# On Managing Multiple WCDMA Carriers under Varying Traffic Conditions

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*Abstract.-***This paper proposes a novel framework for developing advanced frequency planning algorithms in WCDMA scenarios under changing traffic conditions. It is based on an analytical model that captures the influence among the different cells by means of the derivatives of the corresponding cell load factors. Then, the cells having the largest influence can be considered as candidates to operate with a different frequency. The proposed algorithm is compared by means of simulations with an algorithm based on load measurements, revealing that the proposed approach is able to capture the relevant cells more accurately. Finally the proposed approach is generalised to a scenario with multiple cells and frequencies by means of an heuristic allocation method.**

## I. INTRODUCTION

The mobile communications industry is currently shifting its focus from 2G to 3G technology. At the same time, more and more radio engineers are becoming familiar with WCDMA radio technology as long as this is the predominant access mechanism in 3G worldwide [1].

System deployment of 3G networks must be preceded by careful network planning. Planning methodologies for WCDMA are substantially different from TDMA-based radio access networks, as it has been extensively studied in the open literature [2]. The complete frequency reuse in WCDMA technologies simplifies the planning exercise in the frequency domain while at the same time leading to a higher complexity in terms of power levels allocation and management. However, in practical WCDMA systems, it is usual that more than one WCDMA carrier is available for a given operator, which adds a new dimension to the radio network planning process. The additional degree of flexibility may be exploited to reduce the interference in each carrier and increase system capacity by means of a proper frequency assignment to cells. Nevertheless, and to the authors' best knowledge, the problem of allocating frequencies in WCDMA has not been addressed in the open literatures, and the use of additional carriers is usually limited to the existence of hierarchical cell structures (HCS) [3], facing non homogeneous traffic distributions and non-homogeneous mobility patterns by deploying microcells in high traffic areas. In that sense, it is usual to operate the different cell layers with different carrier frequencies, although depending on the interference levels, this condition may be broken [4]. On the other hand, one key issue in wireless cellular networks is that traffic distribution along time and space is inherently dynamic and subject to changes. Then, it is fairly common that real traffic distributions are substantially different from those considered in the planning phase. In order to cope with these situations, dynamic planning mechanisms can be envisaged, so that frequency assignments to cells may vary along time and space. Clearly, from a practical implementation point of view, the adjective "dynamic" here stands for a rather long-term change (i.e. once or twice in a day, several times in a week, etc.), so that dynamic planning mechanisms will be able to cope with sudden but, at the same time, significant and long lasting traffic variations. Furthermore, since the number of carriers per operator in WCDMA systems uses to be rather low, coping with dynamic planning seems to be feasible from a practical point of view.

Traffic variations may be of different nature. One type is traffic variation on the average traffic level (for example, an average traffic increase because e.g. tickets for a unique concert are starting to be sold in a given shop at a given time and day). Another possibility is a variation on the spatial traffic distribution while keeping the same average traffic level (for example, an entrance to an underground station is closed for maintenance for some days, so that people needs to get into the underground through a different entrance).

In this paper, the analytical framework described in [6] is used as the basis for a frequency planning algorithm in a WCDMA system with two available frequencies, considering the uplink direction. This framework is based on the computation of the gradient of the load factors among the different cells. The main characteristic of the proposed framework is that, in contrast to other methodologies, it is able to detect and capture traffic variations (either on traffic average values or on spatial distribution). The proposed frequency allocation scheme will be presented in section II, together with a reference algorithm used for comparison purposes. Section III presents the system level simulation model and the considered scenarios used to obtain the different performance results presented in Section IV. The purpose of these simulations is to emphasize the efficiency of the load gradient methodology in the frequency planning exercise for WCDMA systems, so that the proposed algorithm could be extended to consider the more general case with several frequencies available, which is explained in Section V. Finally, Section VI collects the main conclusions of this paper as well as the future work in this line.

## II. PROPOSED FREQUENCY ALLOCATION SCHEME

Let assume a scenario with different cells in which the spatial traffic distribution is non-homogeneous because of the existence of hot spots. Such hot spots may not in general be permanent but they will change in the different periods of the day and geographical locations, due to e.g. people concentrations at a bus-stop, restaurants areas during the meal times, etc. As a result, the load observed by the different cells as well as the interactions between them may experience significant variations during these periods.

