Time Slot Allocation Based on Normalized Path Gains for TD-CDMA TDD Systems

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Abstract

Time Division Duplex (TDD) mode can provide highly asymmetric services due to the flexible radio resource management. This flexibility allows the use of crossed slots especially when the rate of asymmetry is not the same in all cells. In crossed slots, some cells may be active in downlink while neighboring cells are active in uplink. The presence of crossed slots induces additional interference mechanisms compared to the Frequency Division Duplex (FDD) mode. These additional interference mechanisms can dramatically increase the outage probability. To keep the outage probability at a reasonable level, annoying interference must be avoided. Several methods have been proposed to restrict the allocation of crossed slots only to mobiles that do not generate high inter-mobile interference. In this contribution, we propose an evolution of these methods based on normalized path gain. The normalized path gain is defined as the ratio between the path gain of a mobile toward an interfering base station and its path gain toward its server. The proposed method has shown better performance than other interference avoidance methods and than the conventional common switching point method where all cells have the same slot configuration.

1. Background

Many multimedia services of next generation mobile telecommunication systems have an asymmetric traffic distribution between uplink and downlink. In spite of the high capacity offered by the symmetric Frequency Division Duplex (FDD) mode of UMTS, the downlink bandwidth may be saturated while the uplink bandwidth is not fully used. To alleviate this problem, the Time Division Duplex (TDD) mode must be combined with the Time Division Multiple Access (TDMA) technique. This combination allows an asymmetric management of radio resources due to the flexible allocation of time slots. This flexibility can be ensured by using a dynamic switching point between uplink and downlink in each cell.

According to the position of the switching point, slot allocation techniques may be divided into two categories: common switching point technique and diversified switching point technique. In the common switching point technique, all cells have the same slot configuration. This method does not efficiently exploit the bandwidth when the rate of asymmetry is not the same in all cells, which is the most encountered case; therefore, the latter method can induce high blocking probability. In the diversified switching point technique, each cell has an independent slot configuration. This technique allows a full use of the spectrum and thus, maximum capacity may be reached. However, it authorizes the presence of crossed slots, where a set of cells is active in downlink and another set is active in uplink (fig. 1). In crossed slots, inter-mobile and inter-base station interferences appear. Inter-mobile interference is very difficult to measure and may induce very high outage probability when two close mobiles are active in opposite link directions during the same slot. Nevertheless, the diversified switching point technique outperforms the common switching point technique when an efficient call admission control is used [1][2][3].

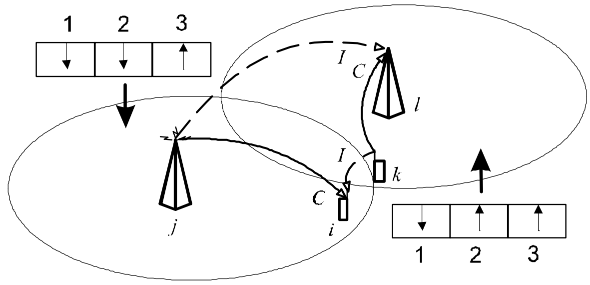

Figure. 1: Crossed time slot (2) in a sytem with two cells.

Inter-mobile interference is very difficult to estimate and need high signalling traffic to be communicated to base stations. However, high inter-mobile interference appears when two close mobiles are active in opposite link directions. Generally, these mobiles are at cell borders. Hence, many algorithms based on path gains between mobiles and base stations are used to detect such mobiles in order to reduce the probability of high inter-mobile interference [4][5][6].

In [6], we have proposed an interference avoidance method based on path gain between a mobile and neighboring cells. In this method, a mobile can be active in an uplink slot, though the same slot is used for downlink in a neighboring cell l, if its path gain toward the base station l is less than a threshold. This method has shown better results than methods proposed in [4] and [5]. However, this method ignores the effect of the uplink power in crossed slots.

Two mobiles with the same path gain toward a neighboring base station may transmit with different powers depending on their path gains toward their server; therefore, these mobiles may introduce different interference powers to the neighboring base stations. Hence, the uplink power effect must be considered in the slot allocation constraint to decrease the outage probability.

