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Dynamic Common Pilot Power Management in a Real Hot Spot Environment

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***Abstract*—This paper focuses on the analysis of 3G mobile communications systems in scenarios with non-uniformly distributed traffic. Special attention is paid to the impact of hot spots on uplink BLER and admission control. Load balance is carried out by dynamically varying common pilot power. Results reveal that the performance of the system in the uplink may be improved when applying such technique.**

Keywords: Hot spot, W-CDMA, Radio Resource Management, Pilot power, Load balance.

I. INTRODUCTION

Third generation mobile communications systems were designed as a solution to support different types of multimedia services. Nowadays 3G networks have been and are still being deployed all around the world. Even though UMTS services demand is still at an initial stage, it is expected to grow and reach penetration rates similar to rates experienced in previous mobile communications systems such as GSM. In W-CDMA based systems the maximization of the capacity (referred as soft-capacity) has become one of the main issues to be tackled. Thus, for a given set of QoS (Quality of Service) requirements [1], the number of users allocated in the system is intended to be increased while preventing the whole system from getting congested. This main target can be reached by means of network planning and Radio Resource Management (RRM) strategies. On one hand network planning is of static nature and is not able to deal with casual congestion situations caused by system fluctuations not considered in advance. On the other hand, radio resource management strategies are the key point aimed to manage congestion situations by optimizing the available resources use. In W-CDMA based systems the capacity is tightly coupled with the amount of interference in the air interface and, contrary to what occurred in 2G systems where the capacity was determined by the spectrum associated to each cell, a proper management of transmitted power and orthogonal code leads to remarkable improvements. The inherent flexibility of W-CDMA systems turns out to be an advantage, but it is worth noting that such flexibility implies that the system is much more sensitive to environment variations related to the interference level, such transmitted power or users' distribution.

The benefit achieved by applying suitable Radio Resource Management strategies is not important in relatively low loaded scenarios but in high loaded scenarios. The importance of RRM strategies grows as the interference level increases and the capacity limits are reached. Thus, effective strategies may become a differentiation issue for operators and manufacturers, since RRM strategies are not subject to standardization.

Most real scenarios present certain areas with specific traffic density (the so-called hot spots) that may degrade not only transmission quality of terminals placed in that area but the whole system performance. As traffic distribution may have an important impact on air interface interference, it is also expected to affect RRM strategies somehow.

Hot spot issue has been considered from different points of view in the literature and several approaches have been proposed. First approaches are deployment solutions. A wide range of proposals including microcell deployment are detailed in [2][3][4]. In particular, in [4] a wise dynamic sectorization is analysed in order to deal with varying hot spot scenarios. In the same way, also repeaters have been considered. Although repeaters were initially intended for increasing the coverage, several studies present important improvements when using repeaters to improve the capacity of hot spots [5][6][7]. Nevertheless, all deployment approaches imply a high investment effort for operators.

Focusing on the load balance by means of common pilot power management, it has been studied mainly for the downlink. Thus, the trade-off existing between power devoted to CPICH and to traffic channels is highlighted in [8] and [10]. Likewise, in [9] the same issue is tackled including cost functions. Finally, special attention should be paid to [11] and [12], where common pilot power management is suggested to improve uplink capacity in a hot spot scenario. In both studies Subramaniam and Anpalagan describe results obtained with a snap-shot based simulator to analyse effects caused by a pilot power management algorithm.

This paper is focused on the analysis of a new RRM technique proposal brought up in the framework of the

EVEREST project to cope with the deterioration of uplink features caused by traffic hot spots. This new approach is based on dynamic pilot power management, where not only path loss is considered but load factor of each cell. The rest of this paper is organized as follows. In Section II simulation model is explained, providing information on the most important parameters as well as on different model considerations. Section II contains a description of the proposed dynamic pilot power management algorithm, as well as details on its most significant parameters. Results obtained by means of simulation are presented in Section IV. Firstly, no CAC procedure is applied. Then, results obtained when CAC is applied are presented. Section V summarizes the study.

