Combination of Dynamic-TDD and Static-TDD Based on Adaptive Power Control

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Abstract—To support dynamic traffic-asymmetry property in future wireless communication systems, we propose a hybrid-TDD scheme, combination of static-TDD and dynamic-TDD. By using adaptive power control, inner/outer scheduling and hybrid-link for guaranteeing safe downlink/uplink time-slots, we can effectively solve the interference problems of the dynamic-TDD scheme. Especially, an adaptive downlink power control strategy in hybrid-link region can efficiently reduce severe BS-BS interference compared with other conventional schemes. Through numerical analysis and simulation results, we prove that our proposed scheme has the best performance compared with other conventional schemes in view of spectral efficiency and downlink/uplink outage probability.

I. INTRODUCTION

The next-generation wireless communication systems should support various multimedia services, such as voice over IP (VoIP), video streaming, interactive gaming and peer-to-peer (P2P) file transfer, etc. Because of these various multimedia services, the traffic asymmetry property will be very remarkable in future wireless communication systems. In this environment, a duplex scheme could be the key solution for supporting the traffic asymmetry property [1]. There are two major duplex schemes, such as frequency division duplex (FDD) and time division duplex (TDD). Especially, in TDD, a proportion of downlink and uplink regions could be instantaneously changed according to the traffic asymmetry property. So, the TDD scheme can be used for supporting the traffic asymmetry property in future wireless communication systems [1]−[7].

The TDD scheme can be further divided into as follows: static-TDD (S-TDD) and dynamic-TDD (D-TDD). Firstly, in the S-TDD scheme, since the proportion of the numbers of downlink and uplink time-slots is fixed, downlink and uplink time-slots among adjacent cells do not cross. Hence, there are only two types of interferences, such as mobile station (MS)-base station (BS) (from MS to BS) interference and BS-MS interference. The MS-BS interference is caused by MSs in their uplink cycle included in adjacent cells when a reference cell is in its downlink cycle, and the BS-MS interference is caused by adjacent BSs in their downlink cycle when a reference cell is in its uplink cycle.

Secondly, in the D-TDD scheme, since the proportion of the numbers of downlink and uplink time-slots is variable, the downlink/uplink crossed regions occur among adjacent cells. Thus, besides MS-BS and BS-MS interferences, there are two additional interferences, such as MS-MS interference and BS-BS interference. The MS-MS interference is caused by MSs in their uplink cycle included in adjacent cells when a reference cell is in its downlink cycle, and the BS-BS interference is caused by adjacent BSs in their downlink cycle when a reference cell is in its uplink cycle as shown in Fig. 1.

In D-TDD, the MS-MS and BS-BS interferences cause severe performance degradation [2]−[7]. That is, in case of the MS-MS interference, downlink signal-to-interference-plus-noise ratio (SINR) values of boundary MSs in a reference cell are decreased due to uplink transmissions of boundary MSs in adjacent cells. In addition, in case of the BS-BS interference, uplink SINR values of all MSs in a reference cell are also severely decreased due to the downlink transmissions of adjacent BSs. In this case, the performance degradation is serious, because the transmission power of the BS is very strong compared with the power of the MS [6]. Therefore, just to support traffic-asymmetry property, if we use D-TDD, we would obtain the worst performance compared with S-TDD.
To solve the problems of D-TDD scheme (BS-BS and MS-MS interferences), several schemes were proposed. However, these schemes mainly focused on solving the problem of MS-MS interference [1]–[5]. To solve the problem of BS-BS interference, W. Jeong and M. Kavehrad used sectored antennas and adaptive-array antenna [6]. Also, J. Nasreddine and X. Lagrange proposed optimal downlink and uplink power control scheme [7]. However, in this scheme, the BS-BS and MS-MS interferences can be induced in every time-slot. There are no safe time-slots against the BS-BS and MS-MS interferences. Therefore, we propose a hybrid-TDD (H-TDD) scheme that can efficiently solve the problems of D-TDD. We prove that our proposed scheme performs better compared with other previous works including the pure S-TDD and D-TDD schemes, regardless of traffic-asymmetry condition.