Although these issues may be covered at some extent by classical radio network planning when devising the number and locations of the different cells and frequency allocations, the dynamics and randomness associated to the human behaviour may lead to situations in which the frequency allocation should be modified due to e.g. an excessive load in certain cells. Under this framework, in this paper, a method is proposed to detect the cells having the highest influence over the rest of the cells in the scenario, thus being able to decide which cells should operate with a different carrier frequency, whenever a carrier frequency should be changed in the scenario.

In particular, the following scheme, denoted as derivatives-based algorithm, is proposed. It selects the base station to change as the one having the highest influence over the rest of the cells in the scenario. To this end, it operates in the following steps:

Step 1.- Compute the derivatives of the cell load factors among the different cells, for $k$=0, ..., $K$, as explained in [6]

Step 2.- Compute the influence $I_k$ of each cell $k$ in the scenario with respect to the rest of cells, according to:

$$I_k = \sum_{\substack{j=0 \\ j \neq k}}^{K} \frac{\partial \eta_j}{\partial \eta_k} \qquad (1)$$

where $\frac{\partial \eta_j}{\partial \eta_k}$ expresses the derivative of the $j$-th cell load factor with respect to the $k$-th cell load factor. Further details about the computation can be found in [6].

Step 3.- Select the cell with the largest value of $I_k$.

For comparison purposes, let also define the so-called load-based algorithm, which changes the carrier frequency of the base station experiencing the highest uplink load factor.

## III. SIMULATION MODEL

The proposed frequency allocation planning has been evaluated by means of Monte Carlo simulations in a scenario with an area of 0.8*0.8 km$^2$ that consists of 1 microcell BS0, and 4 macrocells BS1, BS2, BS3 and BS4. Assuming that two carrier frequencies are available, the objective of the problem addressed here is to choose among the five cells, the most suitable to operate with a different carrier frequency. This scenario is claimed to be illustrative enough to show the potentials of the proposed framework, which could be readily extended to more complex conditions, as will be detailed in section V.

The simulation parameters are summarised in Table I. Each simulation consists in a set of 12000 snapshots and in each snapshot the users are scattered according to the specific traffic distribution. Each user is connected to the cell having the highest Ec/No (chip energy over noise spectral density) of the downlink pilot channel at the UE receiver. For each snapshot, the first run is carried out assuming that all base stations operate with the same carrier. Then, a second run is executed in which the carrier frequency of one cell is changed according to the specific carrier allocation scheme. The performance comparison is obtained in terms of the outage probability, measured as the fraction of users in the scenario whose measured Eb/No is below the required target.

TABLE I
SIMULATION PARAMETERS

| | |
|---|---|
| **Macrocell layer** | |
| BS maximum transmitted power | 43 dBm |
| BS pilot power | 30 dBm |
| Antenna height | 25 m |
| Path loss model | 138.8+35.7 log d(km) |
| Uplink background noise | -106 dBm |
| **Microcell layer** | |
| BS maximum transmitted power | 30 dBm |
| BS pilot power | 20 dBm |
| Antenna height | 10 m |
| Path loss model | 144.3+38.3 log d(km) |
| Uplink background noise | -106 dBm |
| **UE parameters** | |
| UE maximum transmitted power | 21 dBm |
| UE minimum transmitted power | -44 dBm |
| Service bit rate | 64 kb/s |
| Eb/No target | 3 dB |
| Downlink background noise | -99 dBm |
| Chip rate (W) | 3.84 Mc/s |

The simulations have been carried out under different traffic patterns, corresponding to different representative case studies. In all the cases, there is a first traffic layer corresponding to a density of 125 users/km$^2$ homogeneously distributed in the whole scenario. Then, a second layer corresponding to traffic hot spots is considered in different positions and with different traffic densities, depending on the case study:

- Case study 1: In this case, as depicted in Fig. 1, there is a single hot spot located close to the microcell BS0, and having a traffic density of 2000 users/km$^2$.

