A NOVEL APPROACH FOR MULTICELL LOAD CONTROL IN W-CDMA

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Abstract

This paper presents an analytical framework to discriminate the impact that the neighbouring cells have over a reference cell in a multicellular W-CDMA scenario based on establishing the mutual relationships between cells in terms of uplink cell load factor and downlink transmitted power. The derivatives of these two parameters with respect to the neighbouring cells are taken as a measurement of the interactions between cells. Based on this analytical framework a multicell load control algorithm is proposed and compared with other two algorithms by means of simulations.

1 Introduction

The mobile communications industry is currently shifting its focus from 2G to 3G technology. While current 2G wireless networks, in particular GSM, continues evolving by bringing new facilities and services onto the market aided by GPRS functionalities, W-CDMA radio technology is also becoming a reality with the launching of 3G networks. A lot of effort has been carried out up to date in understanding the peculiarities that W-CDMA brings to cellular network deployment and optimization. Nevertheless, intensive research is still needed to devise a comprehensive framework to manage future 3G and beyond W-CDMA based radio access technologies operating in diverse environments and supporting a range of diverse services.

The provision of QoS guarantees requires the reduction of the randomness associated to the wireless cellular scenario (due to e.g. propagation, mobility, traffic generation processes, etc.) and the transformation of the communication channel into as predictive as possible. The only way to achieve this tight control over the air interface is by means of Radio Resource Management (RRM) strategies, including admission and load control, packet scheduling, power control and handover. Particularly, load control is a key element of the different RRM functions since it counteracts system variations by keeping the overall interference below certain constraints thus ensuring the specific QoS requirements [1,5].

On the other hand, another of the main characteristics of the traffic in cellular networks is the non-homogenous spatial distribution. Although network planning can consider this fact, the high dynamics associated to traffic clearly needs additional mechanisms to cope with the potential problems on the network performance for traffic profile distributions significantly different from those expected. Traffic variations along time and space, which result in different load levels in different cells and times, can be for example smoothed with the aid of the handover algorithm, trying to balance load among cells. Other RRM strategies devised from a multicellular perspective, like admission and/or load control mechanisms are other examples [3] to cope with this problem.

In this framework, mechanisms supporting smart load control actions could be of great interest and could be applied at different levels. Specifically, a load control algorithm for W-CDMA is triggered whenever the interference level reaches certain limits which can degrade the performance observed by the users of a reference cell. Then the algorithm tries to remove the excess of interference by acting over those users with lower QoS constraints [4], which may be located either in the reference cell or in neighbouring cells. Consequently, the first issue to include in a smart load control would be the ability to detect those cells affecting the most to the reference cell in order to act over them and achieve the interference reduction with the minimum required changes.

In this context, the contribution of this paper is two-fold. On the one hand, it presents an analytical framework that allows discriminating the impact that the different neighboring cells have over the reference cell both in uplink and downlink directions, by means of estimating the derivative of the reference cell uplink load (alternatively the transmitted power in downlink) with respect to each neighboring cell. On the other hand, and based on this analytical model, an algorithm is proposed that allows the reduction of the load factor (alternatively the transmitted power for the DL) of the reference cell. The paper is organized as follows. Section 2 and 3 present the analytical framework for the uplink and downlink, respectively. Section 4 presents the proposed load control algorithm, whose performance is evaluated and compared against two other algorithms in Section 5. Concluding remarks are given in Section 6.

2 Uplink case

Within a WCDMA cell, all users share the common bandwidth and each new connection increases the interference level of other connections, affecting their quality. Let consider a scenario with K+1 cells and let focus on the central cell, chosen as the reference cell and numbered as the 0-th cell. Each user $i_0 \in \{1..n_0\}$ transmitting to the 0-th cell requires the following condition to be satisfied:

$$\frac{P_{0,i_0} \times \dfrac{W}{R_{i_0}}}{P_N + \chi_0 + \left[P_{R,0} - P_{0,i_0}\right]} \geq \left(\frac{E_b}{N_o}\right)_{i_0} \quad (1)$$

where P_{0,i_0} is the received power at the 0-th cell from the i_0-th user, R_{i_0} is the transmission rate of the i_0-th user, W the total bandwidth, P_N is the thermal noise power, χ_0 is the intercell interference observed in the 0-th cell and $(E_b / N_o)_{i_0}$ stands for the QoS requirement of the i_0-th user. $P_{R,0}$ is the total received own-cell power at the 0-th base station. Since n_0 is the total number of users served by the 0-th cell, $P_{R,0}$ can be written as:

