

# An Interference Reduction Strategy for TDD-OFDMA Cellular Systems

Koudjo M. Koumadi, Kester Quist-Aphetsi, Robert A. Sowah, Amevi Acakpovi

**Abstract**—Downlink/Uplink (DL/UL) time slot allocation (TSA) in time division duplex (TDD) systems is generally uniform for all the cells. This TSA however is not efficient in case of different traffic asymmetry ratios in different cells. We first propose a new 3-coordinate architecture to identify cells in an orthogonal frequency division multiple access (OFDMA) system where each cell is divided into three sectors. Then, this coordinate system is used to derive a TSA for symmetric traffic. Mathematical analysis and simulations are used to show that the proposed TSA outperforms the traditional all uniform type of TSA in terms of total intercellular interference, even under uniform symmetrical traffic. Two adaptation strategies are further proposed to adjust the proposed TSA to asymmetrical traffic with different DL/UL traffic ratios in different cells. Further simulation results show that the adaptation strategies also yield higher signal-to-interference ratio (SIR).

**Keywords**—Crossed TSA, different-entity interference, same-entity interference, uniform TSA.

## I. INTRODUCTION

TDD has gained a lot of attention in recent years and is even part of the OFDMA-based long term evolution (LTE) advanced standards [1]. This is due to numerous advantageous features it presents, as compared to frequency division multiplexing (FDD). Among these features, the ability to dynamically adapt the allocated DL/UL time slot (TS) ratio to the actual traffic asymmetry ratio in the system. For current long term evolution (LTE) and next generation mobile communications systems, not only is the traffic asymmetric, but also adjacent cells may have different traffic asymmetry requirements. However, severe eNodeB (eNB) to eNB and user equipment (UE) to UE interference occurs if adjacent cells operate in opposite DL/UL direction and if omni-directional antennas are used at the eNBs. This issue has attracted large amount of research publications, most designing techniques to mitigate these same entity interference types and take advantage of the dynamic time slot possibility offered by TDD. In [2], the authors proposed a decentralized algorithm based on interference-aware dynamic channel allocation and space-time linear mean-square estimation to achieve improved average throughput as compared to the traditional fixed channel allocation. The work was based on

code division multiple access (CDMA) systems and cannot address OFDMA systems due to some CDMA-specific parameters used in the derivation of the scheme. References [3]-[5] treated TDD-related interference in OFDMA and LTE systems. Reference [4] achieved reduced inter-cell interference by protecting transmission through a sounding/silencing protocol based on signal to interference ratio prediction. While carrier sensing was used in [6] to reach a reduction of inter-cell interference, [3] positively used UE to UE interference to improve coarse frame synchronization in OFDMA-TDD systems.

In the early days of TDD interference mitigation research, several novel strategies were proposed and many of them are the backbones of newly designed algorithms. Very early works suggested that all the cells in a TDD system operate in a DL/UL synchronized way, [7] and [8]. However, this strategy could not support different traffic asymmetry ratios in adjacent cells and time slots are used in an inefficient way. Smart antennas at the base stations (BS) were identified in [9] as a good solution to suppress the same entity interference introduced by TDD systems. Hybrid division duplexing (HDD) were proposed and [10] used TDD strategies to mitigate interference in systems. Cell-sectorization with directional BS (eNB) antennas is another option [11]. References [12] and [13] proposed an interference averaging approach by randomly opposing transmission directions throughout the system. This approach might have serious implementation problems because it suggests multiple switching points between DL and UL operations within a single frame. In [14] and [15], a cell is divided into two zones (inner zone and outer zone) and inter-zone TSA is used. This technique also presents difficulties in real systems because the zone limits might not be easy to find accurately.

In sum, although many research works have been done on TDD interference reduction, there is still room for improvement in order to optimize TDD systems' performance. The strategies mentioned above present implementation difficulties despite the fact that they show great improvement in system performance.

The use of sectors with directional antennas is a well mastered technique in the industry. In this paper, A TSA strategy is proposed which is based on tri-sector cells environment, in which the three sets of sectors use different sets of OFDMA sub-channels. In this environment, co-channel interference occurs only within each set. Even in a sectorized-cell environment however, time slot allocation strategies play a key role in intercellular interference reduction and in radio resource allocation for efficiency. The tri-sector environment

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presents a mutated interference scenario in which the traditional all-uniform DL/UL TSA is inefficient in terms of SIR. For symmetric traffic, we divide the cells (sectors) in two groups. Within each group, the DL/UL operation is uniform while the two groups have opposite DL/UL transmission directions. In case of asymmetric traffic, especially for different traffic asymmetry requirements, two adaptation strategies are proposed to increase time slot efficiency and throughput.

