences of case 2 are explained in Fig. 2. The other-cell interference of case 2 can be obtained as follows. Firstly, the interference which all MSs in the FDD have an effect only on a MS in TDD is calculated. Because all MSs in the TDD are assumed to be distributed uniformly, the interferences of other MSs in the TDD can be easily calculated. Similarly, in order to get the same-cell interference in Fig. 2, this paper firstly calculates the interference on a MS in the TDD by a BS in the TDD and then the interference on other MSs in the TDD from the BS in the TDD. Effects of transmission power in a BS in the FDD are represented in Fig. 3 (case 3). The other-cell interference

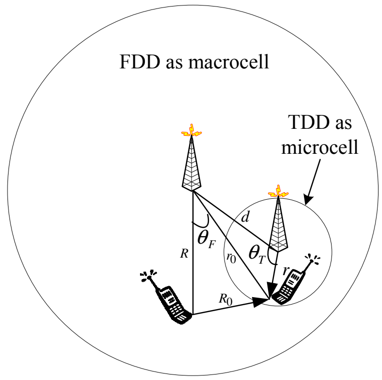

Fig. 2. The interference between the FDD uplink as a macrocell and the TDD downlink as a microcell (case 2)

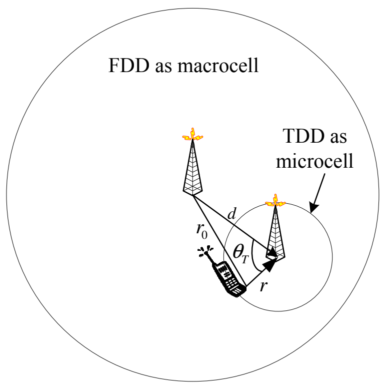

Fig. 3. The interference between the FDD downlink as a macrocell and the TDD uplink as a microcell (case 3)

which a BS in the FDD has an effect on a BS in the TDD is calculated. The same-cell interference that all MSs except its own MS in the TDD have effects on a BS in the TDD for uplink can be calculated, as in Fig. 1. Finally, Fig. 4 represents all the interferences of case 4. The other-cell interference which a BS in the FDD has influence on all MSs in the TDD in Fig. 4 is calculated, with the following method. The interference which can be calculated as a BS in the FDD has an effect on only a MS in the TDD, and then the interference which other MSs receive from a BS in the FDD can be estimated. The same-cell interference in Fig. 4 can be calculated as the same method as that in Fig. 2.

All calculated interferences can be put into the capacity estimation in the TDD system. This paper considers the uplink and downlink capacity of TDD system utilizing the underused FDD uplink which shares the same-frequency band (case 1 and case 2). It is known that, in the TDD cell, the interference

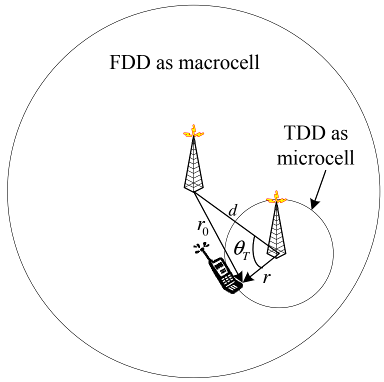

Fig. 4. The interference between the FDD downlink as a macrocell and the TDD downlink as a microcell (case 4)

in the uplink slot can be calculated without any concern with the one in the downlink slot, because they are used at different instances of time. It is also assumed that users are evenly distributed over slots in each frame, so that the number of users in an uplink (or downlink) slot may be equal to the value that is obtained by the division of the total number of users in all uplink (or downlink) slots to the total number of uplink (or downlink) slots.

