Time Slot Allocation Based on a Path Gain Division Scheme for TD-CDMA TDD Systems

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Abstract— **TD-CDMA TDD technique allows UMTS to utilize the bandwidth and the rare radio resource more efficiently if dynamic channel allocation is used. This technique is suited especially for systems that offer highly asymmetric services. However, the rate of asymmetry is not the same in all cells. Hence, it is possible that in some slots, called crossed slots, a set of cells is active in downlink and another set is active in uplink. Inter-BS and inter-MS interferences arise in these slots and can degrade dramatically the QoS. In this paper, we introduce a scheme to prevent mobiles that can introduce very high inter-mobile interference from being active during crossed slots. In this scheme, a mobile can be active during a crossed slot with mobiles of a neighboring cell, if the path gain between the mobile and the neighboring base station is less than a given threshold. for high loads, this scheme has shown better results than common switching point technique where crossed slots are forbidden and other interference avoidance methods.**

Keywords— **Slot allocation, interference avoidance, crossed time slot, TDMA-CDMA, UMTS, TDD**

I. Introduction

In many applications of third generation wireless systems, most of the traffic load is expected to appear in downlink. To efficiently manage the traffic asymmetry, the resource units distribution among links must be adequate to the rate of asymmetry.

In the UTRA-TDD (UMTS Terrestrial Radio Access-Time Division Duplex), uplink and downlink are separated in the time domain [1]. Furthermore, the frame is divided into 15 time slots, which can be allocated either for uplink or downlink in a cell. The boundary between the two links is called "switching point". Moreover, the same time slot may be used for different directions of transmission in different cells. In this case, the time slot is called a crossed slot (figure 1). To guarantee an asymmetric traffic, different techniques were proposed. Some of these techniques are based on common switching point where all cells use the same time slots for each type of links. However, all cells don't have the same asymmetry rate; therefore this technique limits the flexibility of the TDMA-CDMA system. In the diversified switching point technique [2], the number of slots allocated to the downlink in a cell depends on the rate

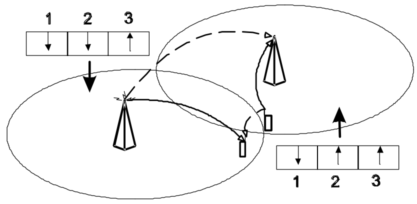

Fig. 1. Downlink (1), crossed (2) and uplink (3) time slots in a sytem with two cells. The represented cells are active in a crossed slot.

of asymmetry between uplink and downlink and thus the resource units can be efficiently distributed among both links. When using the latter technique, the system may experience very annoying types of interference (i.e. inter-MS and inter-BS interferences) [4]. These types of interference appear in crossed slots where some cells are active in downlink and other cells are in uplink. In [5], we have introduced methods that combine power control and slot allocation and give results very close to the optimum. However, these methods are difficult to be implemented in operational networks. In this contribution, we propose a simple method that ameliorates the performance of the UTRA TDD system by avoiding annoying inter-MS interference and we compare it to other methods.

The paper is organized as follows. First, we present the advantages of using diversified switching point technique and its downside. We present also some interference avoidance methods. In the third section, we introduce the interference avoidance method based on the relative path gain. In section 4, the simulation model is presented with its different parameters and assumptions. Simulation results are drawn in section 5. Finally, section 6 presents some concluding remarks and future works.

II. Problem description

The TDMA component in UTRA TDD adds to the resource allocation a new degree of freedom in the time domain: the slot allocation. Thus, the resource unit is a combination of a code, a time slot and the power dedicated to this combination. During a slot, mobiles of the same cell must be active in the same link direction, but mobiles of different cells may be active in opposite link directions in that slot. The slot allocation in UTRA TDD covers both slot allocation to cells (cell slot-allocation) and slot allocation to bearer services (mobile slot-allocation). Once the slot allocation to cells is executed, bearer services can be associated in different way to slots of the convenient link depending on the slot allocation method.

