Cooperative Base Stations for Green Cellular Networks

Choungmo Fofack Nicaise Eric
nicaiseeric@gmail.com
Master UBINET

February 24, 2010

Abstract

In this paper we make a survey of some models that have been proposed to tackle the problem of cellular networks power consumption. We show the relevant aspects of each model, in order to characterize the parameters that we should take in account to achieve an efficient energy saving.

1 Introduction

According to [1] "wireless communications are expected to be a major worldwide cause of energy consumption within few years, with a high impact on carbon dioxide emissions.". This is not really surprising when we take a general view of cellular networks. For instance, cellular networks are quite ubiquitous today, we can use our mobile almost every time and everywhere, that means the infrastructure deployed to provide this service is always turned on, in fact most of the time. We can easily understand why [1] shows that the real cost of networks is not anymore the capital expenditures (CAPEX, cost to deploy or install the network) but the operational expenditures (OPEX, cost to maintain the availability of the services) due to the base stations maintenance. In section 2, we report on the models proposed by different researchers to build a green network by cooperation at the base stations level. In section 3, we go one step further to show that the cooperation at network level can improve energy savings. Then section 4 presents some techniques to enforce an energy efficient network. At the end, section 5 summarizes and concludes the survey.

2 Energy savings by cooperation at the base stations level

In this section, the models presented show how to reduce the power consumption with respect to two main constraints: (i) the minimum coverage and (ii) the minimum required quality of service. With respect to the previous constraints, each model provides different outcomes by applying the cooperation between the the base stations of an operator's network.

2.1 Power saving-oriented network and capacity planning model

The model in [1] is an easy and a simple analytical model that provides the degree of redundancy of a network to achieve a given energy saving. The authors, V. Mancuso and S. Alouf, propose to minimize the allowable and activable number of base stations with respect to (i) and (ii); that leads to the increase of the potential energy saving.

Assumptions: the operational consumption of a base station does not appreciably change with the traffic, for a given capacity. The operational cost basically consists of two parts: a fixed part, C_F, which is incurred just by turning on the site and a second part, C_C, related to the capacity used at the base station. This cost is described by the following equation:

$$C_{tot}^{ps}(t) = C_F R_B(t) + C_C \sum_{i=1}^{R_B(t)} \gamma^{(i)}(t), \tag{1}$$

where $\gamma^{(i)}(t)$ denotes the capacity of the i-th active base station at time t, and $R_B(t) \leq N_B$ is the number of active base stations, at time t, out of the total number of N_B base stations deployed within the network. C_{tot}^{ps} changes over time and is upper bounded by the cost with no power saving.

Methodology: the constraint (i) defines the minimum number of base stations to cover all the area, and according to (ii), the active base stations should hold the QoS requirements and guarantee a full coverage. So the number $R_B(t)$ has a lower bound which depends on the traffic offered at a given time t, and the minimum number of base station in the covered area A. This lower bound is given by the following equation:

$$R_B(t) \geq R_B^{min}(t) = \max\left\{ \left\lceil \frac{A}{A_C} \right\rceil, \min\left\{ \lceil \rho(t) \rceil, \lceil \rho_{max} \rceil \right\} \right\}. \tag{2}$$

According to (2) the choice of R_B represents a limitation on the power that can be saved by turning off some base stations completely, and the choice of N_B represents the degree of the network coverage.

Results: this model has a huge impact on cell planning, it gives the minimum level of coverage redundancy, i.e, $N_B = N_B^{min}$ if we want to achieve a targeted power savings S. Then following equation evaluates this power saving which is the difference between the total cost of network with all deployed base stations working at full capacity, and the cost of the optimized network running with $R_B(t)$ active base stations:

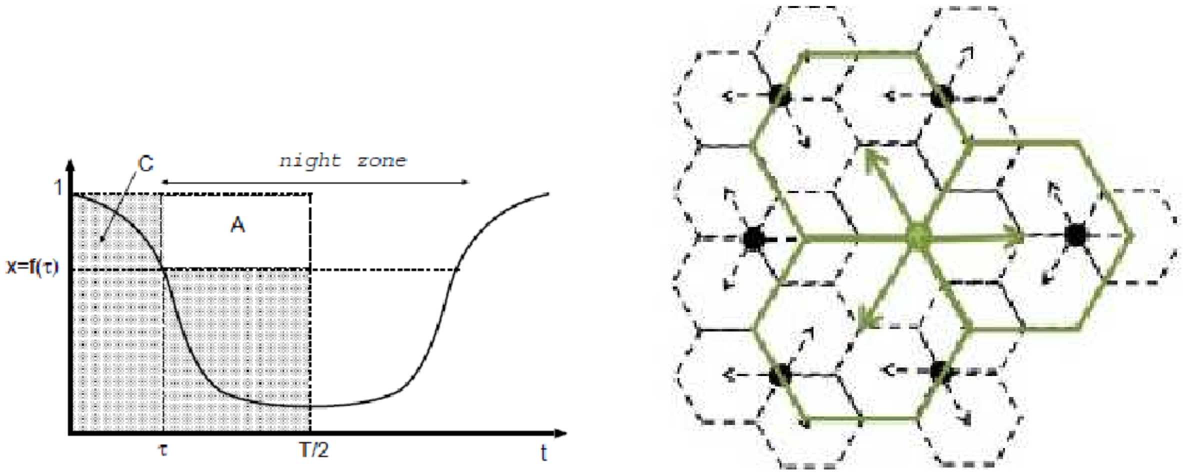
$$S = C_F \left(N_B^{min} - \overline{R_B} \right) + C_C \left(N_B^{min} - \overline{\rho} \right), \tag{3}$$

where $\overline{R_B}$ and $\overline{\rho}$ are the averages over time and probability of $R_B(t)$ and $\rho(t)$, respectively. It is obvious to see that S increases with N_B , so this model concludes that: the availability of a dense and redundant network coverage is a necessary condition for energy efficiency consumption in a cellular network.

2.2 Traffic pattern and network topology model

The model in [2] proposes another view of the problem. As the network's operators already exist, we can compute the potential energy saving but we do not know when to turn off a base station and how to enforce the cooperation of base stations in the network. Hence the authors propose to switch off a base station during a period of time according to its traffic's variation and the topology of the network [2]. For this model, the main idea is to reduce the number of active cells in the access network during the period the normalized traffic $f(t)$ $(0 \leq f(t) \leq 1)$ in the network is low. This model is based on traffic estimation and people behaviors. For example one may turn off some base stations in residential areas during the day because people are moving in general to the town centers, and in offices areas during the night.

Assumptions: the traffic pattern is given or could be measured like in metropolitan areas where we can both reach the peak and the minimum of traffic. The initial network dimensioning is driven by this traffic pattern as shown in Fig. 1(a). We have a large number of small cells, i.e, a dense network topology.



(a) *Traffic pattern*   (b) *Network topology*

Figure 1: In sub-figure (a), we give a simple symmetric curve around $T/2$, that describes the load of the network during a period T. Sub-figure (b) represents a hexagonal three-sectorial network and shows how dense the initial network should be if we target a good power saving.

Note that it has been concluded by the previous model that the redundancy is a required feature of the network.

Methodology: During the “night zone”, the minimum coverage and QoS are handled by a fraction x of active base stations, and the remaining $1-x$ fraction is switched off. Let us call Sc this scenario. Therefore, the new traffic $f^{(Sc)}(t)$ received by the active base stations is equal to their own traffic, plus the handover traffic. The total consumption $C(\tau)$ can be easily written as a sum of the consumption during the “day” (the time intervals $[O,\tau]$ and $[T-\tau,T]$, when $x=1$) and the consumption in the “night zone” (the time interval $[\tau,T-\tau]$, when $x=f(\tau)=f(T-\tau)$). Hence, we have the following equations:

$$f^{(Sc)}(t) = f(t) + \frac{1-x}{x} f(t) = \frac{1}{x} f(t), \tag{4}$$

$$C(\tau) = 2\left[W\tau + Wf(\tau)\left(\frac{T}{2}-\tau\right)\right], \tag{5}$$

where W denotes the power consumption per cell. So the power saving per cell, Net_{Saving}, is a function of the time, the total consumption of a cell, and the value of the current traffic, as shown in the following formula:

$$Net_{Saving} = 1 - \frac{C(\tau)}{WT}. \tag{6}$$

Then, the aim is to find the optimal value τ_m of τ that maximizes the Net_{Saving}, this corresponds to minimizing the total consumption of a cell $C(\tau)$. By derivation of $C(\tau)$, we attain an equation that τ_m verifies:

$$f(\tau_m) - f'(\tau_m)\left(\frac{T}{2}-\tau_m\right) - 1 = 0. \tag{7}$$

At the end, the base stations are not turned off randomly but with respect to the initial topology. In Fig. 1(b) for example, three bases stations out of four are switched off and the remaining base station increases its transmitting power.

