# Analysis of the overall energy savings achieved by green cell-breathing mechanisms

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*Abstract*— **The purpose of this paper is to study the overall savings provided by the utilization of cell breathing in a cellular network taking into account not only the attainable savings in the radio access network (RAN) but also the consequences in the mobile phone. First, we briefly describe some cell breathing algorithms found in literature. None of the references have taken into account so far the impact of the cell-breathing technique on the mobile phone energy consumption. We present a system model that takes into account the radio access network and mobile phone consumptions. Then, we propose a distributed BS-based cell-breathing algorithm that tackles the trade-off between the energy consumed by both the RAN and the mobile devices. Finally, simulation results of the performance are provided for the different state-of-the-art algorithms and our proposal, which permits us to identify the implications of such mechanisms in the overall consumed energy and user perception.**

***Keywords- Cellular Networks; Green Radio; Cell Breathing***

## I. INTRODUCTION

During the last years, an increasing concern on the consumed energy of mobile networks has led research teams to look for new energy-efficient approaches. The increasing consumption affects not only the telecommunication industry budget but also the environment. The emitted pollution of greenhouse gases into the atmosphere and the potential effects of electromagnetic radiation exposure on mobile users are currently hot preoccupations. Some sources like the often-cited Gartner report states that the contribution of the ICT sector is 2% of the total global carbon footprint [1], which corresponds to one quarter of the emissions of vehicular transportation and similar to the values registered for aviation industry [2].

Great efforts into the scientific community have been done to bring new energy-efficient solutions by different engineering approaches such as cognitive radio (CR), radio resource management (RRM), enhanced transmission techniques (MIMO, OFDMA, Etc.), hybrid networks (femtocells and relays) and switching-off & cell breathing, which have been studied and classified in surveys like [3]. Specifically, the cell breathing [4][5] was originally conceived as an alternative to the classic MS-BS association methods (i.e. MS-BS associations in function of SINR) in order to reduce the resulting levels of global interference. Such mechanism is being exhaustively studied in the recent years for energy-efficient networks due its capability for adapting the cell sizes to the distribution of traffic. This feature is being used to shape the energy consumption to the real needs. Its application for energy saving is achieved by adding switching-off modes in order to deactivate any unnecessary BS.

The analysis in this paper goes around the absence of studies on the consequences of using cell breathing for the MS. It is clear that during switching-off periods the number of active cells is reduced as well as the remaining cells get larger sizes, having as result a reduced radio access network (RAN) consumption. However, the farther associated MS will need to increase their transmission power levels, and this is a subject that has not been yet studied. The purpose here is to study the real impact on overall savings in both uplink and downlink, for different cell breathing algorithms found in literature and additionally propose an algorithm that finds a balance for the potential MS-RAN energy trade-off.

The structure of this paper is described here. In section II we give a background of some important proposals done on cell breathing, where we focus on the algorithms that provide the intelligence behind the dynamics of this energy saving technique. We leave section III to define the system model, where we integrate the MS and BSs models, providing an overall panoramic of the whole phenomenon. For section IV we continue with a description of the algorithmic proposal. In section V we provide the simulation results and its analysis. Finally, conclusions are given in section VI .

## II. DIFFERENT APPROACHES ON DYNAMIC GREEN CELL BREATHING ALGORITHMS

In this section we will give a brief a review in dynamic cell breathing algorithms, which govern the BSs activation/deactivation as well as the traffic redistribution and MS-BS association. Let us begin by [6], where the cell zooming technique is presented. For the algorithms provided here, the MS-BS association mechanisms prefer to concentrate the traffic into the highest loaded BSs, allowing the rest of BSs deployed with very low load or zero load going to sleep mode. The algorithm is presented in two

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ways: a centralized, where a cell zooming server coordinates the association; a distributed version where MS decides to whom associate with, based on a utility function by the BSs. In the case of the centralized algorithm, the central server executes the cell deactivation in two phases: first the MS are associated to the BSs by using the criterion of associating the MSs to BSs where the spectrum efficiency is the highest. After this first association phase, some of the BSs will be zero loaded and therefore deactivated. In a second phase, those BSs remaining with low load redistribute their load toward those higher loaded, which allows deactivating some more BSs.

