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Design and performance evaluation of site sleep mode in LTE mobile networks

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Abstract—In this work, we investigate and quantify energy savings resulting from site sleep mode without compromising coverage and QoS experienced by users. As base station sites are largely load-independent with regard to energy, we take benefit of this fact and quantify the power savings by allowing some base station sites to go into sleep mode during their low traffic periods provided their neighboring base station sites can accommodate their traffic. We propose simple controllers that are able to achieve this task while relying exclusively on local information exchanges between neighboring sites using the X2 interface. In order to evaluate energy gains in a realistic setting, we apply the proposed schemes on realistic LTE networks using traffic patterns obtained from measurements. Our results show that, in urban environments, considerable energy gains can be obtained without having to change antenna and site configuration and without compromising QoS.

I. Introduction

The demand for energy, particularly by the network infrastructure, increases with the expansion of mobile usage which forces Mobile Network Operators (MNOs) to spend approximately US$15 billion annually on energy use [1]. Thus, energy efficiency emerges as a strategic priority for (MNOs). Furthermore, despite the fact that mobile radio networks are only a minor producer of green house gas emissions today, the challenges in near future are expected to become significant and can not be ignored [2],[3]. This contribution is bound to increase with rapidly growing capacity demand if significant improvements to network's efficiency are not carried out.

In this context, macro base stations are observed to be the most energy consuming nodes (75-80% of the power consumption in mobile telecommunications in 3G and LTE stages of the overall mobile network consumption [4],[3],[5]). Reducing the power consumption at the level of BSs must thus be at the heart of any green radio scheme. In this work, we investigate, by exploiting the variation in offered traffic at different LTE BS sites, power savings by introducing site sleep mode feature when traffic load is low. Here, by sleep mode, we mean that BS site is deactivated and consumes very low power in order to support dynamic remote activation. In order to permit the unnecessary sites to go in sleep mode, the surrounding neighbors must accommodate the traffic of these sites. One could think of it as cell breathing, wherein for unnecessary BS sites working with a very low load, their cell size is reduced to zero. Cell size of neighboring sites increases with the acceptance of redistributed traffic in order to avoid any coverage holes caused by sites going in sleep mode. We thus propose simple sleep mode controllers that allow taking local decisions about going into sleep mode or activating a sleeping neighbor. Our results show that up to 20% energy savings can be obtained without compromising QoS.

In this work, we make the following main contributions:

- We base our works on realistic environments (live networks).
- We propose simple algorithms that preserve coverage and capacity, while reducing substantially the energy consumption.
- We propose local schemes with minimal information exchanges between sites that can be achieved over the X2 interface.

Related Works

An important set of works on green radio has then been dedicated to the reduction of the transmitted power of the base stations; the idea is to find the optimal transmission power that ensures coverage and capacity (see for instance [6]). This approach is essential for reducing the exposure of persons to electromagnetic radiations. However, alone, these schemes are not sufficient to reduce the energy consumption of wireless networks as a large part of energy consumption remains even for low output power. This is due to the load-independent components of the energy consumption and the presence of pilot channels that make low load resources totally inefficient in terms of energy. This is also the reason that makes energy-aware load balancing techniques not so efficient (an average reduction of the energy consumption of 5% has been observed in [7]).

Unfortunately, energy savings may result in some compromises on coverage as well as user throughput. Switching off the unnecessary network resources by ensuring the target coverage and QoS for the offered traffic could result in very large energy gains. For example, when a network resource like frequency carrier is not necessary to ensure

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Parameter	Description
N_i^{sec}	number of sectors of site i
P_0	minimum non-zero transmitted power at no load
P_{max}	maximum transmitted power (typically 40 Watt)
P_{sleep}	power in sleep mode
Δ_p	slope of load-dependent power consumption (typically 5.2
$\overline{\rho}_i$	variable (from 0 to 1)

TABLE I
Parameter description.

required QoS, it could be turned off to reduce global energy to some extent. Some studies attempt to minimize the number of required macro BS sites by optimizing parameters, while others attempt to analyze the effects through introduction of higher density of smaller, low energy consumption sites [8],[9]. But the focus of these studies is on the network's ability to carry a specific fixed volume of traffic (generally depicted by high traffic).