Results: The power consuming function does not depend on topology, hence regardless of a specific configuration of the network, there is room for considerable energy saving by adopting some simple power-off scheme. Moreover the simulations performed with a real measured traffic pattern of an Italian broadband service provider, show that one can save from 25% to 30% of the total consumption [2].

2.3 Area power consumption model

Since density is a network property that enhances the coverage and the QoS, we need a mean to compare the power consumption of different networks having different size. The paper [3] proposes a new metric based on power consumption of the base stations and regardless of the size of the network. One can change the topology and the density of a network in order to achieve a good coverage, an area spectral efficiency and, of course, the best energy saving with respect to the same value of this new metric. The paper investigates the impact of deployment strategies on the power consumption of mobile radio network. Improved deployment strategies lower the number of sites required in the network to fulfill performance metrics such as coverage and area spectral efficiency. Since increasing inter-site distance D generates larger coverage areas, this paper introduces the concept of area power consumption as a metric rather than using the common power consumption per site metric to compare networks differing by their site density, and therefore to assess the power consumption of the network relative to its size. The aim is to quantify the energy savings through deployment of micro sites alongside conventional macro sites.

Assumptions: the traffic density is uniformly distributed over the Euclidean plane. With respect to energy needs, the paper states that network topologies featuring high density deployments of small, low power base stations yield strong improvements compared to low density deployments of few high power base stations.

Methodology: The network's layouts consist of a varying numbers of micro base station per cell in addition to the conventional macro sites. For both base station types, their power consumption depends on the size of the covered area as well as the degree of coverage required. For example, in urban areas cell radii usually range from about 500 m to 2500 m with coverage of more than 90%. The authors use a simple linear model to link the power consumption of a site s to the average radiated power: $P_s = a_s P_{tx} + b_s$, where P_s denotes the average consumed power per site ($P_s = P_{ma}$ if it is a macro site and $P_s = P_{mi}$ if it is a micro site) and P_{tx} the radiated power per site. The coefficient a_s (a_{ma} or a_{mi}) accounts for the power consumption that scales with the average radiated power due to amplifier and feeder losses as well as cooling of sites. The term b_s (b_{ma} or b_{mi}) denotes power offsets which are consumed independently of the average transmit power. The power consumption of macro sites is virtually independent of traffic load. In contrast, the ability to scale their power consumption with the current activity level is considered one major benefit of micro sites. Consequently, the parameters a_s and b_s should depend on the traffic load. We use three metrics:
- the cell coverage (defined as the fraction of cell area where the received power is above a certain level P_{min})

$$C = \frac{1}{A_C} \int_{A_C} r \; Prob\left(P_{rx}(r) \geq P_{min}\right) \; dr \; d\phi, \tag{8}$$

where P_{rx} is the received power at a distance r from the site. Given the minimum received power P_{min}, we compute the power P_{tx} that should be transmitted: $P_{tx} = \frac{P_{min}}{K} \left(\frac{C}{3}\right)^{\frac{\lambda}{2}} D^{\lambda}$. We recall that D is the inter site distance, λ is the path loss exponent.

- the area spectral efficiency, defined as the mean of the overall spectral efficiency in the reference cell

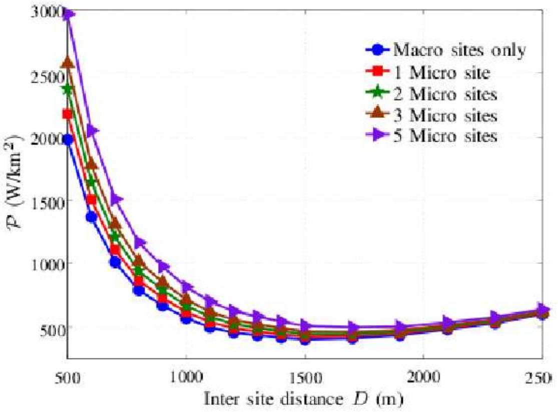


Figure 2: Area power consumption as function of inter site distance for different deployments with $C = 95\%$, $a_{ma} = 22.6$ and $b_{ma} = 412.4\ W$, $a_{mi} = 5.5$ and $b_{mi} = 32.0\ W$.

divided by the cell size and commonly measured in bit per second per Hertz per square kilometer.