$$P_{R,0} = \sum_{i=1}^{n_0} P_{0,i_0} \quad (2)$$

Solving (1) with equality leads to:

$$P_{0,i_0} = \frac{\left(P_N + \chi_0 + P_{R,0}\right)}{\dfrac{W}{\left(\dfrac{E_b}{N_o}\right)_{i_0} R_{i_0}} + 1} = \frac{P_N \dfrac{1}{1-\eta_0}}{\dfrac{W}{\left(\dfrac{E_b}{N_o}\right)_{i_0} R_{i_0}} + 1} \quad (3)$$

Where η_0 is the uplink load factor of the 0-th cell, which measures the theoretical spectral efficiency of a W-CDMA cell, and is defined as [2]:

$$\eta_0 = 1 - \frac{P_N}{P_{R,0} + \chi_0 + P_N} = \left(1 + \frac{\chi_0}{P_{R,0}}\right) \sum_{i=1}^{n_0} \frac{1}{\dfrac{W}{\left(\dfrac{E_b}{N_o}\right)_{i_0} R_{i_0}} + 1} \quad (4)$$

From the transmitter side, the transmitted power by the i_0-th user will be:

$$P_{T,i_0} = L_{i_0,0} \times P_{0,i_0} \quad (5)$$

where $L_{i_0,0}$ is the path loss from this user to the 0-th cell site.

With respect to the intercell interference observed at the reference cell, this can be expressed as:

$$\chi_0 = \sum_{j=1}^{K} \sum_{i_j=1}^{n_j} \frac{P_{T,i_j}}{L_{i_j,0}} \quad (6)$$

where P_{T,i_j} is the transmitted power by the i_j-th user of the j-th cell, n_j is the total number of users in the j-th cell and $L_{i_j,0}$ is the path loss from the i_j-th user in the j-th cell to the reference cell. By combining (3), (5) and (6) it yields:

$$\chi_0 = \sum_{j=1}^{K} \frac{P_N}{1-\eta_j} \sum_{i_j=1}^{n_j} \frac{L_{i_j,j}}{L_{i_j,0}} \frac{1}{\dfrac{W}{\left(\dfrac{E_b}{N_o}\right)_{i_j} R_{i_j}} + 1} \quad (7)$$

At this stage, it is useful to introduce the following definition that reflects the interactions between the cell $j \in \{0..K\}$ and cell 0 in the uplink direction.

$$S_{j,0}^{UL} = \sum_{i_j=1}^{n_j} \frac{L_{i_j,j}}{L_{i_j,0}} \frac{1}{\dfrac{W}{\left(\dfrac{E_b}{N_o}\right)_{i_j} R_{i_j}} + 1} \quad (8)$$

Then, by introducing (7) and (8) in (4) it is possible to express the cell load factor of the 0-th cell as:

$$\eta_0 = \frac{S_{0,0}^{UL} + \dfrac{\chi_0}{P_N}}{1 + \dfrac{\chi_0}{P_N}} = \frac{S_{0,0}^{UL} + \sum_{j=1}^{K} \dfrac{S_{j,0}^{UL}}{1-\eta_j}}{1 + \sum_{j=1}^{K} \dfrac{S_{j,0}^{UL}}{1-\eta_j}} \quad (9)$$

In the above form, it is explicitly reflected the coupling existing in a W-CDMA cellular system, where the resulting cell load in a given cell depends on all users in the scenario or, more specifically, on the load factors of all the other cells.

The sensitivity of the reference cell with respect to the neighbouring cell $k \in \{1..K\}$ can be evaluated by means of the derivative of the load factor of the reference cell with respect to the k-th cell, that can be approximated by:

$$\frac{\partial \eta_0}{\partial \eta_k} \approx \frac{S_{k,0}^{UL}\left(1 - S_{0,0}^{UL}\right)}{\left(1-\eta_k\right)^2 \left(1 + \sum_{j=1}^{K} \dfrac{S_{j,0}^{UL}}{1-\eta_j}\right)^2} \quad (10)$$

Notice that this derivative is computed by assuming independence between the k-th cell load factor and the rest of neighbouring cells. The accuracy of this assumption has been confirmed by means of simulations, observing that it is valid with errors below 10% for most of the load factor ranges. In any case, and as it will be shown in sections 4 and 5, it can be used for radio network engineering purposes as a basis to devise practical algorithms.