The remainder of this paper is structured as follows: Section II describes the relationship between offered traffic and power consumption variations. We also discuss about the impact of sleep mode on the coverage based on actual network layout. Moreover, details about power and power model are provided. In Section III, we present our proposed sleep mode scheme. Section IV provides results and observations about power savings. Section V concludes the paper with some possible research trends for future green networks.

II. Energy efficiency of current over-dimensioned networks

A. Influence of traffic variation on energy consumption

Even if considerable variations in average traffic could be observed with radio network over a 24 hour period, energy consumption does not follow the similar variations. In other words, during the periods when there is little or no traffic, the BS sites still consume a large amount of power. Indeed, the power amplifier is the main power consuming component in a typical macro BS site (responsible of around 55-60% of the overall power consumption at full load) [12], and it continues to consume even when there is no traffic load. The relationship between relative RF output power and BS power consumption are nearly linear as shown by [11]. Hence, linear approximation of the power model seems to be justified and is given by:

$$P_i = \begin{cases} N_i^{sec}\left(P_0 + \Delta_p * P_{out}\right), & 0 < P_{out} \leq P_{max}, \\ N_i^{sec} P_{sleep} & P_{out} = 0. \end{cases} \quad (1)$$

Whereas $P_{out} = P_{max} * \overline{\rho}_i$ is the transmitted power, P_0 is the power consumption at the minimum non-zero transmitted power, Δ_p is the slope of load-dependent power consumption and P_{sleep} represents the power consumption in sleep mode.

The various parameters of the power model for a macro BS site i depending on number of sectors are presented in Table I.

Based on this power model, we illustrate in Figure 1 the load and power consumption variation over a typical day of a base station site consisting of 3 sectors, 10 MHz bandwidth. In this figure, the power consumption is normalized with respect to the consumption at full load, and the traffic load is computed as the ratio between the observed traffic and the maximal capacity, which will be detailed later. It can be observed that a base station with low load is too energy inefficient. We will show next that, in current networks, many base stations have low or no load almost all the time.

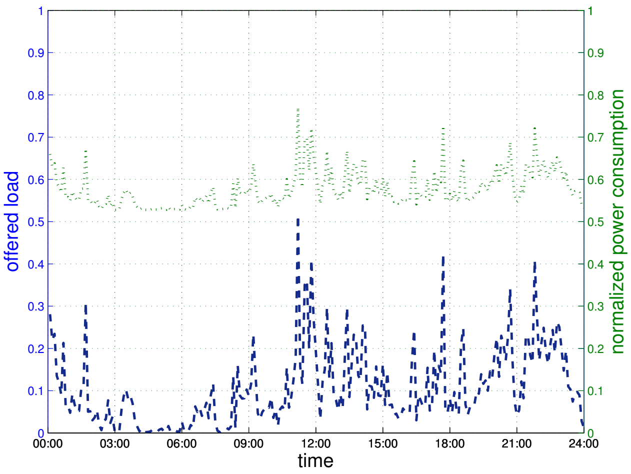

Fig. 1. Power consumption and traffic load variation on a typical site of the network.

B. Coverage in dense urban areas

With the arrival of each new technology, the MNO deploys a number of sites with the objective to ensure coverage and capacity. While coverage is the limiting factor in rural areas, capacity is what matters in dense urban areas. Indeed, the system is over-dimensioned so that the coverage of the different base stations overlaps with the aim of reusing spectral resources geographically in order to have more capacity. This over-dimensioning impact is amplified in the case of 4G deployments as 3G sites may be reused irrespective of the real traffic, making the 4G sites highly under-loaded in the first deployment phases.

In order to illustrate this over-dimensioning, we consider a part of the 4G network in a major European city. Our focus is to obtain the over-dimensioning ratio by identifying the maximum number of sites that can be switched off without compromising coverage. We make use of an operational network optimization tool. The optimization process uses an algorithm based on a combinatorial optimization model where the set of feasible solutions is discrete and the goal is to find the best possible solution. The optimization engine takes coverage criteria as an objective constraint to satisfy.