- Case study 2: In this case, there is also a single hot spot located at an intermediate distance between BS0 and BS2. The traffic density in the hot spot is 8000 users/km$^2$. The situation is shown in Fig. 2.

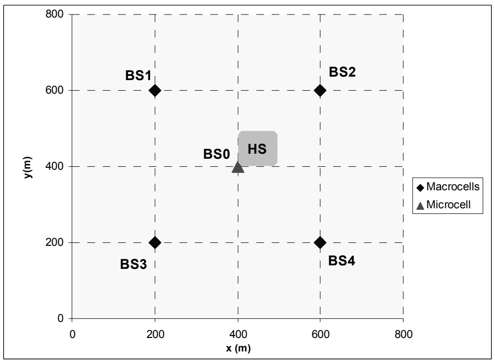

Fig. 1 Traffic distribution in case study 1

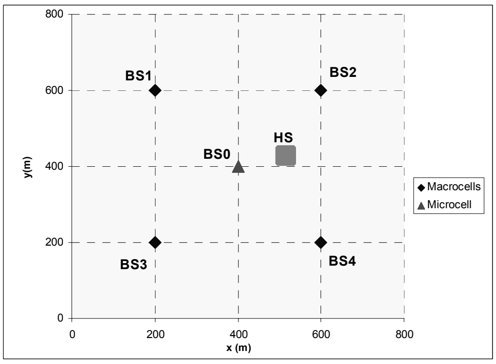

Fig. 2 Traffic distribution in case study 2

# IV. Results

This section discusses some of the results obtained in the analyzed scenarios. In particular, focusing on the case study 1, Fig. 3 presents the histogram of the base station that is selected by the frequency planning algorithm in order to change the carrier, obtained in the different snapshots. It can be observed how the selection is very different for both algorithms: while the load-based algorithm selects most of the time the microcell BS0, which has the highest load factor, the selection of the derivative-based algorithm is done mainly between BS0 and BS2, depending on how the users of the hot spot are distributed with respect to the other base stations. The impact in terms of load factor is plotted in Fig. 4, which reveals that, when all base stations operate with the same carrier, the highest load factor is experienced in BS0, due to the interference coming from users in the hot spot, which are served mainly by BS0 and BS2. In turn, when the carrier of one cell is changed, both algorithms achieve a load factor reduction in all base stations. Nevertheless, the load-based algorithm mainly reduces the load factor in BS0, and at a much lower extent the load factor in the rest of base stations. On the contrary, the derivative-based algorithm achieves a lower reduction in BS0 but a higher reduction in the rest of base stations, thus revealing that it is able to capture better the base station with the highest influence over the scenario. In terms of performance, Table II provides the outage in the scenario when the carrier is the same and when one carrier is changed according to the two algorithms. Notice that the reduction achieved with the derivative-based algorithm is much higher than the reduction obtained with the load-based algorithm.

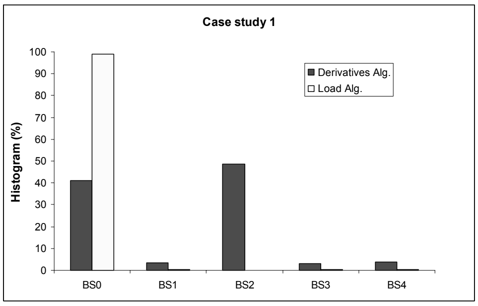

Fig. 3 Histogram of the selected BS in case study 1

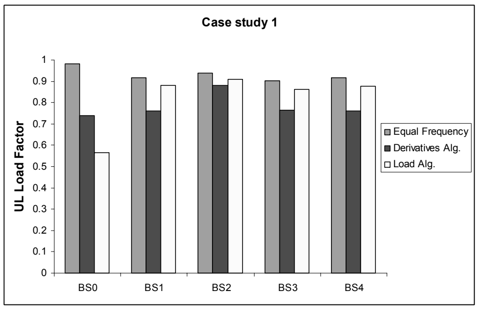

Fig. 4 Average load factor in the different cells in case study 1

TABLE II
OUTAGE PROBABILITY IN THE DIFFERENT SCENARIOS

| | Equal Freq. | Deriv. Alg. | Load. Alg. |
|---|---|---|---|
| Case 1 | 2.52 % | 1.06 % | 1.62 % |
| Case 2 | 28.92 % | 18.28 % | 27.99 % |

