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RESEARCH ARTICLE

A multi-criteria BS switching-off algorithm for 5G heterogeneous cellular networks with hybrid energy sources

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ABSTRACT

In this paper, we study Base Station (BS) switching-off and offloading for next generation 5G heterogeneous (macro/femto) networks supplied with hybrid energy sources. This type of network will form the basis of the high-data rate energy-efficient cellular networks in the years to come. A novel generalized multimetric algorithm is presented. Our proposal is conceived to operate in highly heterogeneous Radio Access Network (RAN) environments, as expected for 5G, where BSs with different characteristics of coverage, radio resources and power consumption coexist. The approach uses a set of metrics with a modifiable priority hierarchy in order to filter, sort and select the BS neighbors, which receive traffic during redistribution and offloading of the BSs to be put into sleep mode. In our analysis, we study the impact of BS power model trends for active, idle and sleep modes on the BS switching-off. We highlight how the continuous evolution of BS components and the introduction of renewable energy technologies play a significant role to be considered in the decision making. The multimetric approach proposed makes it possible to define and accomplish defined network performance goals by adding specific emphasis on aspects like QoS, energy savings or green equipment utilization. Copyright © 2015 John Wiley & Sons, Ltd.

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1. INTRODUCTION

The latest advances in telecommunications have brought about an expansion of the level of services available in the digital era. However, these new features imply an increasing exchange of data across the network. In 2013 global mobile traffic grew 81% corresponding to 1.5 exabytes and devices such as smartphones and tablets will increase their traffic demand ten-fold by 2018 [1]. This latter increase has consequences from both the environmental and economic perspectives. On the one hand, the increase in energy demands implies a more significant contribution from the Information and Communications Technologies (ICT) to the carbon footprint, as well as a higher utilization of non-renewable resources for energy production [2][3]. On the other hand, the higher energy consumption is having a more significant impact on the costs of telecommunications operators worldwide. In that sense, the preoccupation around such matters has brought about an increased interest in finding a means to reduce the energy consumption of the network. In order to achieve this, governments, research institutes, universities and operators have created initiatives to face the challenge. Specifically for mobile networks, the alternatives for enhancement come on 3 different levels [4]: i) the component level: improvements to Base Station (BS) internal components and research on renewable energy supply architectures; ii) the link level: optimization of the radio transmission techniques and energy-aware radio resource management; iii) the network level: adaptation of the cellular topology and its architecture based on specific traffic needs. The component and architectural BS enhancement constitutes itself as an enabler for the upper levels. As a consequence, the power consumption of the BS for the active, idle and sleep modes has been reducing over the recent years. Improvements to power amplifier efficiency have been the major factor in the reduction of energy consumption, which in addition reduces the requirements of the internal cooling system. Here in this paper, we discuss if such a progress at the component level is made and how the changes to the BS power model could affect the algorithms and energy saving techniques proposed for the network level of mobile 5G technologies in the years to come.

Our proposal is based on the principle of combining green cell breathing/offloading and BS switch-off with heterogeneous architecture approaches. Such mechanisms make it possible to adapt the cell sizes and the number of active BSs and their distributions to better track the density of traffic, in order to improve the energy efficiency in mobile networks by mechanisms of BS selection for traffic offloading [5][6][7]. The principle to achieve such energy savings consists of low traffic periods or the so-called "night zones" [8][9] where some BSs experiencing low traffic may be offloaded and switched off, while some other BSs stay active receiving the redistributed traffic.

We can extend the approach toward heterogeneous architectures. In a heterogeneous radio access network a classic macrocellular deployment is combined with two or more layers of devices with different coverage ranges and capacity, e.g. addition of a deployment of small cells like micro, pico, femtocells, or the inclusion of multihop relays. By using these architectures it is possible to achieve a granular allocation of resources and customized network power consumption if sleep modes are additionally considered [10]. These scenarios for Radio Access Network (RAN) deployments in both the short and long terms will become more and more complex with heterogeneous architectures composed of BSs from different technological generations, resource capacity and energy sources. In addition, as discussed in [11], there exist challenges around the cooperation and coordination for these types of schemes which must be addressed.

In this article, we provide a new proposal on BS selection for switching off schemes in a heterogeneous cellular layout. The novelty of this mechanism consists of the utilization of a multimetric Mobile Station (MS) to Base Station (BS) association/redistribution technique, which provides a generalized solution in the domain of switch-off techniques for highly heterogeneous environments. A complete analysis, considering energy consumption and QoS issues, is provided in order to present the flexibility of our solution in the context of networks operator goals and deployment characteristics.

The structure of this paper is as follows. In section 2, we present a brief overview of the energy efficiency problem for the RAN and the new perspectives in heterogeneous networks and renewable energies. In section 3, we provide the main system model and the different BS power models considered. In section 4 we present the general architecture considered and a brief description of the deactivation and reactivation processes. In section 5, we provide a brief description of the benchmark algorithms used for comparison. We leave section 6 to present the novel proposal concentrating on the BS multimetric selection method used for offloading. The description of the scenarios, their corresponding simulation results and respective analysis are presented in section 7. Finally, the conclusions are left for section 8.

2. GENERAL BACKGROUND

The overall consumption of a mobile network is heavily dominated by the BS systems, i.e, the RAN [12]. Despite the fact that the core elements also have an important contribution, the RAN consumption is nearly 60% of the whole budget. Why does the BS deployment consume that much power? The answer lies within the functionality and efficiency of the internal components. A BS is composed of the following elements [13]: a power supply in order to feed the rest of the BS components; an air conditioning system to provide the necessary refrigeration support for the BS circuitry, mainly for the power amplifier (PA); a baseband unit component used for the digital signal processing part and the radio frequency (RF) small signal circuitry for the analogue signal processing; finally, the power amplifier (PA) followed by a feeder coupled to the antenna system which constitutes the transceiver front-end. 60-70% of the whole energy budget is consumed by the power amplifier[14]. Currently, the state-of-the-art amplifier, the pre-distorted Doherty amplifier reaches efficiencies around 45% [14] and a great amount of power is lost due to heat losses. Nevertheless, researchers developing new PA architectures with higher efficiencies promise great advances in this aspect as it is the case of the Class J Amplifier [15] or the Switched Mode Power Amplifier (SMPA) proposal [16].

The enhancements on the PA will eventually reduce the need for other components like the air-cooling. This also will bring about a substantial reduction year-on-year of consumed power and a faster transition response between the different BS states: active (full load), idle (zero load) and sleep mode. In addition, also there exist enhancements in the transmission front-end by using Massive MIMO technologies. This technique seems very promising as it provides better ratios of power to coverage area as well improving the BS and overall network capacity [17]. As mentioned in [4], all these efforts in BS component enhancement are key energy efficiency enablers to boost the savings from upper layer techniques for 5G networks and beyond by providing a framework for the optimization of radio resources by the use of computational algorithms for efficient allocation.

In addition, hardware reductions have brought about other trends in radio architectures as it is the case with heterogeneous networks combining large and small cells. The evolution of the current radio networks is aimed at deploying coverage extension by means of layers of low cost small cells (e.g. pico, femtocells), which consumes proportionally less power than upgrading with a new macrocell BS site [18]. The use of smalls cells provides flexible capacity in the function of daily traffic fluctuations making it possible to boost capacity in high peak traffic but also allowing Macro-BS to switch off during off-peak traffic by means of macro-to-femto offloading [19][20]. Moreover, the possibilities of such a technology allows also for increasing capacity in critical spots by means

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of strategic positioning for example around the macrocell borders [21]. However, small cell deployments also present drawbacks considering the associated economic costs, backhaul network energy consumption [22] and other issues like cell coordination [23], which limits density for such networks. On the other hand, there is also a significant research initiative to push the introduction of green BS systems supplied with renewable energies like solar, wind or hybrid (renewable/diesel) [24][25] bringing an increased heterogeneity to the radio access networks. These green supply sources appear nowadays as a very attractive option in order to avoid fully or partially the use of grid energy or fossil fuel energy for network operation [25]. Although there are still obstacles to overcome for these technologies in Macro-BS systems, like the need for reducing the dimensions of photo-voltaic panels or improving the efficiency of materials [24], the trends of growth exist. Statistics provided by GSMA Green Power Mobile model group mention that in the period from 2011 to 2013, the number of off-grid fully renewable and hybrid sites has increased by a factor of 3 with currently 37000 green BSs and 26000 hybrid BSs [26] in the world. Although this corresponds to a percentage of just around 5% of a total of 640000 off-grid BSs worldwide, forecasts predict a rapid growth of green deployments before 2020 in countries like India [27].