Our considered scenario consists of 19 indoor BS sites (51 sectors), 10 MHz operating at 2.6 GHz carrier frequency. Out of 19 sites, 15 sites are with 3 sectors each, 2

sites in sleep mode	sectors in sleep mode	coverage
0 (0%)	0 (0%)	97.13%
1 (5.26%)	3 (5.88%)	96.11%
4 (21.05%)	10 (19.60%)	95.74%
7 (36.84%)	16 (31.37%)	95.09%
8 (42.11%)	19 (37.25%)	93.24%

TABLE II
The number of sites that are switched off and the corresponding coverage values.

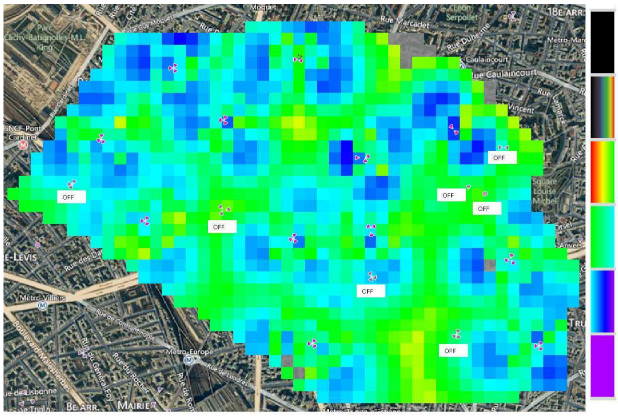

Fig. 2. Coverage map when 7 sites among the 19 are put in sleep mode. The location of sites in sleep mode is indicated in white

sites are with 2 sectors each and each of the remaining 2 sites consist of 1 sector only. We set coverage criteria to be equal or greater than 95%. First, we keep all the sites of our considered network active and observe 97.13% coverage. We go on switching off sites until coverage falls below the set threshold of 95%. We find that 7 out of 19 BS sites (36.84% of total sites) or 16 out of 51 sectors (31.37%) can be switched off while respecting the coverage constraint. But if we further increase the number (%) of sites to be put in sleep mode, then we notice that coverage constraint is violated. The number of sites that are switched off and the corresponding coverage values in % are given in Table II, respectively. Figure 2 illustrates the coverage map when 7 sites are put in sleep mode. Different colors in these maps represent the achievable user throughput in the different positions of the map. If we have a close look at center left side of the map, we find that the color changes from blue (more throughput) to green (less throughput) which means that user throughput decreases to some extent. However, as cited above, the 95% coverage criteria is sill achieved.

C. Base station load and power consumption estimation

The previous figures showed that the system is highly over-dimensioned with regards to the coverage criterion. Our aim in this section is to show that the system is, almost all the time, also over-dimensioned with regards to the capacity criterion.

We first describe how to model the capacity of a cell in the mobile network. Assume that we have a given number of active users, then we have equal, and random, division of resources (i.e, time slots and Resource Blocks in HSDPA and LTE respectively) among users. A user (being alone in the cell) close to the BS will possess different bit rates as compared to the scenario when he is far from the BS. The throughput of user will decrease with the increase of distance from the BS. In realistic settings as illustrated in Figure 2, large peak rate throughput variations can be observed and each cell of the network can be divided into regions with comparable radio conditions and hence a common achievable throughput. Let M_i be the number of regions of radio conditions belonging to the BS site i and p_{ij} the proportion of users of cell i that are situated in region $j \in [1, M_i]$ and have thus throughput C_{ij}. Let the amount of traffic volume offered to cell i per unit time is $V_i = \lambda_i F$ with the assumption that connection demands arrive to the cell according to a Poisson process of intensity λ_i connections per second and each connection brings an average amount of traffic equal to F bits. Then, the normalized traffic load produced by users belonging to radio condition j of site i is given by

$$\rho_{ij} = p_{ij}\frac{V_i}{C_{ij}}$$

The overall normalized load on BS site i is given by [10]:

$$\overline{\rho}_i = \frac{V_i}{C_i}$$

whereas C_i is the capacity of the BS site i and corresponds to harmonic mean of achievable throughput observed over the BS site area and is given by [10]:

$$C_i = (\sum_{j=1}^{M} \frac{p_{ij}}{C_{ij}})^{-1}$$

Note that the harmonic mean gives more weight to cell edge users (i.e., to positions with lower rates) as they stay more in the cell. It can be observed from Figure 1 that this traffic load remains very low (around 20%) all over the day, and this can also be observed on a large proportion of sites, thus making the network also over dimensioned in capacity. We will exploit next these two observations (over-dimensioning in coverage and capacity) in order to design our site sleep mode scheme.

III. Our proposed sleep mode scheme

In this section, we propose a sleep mode scheme for whole BS sites, based on the coverage analysis of the previous section.

As described in Section II-B by using optimization process on a real network layout, we identify two types of BS sites:

- Type I BS sites that always remain active and can accommodate the traffic load offered by their neighboring sites which can go in sleep mode. The list of Type I sites is denoted by A.

- Type II BS sites that can go in sleep mode during their low traffic periods conditioned upon the fact that active surrounding neighboring sites can accept their load. The list of Type II sites is denoted by S.

Note that each BS site of the considered scenario can belong to one type only. During any time period, a BS site of Type I can accommodate, in addition to its own traffic data, the traffic offered by neighboring BS sites of Type II (may vary from 0 to maximum number of sites in S). Similarly, a BS site of Type II can transfer its traffic to 1 or more active BS sites of Type 1 in its surrounding. A BS site i belonging to list A is allowed to accept traffic from a Type II site only if its total normalized load does not exceed a certain threshold. Here, total normalized load is the ratio of the sum of all offered traffic loads (*i.e.*, own load of site i, already accepted load from any site(s) of Type II and load to be accommodated as a result of current request) to the capacity after optimization which is denoted by $C_i^{'}$.

For example, let us consider that a BS site k wants to go in sleep mode, then it can do so only if all of its active neighbors can accommodate its traffic by respecting their normalized load constraint. Let α_{ik} be the fraction of traffic volume which could be transferred on site i from its neighboring site k which wants to go in sleep mode. We ensure that site i could accommodate traffic of its neighbors only if its normalized load $\overline{\rho'}_i(T)$ during ant time period T does not exceed a certain threshold $\overline{\rho}_{th}$ on normalized load, which is given by:

$$\overline{\rho'}_i(T) = \frac{V_i(T) + \alpha_{ik} V_k(T) + \sum_{k' \neq k} \alpha_{ik'} V_{k'}(T)}{\overline{C}_i^{'}} \leq \overline{\rho}_{th} \quad (2)$$

whereas $\sum_{k' \neq k}$ captures the fact that site i might have some load from sites of Type II other than that of site k. Site k can decide to go in sleep mode only if all its surrounding active neighbors can respect their normalized load threshold. Moreover, $\sum_i \alpha_{ik} = 1$ and $\sum_k \alpha_{ik} \geq 0$, the former expression says that traffic of site k could be completely shifted to all its active neighbor(s) i (site k could have one or more active neighbors which share its traffic), while the latter tells that site i could accommodate traffic partially or completely of one or more sites in sleep mode or even from non.

By using the information obtained from coverage maps, we identify, for each leftover spot by site(s) going in sleep mode, BS site(s) covering those spots. Thus, we obtain % load transfer information among BS sites as given by the Figure 3. Type I sites (on x-axis) can accommodate the fraction of load (given on y-axis) from potential site for sleep mode (each curve corresponds to one site of Type II).