The corresponding results for the case study 2 are plot in Fig. 5 and Fig. 6, and the outage is given in Table II. In contrast to the case study 1, the hot spot is now closer to the macrocell BS2 than in case 1 and therefore most of the users are connected to BS2 (notice that, although the hot spot is geographically closer to BS0, due to the 10 dB difference in pilot powers between BS2 and BS0, users are mainly connected to BS2). However, due to the proximity to BS0, a high intercell interference is generated which originates that the cell having the highest load factor is again BS0. As a result, the load-based algorithm mainly changes the carrier in BS0, while the derivative-based algorithm changes mainly the carrier in BS2 (see Fig. 5) because it has a stronger effect over the rest of cells. As a result of that, the derivative-based algorithm is able to reduce significantly the load factor in all base stations in the scenario while the load-based algorithm mainly reduces the load factor in microcell BS0 (see Fig. 6). This turns into a higher outage probability than with the derivative-based algorithm (see Table II).

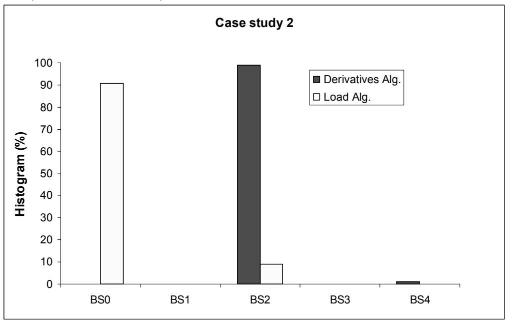

Fig. 5 Histogram of the selected BS in case study 2

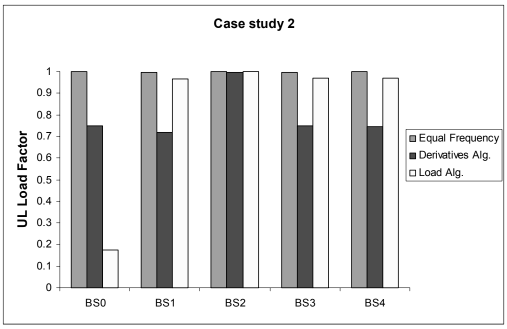


Fig. 6 Average load factor in the different cells in case study 2

## V. Extension of the concept: Methodology

In this section we extend the above concept to a more general scenario. Let us consider a WCDMA system of $K$ base stations and $F$ frequencies. The objective of the proposed frequency management methodology is to derive an efficient frequency assignment to base stations. The scope of this paper concentrates on the case where each base station needs only one frequency. The proposed methodology makes use of coupling matrices, which are intended to reflect the interaction between different cells. In other words, the entry $C_{i,j}$ of the coupling matrix $\boldsymbol{C}$ represents the impact of cell $j$ on cell $i$, and has to represent the amount of interference contributed by one cell to another.

In the coupling matrix based on load gradient, the entry $C_{j,l}$ is computed using the derivative of the load factor in cell $j$ to the load factor in cell $l$ ($\partial\eta_j/\partial\eta_l$), which reflects how the variation of the load factor in cell $l$ affects the variation of the load factor in cell $j$. Furthermore, we define the sum $J_j$ by the sum of the gradient vector related to cell $j$ and given by the following relation:

$$J_j = \sum_{m=1}^{K} \frac{\partial \eta_j}{\partial \eta_m} \qquad (2)$$

The term $J_j$ reflects the impact of load factor variations in all cells on load factor variation of cell $j$. It must be noted here, that the factor $\partial\eta_j/\partial\eta_j$ is included in the sum to have a convenient final expression of $J_j$. The value of this term is a constant (i.e. 1); therefore, it does not have any impact in the following. After sum computation, we find:

$$J_j = B_j \sum_{\substack{l=1 \\ l\neq j}}^{K} \frac{S_{l,j}^{UL}}{(1-\eta_l)^2} \sum_{m=1}^{K} \frac{\partial \eta_l}{\partial \eta_m} \qquad (3)$$

where $B_j$ is given by the following equation:

$$B_j = \frac{1 - S_{j,j}^{UL}}{\left(1 + \sum_{\substack{k=1 \\ k\neq j}}^{K} \frac{S_{k,j}^{UL}}{1-\eta_k}\right)^2} \qquad (4)$$