3. SYSTEM MODEL

3.1. General system model

We consider a set Ω of N Macro-BSs working jointly with a second layer set Φ composed of K femto-BSs. The set Ω is deployed in a hexagonal architecture, whereas Φ is a randomly uniform deployment. In addition, we consider a set of M MS users, also uniformly randomly deployed, that we call Ψ. The technology parameters chosen are based on the current LTE standards. The macro-layer Ω uses a segment of spectrum W_M, whereas the femto-layer Φ uses another non-overlapped segment W_F. Each MS i user has a fixed assignment of spectrum w_i. The power model of a BS j in the active mode is characterized by a fixed consumption P_j^{fixed}, which is the sum of the contributions of different components whose consumed power is considered independent of the transmission power P_j^{Tx} and the power amplifier consumption due to transmission which is directly dependent on the transmission power. The BS j consumed power P_j , in active mode may be expressed by the Eq. 1 [14][28][29]:

$$P_j = P_j^{fixed} + \eta \cdot P_j^{Tx} \tag{1}$$

where η corresponds to a constant that represents the power supply increment needed by the power amplifier per watt transmitted. This simple straight line model, which was proposed by the ICT EARTH project, makes it possible to represent the BS power consumption as a function of the output transmission power. Although there is a relationship with the BS capacity, during idle mode, coverage and signalling represent an important contribution to the transmission power, which remains static despite of the traffic fluctuations. This latter combined with the fixed consumption of elements like cooling and baseband processing justifies the switching-off of any underutilized BS during low traffic periods as it becomes a waste of energy [30]. More comprehensive models like the one presented in [13], which provides a model considering losses and consumption of internal components agrees that a simplified model like the one presented here is sufficient to model the BS power demand in active mode. Last but not least, the sleep mode consumption assumes a BS consumed power P_j equal to a fixed value P_j^{sleep} as also presented in [13][28][29].

For the femto-BS we consider a simple model where a femto-BS consumes a fixed power P_k and a transmission power P_k^{Tx} that is limited by P_k^{Tx-max}, which corresponds to the maximum attainable transmission power. The power in sleep mode for a femto-BS is called P_k^{sleep} . Finally, for an MS i only the transmission power P_i^{Tx} is considered. For this parameter, we work with a maximum output equal to P_i^{Tx-max} for each MS. The main simulation parameters are given in Table I.

3.2. Power model figures for the macro-BS layer

For the macrolayer we use the power models presented in [29]. The original sources of the power models presented in this article are [14][32] and [33], all published works using the framework of the ICT-EARTH Project. In addition, we consider that a fraction of the set of all BSs (macro and femto) are powered by a combination of renewable and non-renewable sources. We call this group of BSs Υ_R. The BSs in Υ_R are partially powered by a renewable source, governed by a random percentage χ. Such a percentage χ can take values from 50 to 100% of the total power supply according to a random uniform distribution.

Firstly, we introduce the state of art (SOTA) 2010 model originally presented in [32]. In this model, the BS site is composed of three sectors, two antennas per sector. The total BS consumption taking the three sectors and the six antennas for full active mode is 1292 W whereas for the idle state (zero load) is 712 W. The power level for the sleep mode is 378 W. A second model [14] corresponds to a predicted model for 2014 taking into account the latest advances in BS circuitry. This is referred to as in [29] as the “Market 2014 BS model”. From [33] a third model is extracted, which corresponds to a BS model before 2010 upgraded with DTX (discontinuous transmission mode) enhancements. Finally, [29] presents an “idealized BS power model” which tends towards the theoretical limits, in which power consumption may approach this in the long term. In Table II, we present the different power levels for the already described models. The values correspond to the power levels of a single BS sector antenna (2 antennas per sector).

Parameter Name	Value or Choice
Wireless Standard Technology	LTE
Intersite Distance	500m
Central Frequency	2000 MHz
Spectrum Bandwidth W_M/W_F	15MHz/5MHz FDD
Path Loss Model	For 2GHz [31]: $L = 127 + 30log(d)$, d in km (femto); $L = 128.1 + 37.6log(d)$, d in km (Macro)
lognormal shadowing standard deviation	10dB(Macro) /4dB(femto)
Resource Block per User	4 (fixed)
Number of Sites	16 3-sector BS sites (4x4)
BS sector parameters	P_j^{Tx-max} = 40W; BS Max. Antenna Gain = 14dB; BS Cable losses = 2dB; BS Noise Figure = 5dB
femto-BS parameters	P_k^{Tx-max} = 100mW; P_k = 10W; P_k^{sleep} = 3W; Antenna Type= Omnidirectional; femtoBS Antenna Gain = 5dB; femtoBS Noise Figure = 5dB
femtoBSs per Macro-BS site	6 (fixed)
femtoBS Distribution	Randomly Uniform
MS parameters	P_i^{Tx} = 200mW; MS Antenna Gain = 0dB; MS Body Loss = 2dB; MS Noise Figure = 9dB
MS Distribution	Randomly Uniform
Number of Montecarlo Distributions	200

Table I. Main Simulation parameters

Power Model	P_j^{fixed}	η	P_j^{sleep}
BS SOTA 2010	119W	2.4	63W
BS Enhanced with DTX	170W	3.4	25W
Market 2014 BS Model	67W	1.25	25W
Idealized BS model	1W	2.9	1W

Table II. Macro-BS Power model values presented in [29]

4. GENERAL ARCHITECTURE AND DEACTIVATION/REACTIVATION PROCESSES

In this section we describe the basics of the baseline architecture considered in the article. The common schemes makes it possible to undertake a fair comparison of the benchmark algorithms with our novel proposal.

4.1. BS offloading and switching-off principles

In order to switch-off a BS the main rule for algorithm design is that coverage must not be compromised and the necessary capacity should be guaranteed, particularly in macro cellular networks. Energy-efficient cell breathing was conceived to fulfill both conditions under the assumption that during low traffic period or "night zones" [8][9], the needed resources are often a relatively small fraction of the maximum capacity. Then, it is possible to switch off a number of BSs by leaving some remaining active BSs with expanded cells for guaranteeing coverage. This cell expansion can be achieved by means of power or tilt angle adaptation.

Switching-off algorithms proposed in the literature work under principle of offloading BSs by redistributing users toward some appropriate neighbors before proceeding with the BS switch off (see Fig. 1). The literature provides ways to select such neighbors as seen in references like [5][6][7]. Firstly, some metrics must be collected and exchanged through the backhaul to be able to effectuate the neighbor selection; then estimations to establish if such neighbors are able to receive the full redistributed load are done. The load is redistributed towards the best neighbor candidate first and then when there is no available capacity for receiving offloaded traffic, the next candidates are requested and so on. For each neighbor some reserved bandwidth should be kept to receive traffic after switch-off to avoid congestion. Then, just if the load is zero in the BS being offloaded, the switching off process takes place. Partial offloading is not accepted and if one or more MSs could not be redistributed according to pre-association estimations, the offloading do not take place. This avoids unnecessary handovers which may degrade performance.