3 Downlink case

In the downlink direction, the Eb/No requirement for the i_0-th user in cell 0 can be expressed as:

$$\frac{\dfrac{P_{T,i_0}}{L_{i_0,0}} \times \dfrac{W}{R_{i_0}}}{P_N + \chi_{i_0} + \rho \times \left[\dfrac{P_{T0} - P_{T,i_0}}{L_{i_0,0}}\right]} \geq \left(\frac{E_b}{N_o}\right)_{i_0} \quad (11)$$

where P_{T,i_0} is the power devoted to the i_0-th user, $L_{i_0,0}$ the i_0-th user path loss, P_N the thermal noise power, R_{i_0} is the downlink transmission rate of the i_0-th user and $(E_b / N_o)_{i_0}$ stands for the downlink QoS requirement of the i_0-th user. In turn, the intercell interference in the downlink is user specific, so χ_{i_0} represents the intercell interference observed by the i_0-th user. Furthermore, orthogonal codes are used in the downlink direction, but some orthogonality is lost due to multipath, so ρ represents the orthogonality factor. The total power transmitted by cell 0, P_{T0}, can be expressed as a function of the power P_{p0} devoted to common control channels and the power devoted to the users as:

$$P_{T0} = P_{p0} + \sum_{i_0=1}^{n_0} P_{T,i_0} \tag{12}$$

Then, by considering equality in (11) and by combining it with (12) it can be obtained that the total transmitted power to satisfy all users' demands should be:

$$P_{T0} = \frac{P_{p0} + \sum_{i_0=1}^{n_0} \dfrac{L_{i_0,0}\left(P_N + \chi_{i_0}\right)}{\dfrac{W}{\left(\frac{E_b}{N_o}\right)_{i_0} R_{b,i_0}} + \rho}}{1 - \sum_{i_0=1}^{n_0} \dfrac{\rho}{\dfrac{W}{\left(\frac{E_b}{N_o}\right)_{i_0} R_{b,i_0}} + \rho}} \tag{13}$$

where the intercell interference is given by:

$$\chi_{i_0} = \sum_{j=1}^{K} \frac{P_{Tj}}{L_{i_0,j}} \tag{14}$$

Substituting (14) in (13), it can be expressed:

$$P_{T0} = \frac{P_{p0} + P_N \sum_{i_0=1}^{n_0} \dfrac{L_{i_0,0}}{\dfrac{W}{\left(\frac{E_b}{N_o}\right)_{i_0} R_{b,i_0}} + \rho} + \sum_{i_0=1}^{n_0}\sum_{j=1}^{K} \dfrac{L_{i_0,0}}{L_{i_0,j}} \dfrac{P_{Tj}}{\dfrac{W}{\left(\frac{E_b}{N_o}\right)_{i_0} R_{b,i_0}} + \rho}}{1 - \sum_{i_0=1}^{n_0} \dfrac{\rho}{\dfrac{W}{\left(\frac{E_b}{N_o}\right)_{i_0} R_{b,i_0}} + \rho}} \tag{15}$$

Like in the uplink direction, at this stage, it is useful to introduce the following definitions, that reflect the interactions between the cell $j \in \{0..K\}$ and the cell 0 in the downlink direction:

$$S_{0,j}^{DL} = \sum_{i_0=1}^{n_0} \frac{L_{i_0,0}}{L_{i_0,j}} \frac{1}{\dfrac{W}{\left(\frac{E_b}{N_o}\right)_{i_0} R_{b,i_0}} + \rho} \tag{16}$$

Furthermore, let define:

$$S_{0,0}^{DL*} = \sum_{i_0=1}^{n_0} \frac{L_{i_0,0}}{\dfrac{W}{\left(\frac{E_b}{N_o}\right)_{i_0} R_{b,i_0}} + \rho} \tag{17}$$

Then, (15) is eventually expressed as:

$$P_{T0} = \frac{P_{p0} + P_N S_{0,0}^{DL*} + \sum_{j=1}^{K} P_{Tj} S_{0,j}^{DL}}{1 - \rho S_{0,0}^{DL}} \tag{18}$$

In the above form, it is explicitly reflected the coupling existing in the downlink of W-CDMA cellular systems, where the resulting transmitted power level in a given cell depends on the transmitted power levels by the other cells.