Using equation (2) for all cells, we find:

$$J_j = B_j \sum_{\substack{l=1 \\ l\neq j}}^{K} \frac{S_{l,j}^{UL}}{(1-\eta_l)^2} J_l \qquad (5)$$

Each element of the right term can be seen as the contribution of a neighbouring load factor variation to the total variation of load factor variation in cell $j$. In this case, the coefficient of each element can represent the impact of a given neighbouring cell to cell $j$. Using these elements, we can define an intermediate coupling matrix $\boldsymbol{A}$ given by:

$$A_{j,l} = \begin{cases} 1 & \text{if } l = j \\ B_j \dfrac{S_{l,j}^{\mathrm{UL}}}{(1\text{-}\eta_l)^2} & \text{otherwise} \end{cases} \qquad (6)$$

Since the cell load has also a significant impact on the interaction with other cells, we multiply each column by the corresponding cell load. Then the final coupling matrix $\boldsymbol{C}$ can be written as:

$$\boldsymbol{C} = \boldsymbol{AL} \qquad (7)$$

where $\boldsymbol{L}$ is a diagonal matrix whose entries are defined by:

$$L_{jj} = \sum_{i_j=1}^{n_j} R_{i_j} \qquad (8)$$

where $R_{i_j}$ is mobile $i_j$ data rate at physical layer in Kbits/s. Coupling matrix $\boldsymbol{C}$ is an asymmetric matrix. In order to have a symmetric matrix, we consider the following matrix to be used in the optimization algorithm:

$$\boldsymbol{O} = \boldsymbol{C} + \boldsymbol{C}^t \qquad (9)$$

where $\boldsymbol{C}^t$ is the transpose of $\boldsymbol{C}$. Each entry $O_{jk}$ combines the $O_{jk}$ combines the impact of cell $j$ on cell $k$ and the impact of cell $k$ on cell $j$ impact of cell $j$ on cell $k$ and the impact of cell $k$ on cell $j$.

Once the coupling matrices have been defined, the objective of the optimization algorithm is to minimize the total outage probability in the system. The total outage probability is defined as the ratio of unsatisfied users to the total number of users. A user is considered unsatisfied if its $E_b/N_0$ is lower than the target $E_b/N_0$. In order to solve the frequency management problem, the outage probability has to be computed using an analytical function. However, in the formulation of this function several assumptions must be taken due to the complexity and the instable nature of the radio interface. These assumptions make the analytical function inaccurate. Moreover, the formulation of this function can be a very complex task, especially in big systems. Therefore, we propose an indirect optimization of the outage probability using the interference profile (i.e. the coupling matrix), which is the most influential parameter in WCDMA systems and has the same trends as the outage probability. Hence, our objective is to minimize the interference profile using an offline heuristic algorithm.

We define $X_f$ as the set of cells operating with frequency $f$. These sets are initially empty sets.

Using the matrix ***O*** a heuristic algorithm that tends to avoid high interactions among cells is defined by the following steps:

1. Cells are sorted using the sum of the corresponding rows in matrix ***O***.
2. The first $F$ cells with the highest sum are distributed over the $F$ frequencies with one-to-one association and the sets $X_f$ are updated.
3. For the next cell $i$ of the remaining sorted cells, define the set of variables $\{\rho_f\}_{f=1..F}$ by:

$$\rho_f = \sum_{k \in X_f \cup \{i\}} O_{i,k} \qquad (10)$$

4. Thereafter, cell $i$ is associated to frequency $f_c$ such that:

$$\rho_{f_c} = \min_{f \in \{1,\ldots,F\}} \rho_f \qquad (11)$$

Therefore, in each step the algorithm reduces the impact of the new cell into the allocated cells and the impact of other cells into the new cells.