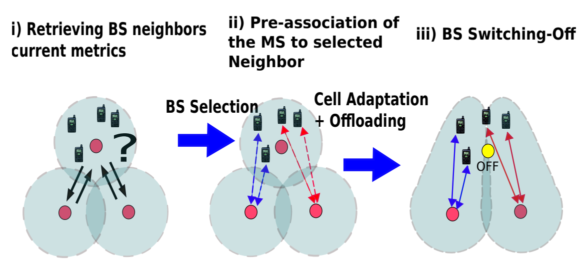

Figure 1. Illustration of the general Offloading/BS switching off procedure with Cell Breathing

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4.2. Congestion issues due to switching off aggressiveness

An unavoidable consequence of offloading is the network congestion. Here, the load imbalance is inherent in any energy efficient algorithm supported on offloading and switching off due to the fact that to maximize the number of BS switched off it is necessary to concentrate the load in some few BSs. Depending on the BS neighbors decision making process, it is possible to establish a strategy that either could aggressively concentrate traffic and switch off or rather adopt a conservative approach on behalf of load balance, benefiting QoS and a reducing congestion by, for instance, preferring high SINR re-associations. It is also possible to enhance congestion control by means of traffic thresholds [6][7] where energy savings and overall available capacity are traded off to regulate the ratio of active to deactivated BS equipment. Traffic thresholds could also be used to limit on the amount of received traffic for redistribution [34] or similarly reserving bandwidth to prevent unavailability during bursts of traffic[5]. Both approaches prevent congestion due to imbalance and capacity degradation. The congestion control by traffic thresholds or reserved bandwidth is not included in this article as we focus on the behavior of the BS selection strategies. In addition, just low and medium network loads are considered in our study, so then congestion is not a major issue.

4.3. Coordination based on Cluster Architecture

Our architecture is divided in several BS clusters of $n \times n$ cells as exhibited in Fig. 2. In this approach each of the clusters has a selected BS cluster head that is responsible for the signalling and synchronization functions, which makes it possible for the algorithm execution BS-by-BS inside the cluster. It must be pointed that the cluster idea is not constrained to a fixed architecture or a given geometry (i.e. hexagonal) but it might be extended without loss of generality, what matters is to group the BSs in clusters in order to subdivide and distribute the control tasks. As seen in Fig. 2 the algorithm sequencing is done by combining the capabilities of the S1 and X2 interfaces, part of the current LTE standards [35]. A Mobile Management Entity (MME) takes charge of a centralized coordination and synchronization of the cluster heads. Under this structure each BS has a time slot of variable duration to execute the BS offloading and switching-off depending on the number of MSs to redistribute and the potential neighbors to select. During each slot just one BS per cluster executes the algorithm.

The monitoring is done through the BS cluster head to the other BSs inside the cluster which defines and synchronizes when to start with the next slot in all clusters thanks to information exchange among all the BS cluster heads in the network. This cluster sequence is triggered by the cluster head, then the sequence is followed BS-by-BS, where each neighbor informs the next in sequence of the start of the new BS algorithm slot by using the X2 interface connectivity. This X2 message can only be sent if the cluster head has been informed that other BSs in other clusters in the current slot also finished the algorithm execution. A given BS just may re-execute the algorithm when its turn in the cluster sequence comes. As the time it takes for those processes inside the BS slot time is of the order of some tens of seconds and at a cluster scale in the order of minutes, its means that the next re-computation for a given slot is separated by some few minutes. This allows for more stability in the network by limiting the transitions to the ON/OFF states or the so called ping-pong effect and at the same time being fast enough to update the network topology in an organized and distributed basis.

On the other hand, independence of the algorithm execution for BSs in different clusters can be guaranteed if a sufficient number of cells in between is ensured for two BSs concurrently running the algorithm. This avoids the data inconsistencies and conflicts produced by BSs sharing common neighbors or directly adjacent BSs executing the algorithm at the same time. For instance, a single BS could be receiving load from two adjacent BSs at the same time, which means inconsistent information on the real capacity of the BS neighbor acceptor. Also the cluster architecture prevents that two adjacent BSs being mutually redistributing the same traffic to each other. In this article we consider a 4x4 cells cluster which gives enough cells in between for two BSs holding same relative cluster position (i.e. same time slot), which provides sufficient and safe separation resulting in a fully independent execution.

4.4. Reactivation mechanism and coverage holes handling

In this article we consider the utilization of MS reverse paging messages in order to reactivate any BS (femto/macro) when there are no BSs covering a given requesting user. Such mechanisms become increasingly a technological necessity [36][37] to better exploit the energy savings provided by small cell environments and also to provide features to handle coverage holes in scenarios like macro/femto where femtocells are not properly overlapped. The challenge here is to provide a BS that is able to switch from sleep to active mode with very short transition time. If we consider soft sleep modes, i.e. a partial switch-off where some circuitry remains active including a wake-up module, this time can be of the order of tens of seconds for modern BS systems [33][38]. Such a coverage handling mechanism could be enhanced considering fast mobility scenarios [39]. In such a situation, as a reverse paging request is sent, this request could be propagated to other neighboring BSs in order to anticipate and provide a faster reaction, for instance, to the trajectory of a user inside a vehicle or high speed train passing near the radio access deployment.

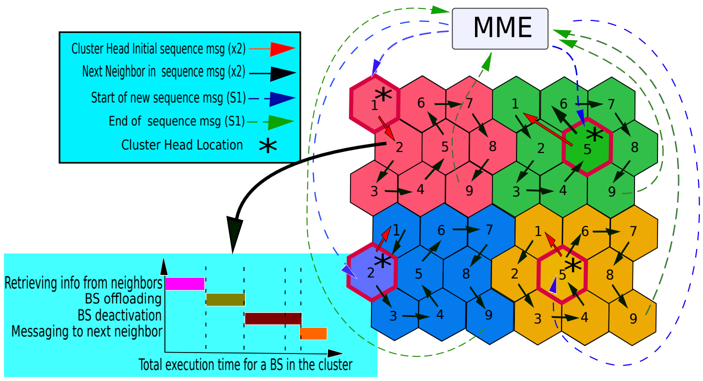

Figure 2. Clusters architecture, signaling and algorithm sequence. Example with 4 cluster of 3x3 cells

5. BENCHMARK ALGORITHMS

The algorithms presented here are two representative proposals conceived for heterogeneous networks (macro/femto) based on the principle of offloading and switching-off. As mentioned earlier, to provide a fair comparison we provide the same architecture and principles for deactivation and reactivation of BSs to all algorithms presented in this article. The benchmark algorithms selected here show the typical case in literature that assumes that always the best energy savings are attained by offloading Macro-BSs into the femtolayer. This might not be always the case for highly heterogeneous networks with BS equipment having different consumption regimes, power supply sources, coverage and capacity characteristics as we will present later on.

Firstly, we present the macro-to-femto offloading proposed in [19]. Here, the authors propose to use a femto-BS layer, which is initially in sleep mode. The equipment of this layer while sleeping is at the same time listening to the medium by means of a low power receiver/sniffer. This sniffer is used to catch ongoing calls being served by the Macro-BS layer. When a call is detected by a femto-BS, the possibility of redistribution (i.e. handover macro-to-femto) is informed to the Macro-BS and the corresponding MS. In the case where the QoS requirements can be guaranteed the redistribution is performed. Therefore, by using this method it is possible to offload and deactivate some Macro-BSs by redistributing their full load to the femto-layer.

A variation of the macro-to-femto offloading proposed in [19] consists of combining it with cell-breathing algorithms in the macrolayer [7]. The idea is to increase the number of Macro-BSs deactivated by having two ways of traffic offloading as presented in [40]. Here, we proposed an algorithm that we called femto-DBCB, i.e. macro-to-femto offloading + Distributed BS Based Cell Breathing. In this algorithm, we have the same assumption from [19] where the femto-layer is by default in sleep mode. However, femto-BSs must be available for any activation request originated at the Macro-layer or by any MSs requesting for service. Then, when a Macro-BS j wants to be switched-off, first it tries the traffic offloading toward the femtolayer, more specifically to any femto-BS neighbor $k, k \in \Phi_j$, where Φ_j is the group of femto-BSs associated to the BS j. To perform the association, the criterion used is to select the femto-BS-to-MS association that provides the highest SINR. Then, when the set of femto-BSs Φ_j is not able to accept some of the users during this first redistribution phase, we use the second way of BS offloading: the cell breathing supported on the macrocellular layer. Here, the BS j executes a distributed BS based cell breathing algorithm [7] and tries to redistribute the remaining load towards the Macro-neighbors. The criterion for redistribution at this layer corresponds to a combined metric of SINR and BS load [7]. The combination of the two approaches, i.e. macro-to-femto offloading + cell breathing should increase the number of deactivated Macro-BS and therefore delivers better RAN savings with respect to the macro-to-femto offloading only.