II. SIMULATION MODEL

For the evaluation of traffic hot spot impact on the performance of the system and the benefit achieved with the strategies proposed a system level simulator has been developed. Only videophone users have been simulated. The scenario under study is composed of 8 base stations (each of them with 3 sectors) of a central urban area in Barcelona (Spain) (Figure 1). The size of the simulated scenario is 1500m×1350m. In the physical layer, a link level simulator that includes the 1500 Hz closed loop power control, 1/3 turbo coding effect and channel impulse response estimation, provides BLER (Block Error Rate) statistics used by the system level simulator [13]. Simulation parameters are summarized in Table 1. No propagation models have been used and path loss data has been obtained from network planning tools. Also, a standard mobility model is considered [14], with 3 km/h mobile speed. Characteristics of the radio access bearer are taken from [15] and given by a Transmission Time Interval (TTI) of 20 ms, a Transport Block (TB) size of 640 bits and a Transport Format allowing to send 2 Transport Blocks per TTI. Taking into account the CRC and turbo-encoding process such transmission requires a spreading factor equal to SF=16 (in uplink).

Table 1. Simulation parameters.

BS parameters	
Cell type	Tri-sectorial
Maximum transmitted power	43 dBm
Thermal noise	-103 dBm
Pilot and common control channel power	30 dBm
UE parameters	
Maximum transmitted power	21 dBm
Minimum transmitted power	-44 dBm
Thermal noise	-99 dBm
Mobile speed	3 km/h
Traffic model	
Call duration	120s
Offered bit rate	64 kb/s (CBR)
Activity factor	1
Call rate	15 calls/h/user
QoS parameters	
BLER target	1%
Eb/No target	2.95 dB

Traffic is distributed in two different layers: a general layer and a hot spot layer. The former is spread around the whole simulation area whereas the latter is limited to a certain location. This hot spot layer is characterised by means of a centre point (a red cross in Figure 1) and a radius (R=50m). L1 denotes hot spot location 1 and L2 hot spot location 2. Each user belongs to one of the layers and there is no chance to shift from one layer to the other. Statistics collected in order to assess the behavior of the system are BLER and admission probability. BLER (Block Error Rate) depicts the percentage of erroneous TB (Transport Block) received by the base station. Admission probability is the probability of admitting a connection request.

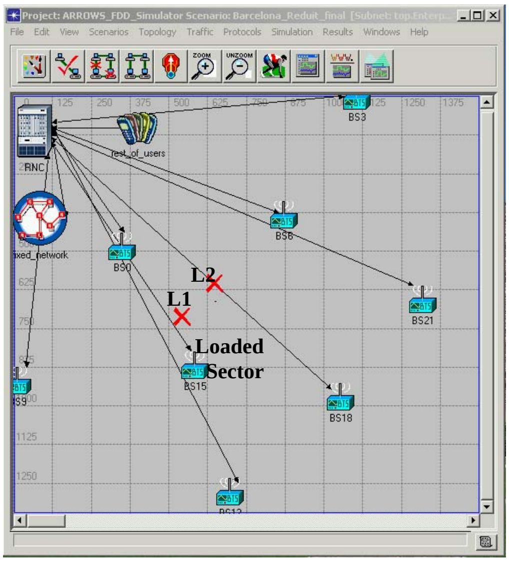

Figure 1. Non uniformly distributed scenario used in simulations.

III. DYNAMIC PILOT POWER MANAGEMENT

The main target of all radio resource management techniques is the minimization of the interference. Focusing on the uplink, transmitted power is the resource that must be used in an efficient way in order to reduce the amount of interference. The dynamic pilot power management strategy that is going to be detailed hereinafter (also called Cell Breathing Algorithm) is based on the premise that the minimum interference scenario is only reached if all users get connected to the Node-B with the lowest transmitted power requirements. In UTRA-FDD, mobile users get connected to the best Node-B among base stations included in the Active Set. Taking into account that base stations are included in or removed from the Active Set according to the received Ec/Io, it is possible to control the serving base station by properly varying pilot powers.

Uplink transmitted pilot power dependencies may be found out by inspecting (1). Not taking into account the service specific parameters and focusing on environment related parameters, path loss (L_p) and load factor (η) appear to determine the transmitted power. It is worth noting that whereas in uniformly distributed traffic scenarios load factor is similar in all Node-Bs and has slight influence on the selection of the serving base station, in non-uniformly distributed traffic scenarios load factor plays a crucial role in the selection.

$$P_T = L_P \frac{P_N}{1-\eta} \frac{1}{\frac{\left(\frac{W}{R_b}\right)}{\left(\frac{E_b}{N_0}\right)_T}+1} \qquad (1)$$

where P_T is the transmitted power, L_p is the path loss, P_N is the thermal noise power, R_b is the user instantaneous bit rate, W is the total bandwidth after spreading (3.84 MHz), η is the uplink load factor and (E_b/N_o) stands for the user requirement.