3 Capacity Analysis in the TDD System

In calculating the interference and capacity in the TDD system [3] [8], this paper considers the first two cases (case 1 and case 2) among all four cases in Table 1 to deal with problems about unused surplus channels, usually the uplink, due to asymmetric traffic characteristics. The notations used in the following analysis are summarized in Table 2. The other-cell interference and the same-cell interference are calulated for the two different cases as discussed above. Fig. 1 shows the interference in the TDD uplink of case 1. In order to calculate the uplink capacity of the TDD system in Fig. 1, the other-cell interference on the BS in the TDD system caused by the MSs in the FDD system must be determined. The same-cell interference on the BS in the TDD system caused by other MSs except its own MS must also be determined. Assuming an ideal power control, the bit energy-to-noise density ratio $(E_b/N_0)_{TDD}^{up-up}$ in the TDD uplink of case 1 can be modelled as (1).

$$(E_b/N_0)_{TDD}^{up-up} = \frac{P_{TDD}}{P_{TDD}(\frac{M_{TDD}^{up-up}}{N_{up}} - 1)\frac{R_{TDD}^{up}}{B} + I_{FDDtoTDD}^{up-up}\frac{R_{TDD}^{up}}{B}} \tag{1}$$

where R_{TDD}^{up} is the uplink data rate for a TDD cell and B denotes the spreading bandwidth (thus, $\frac{B}{R_{TDD}^{up}}$ is the spreading factor). This paper has also

Table 2. The notations used in this paper

Notation	Description
$(E_b/N_0)_{TDD}^{up-up(down)}$	Bit energy-to-noise in the TDD when FDD is uplink and TDD is uplink (downlink)
$(C/I)_{TDD}^{up-up(down)}$	Carrier-to-interference ratio in the TDD when FDD is uplink and TDD is uplink (downlink)
$M_{TDD}^{up-up(down)}$	Total number of users in the TDD when FDD is uplink and TDD is uplink (downlink)
$I_{FDDtoTDD}^{up-up(down)}$	Interference from the FDD cell BS to the TDD cell BS when FDD is uplink and TDD is uplink (downlink)
M_{FDD}^{up}	Total number of users in the FDD uplink
$R_{FDD}(R_{TDD})$	Radius of macrocell (microcell)
$\theta_{FDD}(\theta_{TDD})$	Degrees of an angle of macrocell (microcell)
$P_{FDD}(P_{TDD})$	Required received power at uplink in the FDD (TDD) BS
$P_{TDD,max}$	Downlink transmission power in the TDD BS
$N_{up}(N_{down})$	Number of uplink (downlink) slots in one frame
γ	Ratio of traffic channels to total Tx channels
$1-\gamma$	Ratio of control channels to total Tx channels
$\gamma\phi_i$	Power of traffic channel i in the TDD
h	Orthogonal factor
L_i	Path loss of ith mobile in the TDD mode
d	Distance between FDD BS and TDD BS

assumed that every slot is equally and symmetrically loaded in one frame. Note, however, that this paper ignores the background noise and the shadowing effect to simplify (1), and since the activity factor belongs to the data, it is set as 1. The second term of the denominator in (1) corresponds to the other-cell interference, which can be expressed as (2).

$$I_{FDDtoTDD}^{up-up} = \frac{M_{FDD}^{up} P_{FDD}}{(\pi R_{FDD}^2 - \pi R_{TDD}^2)} \Big(\int_0^{2\pi} \int_0^{R_{FDD}} (\frac{R}{R_0})^4 R dR d\theta_{FDD} - \int_{-\cos^{-1}(\frac{R^2+d^2-R_{TDD}}{2Rd})}^{\cos^{-1}(\frac{R^2+d^2-R_{TDD}}{2Rd})} \int_{d-R_{TDD}}^{d+R_{TDD}} (\frac{R}{R_0})^4 R dR d\theta_{FDD} \Big) \quad (2)$$

where

$$R_0 = \sqrt{R^2 + d^2 - 2Rd\cos\theta_{FDD}} \quad (3)$$

The carrier-to-interference ratio $(C/I)_{TDD}^{up-up}$ is obtained by dividing (1) by the spreading factor, which is given as (4).

$$(C/I)_{TDD}^{up-up} = \frac{P_{TDD}}{P_{TDD}(\frac{M_{TDD}^{up-up}}{N_{up}} - 1) + I_{FDDtoTDD}^{up-up}} \quad (4)$$

Thus, if (4) is expressed as a function of M_{TDD}^{up-up}, the capacity in the TDD uplink of case 1 can be (5).

$$M_{TDD}^{up-up} = N_{up}(\frac{1}{(C/I)_{TDD}^{up-up}} + 1 - \frac{M_{FDD}^{up} I_{FDDtoTDD}^{up-up}}{P_{TDD}}) \tag{5}$$

Fig. 2 shows the interference in the TDD downlink of case 2. The calculation of the other-cell interference in Fig. 2 is similar to that of the other-cell interference in Fig. 1. As it is assumed that all MSs in the TDD have a uniform distribution, the same-cell interference in Fig. 2 using the following method can be calculated.