6. THE HIGHLY HETEROGENEOUS ENVIRONMENT AWARE DBCB ALGORITHM (HHEA-DBCB)

6.1. BS selection mechanism

This proposal is conceived to be adaptable to a heterogeneous network with different consumption regimes and BS types. In such scenarios, a BS can be either from a legacy technology or may be from a recent very highly efficient BS system; some BSs use fossil fuels, while some others could be fed by an electric distribution system, whereas others could be powered by renewable energy. Moreover, in a network of such characteristics we can have BSs with different ranges of coverage, i.e. Macro, micro, pico, femto, Etc. Therefore, it may not be appropriate to control the MS-BS re-association/offloading based on only one single parameter, e.g. load, SINR, consumed power, etc., given the fact that one single parameter may not properly

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consider all the aspects of efficiency as well as the quality and optimization goals of the network. The novelty of our new proposal, the Highly Heterogeneous Environment Aware - DBCB (HHEA-DBCB) is focused precisely on that issue. The procedure is explained in the following.

Instead of using two sets of femto and Macro-BSs Ω and Φ defined separately as before, we consider a new single set $\Upsilon | \Omega \cup \Phi = \Upsilon$ where all BSs are contained. In this set any BS, no matter its type (i.e. femto, Macro), has a global ID g. Therefore, the large and small cell layers is combined in the same group and any BS (macro/femto) may offload traffic to any other BS regardless of which access layer they belong to.

The BS selection mechanism initially must make a MS-BS pre-association before making the decision on whether to redistribute the full BS traffic or not. First, we call $\Upsilon_{g',i}$, the set of potential candidates to redistribute a MS i currently associated with g. These candidates were previously filtered and selected based on what we call a *"candidate profile characteristic"* or priority Level 0, that corresponds to a specific attribute where candidates are better than the current BS g associated to MS i, e.g. reduced consumption power or better SINR level. This pre-filtering is useful to reduce the pool of candidates just to those interesting neighbors based on a dominant characteristic, which reduce the memory and computational resources needed for the decision making algorithm. Then, a second phase starts where just the selected candidates that have passed the pre-filtering phase are sorted according to a given strategy. Here, we establish a set of P metrics with weight priorities for metric selection Π_g for a BS g that consists of:

$$\begin{aligned} \Pi_g &= (\pi_{g,1}, \pi_{g,2}, \cdots, \pi_{g,p}, \cdots, \pi_{g,P}) \\ s.t \quad &, \quad \pi_{g,1} > \pi_{g,2} > \cdots > \pi_{g,p} > \cdots > \pi_{g,P} \end{aligned} \quad (2)$$

Such a set of weight priorities Π_g is used to define the sequence of each of the P different metrics used to select a BS neighbor acceptor $g' \in \Upsilon_{g',i}$ for a MS i. The metrics are checked one-by-one in order to compare all the neighbors into $\Upsilon_{g',i}$. The higher the metric priority, the higher the dominance during candidate sorting and BS selection. Now, we call $\Theta_{g,i}$ the matrix used to store the information of the metrics to redistribute a MS i from g to a $g' \in \Upsilon_{g',i}$. Such a matrix has a size of $[\Upsilon_{g',i}] \times P$ and we call each metric value of the matrix $\theta_{(i,g',p)}$. When for a given metric comparison with priority weight $\pi_{g,p}$, there are two or more BSs into $\Upsilon_{g',i}$ tied with the same metric value, the procedure to break the tie consists of checking the metric with the next priority in sequence with weight $\pi_{g,p+1}$ to see if it breaks the tie or otherwise it continues with the next metric in sequence and so on. If the tie persists and all the P metrics were checked, the tie is broken by choosing the BS g' into $\Upsilon_{g',i}$ with the highest global ID. A simplified flowchart of the described process is shown in Fig 3.

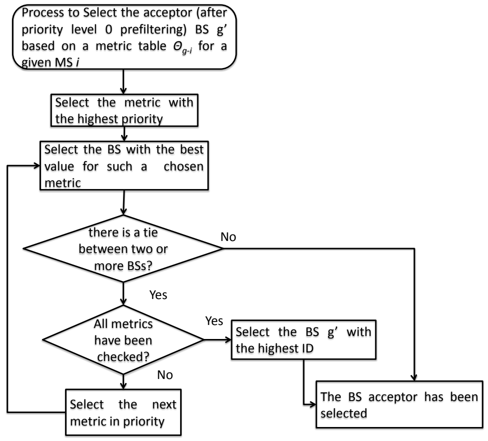

Figure 3. Flowchart of the sorting phase after pre-filtering in HHEA-DBCB.

6.2. Proposed metrics

We propose a set of 3 basic metrics based on power consumption, BS load and SINR. In the strategies to be analyzed later, one metric is used for candidate pre-filtering (Priority Level 0) and the other two are considered for the sorting phase with priorities 1 and 2 respectively, i.e., $P = 2$. Each one of these 3 metrics are described in the following subsections. For the metrics considered, a variable level of truncation of the real values can be considered to control level of tied values between candidates. Less significant figures in the metric values increase the possibility of having tied candidates for a given metric, and hence it gives the possibility of further comparison with metrics of lower priority.

6.2.1. Non-renewable BS power demand per user

A hybrid BS is a system supplied by non-renewable (e.g. electric distribution system, fossil fuel) and renewable energies (e.g. solar panels, windmills) in function of availability as seen in Fig. 4.

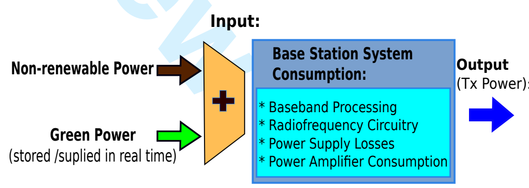

Figure 4. Description of a BS with a hybrid power supply system

An appropriate metric to consider for a potential acceptor g' is the *non-renewable BS consumed power component to provide a given output power P^{Tx} divided by the maximum number of users M_{max}*, which we note it as $P_{g'(NR)}(P^{Tx})/M_{max}$ and call it in the following the non-renewable power metric.

$$\frac{P_{g'(NR)}(P^{Tx})}{M_{max}} = \frac{P_{g'}(P^{Tx}) - P_{g'(R)}(P^{Tx})}{M_{max}} \quad (3)$$

where:

- $P_{g'}(P^{Tx})$ is the total consumed power of the BS g'.
- $P_{g'(R)}(P^{Tx})$ is the renewable consumed power component for the BS g'.

Here, from the total demanded power we take only its non-renewable power component and skip the contribution from any green source. The lower the non-renewable power consumed the better for green radio design. We calculate this metric as the ratio of input power needed per user assuming that each MS receives an average amount of bandwidth (i.e. resource blocks) and some minimal transmission power is needed to fulfill some minimal QoS requirements.

6.2.2. BS Load Level

Load-aware algorithms are quite common as they provide high energy savings by concentrating the load in order to offload and deactivate idle or low load BSs first. By concentrating the load in few highly loaded spots we maximize the number of BS switched-off in a aggressive manner. A well known proposal in this category is the cell zooming algorithm presented in [5]. This algorithm considers load in a generic way considering the allocated resources and presents the definition of normalized load. The algorithm consists of sorting the BSs to be switched-off in function of current load by then prioritizing to deactivate first those with the lowest loads. Other authors have proposed more specific implementations like the one in [41], which deals with a femtocell network of OFDMA/TDD characteristics, providing a switching-off algorithm which optimizes the radio resource allocation considering a granularity at the level of the subcarriers. Currently, many of the latest proposals are based in bioinspired techniques like: Proto-cooperation [34], Genetic Algorithms [42] or Teaching-Learning Based Optimization (TLBO)[43]. For the load metric we consider that a BS g' has a normalized load $L_{g'}$ given by the following equation:

$$L_{g'} = \sum_{i=1}^{M_{g'}+1} \frac{\omega_i}{W_{g'}} \leq 1 \tag{4}$$

where,

- ω_i is the portion of spectrum allocated to any MS i.
- $M_{g'}$ is the number of MSs associated to g'.
- $W_{g'}$ spectrum band assigned to g'.

Therefore, when it is necessary to break the tie with the normalized load metric, a BS g prefers, the neighbor g' with the highest $L_{g'}$ in order to re-associate the MS i. The summation is done for $M_{g'}+1$ users as we must consider the admission of a new MS during calculation. This metric is very appropriate if the goal is to switch off equipment and save energy without regarding too much other significant aspects like QoS.