Noticing the relationship existing between transmitted power and load factor, it appears to be reasonable to increase low loaded cells pilot power to make them more appealing. On the other hand, the higher loaded a cell is, the lower pilot power should be. Working on that principle, the flow diagram of the proposed algorithm is depicted in Figure 2:

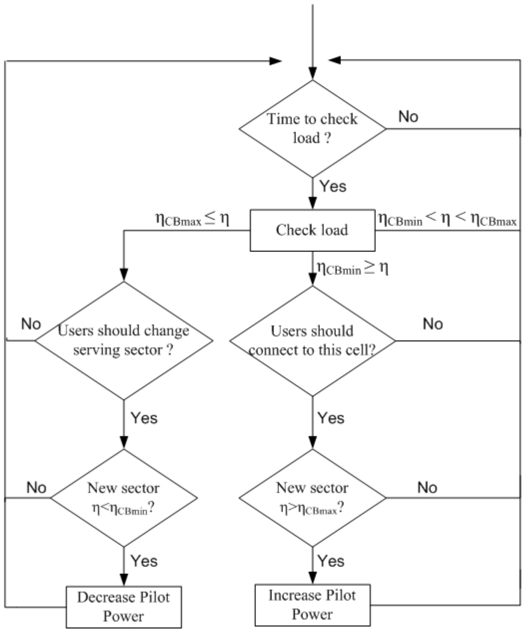

Figure 2. Flow diagram of Cell Breathing algorithm.

Load factor is checked in all sectors or Node-Bs every ΔT_{CB}=20 msec. Possible cell status are: high loaded ($\eta>\eta_{CBmax}$), medium loaded ($\eta_{CBmax}<\eta<\eta_{CBmin}$) or low loaded ($\eta<\eta_{CBmin}$).

If load factor is higher than the upper threshold (η_{CBmax}):

1- Verify if there are users that should be connected to another base station not included in the Active Set.
2- If there are users in such situation, the pilot power is decreased (P_p-ΔP_p).

If cell is low loaded ($\eta<\eta_{CBmin}$):

1- Verify if there are users that could get connected to this cell.
2- If there are users in such situation, the pilot power is increased (P_p+ΔP_p).

A pilot power constrain is established by setting up a maximum and a minimum pilot power limit (P_{pmin} and P_{pmax}). The upper limit (P_{pmax}) avoids excessively high power in the downlink whereas the lower limit (P_{pmin}) prevents the high loaded cells from decreasing pilot power excessively, since it could cause coverage gaps. It is important to realize that decisions are made according to φ factor, extracted from (1):

$$\varphi = L_P \frac{1}{1-\eta} \qquad (2)$$

In an optimum interference scenario all users would get connected to the cell with the lowest φ_i. Likewise, there exists a boundary (φ_i=φ_n) where a mobile terminal would transmit the same power regardless of whether it is connected to i-th sector or to n-th sector. Such boundary depends on the path loss between mobile node and both sectors as well as on load factors. In Figure 3 boundaries are plotted for different ΔL_p= L_{pn}-L_{pi} as load factor functions. Given a couple of network loads (η_i, η_n) if the point is placed in Figure 3 below a given boundary the user will be connected to BS_n whereas if the point is placed above the boundary the user will be connected to BS_i. For instance, for a given η_i=0.6 and η_n=0.4, a mobile terminal would be connected to BS_i if ΔL_p=3dB and to BS_n if ΔL_p=1dB.

Notice that the above situation happens when both base stations (BS_i and BS_n) belong to the Active Set, and therefore the mobile terminal will always be connected to the appropriate base station (the one that can be reached with minimum transmitted power requirements). However, if one of the base stations does not belong to the Active Set, then this optimum transmitted power value could not be reached. Therefore, it is possible to avoid the above described situation by means of an appropriate pilot power management, guaranteeing that the active set takes into consideration the BS with minimum φ factor.