This paper firstly calculates the interference on a MS in the TDD by a BS in the TDD and then the interference on other MSs in the TDD from the BS in the TDD. The bit energy-to-noise density ratio $(E_b/N_0)_T^{up-down}$ in the TDD downlink of case 2 can be (6).

$$(E_b/N_0)_{TDD}^{up-down} = \frac{\gamma \phi_i L_i}{(1-\gamma\phi_i) h L_i \frac{R_{TDD}^{down}}{B} + I_{FDDtoTDD}^{up-down} \frac{R_{TDD}^{down}}{B}} \tag{6}$$

where R_{TDD}^{down} is the downlink data rate for a TDD cell. r_0 and R_0 in Fig. 2 is (7) and (8).

$$r_0 = \sqrt{r^2 + d^2 - 2rd\cos\theta_{TDD}} \tag{7}$$

$$R_0 = \sqrt{R^2 + {r_0}^2 - 2Rr_0\cos\theta_{FDD}} \tag{8}$$

The other-cell interference can be (9).

$$I_{FDDtoTDD}^{up-down} = \frac{M_{FDD}^{up} P_{FDD}}{(\pi R_{FDD}^2 - \pi R_{TDD}^2)} (\int_0^{2\pi} \int_0^{R_{FDD}} (\frac{R}{R_0})^4 R dr d\theta_{FDD} - \int_{-\cos^{-1}(\frac{R^2+d^2-RTDD}{2Rd})}^{\cos^{-1}(\frac{R^2+d^2-R_{TDD}}{2Rd})} \int_{d-R_{TDD}}^{d+R_{TDD}} (\frac{R}{R_0})^4 R dr d\theta_{FDD}) \tag{9}$$

Therefore, if (6) is expressed as a function of $M_{TDD}^{up-down}$, the capacity in the TDD downlink of case 2 can be (10).

$$M_{TDD}^{up-down} = \frac{\gamma}{(C/I)_{TDD}^{up-down}(h + \frac{1}{\pi {R_{TDD}}^2} \int_0^{2\pi} \int_0^{R_{TDD}} (\frac{I_{FDDtoTDD}^{up-down}}{L_i}) r dr d\theta_{TDD})} \tag{10}$$

Table 3. Fixed parameters for simulation

Parameter	Value	Unit
R_{FDD}	1000	m
R_{TDD}	50	m
P_{FDD}	-132.3	dB
P_{TDD}	-122.5	dB
$P_{TDD,max}$	-33.0	dB
$(C/I)_{TDD}$	-8.5	dB
h	0.2	
γ	0.9	
d	300	m
Bandwidth	5	MHz

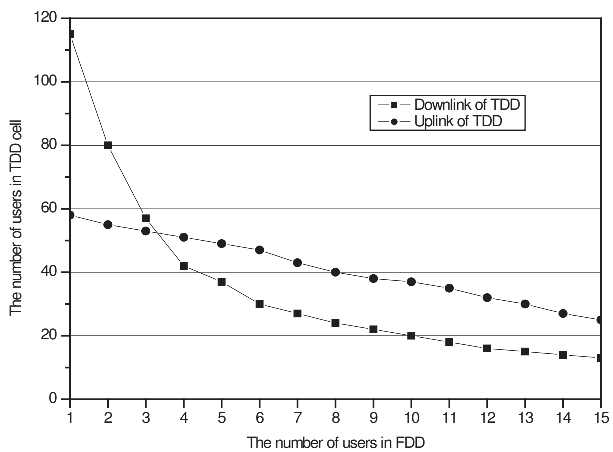

Fig. 5. Comparison of the uplink and downlink capacities of the TDD system where the ratio of slots is the same (downlink : uplink = 7 : 7)