6.2.3. SINR Level

Also a very important point to consider in the functioning of a mobile network is the QoS and specifically its attainable data rate, which is highly dependent of the signal quality represented by the signal-to-interference plus noise ratio (SINR). In such a case we sacrifice the energy savings by giving priority to establish high quality MS-BS associations. For the SINR level, a BS g chooses the neighbor g' with the highest offered SINR $\hat{\gamma}_{g',i}$ as:

$$\hat{\gamma}_{g',i} = max(\gamma_{g',i}), |g' \in \Upsilon_{g',i} \tag{5}$$

By prioritizing this metric we obtain, as a consequence a behavior prone to reduced congestion, load balancing and a less aggressive energy saving strategy. In addition, the use of SINR as dominant metric should also improve the MS performance. Although this element we leave it out of the scope of this article, it is worth to be shortly discussed. Actually, even if the MS power consumption considered as the sum of power from many terminals connected to a single BS might be negligible with respect to the power of Macro-BS itself, what matters is the individual MS performance as a key value for the user perception. In such sense, the MS autonomy is affected if the terminal is forced to work at high power to reach far located BSs after being redistributed. In [7] we have shown how important is to include SINR in MS-BS redistribution to include the overall losses which impact the uplink power allocation. This work was extended in [44] to study the electromagnetic compliance and the Specific Absorption Rate (SAR) increase due to mobile phone uplink power adaptation due to cell breathing. Other similar works like [45] have continued the direction of using the SINR and its implicit relationship with uplink performance as primary metric for MS redistribution in order to sort the priority on switching off by using the criterion of evaluating which BSs can be switched-off while adding less impact on the uplink transmission power.

In our specific case, having SINR as dominant metric, we put the overall energy savings in a second place and as emphasized before prioritizing elements like QoS into the scope or this article. This scheme is useful in scenarios where energy is a flexible constraint and there is marginally more interest on avoiding the data throughput degradation.

6.3. Convergence properties derived from the cluster architecture

Scheduling the algorithm execution based on a cluster sequence (see subsection 4.3) is beneficial to avoid rapid dynamic changes between the ON/OFF states, i.e. the well-known ping-pong effect. That makes it possible to ensure the convergence of the algorithm as the deactivation is not triggered by random fluctuations but a fixed and predefined sequence of steps in the cluster. Each Macro-BS gets switched off only if the traffic is fully redistributed to the neighbors, and this only happens if metric checking have proved that neighbors were better acceptors of the

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redistributed load in terms of the dominant aspects chosen for the metric priority strategy. The re-computation in each Macro-BSs is done just after the whole set of Macro-BSs in the cluster has already executed the algorithm. However, in HHEA-DBCB, femto-BSs also execute the algorithm of offloading and redistribution and it adds some heterogeneity which might be handled with some modifications on the cluster architecture. In this case, femto-BSs do not execute the algorithm following the main sequence of the cluster but they are triggered by a certain threshold, ex. Load level or Non-renewable power consumption. The rule to respect is that femto-BSs must wait if at the same time their main Macro-BS associated is executing the algorithm before attempting the execution. An explanation is provided in Fig. 5 where a group of femto-BSs attempt to get deactivated.

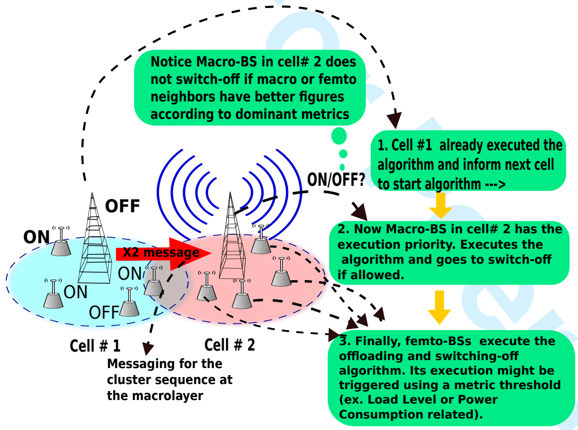

Figure 5. illustration of the triggering mechanism for the femtolayer

After a macro/femto-BS is switched-off, the only way to wake it up is by using the reactivation method discussed in subsection 4.4 . However, with current technologies we shall prioritize the reactivation of femtocells first as the activation/reactivation times are faster with respect to a large cell system.

6.4. Proposed strategies

In a real implementation of the algorithm, we may create what we could call a "BS ranking table" that sorts all values of $\Theta_{g,i}$ in order to facilitate the search of the best BS g'. All potential BS acceptors are classified by means of their weighted metrics. After retrieving all the necessary information from each potential BS acceptor, the candidates are pre-filtered with the priority 0 metric and then a sorting process for the pre-selected candidates is done with priority 1 and 2 metrics. This table is created for each MS i involved. Such a task could be done by each BS executing the offloading procedure by means of exchange and cooperation with other neighbors. There is logically a need to invest in computational resources to coordinate energy efficiency. However, we have shown that approach is distributed, reducing the burden on a single device. In addition, the number of candidates that need to be sorted is reduced with the pre-filtering stage. Furthermore, the energy cost to implement this is tiny compared to other processing in the network, whether distributed or centralized. Turning a BS off will saving significantly more energy.

We consider three types of configurations with three metrics each. The metric in priority level 0 is used to define the candidate profile characteristic (i.e. candidate pre-filtering), whereas metric 1 and 2 are used for candidate sorting and selection as seen in Fig. 6. A comparison of advantages and disadvantages for the dominant criteria is given in Table III. A summary of the three proposed configuration strategies is given in Table. IV.

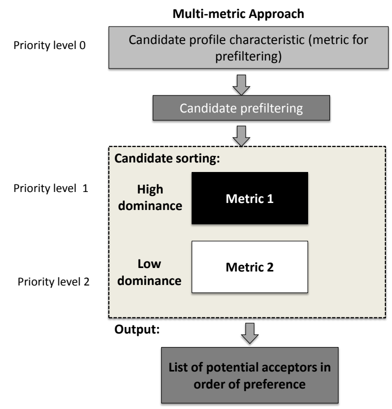

Figure 6. Structure of proposed configurations for HHEA-DBCB.

Dominant Criterion	Advantages:	Disadvantages:
Accumulate Load in few BSs:	High Energy Savings by concentrating traffic in few spots	It can heavily increase congestion in those spots where traffic is concentrated.
Green Energy Utilization:	High Energy Savings with the extra feature of preferring BSs using green sources.	It may create congestion but additionally affects MS throughput by forcing re-associations with far located green BSs
Maximize SINR:	QoS/SINR for Downlink and Uplink are prioritized over pure energy savings	The energy savings are not as high than with the other two criteria.

Table III. Comparison of dominant criteria

Strategy	S1	S2	S3
Candidate profile characteristics (Priority Level 0)	Low & Green Power Consumption	High Normalized Load	Best offered SINR
Metric- Priority Level 1	Offered SINR	Non-renewable power	Normalized Load
Metric- Priority Level 2	Normalized Load	Offered SINR	Non-renewable power

Table IV. Configuration Strategies proposed for HHEA-DBCB

7. SCENARIOS PROPOSED AND ANALYZED RESULTS

7.1. Scenarios proposed

The novel proposal presented in this paper is analyzed throughout simulations. We focus on two representatives scenarios: in the first scenario 10% of the BSs belong to Υ_R, the group of hybrid BSs that use a partial or full supply of renewable energy. For the second scenario, this value increases to 30% of all the BSs. In addition, the two scenarios adopt a different percentage of Macro-BSs using one of the different power models shown previously. For the first scenario, the population of Macro-BSs is shared as shown in Table. V. This scenario represents the case where a larger percentage of Macro-BSs uses legacy technology and just a few correspond to the latest platforms available in 2014 as well as a small percentage of BSs that are able to use hybrid supply systems. The second scenario represents a hypothetical scenario somewhere in the long term future where a new very low consumption BS system has been introduced (i.e."ideal BS model") as well as where the percentage of renewable energy utilization has increased. The scenario descriptions are summarized in Table. V.