The slot allocation to cells can be divided in 2 basic categories: the common switching point were all cells have the same slot configuration and the diversified switching point where each cell may have a different slot configuration. When the diversified switching point is used, the flexibility of the TDMA component is fully exploited: the blocking probability is minimum and the system can reach its maximum capacity. However, the outage probability may be very high due to the inter-MS and inter-BS interferences. To limit the outage probability, these type of interference must be avoided. The common switching point is the most efficient method to resolve this problem. Unfortunately, this method is not very flexible and can induce high blocking probability in real systems where cells have variable and different asymmetry rates [6][7]. Furthermore, it has been shown in [8] that the diversified switching point technique gives better results than the common switching point technique in asymmetric systems, if the mobile slot-allocation is optimal.

It is believed that if the call admission control takes into account a condition that may reduce the inter-MS interference, the outage probability will be reduced. However, the estimation of path gains between mobiles is very difficult and needs a huge data base due to the large number of mobiles; therefore, many methods based on path gain between mobiles and base stations are proposed to prevent high inter-MS interference [2][7][9]. In this paper, we introduce a cell slot-allocation scheme that profits from advantages of methods proposed in the latter articles.

In the so-called "different time slot allocation based on region division" method [9], each cell is divided into two zones : the inner zone near to the base station and the outer zone that enclose the first one. The crossed slots can be allocated only to mobiles of the inner zone for both links. This zone is a circle of radius R_0. This method doesn't take into account mobile's position toward interfering cells. In the "disjoint base station sets" method proposed in [7], a set of n strongest base stations is associated to each mobile. Two mobiles, from different cells, transmitting in opposite link direction can share a slot if the sets associated to these mobiles are disjoint. The number of forbidden cells to a given mobile is fixed and this number is independent of the mobile's position.

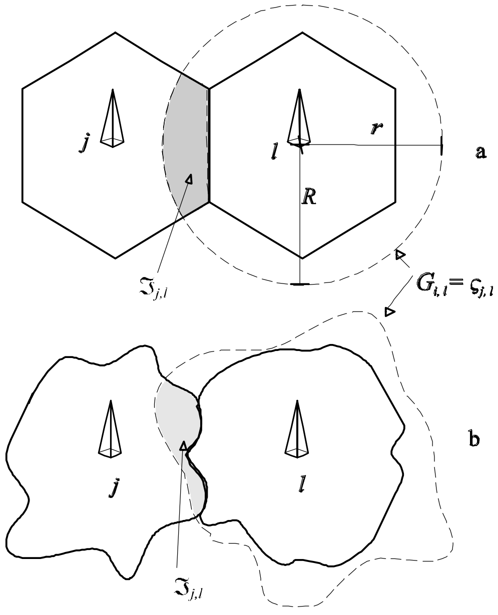

Fig. 2. Forbidden zones in cells when using the interference avoidance method based on relative path gain

III. Description of the proposed scheme

The interference avoidance method based on relative path gain is inspired from the disjoint base station sets method and the different time slot allocation based on region division method. In the proposed method, a mobile i of cell j can be active in crossed slots with mobiles of cell l if the following constraint is verified:

$$G_{i,l} \leq \varsigma_{j,l}, \qquad (1)$$

where $G_{i,l}$ is the path gain of mobile i toward base station l and $\varsigma_{j,l}$ is a constant of the same order of the relative path gain. This constant depends on the type of the environment, the cell radius and the type of service in cells.

Assuming an Okumura-Hata propagation model without shadowing, the path gain may be written as $G_{i,l} = \frac{k}{d_{i,l}^{\gamma}}$ where $d_{i,l}$ is the distance between mobile i and base station j. Constants γ and k depend on the type of environment. From equation 1, we can deduce that the set $\Im_{j,l}$ of mobiles prohibited to be active in crossed slots with mobiles of cell l is limited by the boundary of cell j and a circle. The center of this circle is the base station l and its radius is equal to $(k/\varsigma_{j,l})^{\gamma}$. If the shadowing effect is considered, the path gain became a random variable and the set $\Im_{j,l}$ became an irregular curve (figure 2).

