Power control and slot allocation in a TD-CDMA system

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Abstract- **Power control is a very important feature of CDMA systems and it dramatically impacts the cellular capacity. The UTRA-TDD (Universal Terrestrial Radio Interface with time Division Duplex) adopted for third generation systems is a hybrid radio interface, which mixes TDMA and CDMA schemes. Therefore, power control and slot allocation must be optimised jointly. In this paper, we introduce two slot allocation methods combined with optimal power control. In the first method, we calculate the mean normalized path loss of mobile stations and try to obtain for each cell an allocation with the same mean normalized path loss on all time slots. In other way, we try to obtain the same signal to interference ratio in all cells. The principle of the second method is to group mobile stations with close path loss values on the same slot for each cell and associates a set of high-gain mobile stations of a cell with sets of low-gain mobile stations from neighbouring cells in the same time slot. The second method performs better than the first one and gives very close results to the optimal ones.**

I. INTRODUCTION

Universal Terrestrial Radio Interface with Time Division Duplex (UTRA-TDD) proposed by the Third Generation Partnership Project (3GPP) for urban zones is a hybrid TD-CDMA system. In Europe, a spectrum of 25 MHz (1900-1920 and 2020-2025 MHz) has been defined to licensed applications with UTRA-TDD. In each carrier of 5 MHZ, a *10 ms frame of 15 time slots is defined (fig.1).* These time slots can be used for uplink or downlink, with at least one time slot dedicated to uplink and another one to downlink [1]. The spreading factor used in the uplink ranges from 16 to 1. In the downlink, spreading factor 16 is used for multiple parallel physical channels. In this case, up to 16 users may be served in the same time slot. Spreading factor 1 may be used for one code transmission with high bit rate [2].

The TDD mode is advantageous for public micro and pico cell environments for licensed and unlicensed cordless applications and it supports data rate of up to 2 Mb/s. In addition, the TDD mode presents the possibility of using a dynamic switching point (i.e. boundary between uplink and downlink physical channels) or multiple switching points (fig.1). Therefore, the TDD mode is particularly well suited for environments with high traffic density and indoor coverage, where applications require high data rates and tends to create highly asymmetric traffic [3] (e.g. Internet access).

The resource unit in a TD-CDMA system is a combination of a code, a time slot and the power dedicated to this couple. The number of resource units is limited by interference.

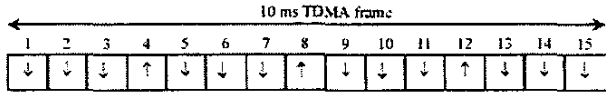

Fig. 1. TDMA frame with asymmetric configuration

Therefore, powerful power control and optimum slot allocation algorithms must be combined to limit interference and to increase the capacity and QoS of the system.

The QoS of a radio interface is an increasing function of the bit error rate (*BER*) that can be derived from the signal to interference ratio *SIR* [4]: $BER = \kappa exp[-\beta(N \times SIR)]$, where N is the processing gain, κ and β are encoding and modulation parameters. Therefore, our objective is to optimize *SIR* for all users.

Several methods have been proposed for channel allocation in TDMA or FDMA systems [5]. On the other side, optimal power control has been studied for a pure FDMA system [6] and may be extended for CDMA systems. However no contribution (to the knowledge of the authors) considers both power control and slot allocation in a TD-CDMA system. This combination is introduced in this contribution.

The remainder of this article is structured as follows: in the next section, we introduce the system model. In section III, we derive a mathematical framework for the optimal power control. Section IV presents two allocation methods combined with the optimal power control. In section V, we present three simulations to investigate advantages of each method. Finally, section VI presents some concluding remarks.

II. SYSTEM MODEL

A. Notation

The studied system is a synchronized bunched system [7][8]. A bunch is a centralized cellular system where a central unit controls a set of remote antenna units. In this system, all link gains between base stations and mobile stations are assumed known through intelligent measuring [9].

In the considered system, N mobile stations are equally distributed over M cells. Indexes i and k always refer to mobile stations while indexes j and l refer to base stations. Furthermore, index j refers to the base station that serves mobile station i (fig.2). This base station is supposed to be the *most favorable one for the mobile station i (i.e. the base* station with the lowest path loss). The set of base station indexes is noted $\Pi = \{1, \ldots, M\}$ and the set of mobile stations connected to base station j is noted S_j. Without loss of generality, we assume that mobile stations are sorted. Then, index i of the set S_j varies in the interval $\left[M+\sum_{l=1}^{j-1}N_l+1,\, M+\sum_{l=1}^{j}N_l\right]$, where N_l is number of active mobile stations in cell l. Hence, there is no intersection between Π and $\bigcup_{j\in\Pi} S_j$ sets.