Scenario	Population Distribution with each Power Model	Population Percentage of BS using renewable sources
Scenario 1	50% BS enhanced with DTX; 30% SOTA 2010; 20% Market 2014	10% of BSs
Scenario 2	20% SOTA 2010; 50% Market 2014; 30% Idealized Model	30% of BSs

Table V. Macro-BS population distribution for the two scenarios.

The simulations performed consider a Monte-Carlo approach. We consider a regular macrocellular BS deployment using a hexagonal architecture with a second layer of femto-BSs randomly deployed using a uniform distribution. The simulation approach consists of having multiple snapshots with different distributions of MS users randomly located. An evaluation of the behavior of each algorithm for each snapshot is done and finally the results are averaged. The results are calculated for different number of users per Macrocell.

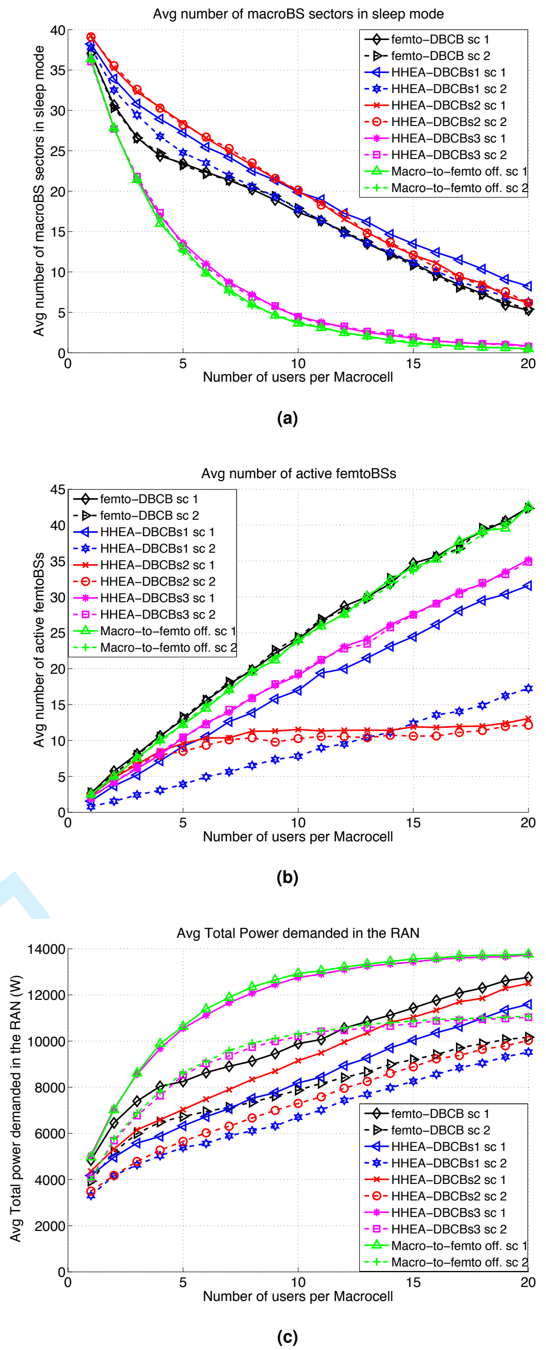

Figure 7. a) Number of switched-off macro-BSs and b) Number of femto-BSs active and c) RAN demanded power for each one of the different algorithms and scenarios analyzed

7.2. Power demand of the different strategies

In Fig. 7 we group a) the number of Macro-BSs deactivated, b) the number of femto-BSs activated and c) the resulting RAN power consumption for each benchmark algorithm with different configurations of our HHEA-DBCB proposals for scenarios 1 and 2.

Firstly in Fig. 7.a we verify that the strategies S1 (Power-SINR-Load) and S2 (Load-Power-SINR) put a higher number of Macro-BSs into sleep mode with respect to benchmark algorithms and also to the strategy S3 (SINR-Load-Power). The reason is that for both S1 and S2, the strategy significantly sacrifices aspects like QoS in return for energy savings, which is not the case for S3 where the approach favours guaranteeing QoS. We also can observe how S1 and S2 show better results than algorithms like femto-DBCB, which combines just macro-to-macro and macro-to-femto offloading features. The advantage of

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HHEA-DBCB is that it makes possible additional femto-to-femto and femto-to-macro offloading, which brings more flexibility and a better way to reorganize the MS-BS associations and resource allocation in terms of the goals defined through the priority sequence. In the specific case of S1 and S2, priority level 0 plays a key role, minimizing non-renewable power consumption per user and concentrating load in high-loaded spots respectively. It can be noticed that S1 is the only approach with two identifiable different curves in Fig 7.a for scenario 1 and 2. This is because S1 has a very high dominance of non-renewable power (priority level 0 for S1), which is affected by the distribution of BS power consumption in the RAN as well as the percentages of renewable energy contribution of each scenario.

On the other hand, in Fig. 7.b we observe the number of femto-BSs active for each approach in each scenario. We see how the figures change for each one of the strategies of HHEA-DBCB in order of their priorities. In the case of S1 we see again changes from one scenario to the other. This is because scenario 1 differs from scenario 2, as a result of introducing the "idealized BS model" into scenario 2 and the increase of the percentage of hybrid powered BSs. This ensures that a good number of offloaded MSs prefer to move from the femtolayer towards the macrolayer, with its good number of low consumption/green Macro-BSs (scenario 2). In the case of S2 the reason for a reduced number of femto-BSs being active is a result of this strategy concentrating the load into any highly loaded femto or Macro-BS, making it possible to offload also many femto-BSs using this approach. Also for S2 we see differences considering the two scenarios, however these are significantly less pronounced compared with S1. This occurs when the dominance of power consumption is put in a second place as in the case of priority level 1 for S2. For S3 and the benchmark algorithms we do not see any fluctuation from one scenario to the other, due to the fact that in all these approaches power is not considered or it has a low dominance in the decision making process as it happens specifically for S3.

The resulting RAN power consumption is presented in Fig. 7.c. In this figure we take into account only the non-renewable consumption. Then, it is evident that the consumption levels in scenario 1 are higher with respect to scenario 2. However, it allows us to notice how the aggressive energy saving oriented approaches of S1 and S2 provide the higher savings when compared with the benchmark algorithm and strategy S3. It can be noticed that in both scenarios strategy S1 presents the lowest RAN power demands. This occurs because of decisions for strategy S1 are clearly dominated by the power consumption levels where the distribution of active BSs and switched off ones is mainly influenced by the lowest non-renewable BS power consumption per user levels.

After the analysis of Fig. 7 we can notice that as the percentage of renewable energy used increases and the breach of power consumption between small cells and the macrocellular layer becomes smaller, the femtocellular technology could become less attractive in terms of pure energy savings for future deployments. As it has been observed by introducing low consumption/green energy equipment in the two scenarios significant reductions in power demand are possible then reducing the dependence on the small cell layer. In some years, as efficiency in components will be further increased it will be possible to deploy relatively low consumption/green energy supplied BSs with high capacity and coverage capabilities in order to consolidate the future 5G framework.

7.3. QoS and energy efficiency trade-off issues

In Figure 8 we group some key performance indicators (KPI) more associated to QoS and Energy-Efficiency. Firstly, in Fig. 8.a and 8.b we observe the average and 5th percentile of the data rate per user. Although, Fig. 8.a gives us an idea of throughput level in the network for each approach, Fig. 8.b provides additional view of MSs with the worst transmission conditions after redistribution. In Fig. 8.a and 8.b we observe that strategy S3 has the best data rates indicators over S1, S2 and the benchmarks due to the high influence of SINR metric. It is interesting that S3 provides even gains on data rate with respect to the macro-to-femto offloading only which also selects acceptors using SINR. The reason is that HHEA-DBCB provides a broad spectrum of decision thanks to the any-to-any offloading, whereas schemes like macro-to-femto have a constrained decision making based on one-way offloading. On the other hand, in Fig. 8.a S1 shows some interesting results. As we considered SINR with priority level 1 for strategy S1 we see how in the first scenario, at some extent, better data rates may be obtained with respect to strategy S2 as the load increases. However, having a high dominance of priority level 0, i.e. the non-renewable power metric, in overall plays significantly against the QoS as S1 chooses low consumption/green BSs with poorer transmission conditions at a greater distance, which is quite noticeable in scenario 2 for both data rate indicators. This latter contrasts with strategy S2 which presents a quite more stable behavior in both scenarios.