In this contribution, we present an evolution of existing interference avoidance methods based on normalized path gain. Like other interference avoidance methods, the proposed method uses path gains between a mobile and interfering base stations to avoid high inter-mobile interference. In addition, it considers the uplink transmitted power by including the path gain between the mobile and its server in the slot allocation constraint.

In the next section, we introduce the time slot allocation scheme based on normalized path gains and we present the implementation procedure. In section 3, the system model is described. Simulation results are drawn in section 4. The last section presents some concluding remarks and future works.

2. The proposed slot allocation scheme

2.1. Method presentation

The slot allocation scheme based on normalized path gains uses the normalized path gain $Z_{i,l}$ instead of the path gain $G_{i,l}$. The normalized path gain $Z_{i,l}$ between a mobile i and a base station l is defined by the ratio of the mobile path gain $G_{i,l}$ toward base station l and its path gain $G_{i,j}$ toward its server j:

$$Z_{i,l} = \frac{G_{i,l}}{G_{i,j}} \tag{1}$$

In the proposed method, a mobile i of cell j can be active in an uplink slot, though the same slot is used for downlink in cell l, if the following constraint is verified:

$$Z_{i,l} \leq \varsigma_{j,l}, \tag{2}$$

where $\varsigma_{j,l}$ is a specific threshold between cell j and l, which depends on radio characteristics and the services offered to mobiles.

The proposed method has the same advantages of the method presented in [6] over other interference avoidance methods and gives better results due to the consideration of power impact of uplink channels.

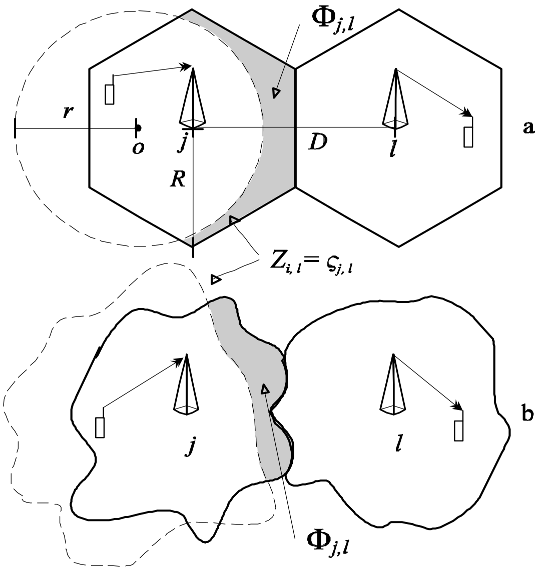

Figure. 2: Forbidden zone in cell j when the slot allocation method schemebased on normalized path gains is used: (a) without shadowing (b) and with shdowing.

2.2. The scheme behavior in an hexagonal network

In a regular hexagonal cellular network, the cell area where crossed slots are not allowed may be calculated. Assuming an Okumura-Hata propagation model without shadowing, the path gain between a mobile i and a base station l may be written as:

$$G_{i,l} = k/d_{i,l}^{\gamma}, \tag{3}$$

where $d_{i,l}$ is the distance between a mobile i and base station l. Constants k and γ depend on the type of environment. From equations (1), (2) and (3), we can deduce that the zone $\Phi_{j,l}$ of cell j where mobiles are prevented from being active in uplink thought that mobiles of cell l are active in downlink is limited by the boundary of cell j and a circle. If we consider a Cartesian coordinate system associated with cell j, the center "o" of the latter circle has the coordinates $\left(-\frac{DS^2}{1-S^2}, 0\right)$, and the radius r of this circle is given by:

$$r = D\left(\frac{S}{1-S^2}\right), \tag{4}$$

where $D = \sqrt{3}R$ is the inter-base station distance, R is the radius of the cell j circumscribed circle and S is a constant given by the following equation:

$$S = \varsigma_{j,l}^{1/\gamma} \tag{5}$$

If the shadowing effect is considered, the path gain becomes a random variable and $\Phi_{j,l}$ becomes an irregular curve (figure 2).