In [7], they propose to use a centralized server that guarantees sequentiality. This server randomly selects the BSs to switch-off from a list of candidates. Before any switching-off attempt by the central server, the consequences on the network are evaluated. To fill the list of candidates, each BS proposes itself as candidate as long as its load is under a certain threshold $A_M$. This threshold is very useful to define the behavior of the RAN. A very low threshold reduces the number of switched off BSs giving priority to the coverage and availability, whereas a high threshold prioritizes the energy savings.

In reference [8] an approach known as procooperation is considered. The algorithm is executed independently by each BS, which makes this proposal a fully BS distributed algorithm. Here, the mutual cooperation among BSs permits to make decisions based on three different thresholds. When the traffic is below a threshold $A_L$ the BS decides to sleep. A pair of neighbors is chosen to be the acceptors of the traffic to be released by this BS. Such acceptor neighbors will share in half the redistributed traffic. Before one of the acceptor candidates accepts redistributed traffic, it must check if the new load after redistribution is below another threshold $A_S$. There is a third threshold $A_H$ that if it is exceeded, the BS can request all surrounding neighbors to take its traffic fully or partially (i.e. in the case there is not enough availability of resources to accept the full traffic). In the case the traffic is fully redistributed this BS goes to sleep mode, whereas if it is not, the BS remains active with a reduced level of transmission power and users associated.

In [9] we proposed a BS distributed algorithm working on a clustered synchronized architecture. We called it the Distributed BS based cell breathing algorithm (DBCB). First, the RAN is divided in BS clusters. Into each one of these clusters, the algorithm is executed in each BS, one by one, following the same sequence with the other clusters. To maintain such synchronization a head cluster is selected and it is in charge of exchanging the cluster status information with other head cluster by using the backhaul, as well as assure the cluster sequential execution of the algorithm. On the other hand, the algorithm run by each one of the BSs consists of redistributing the own traffic to the closest surrounding neighbors, as long as those neighbors can take the whole traffic and moreover, the BS that is executing the algorithm is not the highest loaded among the group composed by itself and its neighbors. In the case the BS can redistribute the traffic, the highest loaded neighbors will be preferred first to redistribute the traffic. If by any reason a blockage occurs and a mobile terminal cannot be accepted by any of the neighbors, the BS performs a rollback going to initial state. This algorithm had shown a very good energy-performance from the RAN point of view. However, in this work we want also to extend the efficiency to the MS by introducing a new algorithm, which takes into account also the transmission power needed by the MSs. This algorithm is conceived in order to be capable of tackle the trade-off between the RAN and MS energy consumption without losing the good results shown by our initial proposal. We will call this algorithm the Mobile Aware DBCB, or simply MA-DBCB.

## III. SYSTEM MODEL

### A. BS Model

First, let us consider a set called $\Omega$ with $N$ BSs sites deployed with certain architecture on a given area. A BS $j$ into the set $\Omega$ is characterized by several parameters. We define a power model for the BS that will permit us to study the total consumption into the radio access network already presented in [9]. Such model is derived from some figures found in [10]-[12], which shows the relationships of input power to output power for a BS. The behavior of a BS $j$ in active mode is characterized by, first, a fixed consumption $P_j^{fixed}$ product of the sum of the contributions of different components whose consumed power is considered not dependent of the transmission power $P_j^{Tx}$. On the other hand, the power amplifier consumption is, on the contrary, highly dependent of transmission power. The power associated to this section that we will name $P_j^{PA}$ is limited between $P_j^{PA_0} \le P_j^{PA} \le P_j^{PA_{\max}}$, where $P_j^{PA_0}$ corresponds to the minimum power consumed by PA section in idle state, and $P_j^{PA_{\max}}$ corresponds to the power consumed at full transmission power $P_j^{Tx_{\max}}$. The maximum power consumption of the BS $P_j^{BS_{\max}}$ occurs when the PA transmission power reaches the value $P_j^{Tx_{\max}}$, where as the minimal consumption will appear during switched-off periods, where the BS works under a low regime power $P_j^{sleep}$, and therefore $P_{sleep} \le P_j \le P_{BS-\max}$, where $P_j$ is the instantaneous consumed power of a BS $j$. All these elements together define the consumed power $P_j(t)$ at a time $t$ of a BS $j$:

$$P_j(t) = \left[ P_j^{fixed} + P_j^{PA_0} + \left( \frac{P_j^{Tx}(t)}{P_j^{Tx_{\max}}} \right) \cdot \left( P_j^{PA_{\max}} - P_j^{PA_0} \right) \right] \cdot X(t)$$
$$+ P_j^{sleep} \cdot \overline{X}(t) \qquad (1)$$