The remainder of this paper is organized as follows: Section II presents the new system environment and interference scenarios. The proposed framework and TSA scheme are also presented in this section, along with some analysis. Section III presents simulation results showing achieved SIR improvements for both symmetric and asymmetric traffic. Section IV concludes the paper.

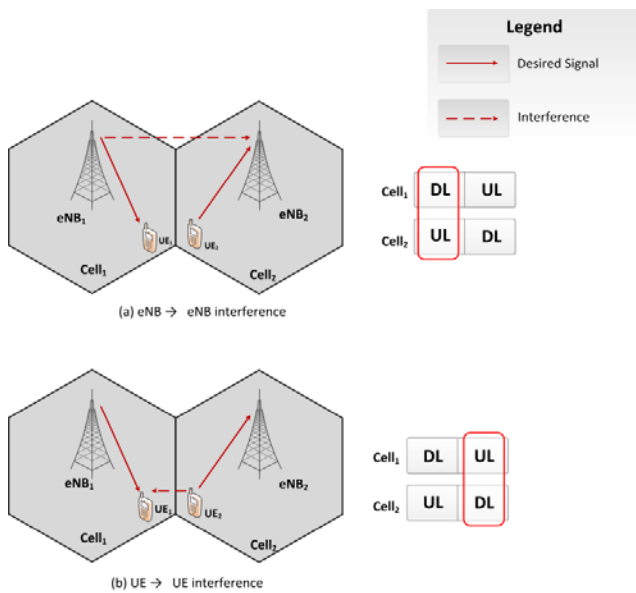


Fig. 1 Same entity interference in crossed TSA

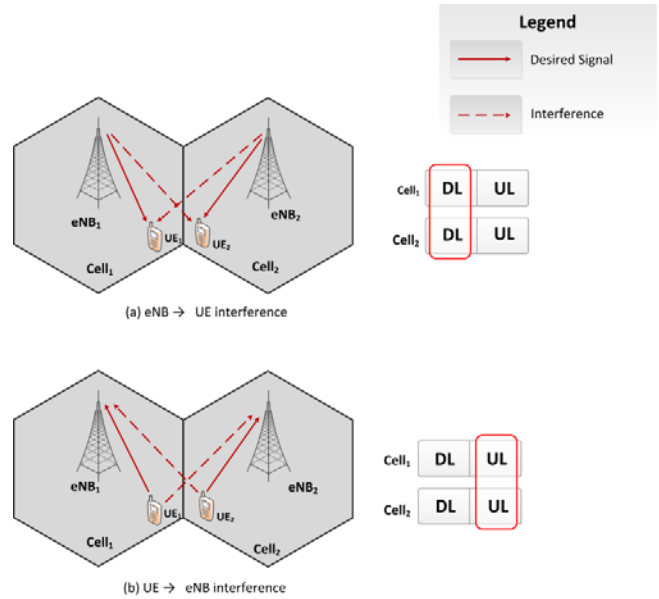


Fig. 2 Different-entity interference in uniform TSA

## II. PROPOSED FRAMEWORK AND TIME SLOT ALLOCATION SCHEMES

### A. Interference Scenarios in TDD Systems

In a multi-cell TDD systems with frequency reuse factor of 1, there are two types of severe inter-cell interference: the different-entity (eNB to UE and UE to eNB) interference when adjacent cells operate in uniform DL/UL TSA, as shown in Fig. 2, and same-entity (eNB to eNB and UE to UE) interference when adjacent cell operate crossed (opposite) DL/UL TSA, as shown in Fig. 1. In Fig. 2 (a), when both cells are in DL transmission and UEs are at the edge of their respective cells, the eNB1's transmission to UE1 will interfere with UE2's reception from eNB2 and vice versa. When both cells are in UL (Fig. 2 (b)), eNB1's reception of UE1's signal is interfered by UE2's UL transmission to eNB2. On the other hand, if two adjacent cells operate in crossed DL/UL TSA, as shown in Fig. 1, assuming that cell1 operate in DL while cell2 operate in UL, UE1's reception is seriously interfered by UE2's UL transmission to eNB2 (Fig. 1 (a)). At the same time eNB2's reception of UE2's signal is even more severely interfered by eNB1's transmission to UE1, given the very likely line of sight (LOS) between the two eNBs.