In the following, a mobile with high normalized path gains is denoted remote mobile. Remote mobiles are generally at the border of cells. These mobiles generate high interference and may have low Carrier-to-Interference Ratio (CIR). If the surface of $\Phi_{j,l}$ increases, the number of remote mobiles during an uplink slots (without crossed slots) increases and thus, the interference received by cell j in these slots increases. On the other hand, if the surface of $\Phi_{j,l}$ decreases, the probability of finding two close mobiles transmitting in opposite link directions during a crossed slot increases; thus, the probability of high inter-mobile interference increases. Therefore, compromise must be taken between these two constraints by using a suitable threshold $\varsigma_{j,l}$.

2.3. Guideline for implementation

To implement the proposed method, we define a set of cells $\Psi_{i,j}$ for each mobile i of cell j. The set $\Psi_{i,j}$, called high interference-cells set, is defined by the following formula:

$$\Psi_{i,j} = \{l / Z_{i,l} > \varsigma_{j,l}\} \tag{6}$$

In UTRA-TDD, base stations transmit with a constant power in the Primary Common Control Physical Channel (P-CCPCH). The value of this power and the E_b/N_0 target are broadcast to all mobiles. Similarly, values of $\varsigma_{j,l}$ for each cell can be also broadcast on the same channel. Moreover, mobiles can measure the received powers from the most favorable base stations (typically 6) in P-CCPCH and estimate their path gains toward these cells. Thereafter, each mobile i builds its high interference-cells set $\Psi_{i,j}$. This set $\Psi_{i,j}$ is communicated to the Radio Network Controller (RNC) unit of the system only at the call initialization and when the set changes. Consequently, the RNC can allocate a slot n for the uplink traffic of mobile i, if each cell of the set $\Psi_{i,j}$ is either active in uplink or not active during slot n.

3. System model

The proposed interference avoidance scheme is evaluated in a UTRA-TDD system of 12 cells and 12 time slots. The simulation area is finite, i.e. no wraparound is used. This implies that border effects will affect the results but that will be the case in a real UMTS TDD system as well.

In this system, the proposed scheme is compared to the diversified switching point technique and to the common switching point technique. Furthermore, it is compared to the interference avoidance scheme based on path gains between mobiles and neighboring base stations.

In the common switching point technique, the switching point is the same for all cells and it varies according to the ratio of total traffic in the two links. In the diversified switching point technique, each cell has only one specific switching point that varies according to the ratio of traffic between uplink and downlink in the cell (figure 3). The interference avoidance schemes are combined with the diversified switching point technique.

The studied slot allocation schemes determine the set of slots that can be used by a new mobile in uplink and downlink. Thereafter, a slot with free codes is chosen

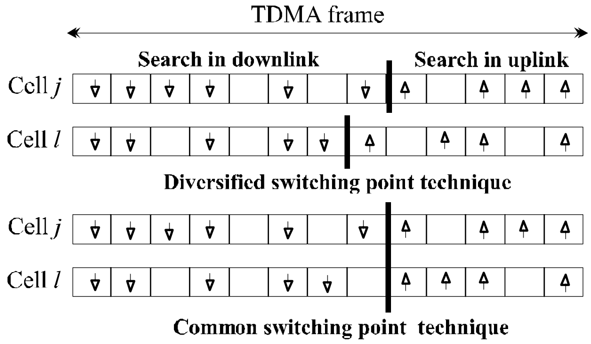

Figure. 3: The diversified and common switching point techniques

randomly from the set of allowed slots. This random procedure is used to increase the probability of high inter-mobile interference.

In simulations, we consider two types of circuit switched services: an asymmetric data service in the 3 central cells and a symmetric speech service in the 9 other cells (figure 4). For both services, calls are generated according to a Poisson process assuming a mean call duration of 120 seconds [7]. The data service needs one code in uplink and 5 codes in downlink with a spreading factor of 13.9 dBm, while voice service needs one code in each link with the same spreading factor.

We consider small hexagonal macrocells with a radius of 0.3 km. Mobiles are assumed connected to the best server and they are uniformly distributed over cells. Furthermore, we consider that all cells have the same mean load (simultaneous active code number); therefore, the arrival rates for data and voice users λ_d and λ_v must verify the following equation:

$$\lambda_d = \frac{c_v}{3 \times c_d} \lambda_v \tag{7}$$

where c_d and c_v are the number of codes in both uplink and downlink used by data and voice users respectively. The constraint on transmitted powers, the target E_b/N_0 and the value of thermal noise are presented in table 1 [8].