$X(t)=1, \overline{X}(t)=0$, if BS $j$ is in active mode at time $t$

$X(t)=0, \overline{X}(t)=1$, if BS $j$ is in active mode at time $t$

Now let us define the available capacity $C_j$ of a BS $j$. For simplicity reasons we consider in this work that maximum cell capacity is fixed to a value $C_j^{\max}$. If we consider that at a BS $j$ serves $M_j$ users, where each one of the MS $i$ requires of allocated resources $c_i$, the BS site capacity should be defined as:

$$C_j = \sum_{i=1}^{M_j} c_i \le C_j^{\max} \qquad (2)$$

Moreover, in the simulations we considered that the system is interference-limited (3G/CDMA), therefore the effective capacity attainable because of increasing interference could be inferior to $C_j^{\max}$. In [9] we have been using the normalized load $L_j$ of a BS $j$ as decision criterion, which is also used in references like [6]. Such normalized load $L_j$ is defined as:

$$L_j = \sum_{i=1}^{M_j} \frac{c_i}{C_j^{\max}} \le 1 \qquad (3)$$

## B. MS Model

Now let us consider a MS $i$ into a set $\Psi$ of $M$ users randomly deployed in a given area. Each MS $i$ consumes a power $P_i$. The numerical values of the different elements we will define here, they were chosen in coherence with real values from industry. During idle mode the mobile consumes a power $P_i^{fixed}$, whereas during a call, a power $P_i^{call}$ is consumed. We consider this power $P_i^{call}$ as the sum of the $P_i^{fixed}$ component (i.e. a minimum consumption always present) plus a component due to transmission, where MS transmitted power corresponds to $P_i^{Tx}$. This power $P_i$ can be therefore defined as:

$$P_i = \begin{cases} P_i^{call} = P_i^{fixed} + \left( \dfrac{1}{\gamma_i} \cdot P_i^{Tx} + P_i^{Tx_0} \right) & \text{During a Call} \\ P_i^{fixed} & \text{Otherwise} \end{cases} \qquad (4)$$

Where $P_i^{Tx_0}$ is the minimum needed power to activate the transmission circuitry, and $\gamma_i$, the efficiency of the RF and transmission components (e.g. power amplifier, antenna, etc.)

## C. Global Network Model

In general lines, the game in a green network mechanisms is to minimize the overall total power consumed $P_{Total}$ i.e. the MSs and the RAN. Cell breathing algorithms had so far only gave proposals for the RAN side neglecting the importance of mobile phone consumption. We also consider that the optimization problem must address both, the MS and the BS. However by reducing the number of active of cells we increase the average distance between the MS and BS, increasing therefore the needed transmission power in uplink. Hence, an energy trade-off appears between the RAN and the MS users. What we want to do is to minimize the impact of cell breathing as much as possible in the MS without a major impact on the RAN, where the major savings are obtained. The overall consumed power $P_{Total}$ is defined as:

$$P_{Total}(t) = \sum_{\Omega} P_j(t) + \sum_{\Psi} P_i(t) \qquad (5)$$

The minimization of $P_{Total}$ is constrained by several parameters: first of all, the maximum cell size is constrained by the limitations in transmission power for uplink and downlink, i.e. the maximum transmission powers $P_i^{Tx_{\max}}$ and $P_j^{Tx_{\max}}$, for a MS $i$ and a BS $j$ respectively; second of all, as we already discussed, any BS $j$ is constrained by a maximum resource capacity given by $C_j^{\max}$; finally, during the network operation, the percentage of blockage $\rho_b$ must be below a maximum acceptable percentage $\rho_{b_{\max}}$. It is the task of any cell-breathing algorithm to deal with such constraints bringing the best energy-efficiency possible into the network.