Let T be the number of time slots used in the downlink and assume that each mobile station is assigned to one time slot in the TDMA frame. The set S_j might be divided in subsets $\{S_j^n, n=1, ..., T\}$, where S_j^n is the set of mobile stations connected to base station j during time slot n.

Due to synchronization, time slots between cells are aligned in time (i.e. time slot n is same in all cells). Hence, there is no interference between different time slots. The thermal noise is neglected. In addition, we assume that intracell interference is cancelled by joint detection algorithms [10][11]. Therefore, we do not consider intracell interference in our model.

Every base station j transmits a total power $P_{T,j,n}$ within time slot n. This power is distributed among mobile stations of cell j such that every mobile station i receives $C_{M,j,n} = G_{i,j}\alpha_{i,n}P_{T,j,n}$, where $\alpha_{i,n}$ is the power portion dedicated to the mobile i during time slot n and $G_{i,j}$ is the path gain (inverse of the path loss) between mobile station i and its base station j. In the following sections, we use the normalized path gain $Z_{i,l}$ between mobile station i and neighboring base station l: $Z_{i,l}=G_{i,l}/G_{i,j}\ \forall i \in S_j^n$ and $j, l \in \Pi$.

The signal to interference ratio *SIR* for a mobile i within time slot n is given by:

$$\Gamma_{i,j,n}=\frac{G_{i,j}\alpha_{i,n}P_{T,j,n}}{\sum_{l\in\Pi-\{j\}}G_{i,l}P_{T,l,n}}=\frac{\alpha_{i,n}P_{T,j,n}}{\sum_{l\in\Pi-\{j\}}Z_{i,l}P_{T,l,n}}. \qquad (1)$$

B. Optimal power control

In this section, optimal power control model during time slot n is described. In [6], the author studies a FDMA/FDD system, where only one mobile station is served in each cell within a time slot. In this section, the power control model described in [6] is generalized and applied to TD-CDMA/TDD system. Therefore, the total power transmitted by each base station is used instead of the power transmitted to each mobile.

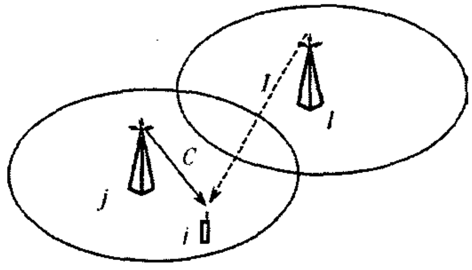

Figure 2. Link between mobile station i and base station j and interference of the base station

These latter powers are recalculated from the total power using the following equation:

$$\alpha_{i,n}=\frac{\sum_{l\in\Pi-\{j\}}Z_{i,l}P_{T,l,n}}{\sum_{l\in\Pi-\{j\}}\sum_{i\in S_j^n}Z_{i,l}P_{T,l,n}}.$$

To satisfy all mobile stations within a time slot n, the *SIR* must satisfy the constraint:

$$\Gamma_{i,j,n}\geq\gamma_n\ \forall i\in S_j^n \qquad \forall\ j\in\Pi,\ n\in\{1,...,T\}$$

Where γ_n is the target *SIR* within the time slot n. By using (1), this constraint may be written as:

$$\frac{1+\gamma_n}{\gamma_n}\alpha_{i,n}P_{T,j,n}\geq\sum_{l\in\Pi-\{j\}}Z_{i,l}P_{T,l,n}+\alpha_{i,n}P_{T,j,n}\ \forall i\in S_j^n,\ j\in\Pi.$$

By adding all inequalities in each cell j and considering matrix in time slot n, we write:

$$\mathbf{Z}^{(n)}\mathbf{P}_{T,n}\leq\frac{1+\gamma_n}{\gamma_n}\mathbf{P}_{T,n}$$