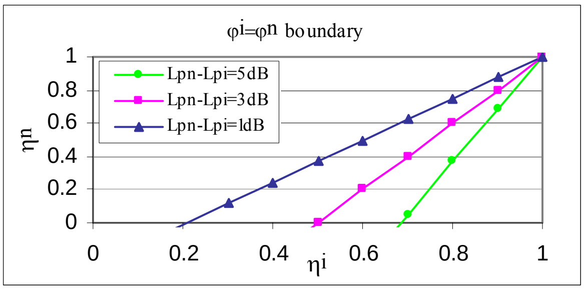

Figure 3. Relationship between load factors and ΔL_p to accomplish φ_i=φ_n .

IV. PERFORMANCE EVALUATION

In this section some results obtained in the considered non-uniformly distributed traffic environment will be exposed. As mentioned in the previous section, traffic is split into two different layers, the uniform layer and the hot spot layer. Simulations presented in this study have been carried out with a constant number of users in the first general layer, 150 users. On the other hand, most figures are a function of the number of users in the hot spot, which is increased in order to figure out the impact of increasing hot spot density on the system performance. The hot spot location is L1 (Figure 1) if not mentioned.

IV.A. Impact of Cell Breathing algorithm in uplink

First simulations have been carried out without applying any CAC (Call Admission Control) and considering ΔP_p=0.5dB (pilot power increase and decrease). Results obtained in the most loaded sector (Figure 1) are depicted in Figure 4. As it was expected, BLER (Block Error Rate) increases as the number of users in the hot spot increases. This effect is owing to the increase of the interference caused by users in the hot spot. It is worth noting that results improve when the Cell Breathing (CB) algorithm is applied. Considering a target BLER of 1%, the number of users allocated in the hot spot while maintaining BLER below the target increases from 30 to 40. It is also true that algorithm is more efficient when the lower threshold (η_{CBmin}) is high. In fact, the lower threshold (η_{CBmin}) determines whether a sector is low loaded. Therefore, this parameter is used to increase low loaded cells pilot power as well as to decrease high loaded cells pilot power. Low values of η_{CBmin} lead to more restrictive conditions of the algorithm, whereas high values allow more relaxed conditions. At the same time, the improvement experienced in the most loaded cells is not translated into deterioration in the performance (in terms of BLER) of neighbouring sectors.

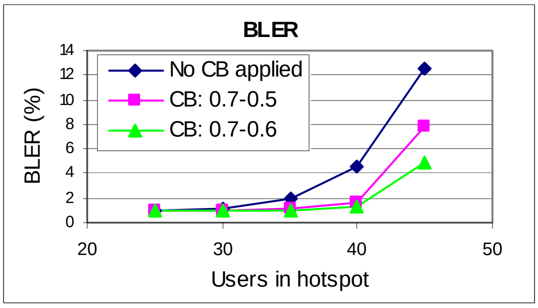

Figure 4. BLER in the most loaded sector of the scenario.

The improvement achieved is due to interference reduction caused by users that have changed the serving sector. Yet, it is remarkable that users transferred from one sector to another do not usually belong to the hot spot, since users connected to the loaded sectors but far from the hot spot (loaded area) are more likely to have surrounding unloaded cells.

Similar results are obtained when the scenario is varied. Table 2 shows BLER for different situations, such as the reduction of the hot spot radius or the change of hot spot location (location 1 and location 2 in Figure 1) when CB is applied (CB) and when CB is not applied (No CB). Although target BLER is set to 1%, a margin is allowed in order to avoid considering quality requirements have not been fulfilled due to non significant fluctuations. Thus, quality requirements will be considered as fulfilled for BLER below 1.2%. First two columns of Table 1 match up with Figure 4.

According to results showed in Table 2, the reduction of hot spot radius (R=25m) together with the maintenance of the hot spot centre location leads to a worse system performance in both cases (with and without CB) if compared to results obtained with R=50m. Notice that such reduction may be seen as an increase of users' density in a limited area, or in the same way an increase of the average distance between hot spot users and serving nodes. This fact implies an added difficulty to fulfil transmitted power requirements, and so it is translated into high BLER values. Nevertheless, CB algorithm is able to cope with the increasing interference caused by the concentration of the hot spot. In this case improvements are not as remarkable as they were for R=50m. The same effect occurs when hot spot is moved away from the closest sector. Columns 5 and 6 from Table 2 (R=50m, location 2) show that BLER grows in such situations due to transmitted power constraints. In this case, effects derived from users' distribution and from distance are coupled, and therefore the number of users with which BLER can be maintained falls below 30.