The remainder of this paper is organized as follows: In Section II, we introduce the basic concept of our proposed scheme and strategies for mitigating the MS-MS and BS-BS interferences. In Section III and IV, we analyze and simulate the performance of downlink/uplink SINR, outage probability, and spectral efficiency of the conventional and proposed schemes. Finally, in Section V, we make conclusions.

II. PROPOSED SCHEME

Fig. 2 shows a frame structure of our proposed scheme. The frame of hybrid-TDD consists of downlink, hybrid-link (HDL) and hybrid-uplink (HUL) and uplink. Our proposed scheme is a combination of the S-TDD and D-TDD schemes. In downlink and uplink regions, our proposed scheme operates as the S-TDD scheme, and in hybrid-link region, our scheme operates as the D-TDD scheme based on adaptive downlink power control. In hybrid-link region, a proportion of the downlink and uplink time-slots would be adaptively changed. Here, the downlink and uplink regions in hybrid-link are represented by hybrid downlink (HDL) and hybrid uplink (HUL). In hybrid-link region, since the proportion of downlink and uplink regions is variable, the downlink and uplink transmissions would be crossed among adjacent cells. Hence, the problems of the MS-MS and BS-BS interferences will occur in the hybrid-link. In our proposed scheme, to solve these problems in hybrid-link, we apply two strategies as follows.

A. Adaptive Downlink Power Control

Adaptive downlink power control is our major contribution in this paper. By using this strategy, we can effectively solve the problem of uplink performance degradation due to the severe BS-BS interference. In the hybrid-link region, when the reference cell is in the uplink cycle, the SINR values of MSs in the reference cell would be decreased due to the strong interferences of adjacent BSs in the downlink cycle. Since the BS transmission power is very stronger than the normal MS transmission power, uplink performance degradation is very serious. In general, the BS power level ($P_{t,BS}$) is about $43dBm$, and the MS power level ($P_{t,MS}$) is about $20$–$23 dBm$. Namely, $P_{t,BS} \geq 100 \times P_{t,MS}$. So, although the distance between a BS interferer and a receiver is farther than the distance between a MS transmitter and the receiver, this interference problem is very serious.

In our proposed scheme, to solve the BS-BS interference problem in the hybrid-link region, we apply an adaptive downlink power control strategy. The transmission power of the BS in the hybrid-link region ($P_{t,BS,hd}$) is calculated by

$$P_{t,BS,hd} = \sum_j f(d_{i,j}, l_j) \times P_{t,BS}. \quad (1)$$

subject to

$$0 \leq \sum_j f(d_{i,j}, l_j) \leq 1. \quad (2)$$

Here, $d_{i,j}$ is the distance between the reference BS $i$ and the adjacent BS $j$, and $l_j$ indicates whether the link status of the BS $j$ is downlink or not. If the link status of the BS $j$ is downlink, $l_j = 1$, otherwise $l_j = 0$. In detail, $f(d_{i,j}, l_j)$ can be represent as

$$f(d_{i,j}, l_j) = \begin{cases} \alpha & , 0 \leq d_{i,j} \leq 2R, l_j = 1 \\ \delta \cdot \alpha & , 2R < d_{i,j} \leq 4R, l_j = 1 \\ 0 & , otherwise \end{cases} \quad (3)$$

In equation (3), $R$ is a radius of a cell, and $\alpha$ is a scaling factor to reduce the BS transmission power. Also, $\delta$ is a weighting factor for $\alpha$. $\delta$ can control the influences of the BSs which are far from the reference BS $i$.

We consider the influences of 1st-tier interferers and 2nd-tier interferers differently, because the influences of the 1st-tier interferers are major. By the fine adaptation of $\alpha$ and $\delta$, we can obtain the optimal cell capacity. If there are few downlink cells, to enhance the SINR value of the uplink users in view of total capacity maximization, we should set the value of $\sum_j f(d_{i,j}, l_j)$ as a small value by the adjustment of $\alpha$ and $\delta$. On the contrary, if there are lots of downlink cells, the value of the scaling function $\sum_j f(d_{i,j}, l_j)$ have to be set as a large value to increase the SINR value of downlink users in view of total capacity maximization. Since the interferences caused by the BSs’ transmissions are very remarkable, the elaborate adjustment of the BSs’ transmission power is very important.