Where:

$$\mathbf{Z}^{(n)}=\begin{bmatrix}1 & \sum_{i\in S_1^n}Z_{i,2} & \cdots & \sum_{i\in S_1^n}Z_{i,M}\\ \sum_{i\in S_2^n}Z_{i,1} & 1 & \cdots & \sum_{i\in S_2^n}Z_{i,M}\\ \cdots & \cdots & \cdots & \cdots\\ \sum_{i\in S_M^n}Z_{i,1} & \sum_{i\in S_M^n}Z_{i,2} & \cdots & 1\end{bmatrix}\qquad \mathbf{P}_{T,n}=\begin{bmatrix}P_{T,1,n}\\ P_{T,2,n}\\ \\ P_{T,M,n}\end{bmatrix}$$

By using total powers transmitted by base stations, we obtain a square non-negative matrix with a reduced number of elements. A necessary and sufficient condition for a non-negative solution $\mathbf{P}_{T,n}$ to this inequality is given by Perron Frobenius theorem: $(1+\gamma_n)/\gamma_n\geq\lambda_n^*$ [6][12], where λ_n^* is the largest real eigenvalue of the matrix $\mathbf{Z}^{(n)}$. Hence, the upper bound of the signal to interference ratio is $\gamma_n^*=1/(\lambda_n^*-1)$. By using this method we can find the upper bound γ_n^* for each time slot.

C. Power control and slot allocation

In this section, power control and slot allocation are combined to profit at most from the flexibility of the TDMA system. Our objective is to guarantee for all users an acceptable *SIR*. So, all upper bound γ_n^* must be larger than the desired *SIR* on all time slots n. Therefore, the minimum upper bound $\gamma^*=\min_{n\in\{1,...,T\}}\gamma_n^*$ must be maximized (i.e. the maximum eigen value $\lambda^*=\max_{n\in\{1,...,T\}}\lambda_n^*$ must be minimized). Note that the T matrixes $\mathbf{Z}^{(n)}$ in a TDMA system depend on the slot allocation of mobile stations in the system. Different distributions of mobile stations give different sets of matrix $\mathbf{Z}^{(n)}$. Therefore, our problem is to find the partition of mobile stations into T time slots $\{S^0, S^1, ..., S^T\}$ that maximizes γ^* (i.e. a set of T matrixes $\mathbf{Z}^{(1)}, \mathbf{Z}^{(2)},\ldots, \mathbf{Z}^{(T)}$).

III. Developed Method for Optimal Partition

A simple solution to find the optimal partition is to study all possible partitions. However, the number of possible cases increases exponentially with the number of mobile stations.

We assume that the N mobile stations are equally spread into all M cells and all T time slots. Therefore, in each cell the total number of mobile stations is N/M and the number of possible partitions in one cell is given by:

$$npc = \frac{(N/M)!}{(N/MT)^T}$$

As we have M cells with a fixed number of mobile stations, the total number of possible partitions is $(npc)^M$. In the other hand, the same chosen partitions distributed in different ways over time slots gives the same interference situation. These repeated cases must be eliminated. Therefore, the total number of possible partitions to investigate in the exhaustive method is: $np = [(npc)^M]/T!$.

This number increases in an explosive manner when N, M or T increases. For a bunched system where M=7, T=7 and N=196, the number of possible partitions is around 1.5×10^{173}. To investigate this huge number of possibilities, we need an unacceptable duration. Therefore, we must find methods that reduce the number of investigated partitions and give good results.

A. Variance minimization method

In the variance minimization method (called method A), we try to obtain the partition that gives the same upper bound of the signal to interference ratio γ_n^* within all time slots of the system. The method includes two steps: first, we find a partition for each cell, then we investigate all combinations of the partitions found in the first step over all system cells.

In the first step, we study each cell j independently: for the set S_j, we find all possible partitions $\{S_j^1, ..., S_j^p, ..., S_j^T\}$, where S_j^p contains N/MT mobile stations of the cell j and we define the variable $x_{j,p}$ as the sum of normalized path gains of mobile stations found in the subset S_j^p. This variable is the sum of elements of the j^{th} line of the matrix $Z^{(p)}$:

$$x_{j,p} = \sum_{l\in\Pi-\{j\}} Z_{j,l}^{(p)} = \sum_{l\in\Pi-\{j\}}\left(\sum_{i\in S_j^p} Z_{i,l}\right)$$

