Energy Savings in 3G Using Dynamic Spectrum Access and Base Station Sleep Modes

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Abstract - The energy consumption and energy efficiency of mobile telecommunication networks are crucial factors for the sustainability of this industry. This paper targets the reduction of the energy consumption at a Base Station level through the adoption of sleep modes during the off-peak periods of the day and relying in the existence of co-located and overlaid frequency bands to provide the coverage and capacity backup for the switched-off cells. Using this method it was possible to achieve power savings of about 43% corresponding to a reduction of over 600 € in energy costs per-site.

Keywords—Green Communications, Energy Savings, cognitive multi-band operation, coverage compensation

I. INTRODUCTION

Several studies reveal that Information and Communications Technology (ICT) systems are responsible for up to 10% of the world energy consumption [1], and within this the mobile networks are relevant consumers. It is estimated that in 2008 there were 60 billion kWh of electricity spent by this industry, about 40 million metric tons of CO\textsubscript{2} emissions [2].

In this context, the Energy Saving (ES) mechanisms have drawn a lot of attention from the operators since they provide a valuable tool to make this industry more competitive by cutting the energy expenses and, at the same time, enabling the mobile corporations to develop a sustainable attitude. The emerging trend of addressing energy-efficiency amongst the network operators has stimulated the interest of researchers in an innovative new research area called “green cellular networks”.

However, in mobile networks, there is a subsystem that stands out in terms of energy consumption share within the whole network which are the BS. These devices are responsible for up to 60 – 80 % of the energy consumption [2] and that makes them outstanding candidates for energy saving purposes. In addition, as the traffic is unevenly distributed during the day there are periods where the BSs operate at low load. Unfortunately, the energy efficiency of BSs is particularly poor in this condition [3].

A. Objectives

This work aims to set a strategy for implementing a load adaptive strategy through the switch off (or sleep mode) of radio equipment at periods of low traffic load. At the same time it opportunistically reallocates users to a lower frequency band, assuming that the operator has network equipment operating in several ones at the same location. This process is called Dynamic Spectrum Access (DSA) [4].

This paper focus specifically on the Third Generation of Mobile Telecommunications Technology (3G) system where many operators worldwide operate on two separate frequency bands, the 900/2100 MHz essentially in Europe, Asia and Africa and the 850/1900 MHz in the Americas. From simple path loss propagation it is shown that the lower band has 7 dB of gain thus requiring less transmitted power to serve the same user. This enables the switch off of the higher band Power Amplifier (PA) and baseband processing equipment after reallocating the users to the lower frequency band during the off-peak periods. The study used real traffic statistics from a Portuguese mobile operator and obtained an energy saving of around 43 %.

B. Related Work

In the scope of energy efficiency in mobile networks, extensive work is ongoing in industry and academia on understanding and evaluating the power consumption in mobile communications. The work developed in [5, 6, 7] studies and parameterizes the power consumption for several types of BSs. Developments such as [8, 9, 10] analyze different types of BS sleep modes including coverage compensation. Several research projects about the energy reduction and efficiency have been developed in the past few year including the ICT-EARTH project, ICTSACRA, ICT-C2POWER, the UK’s Mobile VCE Core 5 Green Radio and the Communicate Green research programs. As for the specific subject of DSA, the papers [11, 12] presents ways of opportunistic user reallocation between different frequency bands of the same operator in a generic form. In the present work the analysis is furthered to the 3G Wide-Band Code-Division Multiple Access (WCMDA) system of a Portuguese mobile operator.

C. Document Structure

This article is structured as follows: Section II covers the first stage of the algorithm that includes the input loading and load balance decision, Section III covers the second step of the algorithm which includes the power savings calculation and energy cost estimation. Section IV presents a critic overview on the obtained results while Section V summarizes the main conclusions from this study and gives some pointers regarding future work.
II. ALGORITHM STEP I – PATTERN ANALYSIS

The motivation behind this first stage of the algorithm is to define the periods of the day that will be the candidates for the ES mechanisms. These correspond to the low-load periods of the day. Since the input traffic is highly volatile it is required to set a base model and afterwards use it as the framework for the ES switch breakpoints definition. As inputs, traffic statistics, site mapping, Key Performance Indicators (KPI) and baseband pool statistics from selected BS were provided by a Portuguese mobile telecommunication company and this information was the basis for all of the work. These stats are from a total of 28 sites located in three different types of zones: Urban, Sub-urban and Rural. The algorithm’s output are the ES configuration parameters for each site, namely the ON/OFF switch hour. Fig.1 presents a flowchart with an overview of this stage.