In summary, through the fine adjustment of the BS transmission power, in case of the uplink cells, the UL SINR
values will be increased remarkably. We can show this effect in simulation results. In addition, in case of the downlink cells, since the transmission power is reduced, the SINR values of the users might be decreased. However, since the interference level as well as the transmission power is reduced together, the reductions of the SINR values are negligible. Therefore, in our proposed scheme, we can efficiently solve the BS-BS interference problem by the adaptive downlink power control.

B. Inner/outer Scheduling Algorithm

In the D-TDD scheme, owing to the MS-MS interference problem, the SINR values of the boundary MSs in the downlink cycle would be severely decreased. Thus, downlink outage probability of cells will be rapidly increased. In our proposed scheme, to solve the problem of MS-MS interference problem, we use inner/outer scheduling algorithm [2]–[4]. Although the conventional schemes already applied inner/outer scheduling algorithm for solving the MS-MS interference problem, there is a little difference in our proposed scheme. The proposed scheme applies the inner/outer scheduling just for the hybrid-link. The reason is that there are no BS-BS and MS-MS interferences except the hybrid-link region.

Through the inner/outer scheduling algorithm, downlink and uplink time-slots would be used by outer-cell MSs, and hybrid-link time-slots would be used by inner-cell MSs. That is, we can solve the downlink performance degradation by the MS-MS interferences. In addition, in the hybrid-link, since the only inner-MSs of cells in the uplink cycle would be interfered by adjacent BSs, the uplink outage probability would be enhanced compared with the dynamic-TDD scheme.

III. Numerical Analysis

To analyze the proposed scheme, we assume that each timeslot of the MAC frame is used just for one user. The total number of time-slots is $M$, and the number of downlink, hybrid-downlink, hybrid-uplink, and uplink time slots are $M_D$, $M_{HD}$, $M_{HU}$, and $M_U$, respectively.

A. SINR

In general, SINR ($\gamma$) is given by

$$\gamma = \frac{P_r}{N_0 + I}. \quad (4)$$

Here, $P_r$, $I$, and $N_0$ are received power, interference power, and noise power, respectively. $P_r$ and $I$ are represented by $P_r = P_l \cdot K \cdot \left(\frac{d_0}{d} \right)^\nu \cdot \psi$ and $I = \sum_{i \neq ref} P_{i,i} \cdot K_{i} \cdot \left(\frac{d_0}{d} \right)^\nu \cdot \psi_i$, respectively. $P_l$ is transmitted power, $K$ is a unitless constant which depends on antenna characteristics and average channel attenuation, $d$ is a distance between a transmitter and a receiver, and $d_0$ is a reference distance for antenna far-field [8]. Also, $\nu$ and $\psi$ are a path-loss exponent and a random variable representing the shadowing effects in propagation, respectively. $\psi$ is a Gauss-distributed random variable with mean zero and variance $\sigma^2_\psi$. In detail, user-SINRs in the reference cell for downlink, hybrid-downlink, hybrid-uplink, and uplink ($\gamma_{dl}$, $\gamma_{hdl}$, $\gamma_{hdl}$, $\gamma_{ul}$) can be calculated as follows.

1) Downlink:

$$P_{r,dl} = P_{l,BS} K \cdot \left(\frac{d_0}{d_{ref, BM}}\right)^{\nu_{BM}} \cdot \psi_{BM} \cdot a_{ref} (1 - b_{ref}). \quad (5)$$

$$I_{dl} = \sum_{i \neq ref} P_{l,BS,i} \cdot K_i \cdot \left(\frac{d_0}{d_{i, BM}}\right)^{\nu_{BM}} \cdot \psi_{i, BM} \cdot a_i \cdot (1 - b_i). \quad (6)$$