For any time period, our proposed algorithm works as follows:

- Calculate average QoS and power consumption for the whole system without sleep mode
- Set the status of all BS sites as ON
- Initialize list of sites in sleep mode during current period s to $\emptyset$
- For each site$k$ belonging to S, we verify one by one
  - For each active neighboring site i of k
  - Calculate normalized load on i by using(2)
  - If normalized load of all active neighbors of k is less than $\overline{\rho}_{th}$
    - Add site k to the list s
    - Set the status of site k as OFF
- Calculate new QoS and power consumption values based on updated sites status and load information
- Hence, calculate percentage power saving and percentage QoS degradation for the whole system

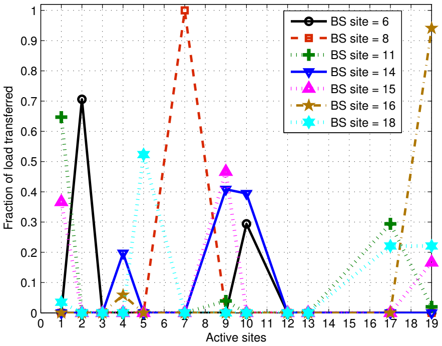

Fig. 3. Load transfer information among BS sites

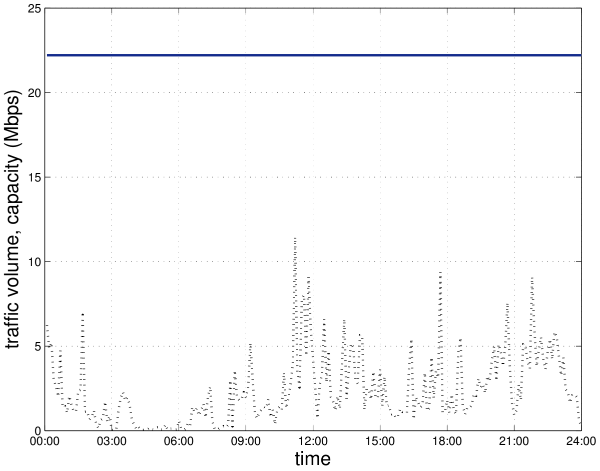

Fig. 4. offered traffic volume on a site which wants to go in sleep mode (site 18)

IV. Discussion and results

The results, achieved through simulations, presented in this section are based on BS sites of real network and real traffic data traces from a European MNO. Before providing the results of power savings, it is important to talk about BS sites actual offered traffic data.

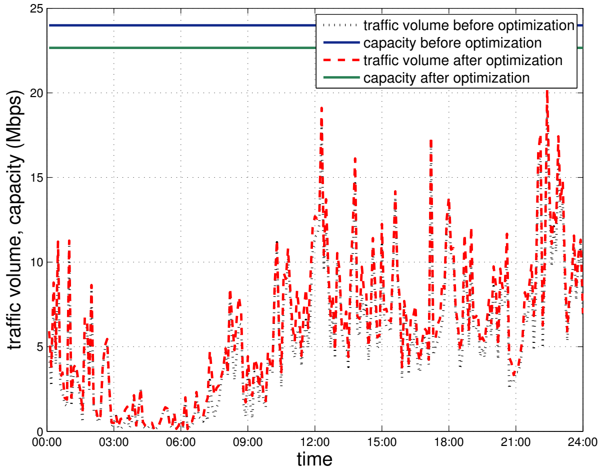

Fig. 5. total offered traffic volume on active site (site 19) before and after load sharing from site in Figure 4

A. Traffic profiles

We consider a actual daily traffic profile divided in periods of 6 minutes each. Each site of Type II transfers its load on its active neighbors among Type I sites before going in sleep mode when their offered traffic is low and their neighbors can easily carry on the additional traffic too. Our considered network scenario consists of 19 BS sites numbered as $1, 2, \ldots, 19$. Among these 19 sites, 12 sites (1,2,3,4,5,7,9,10,12,13,17 and 19) belong to Type I while the rest (i.e.,6,8,11,14,15,1- and 18) are of Type II. We consider one example BS site of Type II, say number 18 which has 4 sites among Type I as its neighbors. The neighboring sites 1,5,17 and 19 share 3.49%, 52.48%, 22,09% and 22,09% load respectively from site 18 during its sleep periods. It is important to mention that each sector has unique actual traffic profiles. But, we have considered total traffic of the BS sites by accumulating the individual traffic volume of all sectors belonging to the same site.