The Figures 8.c and 8.d display the resulting ECR, *Energy Consumption Rating* in (J/Mbit) for each technique in each scenario respectively. For calculating the ECR, we take the power demand of the RAN (in Watts) and divide it by the total network throughput in (Mbit/s). For this calculation again we consider just the non-renewable power component. This specific KPI is useful to estimate the brown energy efficiency with respect to the attained throughput. For instance, analyzing results like those from figure 7.c we cannot conclude which approach is more energy-efficient, because measuring only absolute power neglects the degradation of important aspects like QoS. For both scenarios, strategies S1 and S2 present the best ECR values. In scenario 1 we observe that S1 obtains better ECR results because of having a lower RAN power demand and

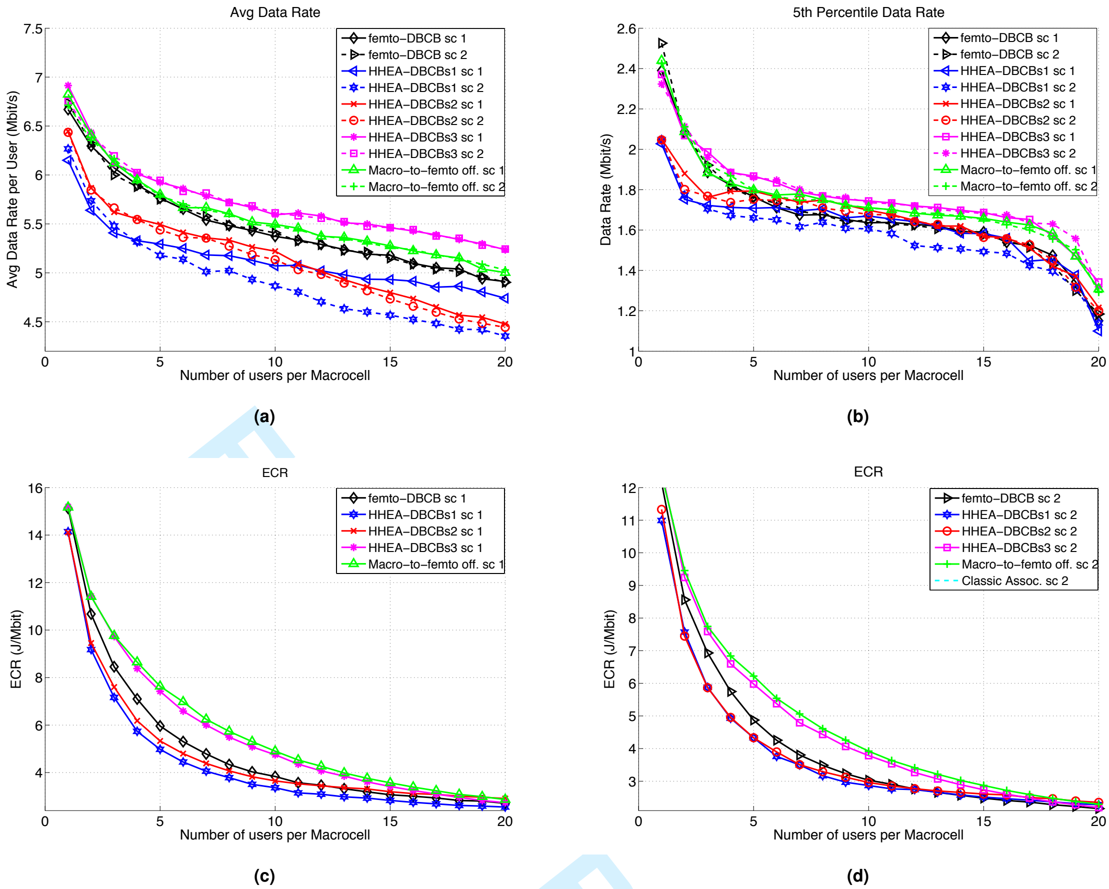

Figure 8. a) Average Data Rate per User b) 5th percentile of Data Rate per user c) Energy Consumption Rating (ECR) [J/Mbit] for scenario 1 and d) ECR for scenario 2, for each one of the algorithms analyzed

at the same time quite similar data rate performance as shown in Fig. 8.a and 8.b. However, we see that due to the degradation of data rate levels for S1 in scenario 2, S1 and S2 present similar ECR values although strategy S2 presents a higher RAN power demand as observed in Fig. 7.c.

7.4. Global observations for the proposed algorithm

After the analysis of these scenarios, we verify that emphasizing the search for BSs with high levels of load and green/low consumption, provides good energy-efficient results although sacrificing to some extent the QoS. Nevertheless the good QoS performance shown by strategy S3 is quite significant. Each strategy appears more useful depending on the characteristics of deployment, the associated strong points and the operator objectives. For instance, in zones where the priority is to handle significant traffic with high QoS demands, priority S3 should be implemented, whereas S1 would be key in zones where green energies can be exploited. In other aspects of the algorithm, we have seen how priority level 0 (pre-filtering) and priority level 1 (High dominant metric for sorting) provide the main approaches to control the behavior of the HHEA-DBCB configuration. Here, one can conclude that the two metrics can be sufficient for decision-making and this could help reducing the computational costs.

8. CONCLUSION

In this paper we have provided a new multimetric technique for BS redistribution/offloading and switching-off schemes for a highly heterogeneous environment. We have seen that by giving a higher priority to the power consumption and the load levels it is possible to redistribute and concentrate the network load into very low consumption and hybrid green BS equipment. However, we have also observed how these types of strategies provide a trade-off to some degree between the energy consumption and the QoS (i.e. Data Rate). In that sense, it is observed how the flexibility of our technique can allow operators to fulfill their performance objectives when different combinations of strategies are considered, and then, policies with more emphasis on capacity and QoS can be also offered.

In addition, we have seen how the proposed strategies have made adapted choices in terms of their respective defined goals, whereas the benchmark algorithms remain rather static before the scenario changes. Also after comparing with the benchmark algorithms we have observed that this technique has a significant advantage, making it possible to achieve any-to-any offloading, where a mobile station can be offloaded to any base station type from any BS of any type. This latter aspect makes this proposal much more flexible at the moment of organizing the MS-BS reassociation and the traffic redistribution, something that allows the amount of active infrastructure to be reduced even further.