A. Traffic Inputs and Daily Model Building

This stage comprehends the analysis on the traffic pattern trends for both speech and data services using the gathered information from the mobile operator. The motivation behind this stage is to build the Daily Traffic Models that will be one of the required inputs for the switch-off decision making. The daily profile fluctuations for the speech case in the considered operator are presented in the normalized form in Fig.2 for all considered sites in all regions. There is a period of low-load roughly from the midnight until 9:00 h, a high-load period from about 9:00 h until 20:00 h which correspond approximately to the business hours and finally a medium traffic-load period from nearly 20:00 h until 0:00 h.

Fig. 2 Normalized daily speech traffic by the type of day.

After importing the traffic inputs, the algorithm creates a daily pattern model by fitting a Trapezoidal function as in [13] to the real traffic measurements from both overlaid band layers creating a model for each day. Also, as in [13], in order to obtain an easier way to model traffic shape, all samples in a day were shifted 5 hours. This procedure enables an easier fitting by the two models since it centers the peak-hours in the daily plot (Equation 1).

\[ t_{\text{sh}}[t] (1) = \begin{cases} t[t] - 5 + 24, & 0 \leq t[t] < 5 \\ t[t] - 5, & 5 \leq t[t] < 24 \end{cases} \]

(1)

The trapezoidal model is modeled by the Equation 2 where \( c_{\text{lb}} \) is the shape’s lower bound, \( c_{\text{ub}} \) the upper one, \( a \) determines the trapezoid’s slope, \( e \) is the shifting parameter while \( \Delta_p \) defines the peak-period duration.

\[ f_{\text{trap}}(t) = \left( c_{\text{lb}} + c_{\text{ub}} \cdot (1 + e^{a(t-b)})^{-1} \right) - c_{\text{ub}} \cdot (1 + e^{a(t-\Delta_p-b)})^{-1} \]

(2)

By analyzing the traffic pattern the algorithm fits the traffic pattern with this shape adjusting iteratively the parameters and shrinking/expanding the shape in order to achieve a model that contains 90% of the traffic sampled values inside its area. This step is illustrated in Fig.4 and is repeated for each available day, sector and site.

Fig. 3 Average data traffic in considered sites.

Fig. 4 Traffic measurements vs. trapezoidal fitting model.
B. Site Capacity Dimensioning

There are several factors that may limit the capacity of a cell in 3G in terms of data and speech traffic. In order to determine the maximum capacity there are a few parameters that should be taken into account. In the present case, we want to figure out the maximum allowed capacity in the lower frequency band in order to evaluate if there is enough room to fit here the traffic generated in the higher frequency band carriers, during the low-load periods of the day and prioritizing the speech traffic.

In WCDMA networks there are four main aspects which may restrain the maximum capacity in a cell. These are the Uplink Interference, the Downlink (DL) power, the availability of DL channel code resources and the Channel Elements (CE) which constitute the basic baseband resource. From all of these it has been found that the CE resource availability in the Uplink (UL) baseband pool is commonly the most restraining factor and therefore will be used for cell capacity dimensioning purposes.

The output that is provided to the Decision block of the algorithm contains the dimensioning parameters, including the maximum allowed traffic for both data and the speech traffic.

C. Operator Policies

It is possible to define a set of parameters that will influence the ES operation mode, i.e., exclusion zones in which the system is forced to operate in a dual band mode even if the pattern model identified that day or time-period as ES eligible. It is also possible to define the minimum amount of time in which is worth to activate the saving mechanism and therefore to prevent short sleep modes and ping-pong effect. This mechanism of policy definition can be useful for occasional and predictable situations, e.g., special events. In the simulations it was also set an exclusion zone for the time period of the day where the most of the traffic is concentrated to avoid Quality of service (QoS) degradation (11h to 21h).

D. Decision Block

This step includes all the required procedures to determine if and when the ES mechanism should be active or not. By analyzing the daily model it determines the best moment to perform the higher frequency band switch-off in order to achieve the best energy efficiency possible. The other inputs are the CE dimensioning for the current site and the operator policies settings. Fig.5 represents a simplified overview of this process from the traffic data interpretation to the ES breakpoints set.

The parameters \( t_{\text{ES,OFF}} \) and \( t_{\text{ES,ON}} \) identify the de-activation and activation time of the mechanism while the \( T_{\text{MAX,ES}} \) corresponds to the maximum allowed load while in the energy saving mode and it is the input imported from the Site Capacity Dimensioning stage. In this stage the algorithm decides whether a sector is an ES candidate and if this condition is true it sets the trigger breakpoints \( t_{\text{ES,OFF}} \) and \( t_{\text{ES,ON}} \).