# IV. CELL BREATHING PROPOSAL.

The original proposal algorithm, the DBCB (Distributed BS-Based Cell Breathing) was presented in [9]. It had shown great advantages compared to other state-of-the-art proposals. First, the use of a centralized server is avoided. Instead of it, a clustered architecture with a synchronized BS-by-BS algorithm execution into each cluster is proposed. This later brings an adaptable architecture for large-scale networks more tolerant to failures than any centralized approach. Additionally, the global synchronization and internal sequentiality of each cluster avoid that two adjacent BSs, or two BSs with common neighbors run the algorithm at the same time, preventing a potential conflict at moment of traffic redistribution and MS-BS re-association. In such clustered approach, each cluster is composed of several BSs.

There is a "cluster head" per cluster, in charge of exchanging messages with other clusters for synchronization purposes. In each cluster, each BS executes the cell-breathing algorithm with an execution sequence that follows a certain order that is identical in all clusters, starting first with the cluster head. The algorithm proposed in [9] it was also conceived to avoid the use of setup thresholds in order to be a fully self-organized mechanism. However, in this new proposal we introduced a threshold $A_T$ that will permit us to control the trade-off of energy between the RAN and the MSs. The automatic selection of this threshold by a BS can be a future research issue. Such threshold is possible of being set up by using machine-learning methods. For instance, a BS can setup by itself such threshold by learning from the patterns of traffic during a monitored period. The specific utility of $A_T$ will be explained later on.

In each BS $j$ that belongs to a cluster of cells $k$ into $\Omega$, the DBCB algorithm is executed. First, the BS $j$ requests to any surrounding neighbor $h \in \Omega_{B_j}$, where $\Omega_{B_j}$ corresponds to the set of current active neighbors, the current normalized load $L_h$. After collecting the normalized load $L_h$ of each neighbor $h \in \Omega_{B_j}$, we can calculate the sum of all the available capacity in the surroundings in order to know if the active neighbors can take charge of the traffic:

$$\sum_{h \in \Omega_{B_j}} (1 - L_h) \geq L_j \tag{6}$$

If the full redistribution is possible, then the BS $j$ decides to redistribute and switch-off based on the following criterion: if the BS $j$ is higher loaded than any of its active neighbors (i.e. $L_j > L_h, \forall h \in \Omega_{B_j}$), the redistribution is not performed and the BS remains active. Otherwise, the set $\Omega_{B_j}$ is sorted in function of the value $L_h$ of each neighbor $h$ in descending order. Traffic will be redistributed first to the highest loaded BSs into the set $\Omega_{B_j}$ if there exists available resources. If a MS $i$ is blocked by the entire set $\Omega_{B_j}$, the whole procedure executed into the BS is rolled-back going back to the previous MS-BS association state (i.e. redistribution is not performed). For the new algorithm version, called mobile aware DBCB (MA-DBCB), we impose additionally a load threshold $A_T$ that blocks the algorithm execution even if the precedent conditions already explained are fulfilled. We will see some similarities with the $A_M$ used in [7] already described in section II. However, here the difference lies on the fact that switching-off decisions are done locally (i.e. a distributed approach). For the MA-DBCB only a BS $j$ with a normalized $L_j$ below the traffic threshold $A_T$ can execute the algorithm. This limits the number of BSs that can be deactivated, which means that the cell density and cell size are controlled.

On the other hand, we used for the original DBCB the metric $M_{DBCB_h}$ to create an association of a MS $i$ and a BS $h \in \Omega_{B_j}$:

$$M_{DBCB_h} = L_h + \frac{c_i}{C_{\max}^h} \tag{7}$$

where, $C_{\max}^h$ corresponds to the maximum capacity of a BS neighbor $h$. Now, in order to take also into account also the uplink losses we propose a new metric $M_{MA-DBCB_h}$ as follows:

$$M_{MA-DBCB_h} = \left[ L_h + \frac{c_i}{C_{\max}^h} \right] \cdot SNR_{ih} \tag{8}$$

where $SNR_{ih}$ is the signal-to-noise ratio of a signal sent by the MS $i$ and measured at the receiver of the BS $h$. $M_{MA-DBCB_h}$ is a metric that takes into account the load of the neighbor $h$, but also takes into account the distance and losses between the BS $h$ and the MS $i$, which it was being neglected in our previous DBCB and that improves substantially the uplink energy efficiency. The importance of reducing the impact of cell breathing on uplink is crucial in order to not affect the user perception of the MS performance, which could be deteriorated if the mobile phone ran out of battery faster during green cell breathing periods.