Let v be the variance of the variable $x_{j,p}$ when varying p:

$$v = \operatorname*{var}_p(x_{j,p}) = \frac{1}{T}\sum_{p=1}^{T}(x_{j,p}-\bar{x})^2$$

Where $\bar{x}$ is the mean value of $x_{i,p}$: $\bar{x} = \frac{1}{T}\sum_{p=1}^{T} x_{j,p}$

In each cell, we choose the partition that minimizes v. Once found, we try to obtain the partition $\{S^0, S^1, ..., S^T\}$ of the set $\bigcup_{j\in\Pi}\{S_j^1, ..., S_j^p, ..., S_j^T\}$ that maximizes the minimum upper bound of all time slots: $\gamma^* = \min_{n\in\{1,...,T\}} \gamma_n^*$, where $\{S_j^1, ..., S_j^p, ..., S_j^T\}$ are the partitions found in the first step. Values of γ_n^* are found by using the Perron Frobenius theorem in each time slot of the studied partition and the final partition is formed by making combinations between partitions of all cells.

Figure 3 presents the partition obtained by applying method A in a system of 2 cells and 2 time slots. In each cell, 2 high-gain mobile stations and 2 low-gain mobile stations are active. This partition minimizes the variance of the variable $x_{j,p}$ in the each cell.

The number of partitions to investigate in this method is given by the next equation:

$$np = M\times npc + (T!)^{M-1} = M\frac{(N/M)!}{T!}\left(\frac{1}{(N/MT)!}\right)^T + (T!)^{M-1}$$

For a bunched system where M=7, T=7 and N=196, the number of investigated partitions is around 16×10^{21}. Hence, we obtain a reduction of 10^{151} in the number of total possible partitions.

As we have many partitions in each cell that minimize the variance of the chosen variable, this method may not give always good results.

B. Normalized path loss sorting method

The main idea of the normalized path loss sorting method (called method B) is to allocate the same time slot to mobile stations that have similar path losses in each cell and associate a set of high-gain mobile stations of a cell to sets of low-gain mobile stations from neighboring cells. A low-gain mobile station has a low sum of normalized path gain. The method consists of two independent steps. In this method also, we try to find partition that gives similar upper bound of the SIR in all time slots. In this method, this target is not reached in the first step but in the second step, which is the same of method A.

First, we sort mobile stations of each cell j using the sum of the normalized gain $z_i = \sum_{l\in\Pi-\{j\}} Z_{i,l}$ of each mobile station i and we group $s = N/MT$ consecutive mobile stations of each cell in a subset S_j^p. Hence, we obtain T subsets S_j^p in each cell. These subsets will be used in the second step to find the total partition that maximizes the minimum SIR of all time slots.

Figure 4 presents the same example as the previous section but with mobile stations distributed using method B.

The number of partitions to investigate of this method is given by the next equation:

$$np = (T!)^{M-1}$$

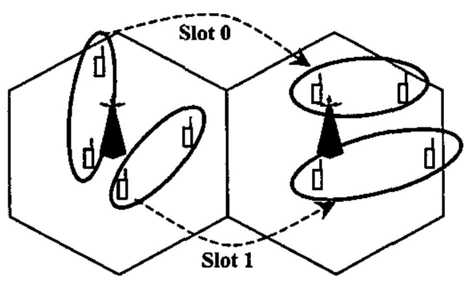

Figure 3. Example of a partition using method A.

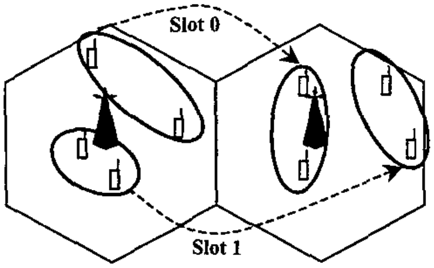

Fig. 4. Example of a partition using method B.

For a bunched system where M=7, T=7 and N=196, the number of investigated partitions is around 16×10^{21} (reduction of 10^{151} in the number of total possible partitions).

IV. SIMULATIONS AND RESULTS

To study the efficiency of our proposed methods, we made three simulations. The simulation area is a regular hexagonal cellular network. The assumed propagation model is Okumura-hata-cost231 model. The shadowing effect is modelled by a Log-Normal distribution with zero mean and 6 dB deviation. It is constant in time and depends only on the mobile position in the cell. In addition, correlation between the shadowing factor of a mobile station and base stations has a coefficient of 0.5 [13]. In all simulations, mobile stations are assumed connected to the best server.