From the above description, it can be observed that the crossed DL/UL TSA leads to the most serious interference situation as the pathloss between the interferer and the victim tends to be weaker, as compared to the uniform transmission case. This is one of the main reasons why TDD operation in early days adopted only uniform TSA across all cells, as suggested in [7] and [8]. This approach was challenged as traffic became more and more asymmetric (more data in DL than UL, and vice versa) with different asymmetry in adjacent cells and systems had to take advantage of the dynamic DL/UL TSA offered by TDD. It will be shown in this paper that even with symmetric traffic, our proposed TSA scheme performs better than the all-uniform TSA.

**B. Proposed Framework and New Interference Scenarios**

Fig. 3 presents the proposed system description. Every cell has three sectors and the angle covered by each sector is 120 degrees. All the sectors in each of the three sector sets share the same group of sub-channels. This means that in each single cell, the total number of available OFDMA sub-carriers is divided into three parts. Each part is allocated to a single sector in the cell. This same configuration is repeated in each and every cell according to Fig. 3, yielding a frequency reuse factor of 1. The sectors with the same filling (striped, blank, or gray) use the same set of sub-carriers.

To better describe the directivity of the interference when sectorization is used, the traditional tier-based cell description is not used. Instead, we use a normal axis for each set of sectors ( $k, m, n$  axis). Without loss of generality, this description concentrates only on the sector set related to the  $k$ -axis. The same reasoning, logic and conclusions are applicable to the other two sets. Each sector is identified by its ordinate (e.g. the value of  $k$ ) on the corresponding axis and by its position  $j$  on the line  $k$  it belongs to. As an example, the sector in white ( $k$ -axis) in cell 1 on Fig. 3 is identified as sector  $(k, 3, 0)$  meaning  $j = 3$  on  $k = 0$  axis. All the sectors are equipped with directional antennas at the eNBs. The UEs have omni-directional antennas. In a frame, there is only one switching point between downlink and uplink time slots.

For the TDD environment described above, the potential interferences (no specific TSA is considered) are: eNB( $k1$ ) to UE( $k0$ ), UE( $k0$ ) to eNB( $k1$ ) for any  $k0$  and  $k1$  such that  $k0 < k1$ ; and eNB( $k$ ) to UE( $k$ ) for any  $k$ . We assume that eNB to eNB interference is basically eliminated or significantly reduced by sectorization and directional antennas.

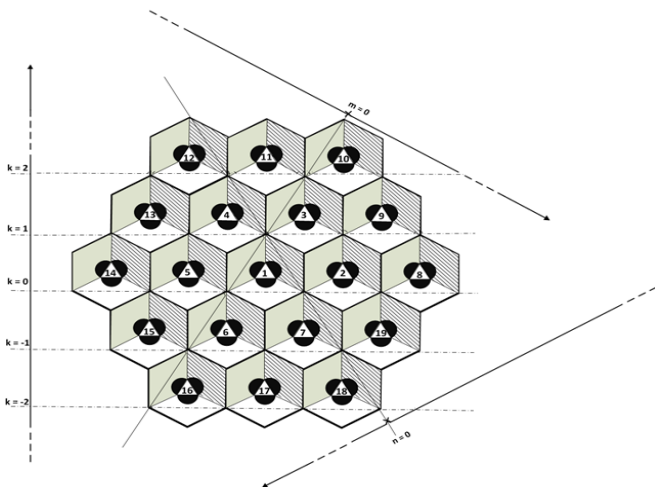


Fig. 3 Proposed system description framework

**C. Proposed TSA for Symmetric Traffic and Analysis**

It can be noticed from the preceding subsection that the most severe type of interference are the eNB( $k+1$ ) to UE( $k$ ), if sectors  $k$  and  $k+1$  transmit synchronously in DL and cell edge; in addition to UE( $k$ ) to UE( $k$ ) interference if the mobiles operate in opposite directions. To eliminate these types of interference, we divide the cells into two groups. The first

group consists of sectors with even  $k$  while the second group consists of sectors with odd  $k$ . Within each group, all the sectors transmit in a synchronized (uniform) DL/UL manner. However, DL and UL transmission directions are opposed between the 2 groups. This way, eNB( $k+1$ ) to UE( $k$ ) DL interference and UE( $k$ ) to eNB( $k+1$ ) UL interference are eliminated. This improves the system SIR outage performance as we shall see in section III. Following is a summary of the proposed TSA for symmetric traffic:

- i. Divide all the sectors into two groups. The first group consists of sectors with even  $k$  ( $k = 2l$ ;  $l = \dots, -2, -1, 0, 1, 2, \dots$ ) and the second group consists of sectors with odd  $k$  ( $k = 2l+1$ ;  $l = \dots, -2, -1, 0, 1, 2, \dots$ );
- ii. Within each group, downlink/uplink operation is synchronized for all sectors. This means that all the UEs in the group receive(transmit) at the same time;
- iii. Downlink/uplink operation between the two groups is opposite. While sectors in the first group operate in DL, sectors in the second group operate in UL and vice versa; the simplest way to achieve this in a frame is to reverse the DL/UL order (uplink first instead of downlink first) in one of the groups, as shown in Fig. 4 (a).

Below, performance analysis of the new TSA for symmetric traffic is provided, as compared to the traditional all-uniform TSA. For simplicity, only path-loss is used in the analysis below. All eNBs transmit with the same power and so do all UEs. We denote by  $I_t^u (I_t^d)$  the mean value of the total UL (DL) interference experienced by a reference sector (in the middle of  $k = 0$ axis) when the traditional all-uniform TSA scheme is used. When the proposed new TSA scheme is used, let  $I_n^u (I_n^d)$  be the mean value of the total UL (DL) interference experienced by the same reference sector (in the middle of line  $k = 0$ ).  $R_{jk}, r_{jk}, P_{UE}, P_{eNB}$  and  $\gamma$  are the distance from UE( $jk$ ) ( $j$ th sector on line  $k$ ) to the eNB in reference sector, the distance from UE( $jk$ ) to the UE in reference sector, UE transmit power, eNB transmit power and path-loss exponent, respectively. It is also assumed that there are  $N$  sectors on each line  $k$ .

In downlink, we have:

$$I_t^d = \sum_{k>0} \sum_{j=1}^N P_{eNB} \cdot R_{jk}^{-\gamma} \tag{1}$$

$$I_n^d = \sum_{\substack{k>0 \\ k=2l}} \sum_{j=1}^N P_{eNB} \cdot R_{jk}^{-\gamma} + \sum_{\substack{|k|>0 \\ k=2l+1}} \sum_{j=1}^N P_{UE} \cdot r_{jk}^{-\gamma} \tag{2}$$

Because of the fact that the axis  $k = 2l+1$  and  $k = -(2l+1)$  are equidistant from the axis  $k = 0$  (reference sector) and that all UEs transmit with the same power  $P_{UE}$ , we may write

$$\sum_{\substack{|k|>0 \\ k=2l+1}} \sum_{j=1}^N P_{UE} \cdot r_{jk}^{-\gamma} = \sum_{\substack{k>0 \\ k=2l+1}} \sum_{j=1}^N P_{UE} \cdot r_{jk}^{-\gamma} + \sum_{\substack{k<0 \\ k=2l+1}} \sum_{j=1}^N P_{UE} \cdot r_{jk}^{-\gamma} \approx 2 \sum_{\substack{k>0 \\ k=2l+1}} \sum_{j=1}^N P_{UE} \cdot r_{jk}^{-\gamma}$$

Also,

$$\sum_{k>0} \sum_{j=1}^N P_{eNB} \cdot R_{jk}^{-\gamma} = \sum_{\substack{k>0 \\ k=2l+1}} \sum_{j=1}^N P_{eNB} \cdot R_{jk}^{-\gamma} + \sum_{\substack{k>0 \\ k=2l}} \sum_{j=1}^N P_{eNB} \cdot R_{jk}^{-\gamma}$$

Therefore, we have:

$$I_t^d - I_n^d = \sum_{\substack{k>0 \\ k=2l+1}} \sum_{j=1}^N P_{eNB} \cdot R_{jk}^{-\gamma} - 2 \sum_{\substack{k>0 \\ k=2l+1}} \sum_{j=1}^N P_{eNB} \cdot r_{jk}^{-\gamma} \quad (3)$$