The main idea of the proposed scheme is to reduce the outage probability without limiting the flexibility of the slot allocation technique. This objective can be reached if we

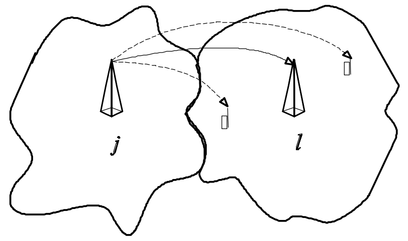

Fig. 3. Inter-BS interference in crossed slot (slolid line) and BS-MS interference (dashed lines)

can predict the existence of close mobiles transmitting in opposite link directions. A mobile that has a high path gain toward a base station is expected to be close to the border of the cell served by the latter base station; thus, there is a high probability that this mobile will introduce high inter-MS interference. Therefore, it is preferred to prohibit this type of mobiles from being active in crossed slots with mobiles of close cells.

Let us consider a mobile i of cell j, which request for an uplink radio resource. We define a set of forbidden cells $F_{i,j}$:

$$F_{i,j} = \{l / G_{i,l} > \varsigma_{j,l}\} \tag{2}$$

A slot n can be allocated to this mobile if each cell of the set $F_{i,j}$ is either active in uplink or not active during this slot. Moreover, slot n cannot be allocated to mobile i if at least one cell of the set $F_{i,j}$ is active in downlink.

The resource allocation scheme is different for downlink. Let us consider that cell j is allocating a downlink resource to mobile i during a slot n. If cell l is active in uplink during slot n, than base station l receives an inter-BS interference $I_{l,j}$ from cell j. Otherwise, if cell l is active in downlink, mobiles of this cell receive a BS-MS interference from cell j. The mean value of the latter interference (BS-MS interference) is very comparable to $I_{l,j}$ (figure 3). Thus, it is not suitable to prohibit mobiles of cell j with high relative path gain toward l from being active in downlink during slot n.

Due to the dynamic nature of the proposed interference avoidance method, the blocking probability in the system is less than the one found in a system using the different time slot allocation based on region division method. In figure (4), we can observe that the prohibited zone in cell j is reduced when using the interference avoidance method based on relative path gain with the same cell slot-configuration; Hence, the mean number of mobiles that can be active in the studied slot is higher when using the proposed method, and thus the blocking probability of the overall system is reduced.

In the disjoint base station sets method [7], the number of forbidden cells is fixed. This property decreases the flexibility of the system by prohibiting mobiles, close to their

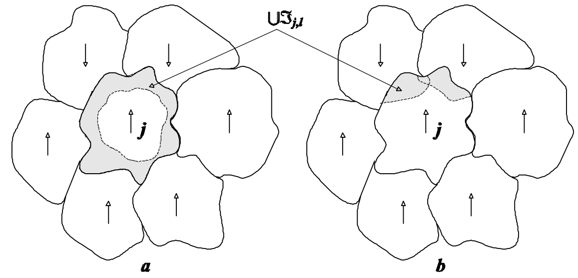

Fig. 4. Prohibit zone in cell j with the different time slot allocation based on region division method (a) and with the interference avoidance method based on relative path gain (b)

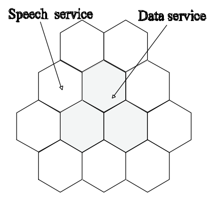

Fig. 5. Cell system used in simulations

servers, from being active in crossed slots with the forbidden cell. In addition, some mobiles can be close to borders of two cells. These mobiles are forbidden from being active in crossed slot with only one of these cells. However, they can generate very high inter-MS interference in the other cell and increase the outage probability. This problem can be solved by using the proposed method where the number of forbidden cells varies depending on mobile's position and its environment.