- the area power consumption defined as the average power consumed in a cell divided by the corresponding average cell area:

$$P = \frac{P_C}{A_C}. \tag{9}$$

In eq. (9), $A_C = \frac{\sqrt{3}}{2}D^2$ and the power consumption per cell P_C is computed by adding the power of the macro site P_{ma} to the average power NP_{mi} of N micro sites located in the same cell, i.e., $P_C = P_{ma} + NP_{mi}$. The area power consumption is measured in Watts per square kilometer. Then the area power consumption P is a density of power per area (power consumption per cell over the cell area).

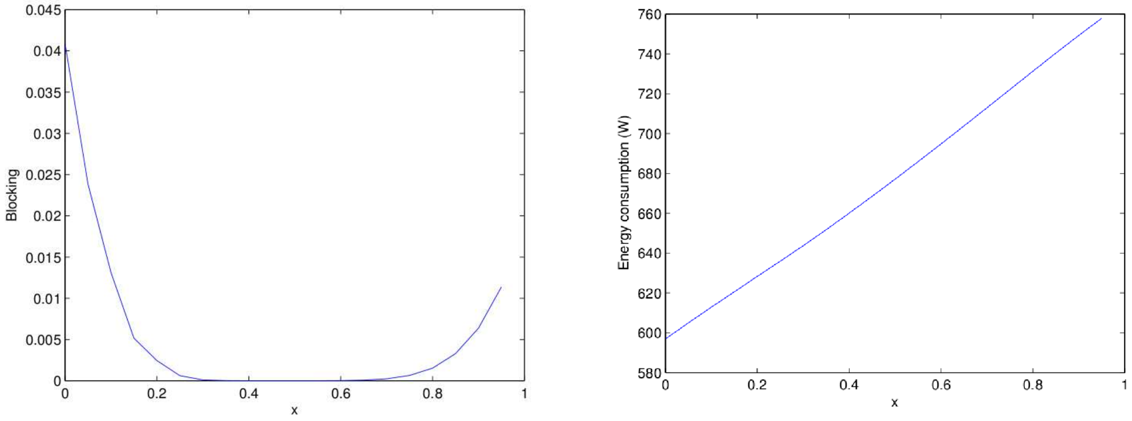
Results: For $\lambda = 2$, P is not affected by the site distance D since the P_C and A_C increase with D^2. For $\lambda > 2$, there exists a positive site distance D^* which minimizes the area power consumption of the network as the Fig. 2 shows.
The deployment of micro sites allows to significantly decrease the area power consumption in the network while still achieving certain area throughput targets, and this deployment strongly depends on the offset power consumption of both macro and micro sites.

3 Energy savings by cooperation at the network level

In this section, we will introduce the notion of “sleep mode”. We will not introduce it at the base station level, but at the system level (a cooperation between an operator’s systems, a 2G/3G network for example), and further at the network level(a cooperation among operators). Many researchers have investigated the impact of these approaches on the total energy savings [4] [5].

3.1 System selection within an operator’s network

The model in [4] tackles the power saving problem from the radio resource management perspective. The authors develop a system selection algorithm for heterogeneous networks like 2G/3G networks. In



(a) *Blocking rate*

(b) *Energy consumption*

Figure 3: the blocking rate and the energy consumption for different selection policies (offered traffic: 15 Erlang).

fact, the traffic is spilt between the two systems in an optimal way so that the energy consumption is minimized subject to a Quality of Service constraint.
Methodology: the model considers a traffic of λ Erlang by cell. For this traffic, a proportion x of calls is accepted in 2G/GSM and the remaining users are allocated to 3G/UMTS. The offered traffic is then $\lambda_{2G}(x) = x\lambda$ and $\lambda_{3G}(x) = (1-x)\lambda$, for GSM and UMTS, respectively. So, knowing the overall blocking rate $b_{2G}(x)$ (and $b_{3G}(x)$ resp.) and energy consumption $E_{2G}(x)$ (and $E_{3G}(x)$ resp.) for each proportion of 2G traffic x (and 3G traffic $1-x$ resp.), the optimal value x_{opt} is that minimizing the power while keeping the blocking probability under a $target$ (e.g. 1%):

$$x_{opt} = \arg_{[0,1]} \min(E_{2G}(x) + E_{3G}(x)), \tag{10}$$

subject to:

$x_{opt} b_{2G}(x_{opt}) + (1 - x_{opt}) b_{3G}(x_{opt}) \leq target$

This optimization problem can be solved by trying different values of x. The energy consumption (and the blocking rate resp.) can be plotted as shown in Fig. 3(a) (and 3(b) resp.). It can be seen that, if only the classical performance criterion (i.e. the blocking rate) were taken into account, the optimal value of x would have been around of 0.45. However, as the aim is to minimize the energy consumption while keeping blocking under the target of 1%, the optimal value of x is equal to 0.15. Note that the energy consumption grows linearly and even no traffic is driven by the 2G system for instance (i.e. $x = 0$), we still have $600W$ of energy consumed. In order to achieve a best energy saving by the cooperation within an operator's network, we should reduce at most as possible this offset of energy consumption. The next model will tackle this issue.