If we assume that the sector  $jk$  is at a reasonable distance from the receiving UE in the reference sector, we may reasonably assume that  $R_{jk} \approx r_{jk} = d_{jk}$  ( $R_{jk} - r_{jk}$  is negligible as compared to  $r_{jk}$  and  $R_{jk}$ ), for most sectors. This assumption is more reasonable for the case of a single UE per sector, but it can be extended to our case because in any given time slot, only one UE will be allocated a given sub-channel. Therefore, the situation is similar to one UE case. So, we have:

$$I_t^d - I_n^d = \sum_{\substack{k>0 \\ k=2l+1}} \sum_{j=1}^N d_{jk}^{-\gamma} \cdot (P_{eNB} - 2P_{UE}) \quad (4)$$

If  $P_{eNB} > 2P_{UE}$  (which is generally the case because eNBs with their large antennas transmit with a much higher power than UEs with their small antennas can), the new TSA will always reduce the mean interference power by  $I_t^d - I_n^d$  (expressed in (4)) as compared to the traditional all-uniform TSA. The bigger  $P_{BS} - 2P_{MS}$ , the bigger improvement we have.

In uplink, we have:

$$I_t^u = \sum_{k<0} \sum_{j=1}^N P_{UE} \cdot R_{jk}^{-\gamma} \quad (5)$$

$$I_n^u = \sum_{\substack{k<0 \\ k=2l}} \sum_{j=1}^N P_{UE} \cdot R_{jk}^{-\gamma} \quad (6)$$

$$I_t^u - I_n^u = \sum_{\substack{k<0 \\ k=2l-1}} \sum_{j=1}^N P_{UE} \cdot R_{jk}^{-\gamma} \quad (7)$$

It can be seen that the number of interfering cells in UL is reduced by half if the proposed TSA is used instead of the traditional all-uniform TSA.

Note that both the traditional and the proposed TSA schemes mentioned above are suitable only for symmetric traffic.

For asymmetric traffic, they may be based on the system average asymmetry ratio and are not efficient in terms of time

slot usage and throughput. We propose the following two strategies for adaptation to situations where different sectors or cells have different traffic asymmetry ratios.

#### D. Adaptation to Asymmetric Traffic (Strategy 1)

The first proposed strategy is to find the average asymmetry ratio in the sector set and then allow a certain degree of sector-based extension around the average allocation. This method allows each sector to adjust the TSA around the system average, according to its own traffic requirement. This adaptation strategy is illustrated in Fig. 4 (b) and can be summarized as follows:

- i. Find the average asymmetry ratio of the traffic over the sectors within the same sector set;
- ii. Allocate the time slots to every sector in the set according to the average found in (i);
- iii. Allow each sector to shift its DL/UL switching point to the right or to the left, by a number (equal to or less than a maximum) of time slots, in order to adjust the TSA to the actual traffic asymmetry ratio in the sector. This means that there is a certain number of possible extension time slots (more for DL or for UL) beyond the average found in (i);
- iv. The average asymmetry ratio can be obtained periodically and the allocation adjusted after a certain number of frames;
- v. This strategy is a complement to the main TSA scheme presented in subsection B.

This adaptation strategy yields a more efficient usage of time slots but it creates cell edge UE( $k$ ) to UE( $k$ ) interferences because the transmission within the same line  $k$  is no longer synchronous.

#### E. Adaptation to Asymmetric Traffic (strategy 2)

Another adaptation strategy is to first find the ratio for each line  $k$  instead of system-based average ratio. All sectors with the same  $k$  will then operate in a DL/UL synchronous way, according to the line  $k$ -average. Fig. 4 (b) illustrates this adaptation strategy, which can be summarized as follows:

- i. Find the average asymmetry ratio for each line- $k$ ;
- ii. Every sector on any specific line- $k$  operates according to the line- $k$  average asymmetry ratio;
- iii. This strategy is a complement to the main TSA (TSA for symmetric traffic) which was introduced in subsection B;
- iv. The implementation can be centralized. This means that on each line- $k$ , an eNB will be chosen to collect data from all eNB and perform the computation of the line- $k$  average traffic asymmetry ratio. This average will then be forwarded to all the eNBs on the line. The frequency of this operation may depend on the traffic situation.