IV. Simulation model

The interference avoidance method is evaluated in a UTRA-TDD system [1] of 12 cells and 15 time slots. We suppose that 2 time slots are used only to exchange control information; thus, the system uses only 13 time slots for data transfer. We consider two types of circuit switched services: a data service in the 3 central cells and a speech service in the 12 other cells (figure 5). For both services, calls are generated according to a Poisson process assuming a mean call duration of 120 seconds [10]. A data service link uses one code on uplink and 9 codes in downlink, while voice service link uses two codes in each links. Mobiles are distributed over cells in such a way that we obtain the same mean traffic (simultaneous active code number) in each cell (table I).

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

$$P_r = P_e \frac{k}{d^{\gamma}_{x,y}} a_{x,y}, \tag{3}$$

where P_r and P_e are respectively the received and transmit-

TABLE I
SIMULATION PARAMETERS

	Data		speech	
	uplink	downlink	uplink	downlink
Rate [kbps]	8	144	12.2	12.2
Codes/user	1	9	2	2
E_b/N_0 [dB]	2.2	2.2	6.1	3.7
Thermal noise	-103	-98	-103	-98
Max Tx power [dBm]	21	33	21	33
Power cntrl range [dB]	65	30	65	30

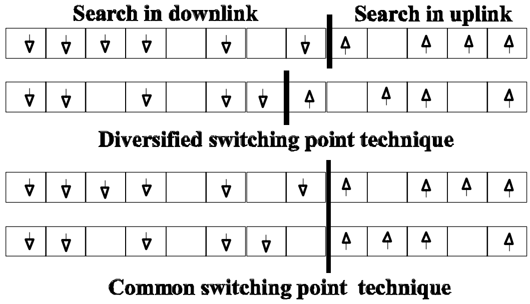

Fig. 6. Slot allocation methods

ted powers, k and γ are constants that depend on the type of environment and d is the distance between the transmitter and the receiver. The factor $a_{x,y}$ models the shadowing effect. It is a time constant, Log-Normal variable with zero mean. To take into account the different type of correlation between shadowing factors, we consider three type: BS-MS, MS-MS and BS-BS shadowing factors. The shadowing factor $a_{i,l}$ between a mobile i and base station j can be written as: $a_{i,l} = a_{c,j}.a_{s,i,j}$, where $a_{c,i}$ is the common factor of the mobile and $a_{s,i,j}$ is the specific factor to base station j [11][12]. The first factor models the effect of obstacles close to the mobile and it is common for all base stations. The second factor models the effect of far obstacles. To model the shadowing factor $a_{i,k}$ between two mobiles i and k, we must consider the common factor $a_{c,x}$ for both mobiles; therefore, $a_{i,k} = a_{s,i,k}.a_{c,i}.a_{c,k}$. Moreover, we suppose that shadowing factors $a_{j,l}$ between base stations are uncorrelated and they are equal to $a_{s,j,l}$. Due to the height of base stations antenna, we consider that shadowing factor deviation is higher when a mobile is one of the end terminals; therefore, we consider that all the shadowing factors ($a_{s,i,k}$, $a_{s,i,j}$, $a_{s,j,l}$ and $a_{c,i}$) has the same 4.24 dB deviation and thus global shadowing factors $a_{i,l}$, $a_{i,k}$ and $a_{j,l}$ have respectively a deviation of 6 dB, 7.34 dB and 4.24 dB .

Mobiles are assumed connected to the best server. Open loop power control is used in uplink while in downlink the closed loop power control with 1 dB step is implemented [13][14]. The joint detection technique is used to decrease the intracell interference. Hence, the intracell interference factor are 0.1 and 0.2 respectively in downlink and uplink [8][15].