3.2 Sleep mode for the operator's systems

The sleep mode has been introduced for base stations, and the authors of paper [4], Elayoubi and Al., propose to improve the system selection algorithm by enabling a system to sleep or to run with its minimum power. In fact the system selection reduces the energy consumption according to the radio

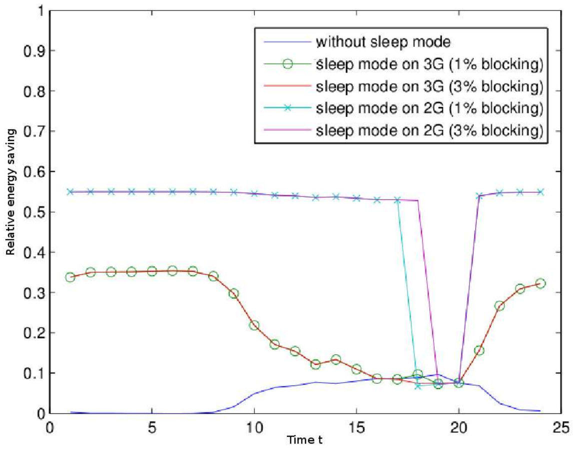


Figure 4: Relative energy savings over time, with and without sleep mode of 2G and 3G systems for different blocking rates.

frequency load, but as we saw in [1], a large constant part of energy consumption is induced by running the base stations.
Methodology: the model thus propose to introduce a sleep mode where an entire system either 2G or 3G can be shut down when possible to save energy. Turning off the 2G system (or 3G system resp.) is equivalent for a system selection where the proportion of calls accepted in 2G/GSM is $x = 1$ (or $x = 0$ for the 3G/UMTS resp.). Unfortunately, Fig. 3(a) shows that theses values of x (i.e $x = 0$ and $x = 1$) correspond to a blocking rate larger that the *target* of 1%. So, a minor degradation of the QoS by allowing a blocking of 2% makes the value $x = 1$ acceptable. Hence, this scenario leads to a tradeoff between energy saving and QoS degradation. In other words by switching off the 2G/3G system, the sleep mode will result in a blocking larger than 1%. So if we want to keep the target of 1% as the blocking rate constraint, this means that priority is given to QoS if no large energy savings are expected. Furthermore a base station in sleep mode will not be switched off but it will run with 10% of its total energy consumption (this corresponds to a low energy mode rather than sleep mode).

Results: while the gain remains lower than 10% for the energy-aware system selection, the energy saving could attain 30% of energy consumed when sleep mode is possible for 3G system and 55% for sleep mode with 2G system. Fig. 4 illustrates also the energy saving when the target blocking is increased to 3% in order to allow base stations entering in sleep mode even in high traffic hours. The relative energy improvement remains thus limited compared to the high degradation of the QoS. The authors recommendes to keep the target QoS and entering sleep mode only in low to medium traffic hours.

3.3 Cooperation at the network operators level enables Network Sleeping

In section 2.2, we tackled the issue of the energy-aware management of individual cellular access networks, estimating the amount of energy that can be saved by an operator that tries to optimize its energy consumption by reducing the number of active cells in its own access network during the periods when they are not necessary, because traffic is low.
In [5], Ajmone Marsan and Meo evaluate the energy saving that can be achieved with the energy-aware cooperative management of the cellular access networks of two operators offering service over the same

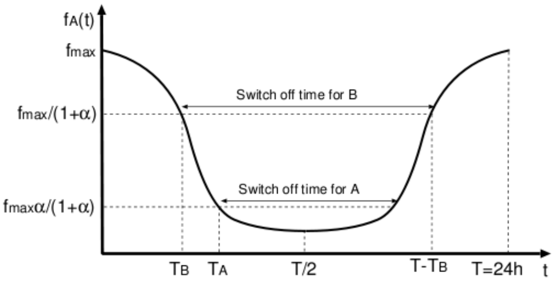


Figure 5: Typical daily traffic profile for network A, $f_A(t)$, and possible switch-off periods for networks A and B (only one at a time can be switched off).

area. They evaluate the amount of energy that can be saved by using both networks in high traffic conditions, but switching off one of the two during the periods when traffic is so low that the desired quality of service can be obtained with just one network. When one of the two networks is off, its customers are allowed to roam over the one that is on.