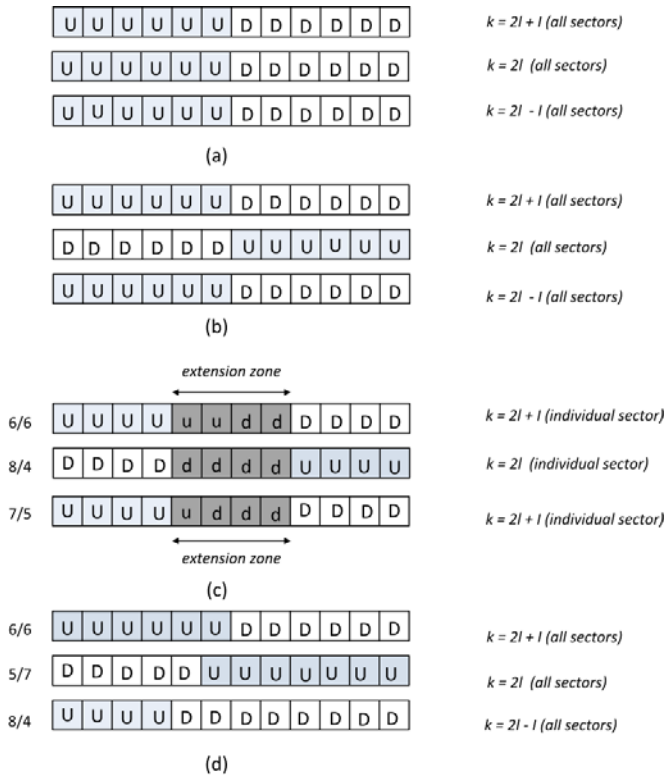


Fig. 4 (a) All-uniform TSA; (b) Proposed TSA; (c) Adaptation strategy1; (d)Adaptation strategy 2

This method reduces the cell edge “intra-line” UE(k) to UE(k) interference introduced by the adaptation strategy 1 but it reduces the sector level TSA flexibility. Consequently, time slot efficiency and throughput are reduced.

### III. SIMULATION AND RESULTS

#### A. Simulation Environment

TABLE I  
 SIMULATION PARAMETERS

| PARAMETER                | VALUE  |
|--------------------------|--------|
| BS transmit power        | 25 W   |
| MS transmit power        | 100 mW |
| Cell radius              | 1000 m |
| Shadowing std. deviation | 8 dB   |
| Path-loss exponent       | 3.6    |
| Antenna FBR              | 30 dB  |

Using Monte Carlo simulation, we compare SINR’s cumulative distribution function for both the traditional all-uniform and the proposed TSA (for symmetric traffic) and investigate outage probability in both DL and UL for all the TSA schemes and strategies mentioned so far. A 19-cell environment is simulated. UEs are uniformly distributed over the cells. Frequency-flat fading channel is assumed with path-loss exponent equal to 3.6 and lognormal shadowing with standard deviation equal to 8 dB in both DL and UL. For simplicity, all eNBs transmit with the same power (25W) and all UE transmit with the same power (100mW). At the BS, the

antennas’ front-to-back ratio (FBR) is 30 dB. The cell radius is assumed to be 1000m. Table I summarizes simulation parameters. For symmetric case, the traffic is perfectly symmetrical (same number of required time slots in downlink and uplink). For asymmetric traffic case, the traffic is randomly generated but the average DL/UL traffic asymmetry ratio is 60%/40%. There are 12 time slots in each frame. The number of requested time slots in the DL follows Gaussian distribution of mean 7. The standard deviation takes the values of 3. The total (UL and DL) number of requested time slots is always 12 for each sector. Data are measured in the reference cell (cell 1 on Fig. 2). If  $\mu$  and  $\sigma$  are respectively the mean and the standard deviation of SINR, then the outage probability is defined as:

$$P_{out}(SINR_0) = P_r(SINR < SINR_0) = 1 - Q[(SINR_0 - \mu) / \sigma] \quad (8)$$

where  $SINR_0$  is the required SINR.

#### B. Simulation Results

SINR cdf for symmetric traffic is presented in Fig. 5. It can be noticed that the proposed TSA outperforms the traditional all-uniform TSA in the DL for symmetric traffic. This is because the proposed TSA eliminate all DL eNB(k+1) to UE(k) interferences. In the UL, there is no noticeable improvement over the traditional TSA. One explanation to this is that the UE transmit power is not big enough to show a difference between the two schemes, as described by (7).