## V. SIMULATION AND RESULTS

In this section, we analyze the impact of the cell breathing algorithms proposed in [6]-[9], but as we already mentioned focusing more on the effect on the MS. A Montecarlo simulation was performed for such purposes. Here, a set of BSs is deployed in a given area and a set of randomly located MSs attempt to associate to the RAN to perform call/access a network service. In Table 1 we summarize the main simulation parameters. The algorithms simulated here are: the classic MS/BS association with no sleep mode capabilities; the distributed (DCZ) and centralized cell zooming (CCZ) in [6]; the sequential switching off cell breathing presented in [7] (SSOCB); the protocooperation cell-breathing (PCB) from [8]; the distributed BS based cell breathing (DBCB) from [9] and its mobile aware version MA-DBCB proposed in this article. All algorithms experience the same values of blockage percentage into the interval of normalized network load displayed that goes from 0 to 0.5 ( $\rho_b$ between 0% to 5%).

TABLE I. MAIN SIMULATION PARAMETERS

| **Parameters** | |
|---|---|
| ***Name*** | ***Value or Choice*** |
| BS site type | 3-sector antenna BS |
| Max. Data Rate DL | 14.4Mbps |
| Number of Sites | (6x6) 36<br>4 (3x3) clusters for DBCB |
| Intersite Distance | 500 m |
| Data Rate per mobile | 256kbps (fixed) |
| $P_j^{Tx-\max}$ | 100 Watts |
| $P_j^{fixed} + P_j^{PA_0}$ | 900 Watts |
| $P_j^{PA\max} - P_j^{PA_0}$ | 600Watts |
| $P_{sleep}$ | 150 Watts |
| $P_i^{Tx-\max}$ | 0.75 Watt |
| $P_i^{Tx_0}$ | 0.3 Watts |
| $P_i^{fixed}$ | 0.2 Watts |
| $\gamma_i$ | 0.5 |
| Path-Loss Model | COST 231 HATA |
| Central Frequency | 2100 MHz |
| MS Distribution | Uniform |
| Standard Wireless Standard | 3G/W-CDMA |
| Number of Montecarlo distribution per calculated point | 1000 |
| PCB Algorithm Thresholds | $A_H = 0.9, A_L = 0.3, A_S = 0.7$ |
| SSOCB Threshold | $A_M = 0.25$ |
| DBCB v2 Threshold | $A_T = 0.25$ |

We start our analysis by looking first at the RAN. In Fig. 1 we present the number of BS switched in function of different levels of network load. We see how the previous version of DBCB is able to switch-off more BSs compared to the rest of algorithms. We also notice that for the MA-DBCB these values are only slightly reduced being very tied to the SSOCB proposed in [7]. For Fig. 2 we see the global consumption including the RAN consumption and the MSs consumption. This consumption is nearly totally influenced by the results on the RAN due the fact that a BS site consumes a power that goes from 150 watts to 1500 watts approximately. For instance, our simulations show that for a normalized network load of 0.5 only 2% of the overall energy consumption corresponds to the mobile terminals. However, the MS energy consumption is something important for the user and consequently the user perception is something that must not be neglected by the operator. The users are interested in devices with long battery duration, more in the case where an electrical outlet is not easily available. A MS may need increase its transmission power when the number of active BSs is reduced. This latter given the fact that the MS-BS average distance increases because of having less cells covering larger areas. Moreover, this increment of MS transmission power may be potentially harmful for the human body. Analyzing the MS consumption we see in Fig. 3 that the DBCB was not very good compared to the rest of algorithms proposed from the user perspective, whereas we see how the inclusion of the new features in the new MA-DBCB reduces significantly the average MS consumption without a significant loss of energy-performance in the RAN. Actually, the MA-DBCB over-performs algorithms like the SSOCB from the MS point of view. We see reductions of the energy consumed by the MS up to 13% at very low load (normalized loads below 0.1) when we compare MA-DBCB and SSOCB. We notice how if we reduce the BS density and cell size increases, some MSs will have to transmit farther, therefore increasing the necessary average transmission power and compromising maybe their battery lifetime. Finally, we can see the maximum transmission power reached by the MSs deployed for different levels of load for the different cell-breathing algorithms in Fig. 4. We see again a noticeable improvement from DBCB to MA-DBCB.