Methodology: the model denotes by N_A and N_B the numbers of customers of the two operators, and by $f_A(t)$, $f_B(t)$, with $t \in [0, T]$ spanning over 24 hours, the daily normalized traffic profiles of the two networks. It is assumed that the daily traffic profile repeats periodically, and that the average per-user traffic in the two access networks is the same, so that the overall traffic in the network is proportional to the respective number of users:

$$\frac{f_A(t)}{N_A} = \frac{f_B(t)}{N_B}. \tag{11}$$

Let $\alpha = N_B/N_A$, then $f_B(t) = \alpha f_A(t)$.
Since each access network is dimensioned so as to carry its peak traffic with the desired level of QoS (which we assume to be equal for the two networks), when the traffic reduces to a level such that just one network is able to carry the traffic of both without violating QoS constraints, the other network can be switched off.

In particular, network B can be switched off from time T_B until time $T - T_B$ (because of the symmetry assumption of the traffic as shown in Fig. 5), if:

$$f_A(T_B) + f_B(T_B) = f_{max}.$$

However, since $f_B(T_B) = \alpha f_A(T_B)$, this means: $f_A(T_B) = \frac{f_{max}}{1+\alpha}$, so that T_B can be obtained as:

$$T_B = f_A^{-1}\left(\frac{f_{max}}{1+\alpha}\right).$$

Similarly, network A can be switched off from time T_A to time $T - T_A$, when:

$$f_A(T_A) + f_B(T_A) = \alpha f_{max},$$

since αf_{max} is the maximum traffic in network B, for which such network was dimensioned. T_A can be obtained as:

$$T_A = f_A^{-1}\left(\frac{\alpha f_{max}}{1+\alpha}\right).$$

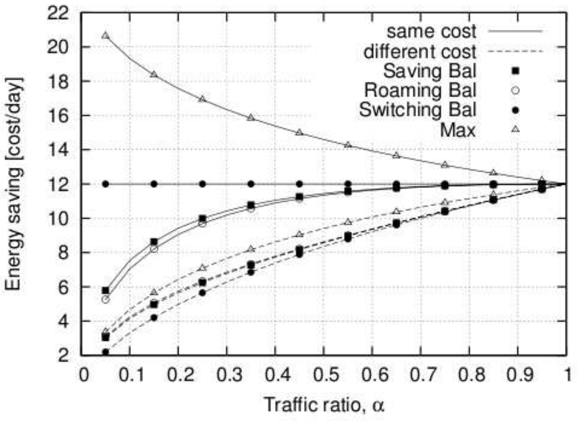


Figure 6: Energy savings under variable cost models and switch-off pattern.

The total cost of operating each of the two networks can be roughly estimated as a cost per user C_U (which represents the total network CAPEX + OPEX capital and operational expenditures divided by the number of subscribers; the paper assumes C_U to be the same for the two operators) multiplied by the number of customers, minus the energy saved by switching off the network, which is computed as an energy cost per unit time, C_e, multiplied by the switch-off period duration, and by the switch-off frequency. The cost for networks A and B, are, respectively:

$$C_A = C_U N_A - C_e(A)(T - 2T_A)P_A \; and \; C_B = C_U N_B - C_e(B)(T - 2T_B)P_B,$$

where the switch-off pattern, i.e the selection of which base stations have to be switched off, P_A and P_B are the fraction of days in which networks A and B are switched off ($P_A + P_B = 1$). The total energy saved can be expressed as:

$$C_e(A)(T - 2T_A)P_A + C_e(B)(T - 2T_B)P_B.$$

The roaming costs are corresponding to the traffic generated by customers of operator B that is carried by network A and the balancing of the switch-off frequencies implies $P_A = P_B = 0.5$. Several alternatives are studied, as regards the switch-off pattern: the one that balances the switch-off frequencies, the one that balances roaming costs, the one that balances energy savings, and the one that maximizes the amount of saved energy.