Here, $P_{r,dl}$ is the received power of the MS, and $I_{dl}$ is the interference power of the MS. Also, $P_{l,BS}$ is the transmission power of the BS, and sub-words ‘ref’ and ‘BM’ are the abbreviations of ‘reference’ and ‘from the BS to the MS’, respectively. In equation (5) and (6), $a_i$ means whether the corresponding time-slot is used ($a_i=1$) or not ($a_i=0$), and $b_i$ means that current time-slot is downlink ($b_i=0$) or uplink ($b_i=1$). Thus, through equation (4), $\gamma_{dl}$ can be calculated by

$$\gamma_{dl} = \frac{P_{r,dl}}{N_0 + I_{dl}}. \quad (7)$$

2) Hybrid-downlink: $P_{r,hd} = P_{r,dl}$, and $I_{hd}$ is described as

$$I_{hd} = \sum_{i \neq ref} \sum_{j \neq ref} f(\cdot) \cdot P_{l,BS,i,j} \cdot K_{i,j} \cdot \left(\frac{d_0}{d_{i,j, MM}}\right)^{\nu_{i,j, MM}} \cdot \psi_{i,j, MM} \cdot a_i \cdot (b_i). \quad (8)$$

In equation (7), $f(\cdot)$ is a scaling factor for the BS transmission power, and $0 \leq \sum f(\cdot) \leq 1$. $f(\cdot)$ could be fixed or variable. When $f(\cdot)$ is a fixed value, the system operation can be simpler than the variable case. Otherwise, the system performance can be improved compared with the fixed case. In the ‘variable’ case, according to the ratio of the total number of cells to the number of downlink cells, $\sum f(\cdot)$ is adjusted. In the hybrid-downlink, through equation (4), $\gamma_{h}d$ is obtained by

$$\gamma_{h}d = \frac{P_{r,hd}}{N_0 + I_{hd}}. \quad (9)$$

3) Hybrid-uplink:

$$I_{hu} = \sum_{i \neq ref} \sum_{j \neq ref} f(\cdot) \cdot P_{l,MS,i,j} \cdot K_{i,j} \cdot \left(\frac{d_0}{d_{i,j, MB}}\right)^{\nu_{i,j, MB}} \cdot \psi_{i,j, MB} \cdot a_i \cdot (b_i). \quad (10)$$

Here, $P_{r,hu}$ is the received power of the BS, and $I_{hu}$ is the interference power of the BS. From equation (8) and (9), $\gamma_{hu}$ is calculated by $\gamma_{hu} = \frac{P_{r,hu}}{N_0 + I_{hu}}$.

4) Uplink: $P_{r,ul} = P_{r,hu}$, and $I_{ul}$ is

$$I_{ul} = \sum_{i \neq ref} \sum_{j \neq ref} P_{l,MS,i,j} \cdot K_{i,j} \cdot \left(\frac{d_0}{d_{i,j, MB}}\right)^{\nu_{i,j, MB}} \cdot \psi_{i,j, MB} \cdot a_i \cdot b_i. \quad (11)$$

Hence, $\gamma_{ul}$ is represented by $\gamma_{ul} = \frac{P_{r,ul}}{N_0 + I_{ul}}.$
Among conventional schemes, the DTSA algorithm means the best performance regardless of traffic asymmetry conditions. Through the simulation results, we can prove that our proposed scheme has the better SINR values compared with other conventional schemes. However, since the interference level as well as the transmission power is reduced together, the decrement of the SINR values is not remarkable. Also, as shown in empirical uplink SINR CDF in Fig. 3, we can show that the dynamic-TDD scheme and the DTSA algorithm have much smaller SINR values compared with our proposed scheme. These performance degradation in the dynamic-TDD scheme and the DTSA algorithm is caused by BS-BS interference. On the contrary, as shown in Fig. 3, by using adaptive downlink power control scheme, we can show that our proposed scheme can solve the BS-BS interference problem.

B. SINR

1) DL:UL = 1:1: As shown in empirical downlink SINR CDF in Fig. 3, since our proposed scheme reduces the BS power level in hybrid-downlink region, the downlink SINR values in our proposed scheme are slightly decreased compared with other conventional schemes. However, since the interference level as well as the transmission power is reduced together, the decrement of the SINR values is not remarkable. Also, as shown in empirical uplink SINR CDF in Fig. 3, we can show that the dynamic-TDD scheme and the DTSA algorithm have much smaller SINR values compared with our proposed scheme. These performance degradation in the dynamic-TDD scheme and the DTSA algorithm is caused by BS-BS interference. On the contrary, as shown in Fig. 3, by using adaptive downlink power control scheme, we can show that our proposed scheme can solve the BS-BS interference problem.