Like in the uplink direction, the derivative of the power of the reference cell with respect to the power of the *k*-th cell reflects the sensitivity of the reference cell with respect to the *k*-th cell. In this case, the derivative can be approximated by (19). Notice that, similarly to the uplink case, independence is assumed from the *k*-th cell with respect to the rest of neighbouring cells.

$$\frac{\partial P_{T0}}{\partial P_{Tk}} \approx \frac{S_{0,k}^{DL}}{1 - \rho S_{0,0}^{DL}} \tag{19}$$

4 Load Control Algorithm

The framework based on derivatives for W-CDMA uplink and downlink characterisation together with the explicit formulation of the coupling among the different cells in the environment is claimed to have a wide range of applicability examples, mostly in the context of RRM strategies. As an example, an uplink and downlink load control algorithm is presented in the following together with some performance results.

Let's assume a scenario with two types of services, real time (RT), that operate at constant bit rate and have stringent delay constraints, and non real time (NRT), whose bit rate is variable and can be adjusted to control the overall system load at the expense of a delay increase. The objective of the load control in the uplink direction is to keep the load factor below a maximum η_T and in the downlink direction to keep the fraction of transmitted power with respect to the maximum available power (i.e. P_{T0}/P_{max0} for cell 0) under a given bound ϕ_T. These constraints ensure that the Eb/No requirements for the different users are met. Consequently, the load control algorithm is triggered in the corresponding direction when any of these two conditions does not hold and it acts over the NRT users by decreasing their bit rate and thus reducing the interference that they introduce in the network. A non-homogeneous spatial distribution is assumed, and it is assumed a higher concentration of RT users in the reference cell, so that the load control algorithm must act over the NRT users in the neighbouring cells.

4.1 Uplink direction

The algorithm in the uplink direction would operate in the following steps, and the objective is to reach a load factor lower or equal than η_T in cell 0, so the algorithm is triggered when $\eta_0 > \eta_T$.

Step 1.- Select the cell *k* with maximum:

$$\left(\eta_{k,NRT} \cdot \frac{\partial \eta_0}{\partial \eta_k}\right) \tag{20}$$

where $\eta_{k,NRT}$ is the amount of load factor devoted to NRT traffic in cell *k*. By doing this, the algorithm selects the cell whose NRT users have a largest influence over the central cell, as represented by the derivative.

Step 2.- The load factor reduction to be achieved in the selected cell k is estimated by:

$$\Delta\eta_k = \frac{\Delta\eta_0}{\left(\frac{\partial\eta_0}{\partial\eta_k}\right)} \qquad (21)$$

where $\Delta\eta_0=\eta_0-\eta_T$ is the desired reduction in cell 0.

Step 3.- Order the NRT users in the selected cell k in a table in decreasing order of the factor $I^{UL}_{i_k,0}$, where:

$$S^{UL}_{j,0} = \sum_{i_j=1}^{n_j} \frac{L_{i_j,j}}{L_{i_j,0}} \frac{1}{\frac{W}{\left(\frac{E_b}{N_o}\right)_{i_j} R_{i_j}}+1} = \sum_{i_j=1}^{n_j} I^{UL}_{i_j,0} \qquad (22)$$

By doing this, NRT users are ordered taking into account their influence over cell 0.

Step 4.- Inhibit the transmissions of the users in the table until reaching the desired reduction of $\Delta\eta_k$ or until having inhibited all the users.

Step 5.- Measure η_0 and if it is still higher than η_T return to step 1.

4.2 Downlink direction

Similarly, the objective of the algorithm in the downlink direction is to limit the power fraction with respect to the maximum available power (i.e. P_{T0}/P_{max0}) to a given bound ϕ_T, so the algorithm is triggered when $P_{T0}>\phi_T \cdot P_{max0}$. Then, the steps of the algorithm would be as follows:

Step 1.- Select the cell k with maximum:

$$\left(P_{k,NRT} \cdot \frac{\partial P_{T0}}{\partial P_{Tk}}\right) \qquad (23)$$

where $P_{k,NRT}$ is the amount of transmitted power devoted to NRT traffic in cell k. By doing this, the cell with largest influence over the cell 0 is selected.