## VI. CONCLUSIONS

In this paper we have studied the effect of different cell-breathing algorithms on both, the RAN and the MS energy consumption, highlighting the existing trade-off between both sides. The fact of reducing the density of active BS implies greater cell sizes and therefore greater MS-BS average distances, which consequently means higher MS transmission power for some farther MSs. We proposed a new version of the previously defined DBCB algorithm, a clustered distributed algorithm conceived for large-scale networks. We called this new version MA-DBCB. Among the new features, we included the utilization of the SNR in the association metric in order to not neglect also the MS-BS distances and the losses associated. In addition, a BS load threshold is added in order to limit the number of BS that execute the algorithm, which introduces a knob that permits to control the balance of consumed energy between the RAN and MS. We have strongly emphasized the importance of balance, due the fact that for operators not only is important the RAN energy costs but additionally the resulting user perception that can be affected by things like shorter battery lifetime of the MSs due the absence of closer available BSs. Future research on cell breathing should work on the utilization of femto-cells in order to overcome this MS-RAN energy trade-off due its capability of establish denser and granular radio access deployment.

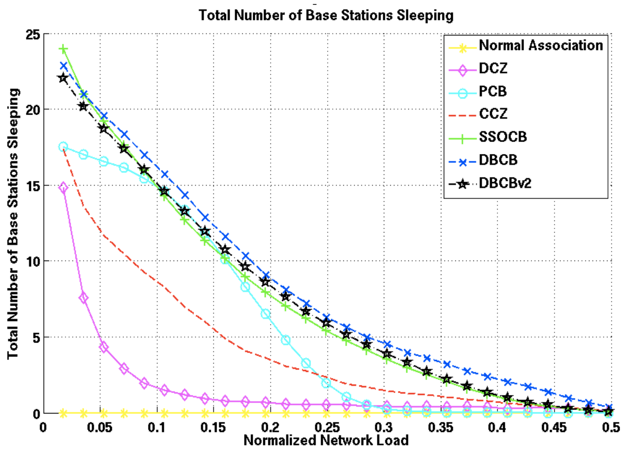

Figure 1. Number of BS switched-off for each one of the algorithms

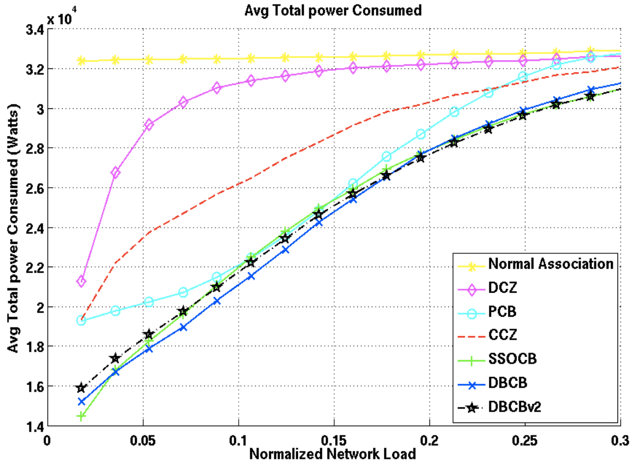

Figure 2. Global Network Consumption for each algorithm including the RAN and MS deployment.

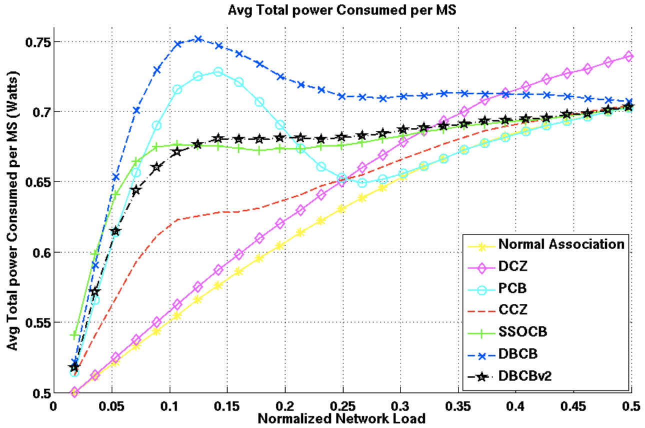

Figure 3. Average MS Consumption by using each one of the cell-breathing algorithms.