A. *First simulation*

In the first simulation, results of both methods are compared with the result of the optimal (i.e. exhaustive) method for a system of 16 mobile stations, 2 cells and 2 time slots. With such values, the total number of partitions is 3 175 200, and all possible partitions may be investigated. The shadowing effect is neglected. Therefore mobile stations are served by the nearest base station.

Table 1 shows results of the first simulation for several mobile station distributions in cells. Method B gives always a satisfactory result and the minimum upper bound of the *SIR* given by this method is never 3 dB below the optimal minimum upper bound. In the other hand, method A may degrade the *SIR* by more than 3 dB.

In this simple system, method B gives a partition with a minimum upper bound of *SIR* very close to the optimal value, but it allows a dramatic reduction of the number of studied partitions.

TABLE 1
Results of the first simulation

	Method A	Method B
Maximal difference between the optimal γ^* and the γ^* of a method	5.0 dB	0.73 dB
Percentage of cases where the difference between the optimal γ^* and the γ^* given by a method is more than 3 dB	10%	0%
Percentage of cases where γ^* of a method is equal to the optimal γ^*	2.9%	11.9%

B. *Second simulation*

The objective of the second simulation is to compare results of the two methods in a more generalized system. Hence, we consider 36 mobile stations distributed uniformly over 3 cells (12 mobile stations by cell) and 4 time slots. The shadowing effect is neglected in this simulation too.

The simulation of several samples of mobile stations distribution has given results shown in table 2.

Results of the second simulation show that γ^* given by method B is always better than γ^* given by method A, and in 26% of cases method B is better than method A (i.e. γ^* given by method B is at least 3 dB higher than γ^* given by method A).

C. *Third Simulation*

In the previous simulations, we have seen that method B is better than method A. Therefore, in this simulation we will test only method B in a more realistic system. Hence, we compared the minimum upper bound given by method B with the minimum upper bound founded in a random distribution of mobile stations over time slots. The considered system contains 84 mobile stations uniformly distributed over 3 cells. The downlink frame is composed of 7 time slots with 4 mobile stations on each one. Several simulations were made. In each simulation, we have considered several distributions of mobile stations in cells.

The mean value of γ^* in all simulations is given in Table 3. In this table, we can see that the mean value of γ^* given by method B and the random method are respectively around 5.3 dB and –0.3 dB. In addition, the mean value of the difference between the two γ^* is around 5.5 dB.

V. CONCLUSION AND FUTURE WORK

In this paper, we have introduced a simple method to calculate the upper bound of *SIR* in the downlink. This method considers total power transmitted by base stations of a system instead of specific power dedicated to each mobile station. Therefore, the number of variables and the size of matrix are very small. In addition, whatever the distribution of mobile stations over cells, we obtain a square matrix and the power control optimization can be applied. This method can be used to obtain the upper bound of *SIR* and to investigate the efficiency of DCA and reorganization algorithms.

To benefit from the slot allocation flexibility in a TD-CDMA system, we developed two methods in the purpose of finding a partition of mobile stations that maximizes the minimum *SIR* of all time slots. It was found that it is better to group mobile stations with close path loss values on the same slot for each cell and associate the set of high-gain mobile stations of a cell in the same time slot with sets of low-gain mobile stations from neighboring cells.

When dynamic switching point scheme is used in a UTRA-TDD system, mobile station-mobile station and base station-base station interferences may be produced when the same time slot is allocated both for uplink and downlink in different cells. A further step of our work is to study the performance of the allocation algorithm in these cases.

TABLE 2.
Results of the second simulation

Percentage of cases where γ^* given by method B is larger than γ^* given by method A	**100%**
Percentage of cases where the difference between γ^* given by method B is and γ^* given by method A is larger then 3 dB	**26%**

TABLE 3
Confidence interval $[X_i, X_s]$ of γ^* of the normalized path loss method and random method, in addition to theirs difference.

	γ^* given by the method B	**γ^* given with random allocation**	**Difference between γ^***
Mean value	5.29	-0.29	5.58
Variance	0.026	0.041	0.028
Lower bound X_i (with 5% probability of error)	5.28	-0.31	5.57
Upper bound X_s (with 5% probability of error)	5.30	-0.27	5.59

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