The assumed propagation model is an Okumura-hata-cost231 model with shadowing:

$$P_r = P_e \frac{k}{d_{x,y}^{\gamma}} a_{x,y}, \tag{8}$$

where P_r and P_e are respectively the received and the transmitted powers, k and γ are constants [9], which

Table 1: Simulation parameters [8]

	uplink	downlink
$(E_b/N_0)_T$ [dB]	6.1	3.7
Thermal noise	-103	-98
Max Tx power [dBm]	21	20
Max BTS power [dBm]	-	33
Mobile Power cntrl range [dB]	65	25
BTS power cntrl range [dB]	-	30

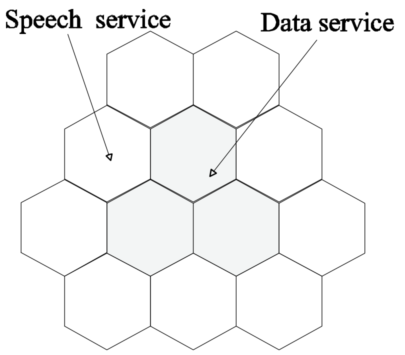

Figure. 4: Traffic distribution over cells

depend on the type of environment (table 2), and d is the distance between the transmitter and the receiver. Factor $a_{x,y}$ models the shadowing effect. It is a time constant, Log-Normal variable with zero mean [6] (table 2). Simulation minimum coupling loss (MCL) between different transmitters and receivers [8] are also given in table 2. It can be noted that the shadowing factor variance and path losses between two mobiles are very high compared to those between two base stations due to the low altitude of mobile antennas.

In UTRA-TDD, open-loop and closed-loop power control procedures are used respectively in uplink and downlink. The use of closed loop power control induce an oscillation in the received E_b/N_0. Thus, perfect open-loop power control is used in both links to decrease the effect of power control on the instantaneous E_b/N_0 of mobiles when the performance of the slot allocation schemes is evaluated. Joint detection technique is used to decrease intracell interference [10]. Intracell interference factors are 0.1 and 0.2 respectively in downlink and uplink. To reduce the complexity of the joint detection technique, the maximum number of codes per slot is reduced to 10 in each cell. Mobility and fast fading are not considered in simulations.

4. Simulations and results

For each slot allocation scheme, the percentage U of unsatisfied codes is estimated:

$$U = \frac{N_u}{N_l} \times 100, \tag{9}$$

where N_l is the number of all requested codes and N_u is the number of unsatisfied codes over all frames, mobiles and cells.

Table 2: Propagation model constants

	$BS-BS$	$BS-MS$	$MS-MS$
k [dB]	-112.7	-127.7	-147.4
γ [dB]	35.5	35.5	40
var[$a_{x,y}$] [dB]	4.24	6	7.34
MCL [dB]	92.32	52.67	38.02

All the codes of an unsatisfied user are considered as unsatisfied codes. A user is considered as unsatisfied when one of the following events happens:

- the user call is blocked by the call admission control,
- the user call is dropped after 5 seconds of low quality connection,
- the connection was considered of low quality for more than 5% of the call session.

We define $(E_b/N_0)_M$ as the mean value of of E_b/N_0 over two frames, i.e. one Transmission Time Interval (TTI), for a given connection. A low quality connection is defined as a connection where:

$$(E_b/N_0)_M < (E_b/N_0)_T - 0.5 \text{ dB}, \tag{10}$$

in either uplink or downlink. Furthermore, we define the the percentage of bad-quality codes as the percentage of dropped codes summed to the percentage of codes that have been considered of low quality for more than 5% of the user call session.

Each point in the presented plots is the result of 40 simulations. In each simulation, we emulate an active mobile system during half-hour. The normalized path gain is always less than one because each mobile is served by the best server. Hence, when $\varsigma_{j,l} = 1$, the slot allocation scheme based on normalized path gain is reduced to the simple diversified switching point and the sets of high interference-cells are reduced to the null set. In all simulations, we have supposed that all cells have the same normalized path gain threshold ς.