In the common switching point technique, the switching point between both links is the same for all cells and it varies according to the ratio of total traffic of both links. The movable switching point [6] is used in the diversified switching point technique where each cell has a specific switching point that varies according to the ratio of traffic of both links in the cell (figure 6). The same method is used when the interference avoidance methods are added. To reduce the complexity of the joint detection technique, the number of codes per slot is reduced to 11 in each cell. A slot is randomly associated to a mobile if the code constraint is verified. Otherwise, the mobile call is blocked. When a mobile is accepted in the system, it will be active until the end of its call whatever the E_b/N_0.

V. SIMULATION RESULTS

The performance of methods is measured by the rate of satisfied resources, which is defined as:

$$S = \frac{N_s}{N_l}, \tag{4}$$

where N_s is the number of satisfied radio resources over all frames, mobiles and slots. A satisfied radio resource is a channel received with an E_b/N_0 higher than the desired threshold during a frame. The factor N_l is the mean number of all possible active codes over all frames and it is given by: $N_l = N_m.N_f.N_c$, where N_m, N_f and N_c are respectively the number of requesting calls in the whole simulation, the mean number of frames where a mobile is active and the mean number of codes associated to a mobile. In downlink, the E_b/N_0 oscillates around the desired threshold due to the nature of the closed loop power control; therefore, a radio resource in downlink is considered satisfied if it is received with an E_b/N_0 higher than the (threshold-0.5 dB).

The rate of satisfied resources are shown in figure 7. In this figure, the threshold $\varsigma_{j,l}$ was deduced from a path gain without shadowing and with a distance $d = 0.5\ R$, where R is the cell radius. It was shown by simulations that it is the most suited value. Moreover, different values of the threshold in the different time slot allocation based on region division were used and the best results are shown in the figure. When the load increases in cells, the performance of the proposed method became better than other methods. For low loads, the resource units are not fully utilized in the downlink, which is the limiting link in asymmetric systems. Moreover, the blocking probability is not very high and the performance is highly related to the satisfied users. Hence, the common switching point technique, which pro-

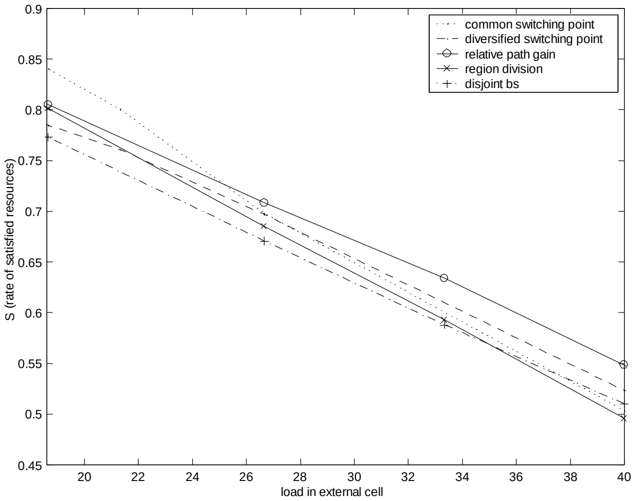

Fig. 7. Simulation results for the different allocation techniques

hibits crossed slots, is the most suited method for low loads. However, when the load increases the performance of the common switching point technique decreases and the proposed method appears as the best method. For high loads, download slots will be saturated if the common switching point is used because the blocking probability is very high. If the diversified switching point is used, the blocking probability decreases but the number of satisfied users decreases also due to the high inter-MS interference. Therefore, the proposed method, which prevents such interference, gives the most satisfactory results. The performance of other interference avoidance methods is improved when the load is increased but theirs results are lower than the proposed method.

In this simulation, we consider a random slot allocation. Thus, the number of satisfied users is at its minimum and the diversified switching point techniques works at the worst situations. The performance of the interference avoidance method based on relative path gain and the existing interference avoidance methods will be more satisfactory if a more efficient slot allocation is combined with the diversified switching point technique.

VI. Conclusions and Future Works

In this contribution, we have proposed an improvement to the existing interference avoidance methods. The proposed method has given more satisfactory results than other existing methods for high loads. Moreover, the common switching point is suited for low loads in spite of the highly asymmetrical services.