2) DL:UL = 1:3: The static-TDD scheme has the best SINR CDF compared with other schemes. In this traffic environment, since the capacity of downlink frame is much larger than the downlink traffic that has to be serviced, the total interference level is very small. On the contrary, in case of uplink cycle in the static-TDD scheme, since the capacity of uplink frame is much smaller than the uplink traffic that has to be serviced, much uplink traffic would be dropped, as shown in empirical uplink SINR CDF in Fig. 4. Thus, the uplink spectral efficiency will be severely degraded. In addition, similar to 1:1 case, by using adaptive downlink power control scheme, our proposed scheme has better SINR values compared with the dynamic-TDD scheme and the DTSA algorithm.

3) DL:UL = 3:1: All schemes have the similar SINR values, as shown in empirical downlink SINR CDF in Fig. 5. But, in the static-TDD scheme, since the capacity of downlink frame is much smaller than the downlink traffic that has to be serviced, much downlink traffic cannot be serviced. Thus, downlink spectral efficiency will be degraded. Also, similar to 1:1 case, as shown in empirical uplink SINR CDF in
Fig. 5, we can show that the dynamic-TDD scheme and the DTSA algorithm have much smaller SINR values compared with our proposed scheme and the static-TDD scheme. These performance degradations in the dynamic-TDD scheme and the DTSA algorithm are caused by BS-BS interference. In this figure, we can show that, by using adaptive downlink power control scheme, our proposed scheme can solve the BS-BS interference problem. Also, in this traffic environment, since the uplink capacity of static-TDD is much larger than the uplink traffic that has to be serviced, the total interference level is very small. So, the static-TDD scheme has the best SINR CDF compared with other schemes.

C. Outage probability

From Fig. 6, we can show that our proposed scheme decreases the downlink outage probability compared with the dynamic-TDD scheme and the DTSA algorithm, by applying the hybrid-link and the inner/outer scheduling algorithm. Also, in case of the uplink outage probability, owing to severe BS-BS interference problem, the dynamic-TDD scheme and the DTSA algorithm have very high outage probability values compared with the static-TDD scheme. On the contrary, we prove that our proposed scheme can remarkably enhance the uplink outage probability by applying the adaptive downlink power control strategy, as shown in Fig. 7.

D. Spectral efficiency

In case that the DL/UL frame ratio is similar to the DL/UL traffic generation ratio, the static-TDD scheme has the good performance. But, in the other cases of traffic asymmetry, the spectral efficiency of the static-TDD scheme is severely degraded compared with our proposed scheme, because the frame ratio is fixed. Compared with the DTSA-algorithm and the static-TDD scheme, the dynamic-TDD scheme has larger spectral efficiency regardless of the variation of DL/UL traffic asymmetry. However, uplink outage probability of dynamic-TDD scheme is the highest compared with other schemes, as shown in Fig. 7. In case of the DTSA-algorithm, although this algorithm has lower outage probability compared with the dynamic-TDD scheme, the spectral efficiency of the DTSA algorithm is smaller than that of the dynamic-TDD scheme. So, we cannot say that the DTSA algorithm is a solution of MS-MS and BS-BS interference problems.

However, as shown in Fig. 8, we can show that our proposed scheme has the largest spectral efficiency compared with other schemes, regardless of traffic asymmetry conditions. In addition, our proposed scheme has lower outage probability compared with the dynamic-TDD scheme and the DTSA algorithm.

V. CONCLUSIONS

In this paper, to solve the problems of MS-MS and BS-BS interferences in the dynamic-TDD schemes, we have applied adaptive downlink power control, hybrid-link, and inner/outer scheduling. Through these strategies, we have effectively solved the problem of the dynamic-TDD system, and obtained the better spectral efficiency and outage probability compared with the static-TDD scheme, the dynamic-TDD scheme and the DTSA algorithm. Consequently, we can conclude that our proposed scheme, hybrid-TDD, is the best available in view of supporting traffic asymmetry property in next-generation wireless communication systems.

REFERENCES