In figure 5, the percentage of unsatisfied codes is plotted as a function of the normalized path gain threshold ς when the normalized cell load is 0.6. Moreover, the percentage of bad-quality codes and the percentage of blocked codes are also plotted. The optimal performance is obtained for $\varsigma = 0.65$ (-1.9 dB). This value will be used to compare the proposed scheme to existing slot allocation schemes.

As depicted in figure 5, the percentage of bad-quality codes is a increasing function while the percentage of blocked codes is a decreasing function of ς as expected. When the value of ς increases, the cardinality of sets $\Psi_{i,j}$ decreases, allowing more active mobiles in crossed slots. Therefore, more radio resources will be available but the probability of high inter-mobile interference will increase. Hence, the percentage of blocked codes decreases while the percentage of bad-quality codes increases. Moreover, we can see that the percentage of bad-quality codes is the limiting factor when the interference avoidance scheme is used. We can note also that the scheme performance is approximately unchangeable when the normalized path gain threshold is near to the optimal value (i.e. in 1.5 dB margin).

In figure 6, the percentage of unsatisfied codes is plotted as a function of the normalized cell load for each slot allocation scheme. The normalized path gain threshold and the path gain threshold for the interference

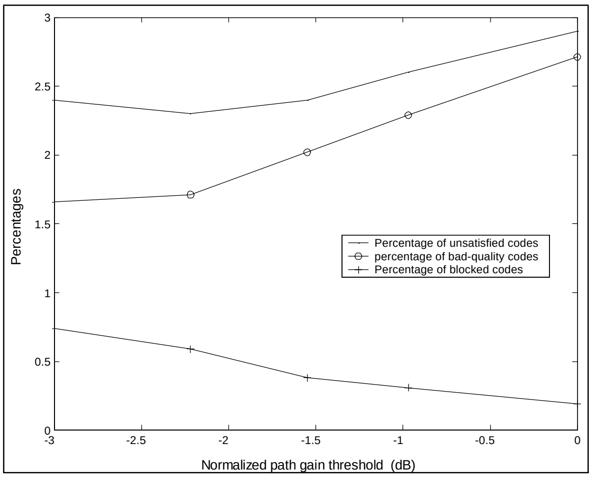

Figure. 5: The percentage of unsatisfied, bad-quality and blocked codes as a function of the threshold

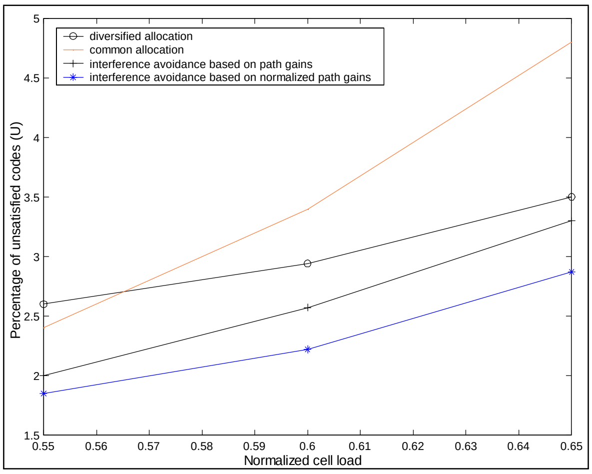

Figure. 6: The percentage of unsatisfied codes as a function of the normalized cell load

avoidance schemes are respectively -1.9 and -113 dB. We can note that the common switching point technique gives better results than the diversified switching point technique for low cell loads. However, the percentage of unsatisfied codes in the common switching point technique become higher compared to the one offered by the diversified switching point technique as the cell load increases. This result is due to the fact that the radio resources offered by the common switching point in the downlink of asymmetric cells become scarce when the load exceed a threshold. Moreover, the uplink slots of symmetric cells will suffer from high mobile-base station interference due to the limitation in the number of slots.

The percentage of unsatisfied codes offered by the proposed scheme is always less than the percentage of unsatisfied codes offered by the interference avoidance scheme based on path gains and certainly from the one given by the common switching point and the diversified switching point techniques.