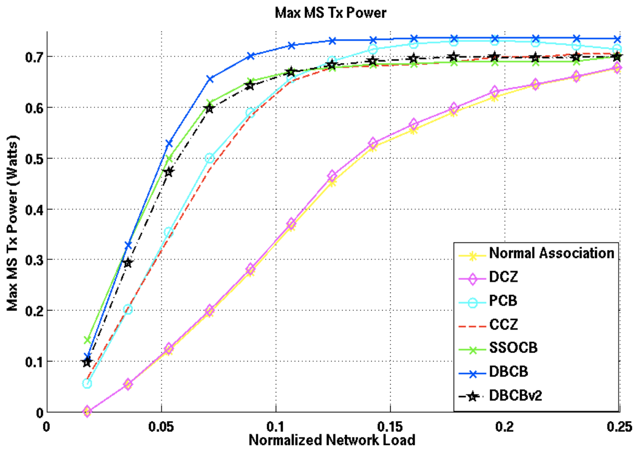

Figure 4. Maximum Transmission power in the MS for each one of the algorithms studied.

## REFERENCES

[1] Gartner, “Green IT: The New Industry Shockwave,” presentation at Symposium/ITXPO conference, April 2007.

[2] U. Barth, Alcatel-Lucent, Bell Labs Stuttgart, "How To Reduce-Green House Gas Emissions From Ict Equipment", Wireless Networks, EARTH research project, ETSI Green Agenda, 26 Nov 2009.

[3] Suarez L.A.**;** Nuaymi L.; Bonnin J.M.; “An overview and classification of research approaches in green wireless networks,” *EURASIP Journal on Wireless Communications and Networking*, *Special Issue: Green Radio*, April 2012

[4] Yates R. D.; C-Y. Huang; "Integrated power control and base station assignment," *IEEE Trans. on Vehicular Technology*, Vol. 44, no. 3, Aug. 1995.

[5] Hanly S.V.; "An algorithm for combined cell-site selection and power control to maximize cellular spread spectrum capacity," *IEEE Journal on selected areas in communications*, Vol. 13, No.7, Sep. 1995.

[6] Zhisheng Niu; Yiqun Wu; Jie Gong; Zexi Yang; , "Cell zooming for cost-efficient green cellular networks," *Communications Magazine, IEEE* , vol.48, no.11, pp.74-79, November 2010

[7] Micallef, G.; Mogensen, P.; Scheck, H.-O.; , "Cell size breathing and possibilities to introduce cell sleep mode," *Wireless Conference (EW), 2010 European* , vol., no., pp.111-115, 12-15 April 2010

[8] Hossain, M.F.; Munasinghe, K.S.; Jamalipour, A.; , "An eco-inspired energy efficient access network architecture for next generation cellular systems," *Wireless Communications and Networking Conference (WCNC), 2011 IEEE* , vol., no., pp.992-997, 28-31 March 2011

[9] Suarez L.A.; Nuaymi L.; Bonnin J.M.; “Energy performance of a distributed BS based green cell breathing algorithm”, accepted to ISWCS 2012.

[10] EARTH, INFSO-ICT-247733 EARTH, "Energy efficiency analysis of the reference systems, areas of improvements and target breakdown" Dec 2010.

[11] Ferling, D.; Bohn, T.; Zeller, D.; Frenger, P.; Gódor, I.; Jading, Y.; Tomaselli, W.; , "Energy efficiency approaches for radio nodes," *Future Network and Mobile Summit, 2010* , vol., no., pp.1-9, 16-18 June 2010

[12] Correia, L.M.; Zeller, D.; Blume, O.; Ferling, D.; Jading, Y.; Gódor, I.; Auer, G.; Van Der Perre, L.; , "Challenges and enabling technologies for energy aware mobile radio networks," *Communications Magazine, IEEE* , vol.48, no.11, pp.66-72, November 2010