5. Add cell $i$ to set $X_f$.
6. Repeat from 3

In this algorithm, we distribute the cells with the highest interference contribution over frequencies at the beginning because the frequency allocation of these cells has the highest impact on interference patterns. Hereafter, the other cells are distributed such as the total cell interaction is minimized. Using this method, we can avoid the allocation of the same frequency to cells with high interaction.

In this section, we present some sample results obtained in a layout with 37 hexagonal macrocells and 8 microcells. Specifically, Fig. 7 shows several values of matrix ***O*** in this scenario. It should be noted that the entries of matrix ***O*** are used by variables $\rho_f$. From this example we can see that the matrix efficiently reflects the interaction between cells. For instance, the interaction between microcells is very low (0.03) because mobiles in these cells have very low pathloss toward their servers and very high pathlosses toward other base stations. However, the interaction between microcells and macrocells is very high (24). Indeed, some mobiles that are geographically near to microcells are connected to a macrocell due to the difference in pilot power. Therefore, these mobiles introduce high interferences into microcells. Moreover, the interaction between macrocells is higher when these macrocells are close. Therefore, the proposed coupling matrix takes into account both cell loads and geographical positions. Finally, the outage probability given by the HCS method (i.e. allocating one frequency to microcells and the other to macrocells) and the heuristic algorithm are 7.5% and 1.7% respectively and thus a 76% reduction is obtained when the proposed method is used.

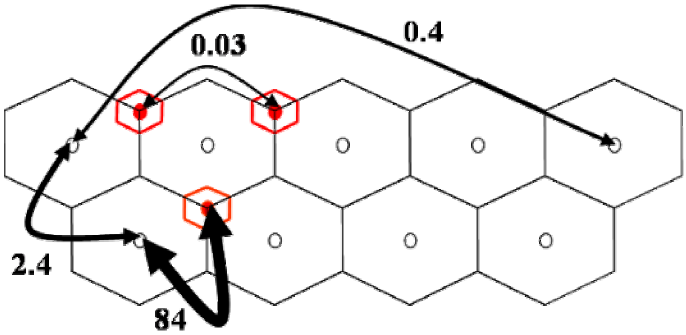

Fig. 7 The entries of matrix ***O*** in the second case study and layout 2

## VI. Conclusions and Implementation remarks

The framework presented in this paper has intended to stress the importance of time/space traffic distribution in WCDMA planning, particularly focusing in the case of multiple carriers belonging to the same operator, which is a realistic reference scenario that has hardly been covered in the open literature. To this end, a frequency allocation algorithm has been developed based on detecting the cells having the largest influence over the rest of neighbouring cells in the scenario. The algorithm has been compared with an algorithm that changes the cell having the highest load factor. It is obtained that the proposed algorithm is able to better capture the influence among the different cells under different traffic non-homogeneity conditions, thus deciding the appropriate cell to operate with a different frequency.

Finally, the extension of these concepts into a robust and complete methodology has been detailed, introducing the coupling matrices as well as heuristic optimisation algorithms. Some illustrative results of the entries of such matrix have been shown. Further results are envisaged as future work.

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## References

[1] J. Bannister, P. Mather, S. Coope, *Convergence Technologies for 3G Networks*, John Wiley and Sons, 2004.

[2] J. Laiho, A. Wacker, T. Novosad, *Radio Network Planning and Optimisation for UMTS*, John Wiley&Sons, 2002.

[3] L. Ortigoza-Guerrero, A.H. Aghvami "A distributed dynamic resource allocation for a hybrid TDMA/CDMA system", *IEEE Transactions on Vehicular Technology*, Vol. 47, No. 4, 1998, pp. 1162 - 1178.

[4] T. Rautiainen, "Breaking the Hierarchical Cell Structure in WCDMA Networks", *IEEE 55th VTC Spring conference*, Birmingham, USA, 2002.

[5] I. Jami, H. Tao, "Micro-cell planning within macro-cells in UMTS: downlink analysis", *3rd International conference on 3G communication technologies* (3G 2002), London, 2002.

[6] J. Pérez-Romero, O. Sallent, R. Agustí, "A novel approach for multi-cell load control in WCDMA", *5th International conference on 3G communication technologies* (3G 2004), London, 2004