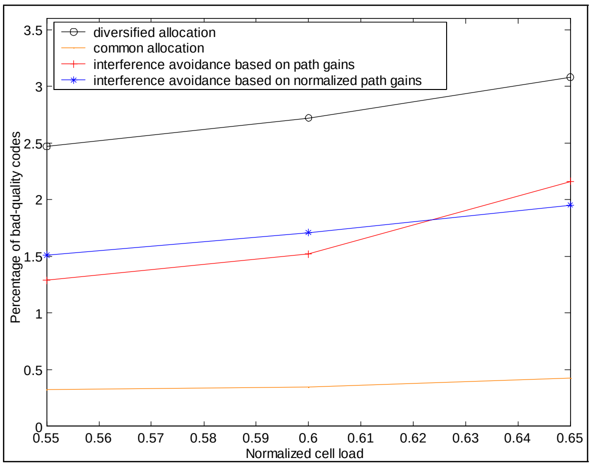

Figure. 7: The percentage of bad-quality codes as a function of the normalized cell load.

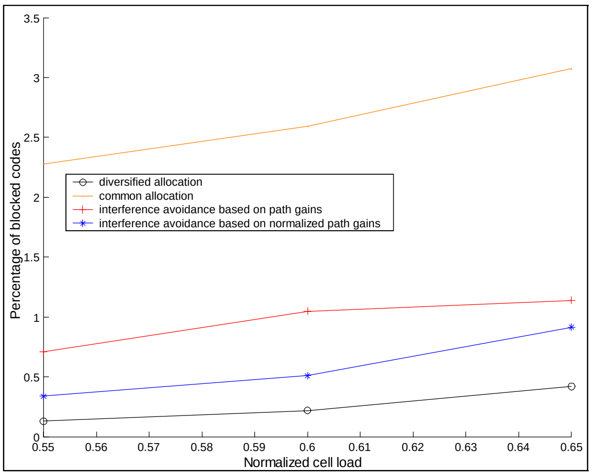

Figure. 8: The percentage of blocked codes as a function of the normalized cell load.

In figure 7 and 8, the percentages of bad-quality codes and blocked codes are respectively plotted as a function of the normalized cell load.

As expected, these figures show that the common switching point technique is limited by the blocking probability while the diversified switching point technique is limited by the outage probability due to high inter-mobile and inter-base station interference. When the interference avoidance methods are used, the percentage of blocked codes is higher than the one obtained by the simple diversified switching point technique. This is due to the constraint in the allocation of crossed slot. However, this constraint allows the slot allocation technique to avoid high inter-mobile interference and thus, to decrease the percentage of bad-quality codes.

For high cell loads, the percentage of bad-quality and blocked codes are lower when the proposed method is used instead of the interference avoidance method based on normal path gains (figure 7 and 8).

5. Conclusion

In this paper we have presented an evolution of some existing schemes that avoid high inter-mobile interference. As other interference avoidance schemes, the proposed scheme uses the path gain between mobiles and base stations to avoid high inter-mobile interference. Moreover, the proposed scheme integrates the effect of uplink transmitted power by using the normalized path gain instead of the normal path gain.

The proposed scheme has shown better results than other slot allocation techniques. The proposed interference avoidance scheme can increase the system capacity without increasing the signaling traffic, i.e. only one new signaling message is added.

The optimal threshold is difficult to estimate because it depends on several non constant parameters. Nevertheless, simulation results has shown that the effect of the threshold is not important near to the optimal threshold. Moreover, the proposed scheme has offered better performance than both diversified and common switching point techniques for a threshold higher than -3 dB. Therefore, a threshold higher than -3 dB can be randomly chosen and the performance of the proposed scheme will be always higher than the performance of the diversified and the common switching point techniques.

Moreover, an adaptive version of the proposed scheme can be used in real systems. In this adaptive scheme, the threshold varies depending on the blocking and bad-quality code percentages, and the cell load of neighboring cells. The interference avoidance scheme based on normalized path gains may be used also in the slot-reallocation procedure (i.e. inter-slot handover) to reduce high inter-mobile interference generated by the variation in the radio interface.

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