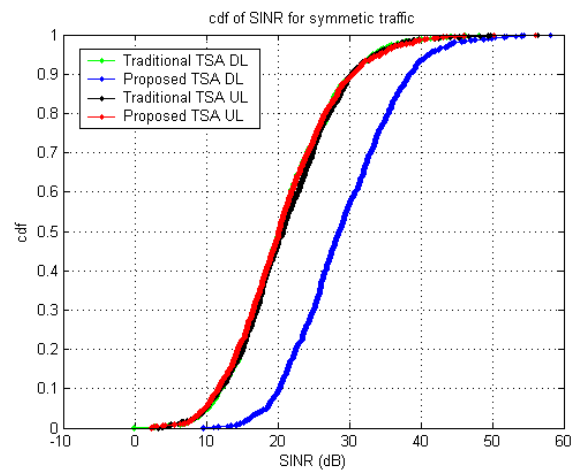


Fig. 5 Symmetric traffic (cdf of SINR)

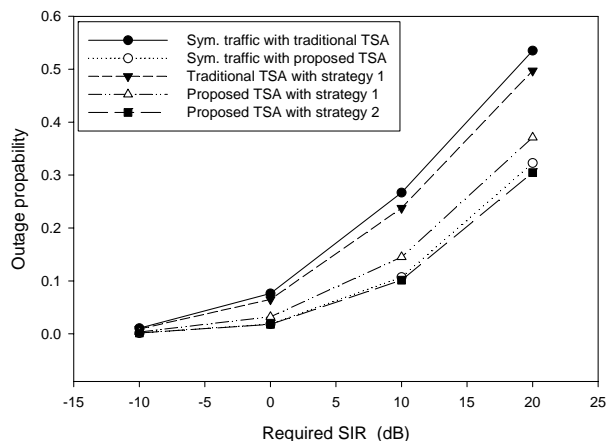


Fig. 6 Downlink outage probability

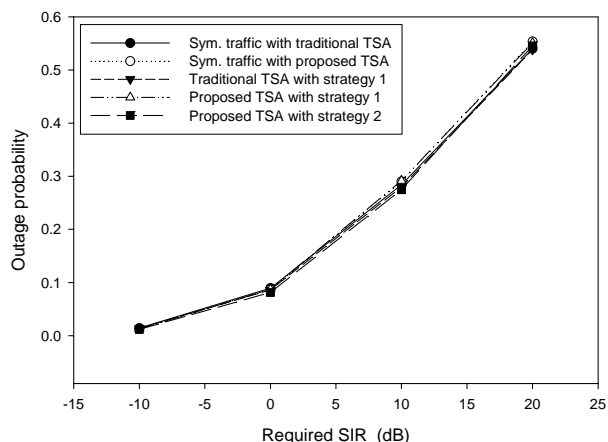


Fig. 7 Uplink outage probability

If we increase the UEs' transmit power, the SINR improvement achieved by the proposed TSA will also increase according to (7). Another explanation is that we assumed perfect directivity for eNB antennas in our mathematical analysis. Therefore, in the analysis, we ignored eNB to eNB uplink interference. In the simulation; however, the environment is more realistic. We assume antenna front-to-back ratio of 30 dB, instead of the ideal assumption of perfectly directional BS antennas. The same reasons explain the SINR outage probability results shown in Fig. 7.

In the downlink on the other hand, the improvement achieved by the proposed TSA and its adaptation strategies, over the traditional TSA is very clear, as shown on Fig. 5 (for symmetric traffic) and on Fig. 6 (for asymmetric traffic). Adaptation strategy 2 shows better SINR performance as compared to adaptation strategy 1 because strategy 2 yields more unused (idle) time slots, leading to less total interference.

#### IV. CONCLUSION

All-uniform DL/UL TSA is not the best strategy if smart antennas or directional eNB antennas are used in TDD systems. It was shown by mathematical analysis and simulation that, using the proposed TSA scheme and its adaptation strategies, not only can we efficiently support cell-

based traffic asymmetry ratios but we can also significantly reduce SINR outage probability. Even though adaptation strategy 2 outperforms adaptation strategy 1 in terms of interference, more work is needed to compare their respective throughput. The overheads generated and their implications also need further studies.

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