Table 2. BLER in the most loaded sector in different scenarios.

	Hot spot radius	50m	50m	25m	25m	50m	50m
	Hot spot location	L1	L1	L1	L1	L2	L2
	Algorithm	No CB	CB	No CB	CB	No CB	CB
Users in hot spot	30	1,09	1,00	1,11	1,01	2,77	1,35
	35	2,02	1,03	3,94	1,11	8,15	2,06
	40	4,54	1,23	13,8	9,25	24,13	14,79
	45	12,60	4,83	22,23	18,28	37,37	35,25

IV.B. Call Admission Control inclusion

Call Admission Control is devoted to decide whether a new connection should be admitted or rejected. This RRM strategy (CAC) makes the decision according to cell load level. Thus, it is expected that minimum interference scenarios lead to high admission probabilities. The importance of admission probability lays on the fact that the higher the admission probability is, the larger the number of accepted users is, and therefore, the higher the system efficiency is. In particular, a maximum admission threshold (η_{ADMmax}) of 0.75 has been considered throughout simulations.

Despite positive results obtained when no CAC was applied, the inclusion of a CAC reduces the admission probability of the high loaded sector (Figure 5). The reason lays on the handover thresholds. Mobile terminals can only get connected to sectors included in the Active Set (in our study the Active Set size is equal to 2). Therefore, if the serving sector is removed from the Active Set before the appropriate sector is included, the mobile terminal does not transmit neither to the desired sector nor to the old serving sector, but to another sector (the second sector included in the Active Set). This fact causes an increase in interference. When CAC is not included no decisions related to interference levels are made. In case CAC is included, admission decisions are made according to average interference levels (affected by temporary interference increases), and so the admission probability reflects such an increase. Then the admission probability is degraded.

Working on obtained results, the removal of a sector from the active set appears to be much more critical than the inclusion of a new sector. Thus, a decrease in pilot power is more critical than an increase, since the desired new sector should be included in the Active Set before removing the current loaded sector.

Different values for pilot power increase (ΔP_{pUP}) and decrease (ΔP_{pDOWN}) are set in order to make the Active Set removal process stricter than the including process. Figure 5 plots the improvement reached when ΔP_{pUP}=0.5dB and ΔP_{pDOWN}=0.1dB.

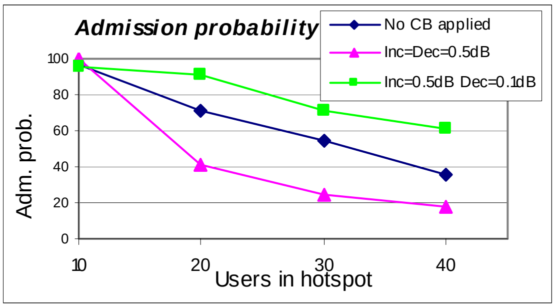

Figure 5. Admission probability in the most loaded sector with and without applying CB algorithm.

BLER level is kept below 1.2% when CAC is applied. Thus, admission threshold (η_{ADMmax}) can be pulled up only if target BLER is assured. In this case the maximum capacity can be defined as the maximum number of users that maintain admission probability above 90%. According to this criterion, Table 3 presents the sector capacity (in terms of hot spot users) for η_{ADMmax}=0.75 and η_{ADMmax}=0.9. It is worth noting that CB algorithm not only works for high loaded cells but obteins the best performance when load is high. Improvements achieved by CB algorithm become more significant as the interference level grows to a critical level.

Table 3. Maximum capacity of the most loaded sector (ΔP_{pUP}=0.5dB and ΔP_{pDOWN}=0.1dB)

Admission threshold (η_{ADMmax})	Hot spot users without CB	Hot spot users with CB	Improvement
0.75	15	20	33.3%
0.9	27	48	77.7%

V. CONCLUSIONS

This paper presents an algorithm to dynamically select the common pilot power in non-uniformly distributed traffic scenarios. Results obtained show that an improvement is achieved if algorithm parameters are properly selected, in particular power increase and decrease. Regarding such parameters, it has also been shown that decreasing power is more critical that increasing it. Finally, performance of the algorithm has been checked in high loaded conditions, proving that such situations stress the algorithm improvement.

VI. ACKNOWLEDGMENTS

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