III. ALGORITHM STEP II - POWER CONSUMPTION ESTIMATION

The flowchart of the second stage of the algorithm is represented in Fig.6. This step of the algorithm identifies the transmitted power as a function of the traffic for each site and quantifies the savings of the whole ES process.

A. Traffic to Power Model

In this stage it is defined a correspondence between the transmitted power and the actual network traffic at a certain moment. There is a share of this power that is load dependent and another share that is transmitted continuously even when there is no load. This last share corresponds to the pilots signals broadcast, like the CPICH among other signaling channels. In Fig.7 it is represented a typical traffic vs. load function. The function generated will be used to quantify the transmitted power for a given traffic load and it is in the form of \( P(T_{\text{ERL}}) = a + b \cdot \log(T_{\text{ERL}}) \) where \( a \) is the load independent share and \( b \) is the traffic versus load weighting factor.

![Energy saving ON/OFF switch breakpoints definition stage.](image)

![Typical transmitted power model of a UMTS 900 site.](image)
B. Base Station Power Consumption

To evaluate the ES potential of the developed algorithm it is necessary to apply a BS power model assessing the power consumption of the different components. Using a guideline from the hardware vendor [14] it is possible to estimate the BS consumed power \( P_{BS} \) which includes the \( P_{BB} \) baseband processing hardware power, \( P_{RF} \) PA radio frequency small-signal transceiver power and the \( P_{PA} \) the PA power consumption power, according to Equation 3. The RF load \( Q_{RF} \) consists in the current transmitted carrier power divided by the maximum transmission power imposed by the power amplifier and the baseband processing power dependence on this parameter is negligible. This RF load estimation is calculated using the traffic to power model defined for each site expressed in Watt:

\[
P_{BS} (Q_{RF}) = P_{RF} (Q_{RF}) + P_{PA} (Q_{RF}) + P_{BB}
\]  
(3)

Considering \( N_{sec} \) per-site and the loss factors for the Direct Current (DC) converter \( \sigma_{DC} \), the main supply \( \sigma_{MS} \), and the active cooling \( \sigma_{cool} \), one can refer to the Equation 4 for the calculation of the site supplied power in Watt. It were used the typical values defined in [6] for the loss factors of the macro cell-sites

\[
P_{supply} (Q_{RF}) = \frac{N_{sec} \sum_{i=1}^{N_{sec}} P_{BS,i}(Q_{RF})}{(1-\sigma_{DC})(1-\sigma_{MS})(1-\sigma_{cool})}
\]

(4)

C. Gain Evaluation and Economical Analysis

In this step the comparisons about the power consumption with and without using the ES feature are made. The gains are evaluated and the correspondent energy cost is calculated assessing the effectiveness of the proposed algorithm. Besides this information, these output files contain also all the defined ES parameters like the ON/OFF switch hour for each day in a sector of a site, the speech and data traffic volume, the data service delay and the transmitted power.

IV. Results and Assessments

This section presents an overview on the output results from the simulator like the average ES switch breakpoints, power consumption comparison and the achievable energy expense savings.

A. Average ES Duration

As for the average ES duration period, the obtained results were close to the 14 h maximum which corresponds to the full ES operation during the allowed period by the network policies. The ES period average duration was 13h 51m for the urban case, 13h 48m for the sub-urban one and 14h for the rural one. The results are consistent with the traffic volume in each of these situations.

B. Quality of Service

In the CE dimensioning stage it was defined a maximum allowed capacity for each kind of service. Bellow it is presented the comparison between the maximum admissible load and the one which was effectively offered to the network during the ES-active time period in each situation.

1) Speech

For the speech services it was considered a Grade of Service (GoS) of 2% and the number of users was calculated from the provided data logs by the operator and as one can verify from the Table I that there are no capacity issues for the speech case.

<table>
<thead>
<tr>
<th>Site Location</th>
<th>Max Dimensioned</th>
<th>Actual Traffic</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N users</td>
<td>Average</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td>Urban</td>
<td>41</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Sub-urban</td>
<td>35</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Rural</td>
<td>24</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

2) Data

The bandwidth usage ratio is below the 50 % for the first two presented cases. As for the rural situation the usage ratio is slightly higher. Globally, in only 3.22 % of the total considered time period it was registered a delay delivering the data traffic when ES is used.