It is believed that diversified switching point will be more satisfactory if a more efficient slot allocation scheme is used with the interference avoidance method. Furthermore, the interference avoidance method based on relative path gain will give better results than other methods if the rate of services is variable in time and if the handover is taken into account. In this case, a variable threshold can be used in the proposed method to compensate the effect of the load variation.

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References

[1] Third Generation Partnership Project (3GPP), Technical Specification Group Radio Access Network, "Physical Channels and mapping of transport channels onto physical channels", 3GPP TS 25.221 (Release 5), April 2002.

[2] W. S. Jeon and D. G. Jeong, "Comparison of Time Slot Allocation Strategies for CDMA/TDD Systems", IEEE Journal on Selected Areas in Communications, vol.18, No. 7, pp. 1271-1278, Jul. 2000.

[3] I. Forkel, T. Kriengchaiyapruk, B. Wegmann and E. Schulz, "Dynamic Channel Allocation in UMTS Terrestrial Radio Access TDD Systems", in Proceedings of the 53rd Vehicular Technology Conference (VTC 2001 Spring), vol. 2, pp. 1032 -1036, 2001.

[4] H. Holma, S. Heikkinen, O.-A. Lehtinen and A. Toskala, "Interference considerations for the time division duplex mode of the UMTS Terrestrial Radio Access", IEEE Journal on Selected Areas in communications, vol.18, No. 8, Aug 2000.

[5] J. Nasreddine, X. Lagrange,"Power Control and slot allocation in TD-CDMA system", in Proceedings of the IEEE Vehicular Technology Conference Spring, 2002.

[6] M. Lindström and J. Zander, "Dynamic Link Asymmetry in 'bunched' wireless networks", in Proceedings of the IEEE Vehicular Technology Conference Fall, pp. 352-356, 1999.

[7] M. Lindström, "Improved TDD Resource Allocation through Inter-Mobile Interference Avoidance", in Proceedings of the IEEE Vehicular Technology Conference Spring, 2001.

[8] J. Nasreddine, X. Lagrange, "Comparison of different slot allocation schemes in a TD-CDMA TDD system", Workshop in Applications and Services in Wireless Networks (ASWN), May 2002.

[9] S.-H. Wie and D.-H. Cho, "Time Slot Allocation Scheme based on a Region Division in CDMA/TDD Systems", in Proceedings of the IEEE Vehicular Technology Conference Spring, 2001.

[10] Technical Report. Universal Mobile Telecommunications System (UMTS). "Selection procedures for the choice of radio transmission technologies of the UMTS", TR 101 112 V3.2.0 (UMTS 30.03 version 3.2.0), April 1998.

[11] A. J. Viterbi, A. M. Viterbi and E. Zehavi, "Other-Cell Interference in Cellular Power-Controlled CDMA", IEEE Journal on Communications, vol. 42, No. 2, February 1994, pp. 1501-1504.

[12] H.W. Arnold, D.C. Cox, R.R. Murray, "Macroscopic diversity performance measured in the 800-MHz portable radio communications environment", *IEEE Transactions on antenna and propagation,* vol. 36, No 2, Feb. 1988.

[13] Third Generation Partnership Project (3GPP), Technical Specification Group Radio Access Network, "Physical Layer Procedures (TDD)", 3GPP TS 25.225 (Release 5), October 2002.

[14] Third Generation Partnership Project (3GPP), Technical Specification Group Radio Access Network, "Radio Resource Control (RRC); Protocol Specification", 3GPP TS 25.331 (Release 5), September 2002.

[15] A. Klein, G. K. Kaleh and B. P. Walter, "Zero Forcing and Minimum Mean-Square-Error Equalization for Multiuser Detection in Code-Division Multiple-Access Channels", IEEE Transactions on Vehicular Technology, vol. 45, No. 2, May 1996, pp. 276-287.