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REFERENCES

1. Cisco, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013-2018," 2014.
2. GeSI, "Global e-sustainability initiative: SMART 2020: Enabling the low carbon economy in the information age," 2008.
3. GeSI, "Global e-sustainability initiative: GESI Smarter 2020: The role of ICT in driving a sustainable future," 2012.
4. L. Suarez, L. Nuaymi, and J.-M. Bonnin, "An overview and classification of research approaches in green wireless networks," *EURASIP Journal on Wireless Communications and Networking*, vol. 2012, no. 1, p. 142, 2012. [Online]. Available: http://jwcn.eurasipjournals.com/content/2012/1/142
5. Z. Niu, Y. Wu, J. Gong, and Z. Yang, "Cell zooming for cost-efficient green cellular networks," *Communications Magazine, IEEE*, vol. 48, no. 11, pp. 74–79, 2010.
6. G. Micallef, P. Mogensen, and H.-O. Scheck, "Cell size breathing and possibilities to introduce cell sleep mode," in *Wireless Conference (EW), 2010 European*, 2010, pp. 111–115.
7. L. Suarez, L. Nuaymi, and J.-M. Bonnin, "Analysis of the overall energy savings achieved by green cell-breathing mechanisms," in *Sustainable Internet and ICT for Sustainability (SustainIT), 2012*, 2012, pp. 1–6.
8. L. Chiaraviglio, D. Ciullo, M. Meo, and M. Marsan, "Energy-efficient management of UMTS access networks," in *Teletraffic Congress, 2009. ITC 21 2009. 21st International*, 2009, pp. 1–8.
9. M. Marsan, L. Chiaraviglio, D. Ciullo, and M. Meo, "Optimal Energy Savings in Cellular Access Networks," in *Communications Workshops, 2009. ICC Workshops 2009. IEEE International Conference on*, 2009, pp. 1–5.
10. H. Claussen, L. T. W. Ho, and F. Pivit, "Effects of joint macrocell and residential picocell deployment on the network energy efficiency," in *Personal, Indoor and Mobile Radio Communications, 2008. PIMRC 2008. IEEE 19th International Symposium on*, 2008, pp. 1–6.
11. E. Oh, B. Krishnamachari, X. Liu, and Z. Niu, "Toward dynamic energy-efficient operation of cellular network infrastructure," *Communications Magazine, IEEE*, vol. 49, no. 6, pp. 56–61, 2011.
12. P. Chung, "Green Radio–the case for more efficient cellular base stations, (slides) UK-Taiwan ICT Workshop: Smart & Green Communications, University of Taiwan," 2010.
13. Auer, G. et Al, "How much energy is needed to run a wireless network?" *Wireless Communications, IEEE*, vol. 18, no. 5, pp. 40–49, 2011.
14. Correia, L.M. et Al, "Challenges and enabling technologies for energy aware mobile radio networks," *Communications Magazine, IEEE*, vol. 48, no. 11, pp. 66–72, 2010.
15. Congzheng Han et Al, "Green radio: radio techniques to enable energy-efficient wireless networks," *Communications Magazine, IEEE*, vol. 49, no. 6, pp. 46–54, 2011.
16. Opera-Net, "Optimising power efficiency in mobile radio networks, project stand No. 42, NEM Summit 2010, (Slides) Barcelona, Spain," 2010.
17. P. Frenger, M. Olsson, and E. Eriksson, "Radio network energy performance of massive mimo beamforming systems," in *Proc. PIMRC 2014, Washington D.C., USA*, 2014.
18. G. Micallef, P. Mogensen, and H.-O. Scheck, "Mobile operators have set ambitious targets–is it possible to boost network capacity while reducing its energy consumption?" *EURASIP Journal on Wireless Communications and Networking*, vol. 2012, no. 1, p. 34, 2012. [Online]. Available: http://jwcn.eurasipjournals.com/content/2012/1/34
19. I. Ashraf, L. T. W. Ho, and H. Claussen, "Improving Energy Efficiency of Femtocell Base Stations Via User Activity Detection," in *Wireless Communications and Networking Conference (WCNC), 2010 IEEE*, 2010, pp. 1–5.
20. K. Samdanis, T. Taleb, D. Kutscher, and M. Brunner, "Self organized network management functions for energy efficient cellular urban infrastructures," *MONET*, pp. 119–131, 2012.
21. M. Shakir, K. Qaraqe, H. Tabassum, M.-S. Alouini, E. Serpedin, and M. Imran, "Green heterogeneous

small-cell networks: toward reducing the co2 emissions of mobile communications industry using uplink power adaptation," *Communications Magazine, IEEE*, vol. 51, no. 6, pp. 52–61, June 2013.

22. S. Tombaz, P. Monti, F. Farias, M. Fiorani, L. Wosinska, and J. Zander, "Is backhaul becoming a bottleneck for green wireless access networks?" in *Communications (ICC), 2014 IEEE International Conference on*, June 2014, pp. 4029–4035.
23. F. Pantisano, M. Bennis, W. Saad, M. Debbah, and M. Latva-aho, "On the impact of heterogeneous backhauls on coordinated multipoint transmission in femtocell networks," in *Communications (ICC), 2012 IEEE International Conference on*, June 2012, pp. 5064–5069.
24. M. Marsan, G. Bucalo, A. Di Caro, M. Meo, and Y. Zhang, "Towards zero grid electricity networking: Powering BSs with renewable energy sources," in *Communications Workshops (ICC), 2013 IEEE International Conference on*, June 2013, pp. 596–601.
25. Piro, G. et Al, "Hetnets powered by renewable energy sources: Sustainable next-generation cellular networks," *Internet Computing, IEEE*, vol. 17, no. 1, pp. 32–39, Jan 2013.
26. GSMA Green Power for Mobile, "Green power deployment tracker," http://www.gsma.com/mobilefordevelopment/programmes/green-power-for-mobile/tracker.
27. Integra-LLC, "Green alternatives to diesel powered mobile base stations," http://www.integrallc.com/2014/03/18/green-alternatives-to-diesel-mobile-base-stations/.
28. ICT-EARTH, "INFSO-ICT-247733 EARTH: Energy efficiency analysis of the reference systems, areas of improvements and target breakdown," 2010.
29. H. Holtkamp, G. Auer, and H. Haas, "On Minimizing Base Station Power Consumption," in *Vehicular Technology Conference (VTC Fall), 2011 IEEE*, 2011, pp. 1–5.
30. C. Peng, S.-B. Lee, S. Lu, and H. Luo, "GreenBSN: Enabling Energy-Proportional Cellular Base Station Networks," *Mobile Computing, IEEE Transactions on*, vol. 13, no. 11, pp. 2537–2551, Nov 2014.
31. 3GPP, "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; 3GPP TR 36.814-900, Evolved Universal Terrestrial Radio Access (E-UTRA): Further advancements for EUTRA physical layer aspects (Release 9)," 2010.
32. Auer, G. et Al, "Cellular Energy Efficiency Evaluation Framework," in *(VTC Spring), 2011 IEEE 73rd*, 2011, pp. 1–6.
33. Frenger, P. et Al, "Reducing Energy Consumption in LTE with Cell DTX," in *Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd*, 2011, pp. 1–5.
34. M. Hossain, K. Munasinghe, and A. Jamalipour, "An eco-inspired energy efficient access network architecture for next generation cellular systems," in *Wireless Communications and Networking Conference (WCNC), 2011 IEEE*, 2011, pp. 992–997.
35. 3GPP, "LTE; Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 Application Protocol (X2AP), TS 36.423 R 11," 2014.
36. L. Haratcherev, C. Balageas, and M. Fiorito, "Low consumption home femto base stations," in *proc. PIMRC 2009*.
37. Conte, A. et Al, "Cell wilting and blossoming for energy efficiency," *Wireless Communications, IEEE*, vol. 18, no. 5, pp. 50–57, 2011.
38. Vereecken, W et Al, "The effect of variable wake up time on the utilization of sleep modes in femtocell mobile access networks," in *Proc. WONS 2012*.
39. L. Suarez, L. Nuaymi, and J. Bonnin, "Energy-efficient bs switching-off and cell topology management for macro/femto environments," in *Elsevier Computer Networks Special Issue Green Communications*, 2015.
40. Suarez, L., et Al, "Analysis of a green cell breathing technique in a hybrid network environment," in *Proc. Wireless Days 2013, Valencia, Spain*, 2013.
41. H. Nabuuma, E. Alsusa, and W. Pramudito, "A load-aware base station switch-off technique for enhanced energy efficiency and relatively identical outage probability," in *Vehicular Technology Conference (VTC Spring), 2015 IEEE 81st*, May 2015, pp. 1–5.
42. F. Alaca, A. Sediq, and H. Yanikomeroglu, "A genetic algorithm based cell switch-off scheme for energy saving in dense cell deployments," in *Globecom Workshops (GC Wkshps), 2012 IEEE*, 2012, pp. 63–68.
43. D. Davarpanah, M. Zamani, M. Eslami, and T. Niknam, "Joint successive base station switch off and user subcarrier allocation optimization for green multicarrier based cellular networks," in *Electrical Engineering (ICEE), 2015 23rd Iranian Conference on*, May 2015, pp. 504–507.
44. L. Suarez, L. Nuaymi, C. Person, and J.-M. Bonnin, "Impact of energy-efficient cell-breathing on the electromagnetic radiation levels of mobile phone devices," in *Personal, Indoor, and Mobile Radio Communication (PIMRC), 2014 IEEE 25th Annual International Symposium on*, Sept 2014, pp. 1926–1930.
45. I. Aydin, H. Yanikomeroglu, and U. Aygolu, "User-aware cell switch-off algorithms," in *Wireless Communications and Mobile Computing Conference (IWCMC), 2015 International*, Aug 2015, pp. 1236–1241.

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