Results: The model indicates in Fig. 6 that almost 25% of the total energy consumed by the two networks can be saved, and suggest that, to reduce energy consumption, new cooperative attitudes of the operators should be encouraged or even enforced by regulation authorities.

4 Techniques for enforcing an energy efficient network

4.1 Self Organizing Networks (SONs)

A SON is a network that has the ability to automate the management processes. This feature allows to minimize the lifecycle cost of running a network by eliminating manual configuration of equipment at the time of deployment, right through to dynamically optimizing radio network performance during operation. The ultimate aim is to reduce the unit cost and retail price of wireless data services.

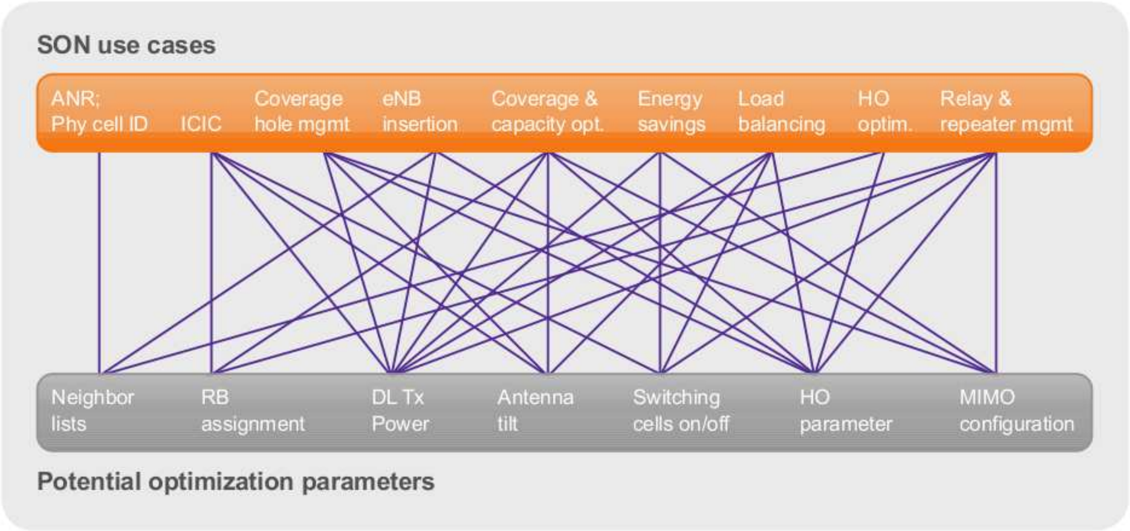


Figure 7: SON use cases and potential target parameters [6].

An example of SON is proposed by Nokia Siemens Networks to enforce an energy efficient cellular networks by sustaining both network quality and a satisfying user experience. One of the key issues is pinpointing the parameters to be targeted for optimization.
A few key parameters can serve several SON use cases, and certain parameters are a good match for a selected use case. This is a meaningful insight because it minimizes the risk of jeopardizing benefits and triggering conflicts or adverse effects such as oscillations when tuning several parameters at a time. One of the key enablers for robust and converging algorithms will be to clearly define responsibilities among parameters as we can see in Fig. 7. For instance tuning the switching cells on/off parameter can trigger a good energy saving, but this leads to pay attention to the load balancing also. There are many cross dependencies between the SON use cases and the potential optimization parameters that should be checked at the same time. So, SON has emerged as a key technology requirement.

4.2 Power saving algorithms

The algorithms developed in [7], aim to control a network with a low load regime by dynamically turning off some base stations in order to minimize the average energy consumption of the network with respect to the traffic demands.
Assumptions: a base station can be activated or turned off, so its energy consumption is either maximal or null to hold all the traffic. The inter-cell interference is handled by frequency reuse techniques.

Methodology: this optimization problem is formalized by linear programming. If all the channel information and the traffic requirements are known at the network side, one can find an algorithm that determine which base stations can be switched on/off. Two algorithms are used to solve the problem.
- A centralized algorithm: It is a greedy algorithm.
First, It initializes B as the set of Base Stations, and U as the set of all users. Also, the coverage of a base station is finite, and the set of users that can potentially be covered by a base station b is denoted