4 Result and Discussion

In this section, this paper calculates the capacities for uplink and downlink of the TDD system using the equations illustrated in section 3. The simulation parameters used are summarized in Table 3. The values of P_{FDD}, P_{TDD}, and $P_{TDD,max}$ are determined from a simulation. In Fig. 5, let us examine the situation, where the ratio of slots is the same between uplink and downlink; that is, the uplink slot number (N_{up}) is 7 and the downlink slot number (N_{down}) is also 7 among all 14 slots for data in one frame. This paper performs the following simulation with the values of parameters in Table 3. Therefore, the result of the simulation with these conditions can be discussed in this paper. To compare the capacities of downlink and uplink in the TDD cell, the number of users in the TDD cell is examined, as the number of users in the FDD cell increases. In Fig. 5,

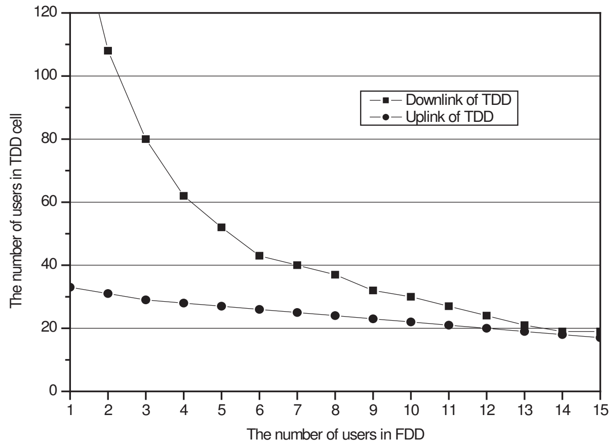

Fig. 6. Comparison of the uplink and downlink capacities of TDD system where the ratio of slots are different (downlink:uplink=10:4)

as the number of users in the FDD uplink increases, the number of users in each of the TDD uplink and downlink is decreased. For instance, as the number of users in the FDD uplink increases by a range of 4 to 12, the number of users in the TDD uplink decreases by a range of 50 to 30. In the case of the TDD downlink, similar results are acquired. When the number of the FDD users is smaller than 4, the TDD cell capacity is limited by the uplink. On the contrary, it can be noted that, with these results, the capacity of the downlink is limited when the number of users in the FDD ranges from 4 to 15. This result shows that, in the case of asymmetric traffic, as a great number of resource wastes occur, the number of downlink slots in one frame for the TDD cell should be increased.

In Fig. 6, this paper considers the other situation, where the ratio of slots are asymmetric between uplink and downlink; that is, the number of uplink slots (N_{up}) is 4 and the number of downlink slots (N_{down}) is 10 among 14 slots for data in one frame. Like Fig. 5, Fig. 6 shows that as the number of users in the FDD system increases, the number of uplink and downlink users in the TDD system decreases. When the number of users in the FDD system ranges from 4 to 7, if the asymmetric ratio of downlink and uplink traffic is 2:1, the resource waste is nearly non-existent. Therefore, this paper shows the fact that the asymmetric slot allocation can maximize the whole system capacity and the resource waste problem due to asymmetric traffic characteristics are improved.

5 Conclusion

The proposed modeling can be adopted for the situation in which the service is asymmetric between uplink and downlink. The coverage of the TDD system will be smaller for low and medium data rate services than the comparable FDD service. To avoid interference, furthermore, the smaller cells are better choices. Therefore, the TDD system is most suitable for small cells with high data rate services. In this paper, considering the other-cell interference from the FDD uplink and the same-cell interference in the TDD cell from a standpoint of the TDD cell, the capacities of uplink and downlink which belong to the TDD cell are investigated. The results indicate that the capacity of the TDD system may be limited by any link of the TDD cell as a microcell in the case of sharing the FDD uplink band as a macrocell.

In many services of the next generation mobile communication system, it is obvious that asymmetric traffic characteristics will exist between uplink and downlink. The overall capacity will be maximized in the TDD cell as long as the ratio of the number of slots used by the frame in the TDD cell is controlled to maximally apply the asymmetry between uplink and downlink in line with the characteristics of the service used in the TDD cell. According to the results, it has to be pointed out that the asymmetric slot allocation between uplink and downlink in the TDD cell utilizing the underused FDD uplink which shares the same frequency band plays an important role in planning of the hierarchical cell structures.

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