Step 2.- The power reduction to be achieved in the selected cell k is given by

$$\Delta P_{Tk} = \frac{\Delta P_{T0}}{\left(\frac{\partial P_{T0}}{\partial P_{Tk}}\right)} \qquad (24)$$

where $\Delta P_{T0}=P_{T0}-\phi_T \cdot P_{max0}$ is the desired power reduction in cell 0.

Step 3.- Order the NRT users in cell k in a table in decreasing order of their transmitted power

Step 4.- Inhibit the transmissions of the users in the table until reaching the desired reduction of ΔP_{Tk} or until having inhibited all the users.

Step 5.- Measure $\phi_0 = P_{T0}/P_{max0}$ and if it is still higher than ϕ_T return to step 1.

After the execution of the algorithm in both the uplink and downlink directions, and once the load factor and/or downlink power is below the thresholds during some time, a congestion recovery algorithm [4] would re-establish in a controlled way the transmission capabilities of NRT users. The analysis of this recovery algorithm is out of the scope of the paper.

5 Performance evaluation

The scenario consists of 23 omnidirectional cells with separation between them 1 km. 10 RT users are allocated in the central cell and a variable number of NRT users (50 to 300) are uniformly distributed in the rest of the cells. The Radio Access Bearer considered is 64/384 Kbps for both RT and NRT services.

The average uplink cell load factor and downlink transmitted power level in the central cell without load control algorithm are shown in Figure 1 for different NRT users. The load control algorithms will act to counteract instantaneous deviations from the average value that exceed the maximum of η_T=0.8 and ϕ_T=0.8 in uplink and downlink. The algorithm only acts over the six neighbouring cells of the central cell, the rest of cells are only considered to avoid the border effect.

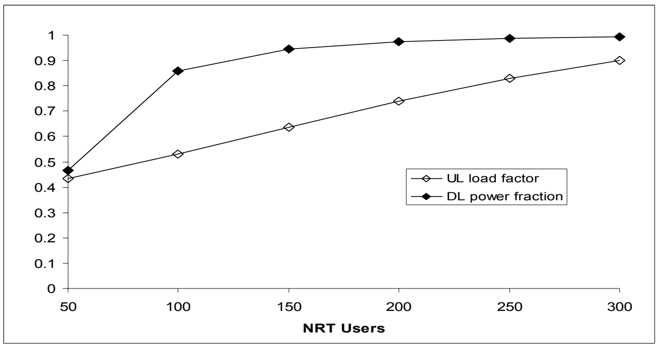

Figure 1: Average UL load factor and DL power fraction in cell 0

In order to show the suitability of the proposed algorithm, denoted in the results as "*Derivatives Algorithm*", two other reference algorithms are considered for comparison purposes. They operate in the same steps previously explained but with the following differences:

- *Algorithm A*: In step 1 the base station to be reduced is chosen randomly between the six neighbouring cells. In step 3 the NRT users of the selected cell are not ordered.
- *Algorithm B*: In step 1 the base station with the highest NRT load/power is chosen. In step 3 the NRT users of the selected cell are not ordered.

The three considered algorithms are able to reduce the UL load factor or DL power fraction down to the required value and therefore, the performance will be compared in terms of the algorithm efficiency when executing the reduction. This will be measured by the percentage of NRT throughput reduction and by the algorithm duration. Particularly Figure 2 and Figure 3 show the NRT throughput reduction for the uplink and downlink cases. It can be observed that the algorithm based on derivatives achieves the load reduction with the lowest NRT throughput reduction. The difference with respect to the Algorithm A is very high, whose reduction is around 80%, meaning that it inhibits almost all the NRT users in the neighbouring cells. On the contrary, the algorithm based on derivatives and the Algorithm B perform much better. It is worth mentioning that when the number of NRT users is small (e.g. 50 users), the required NRT throughput reduction in the uplink is close to 100% since in this case the very sporadic cases in which the load factor is higher than 0.8 are mostly due to the RT users of the central cell than to the NRT users.