<table>
<thead>
<tr>
<th>Site Location</th>
<th>Bandwidth Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>22.6 %</td>
</tr>
<tr>
<td>Sub-urban</td>
<td>48.6 %</td>
</tr>
<tr>
<td>Rural</td>
<td>64.2 %</td>
</tr>
</tbody>
</table>

The usage ratio is higher in the data situation since a higher priority was intentionally given to the speech then to this type of traffic in the dimensioning stage.

C. Predicted Power Consumption

Table III indicates the power consumption of a cell site with a 3G dual band system, including a BS for each of the bands which is the typical type of deployment. The power consumption estimation was performed using the previously referred model for the situation when the ES mechanism is enabled and disabled for each type of location. In all situations the energy savings are over 40 %

<table>
<thead>
<tr>
<th>Site Location</th>
<th>P_{supply} (W)</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without ES</td>
<td>With ES</td>
</tr>
<tr>
<td>Urban</td>
<td>1510.23</td>
<td>864.63</td>
</tr>
<tr>
<td>Sub-urban</td>
<td>1508.26</td>
<td>852.17</td>
</tr>
<tr>
<td>Rural</td>
<td>1505.00</td>
<td>848.79</td>
</tr>
<tr>
<td>Global Average</td>
<td>1507.83</td>
<td>855.20</td>
</tr>
</tbody>
</table>
D. Economical Overview

In this section the energy consumption is translated into the most important factor of a mobile operator: the actual cost.

For any of the further calculations it was used the reference electricity price per kWh in Portugal in 2013 for industrial consumers which according to [15] is 0.1488 €/kWh. Table IV presents the annual cost of a BS with the previously described configuration.

<table>
<thead>
<tr>
<th>Site Location</th>
<th>Without ES</th>
<th>With ES</th>
<th>Savings (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>1,489.81 €</td>
<td>8531.8 €</td>
<td>636.62 €</td>
</tr>
<tr>
<td>Sub-urban</td>
<td>1,487.51 €</td>
<td>840.74 €</td>
<td>647.66 €</td>
</tr>
<tr>
<td>Rural</td>
<td>1,484.52 €</td>
<td>837.45 €</td>
<td>647.06 €</td>
</tr>
</tbody>
</table>

Finally, an analysis of the possible savings is drawn using as a framework a Portuguese mobile operator deployment. As a gross estimate this operator owns 2000 macro cell sites with band co-location among its network. Given the kind of demographic distribution in this country one can consider that these cell sites are distributed in the following way: 45 % in the urban areas, 35 % in the suburban and 20 % in the rural areas. Table V presents an estimate on the total possible expenditure savings achievable using the proposed method.

<table>
<thead>
<tr>
<th>Site Location</th>
<th>Distribution</th>
<th>BS number</th>
<th>Savings (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>45 %</td>
<td>900</td>
<td>572,966 €</td>
</tr>
<tr>
<td>Sub-urban</td>
<td>35 %</td>
<td>700</td>
<td>452,736 €</td>
</tr>
<tr>
<td>Rural</td>
<td>20 %</td>
<td>400</td>
<td>258,827 €</td>
</tr>
<tr>
<td>Total</td>
<td>100 %</td>
<td>2000</td>
<td>1,284,530 €</td>
</tr>
</tbody>
</table>

V. CONCLUSIONS

In the considered scenario the use of ES solutions allowed savings of more than 1.25 million euros each year only in 3G deployments with dual-band by using DSA. In actual deployments, operators tend to install co-located multi-technology equipment allowing the DSA to be a valuable strategy to provide coverage and capacity when using ES mechanisms to put the higher frequency bands into sleep mode. Considering this multi-technology environment combined with a smart user band re-selection mechanism, much higher savings would be achieved.

One of the biggest challenges is definitely the preservation of the user perceived quality while the system is in ES mode. The proposed method uses an iterative algorithm to identify and create daily patterns and this strategy may not be always reliable especially in days with abnormal traffic profiles, e.g. peak-load situations during the night. It also prioritizes the speech traffic on behalf of the data traffic which may not be the most suited strategy for particular types of cell sites with an intensive use of the data services. For this case a dynamic resource allocation with tunable parameters in the cell dimensioning stage could be used in order to set each cell peculiarities. However the paper paves the road for new improvements in terms of traffic pattern identification and eventually traffic forecasting. This way, by having a complete picture of each site traffic profile trends it is possible to develop a self-learning algorithm that can identify and predict the future patterns and take advantage of the off-peak periods to achieve considerable energy savings.

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