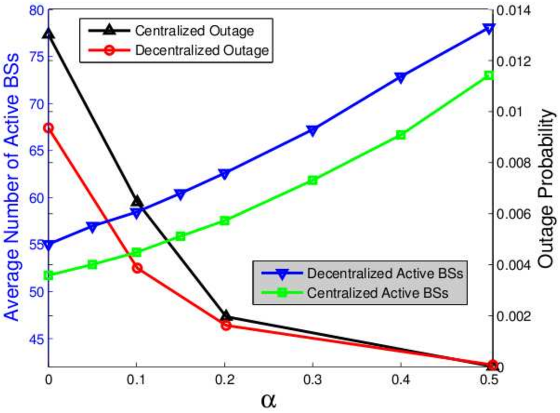


Figure 8: Performance of base station energy saving algorithms.

by U_b.
When the algorithm terminates, if $B = \emptyset$, the remaining base stations are switched off. If $U = \emptyset$, the remaining users are in outage. Because energy saving is for low traffic load scenario, outage should not happen with this algorithm. However, because the traffic is concentrated in the active base stations, with the random arrival of users, outage may occur in the future before the next decision time.

- A decentralized algorithm: this algorithm runs locally on user side.

In fact a user selects a base station so as to increase the traffic of the relatively high loaded ones. The underlying motivation is to give higher weight to the base stations with relatively high load, and this aims to concentrate traffic in these base stations and enable to sleep more base stations. The decentralized algorithm can start with any initial $user - BaseStation$ association state.
If no two users take action simultaneously, the distributed base station selection will converge to an equilibrium. This is because the base station selection set of each user is finite. After the algorithm converges, the base stations with no associated user will enter the sleep mode. The implementation of this algorithm can be performed in a similar way to adopt load balancing solutions in a cellular network.

Results: In Fig. 8, it is shown that with increased the protection margin α (that enables a base station to run far from its full capacity),both algorithms shut off less base stations, and greatly reduce the outage ratio. Also, the decentralized algorithm has better outage performance, while it activates more base stations. The above observations illustrate a tradeoff between energy saving and coverage guarantee, which is crucial for any energy saving mechanism design. As [7] suggested, we can improve the algorithms by enabling an individual and dynamic tuning of α.

5 Conclusion

In this paper, we have surveyed the models and algorithms published in the literature to tackle the power saving problem in cellular networks, since the ICT becomes a major worldwide cause of energy consumption. First, the models enlight that base station consumption cause a huge energy cost, and unveil that simple sleep mode operations are enough to reduce the cost significantly. Therefore they propose different approaches of cooperation starting at the base stations level and then at the system level inside a network and ending by cooperations among operators.

For the cooperation at the base stations level, model's outcomes are very interesting since one can compute the power saving, the minimum number of base stations (section 2.1), one can switch off the base station according to the existing network topology (section 2.2) and compare the different networks obtained with different switch off schemes (section 2.3).
At the network level, the paper reports how an operator can efficiently use its network by applying a cooperation between its different deployed systems to achieve a large energy saving. The paper shows that a cooperation between operators is really possible and can reduce the total consumption of ICT at regional, national or international level.
In the final part, the paper emphazises some techniques and algorithms proposed to enforce an energy efficient network.

References

[1] V. Mancuso and S. Alouf, "Making the base station green: a survey on strategies for reducing cost and pollution in wideband cellular networks," 2009.

[2] M. Ajmone Marsan, L. Chiaraviglio, D. Ciullo, and M. Meo, "Optimal energy savings in cellular access networks," in *Proc. IEEE ICC09 Workshop, GreenComm'09*, June 2009.

[3] A. Fehske, F. Richter, and G. Fettweis, "Energy Efficiency Improvements through Micro Sites in Cellular Mobile Radio Networks," in *Proceedings of the International Workshop on Green Communications (GreenComm'09), Honolulu, USA, 30 Nov - 04 Dec 2009.*

[4] L. Saker, S. E. Elayoubi, and H. O. Scheck, "Energy-aware system selection in cooperative networks," in *Proc. of VTC Fall*, 2009.

[5] M. Ajmone Marsan and M. Meo, "Energy efficient management of two cellular access networks," in *GreenMetrics 2009 Workshop (In conjunction with ACM SIGMETRICS / Performance 2009)*, 2009.

[6] Nokia Siemens Networks, "Introducing the Nokia Siemens Networks SON suite - an efficient, future-proof platform for SON," Nov. 2009.

[7] S. Zhou, J. Gong, Z. Yang, Z. Niu, and P. Yang, "Green Mobile Access Network with Dynamic Base Station Energy Saving," IEICE, Tech. Rep. vol. 109, no. 262, IA2009-50, pp. 25-29, Oct. 2009.