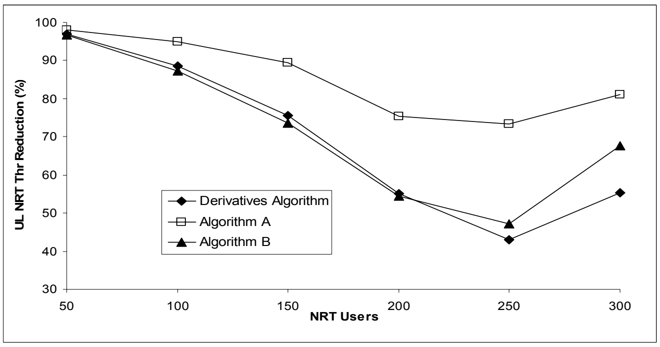

Figure 2: UL NRT throughput reduction in neighbouring cells

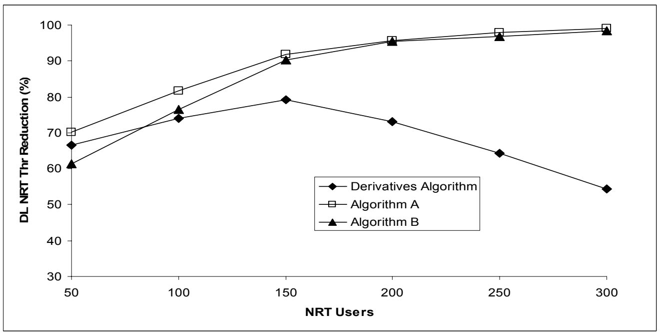

Figure 3: DL NRT throughput reduction in neighbouring cells

Furthermore, and according to Figures 4 and 5, the algorithm duration is much smaller for the derivatives algorithm, which in a few iterations is able to achieve the required load reduction, while the Algorithm A requires quite more iterations and the one Algorithm B based only on NRT load requires an intermediate number of iterations. The lower the number of iterations the most effective the algorithm is, indicating that it is able to identify those cells and users with the highest influence on the air interface load.

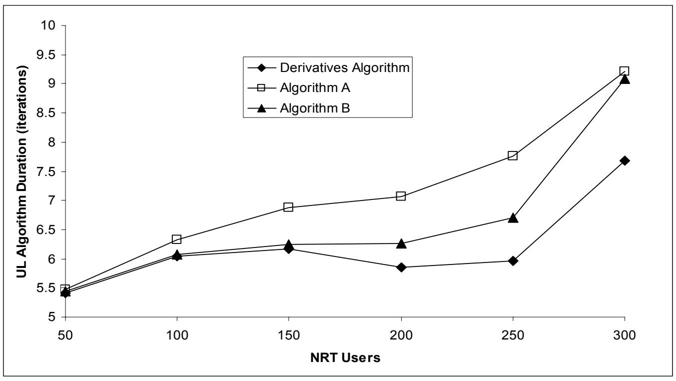

Figure 4: UL algorithm duration

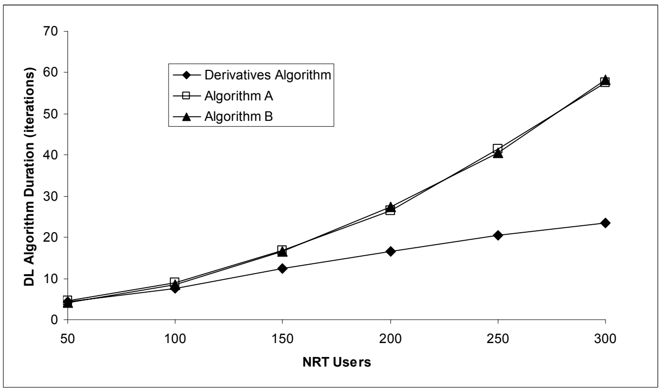

Figure 5: DL algorithm duration

6 Conclusions

As a first contribution, this paper has presented the interactions that exist between neighbouring cells in a multicellular scenario in both the uplink and downlink direction by means of relating the uplink cell load factor and downlink transmitted power of the different cells. Based on this relationship, the derivative of the uplink load factor and downlink transmitted power of the neighbouring cells with respect to those of the reference cell has been taken as a measurement of the degree of interactions between cells.

Based on the above analytical framework, and as a second contribution, the paper has presented a load control algorithm for both the uplink and downlink directions in order to keep the load factor and the transmitted power under certain bounds. The algorithm shows better efficiency than other reference algorithms thanks to a better identification of the cell having the most influence over the reference cell.

Acknowledgements

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