Moreover, in general, we observe that capacity of most BS sites of Type I after optimization process decreases which is quite normal because of increase in their coverage. But, interestingly, some BS sites have increased in capacity after optimization process which happens due to the interference reduction from neighboring sites that go in sleep mode, which overcomes the reduction as a result of more coverage.

Figures 4 and 5 provide real traffic data and capacity (both in mbps) of site 18 and site 19 without and after load transfer. One can easily notice that traffic load of site 18 is very low particularly during night periods during which site 19 does not possess heavy offered traffic and can easily accommodate transferred traffic from site 18. The same is true for other active neighbors of site 18 (similar type of figures). Figure 6 shows the status of site 18 as ON/OFF over 24 hours.

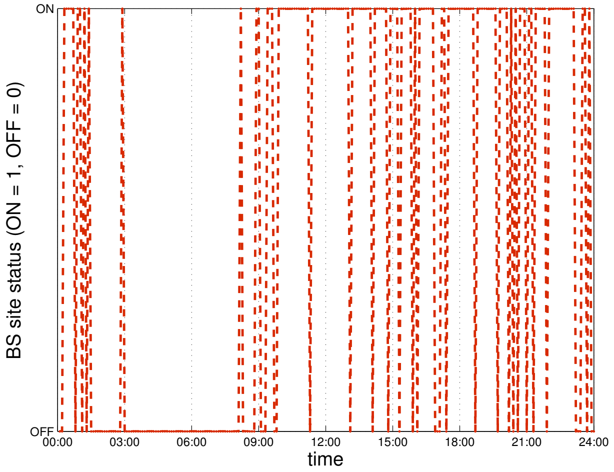

Fig. 6. ON/OFF status of candidate sleep site (site 18)

Mode	Power needed (in Watts)		
	$N_i^{sec} = 3$	$N_i^{sec} = 2$	$N_i^{sec} = 1$
at full load P_0	1350	900	450
at no load	712	474.67	237.33
In sleep(P_{sleep})	72	48	24

TABLE III
Required Power values (in Watts) for any macro BS site with 1, 2 or 3 sectors.

B. Overall power savings

Our results are based on the values of different parameters presented in Table III.

Figure 7 shows the power consumptions in kilowatts over a 24 hours period. Power saving are obtained by comparing average power consumption values with sleep mode to those without sleep mode. We observe significant daily average power savings of 18.70% (from 7.38% to 27.72%) (refer to Table IV).

Figure 8 plots average power savings and QoS reduction (both in %) scaled up from 0 to 30 and 0 to 12 respectively against various threshold values of normalized offered load on active sites,. 60% threshold on normalized load of each Type I site is considered approximately optimal threshold when we set minimum acceptable average power savings of 18% while minimum acceptable average QoS reduction less than 8%. For threshold values above or below 60%, one of the acceptable criteria is violated.

	Power consumption (kW)	% Power savings	
no sleep mode	321.74	minimum	7.3831
with sleep mode	261.61	maximum	27.7202
savings	60.13	average	18.6996

TABLE IV
Total power consumption and savings during one day.

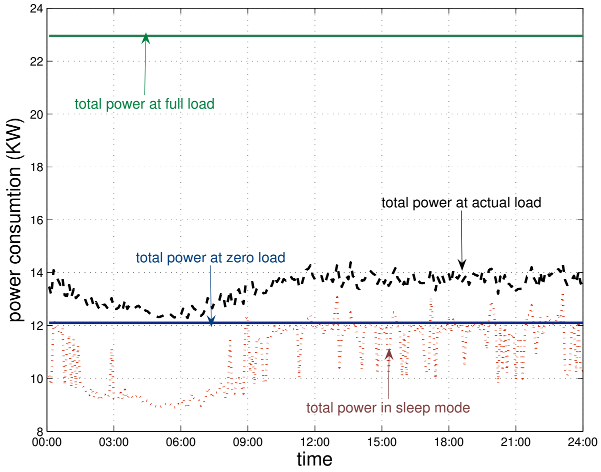

Fig. 7. Overall power consumptions without sleep mode, with sleep mode, at no load and at full loadover 24 hours

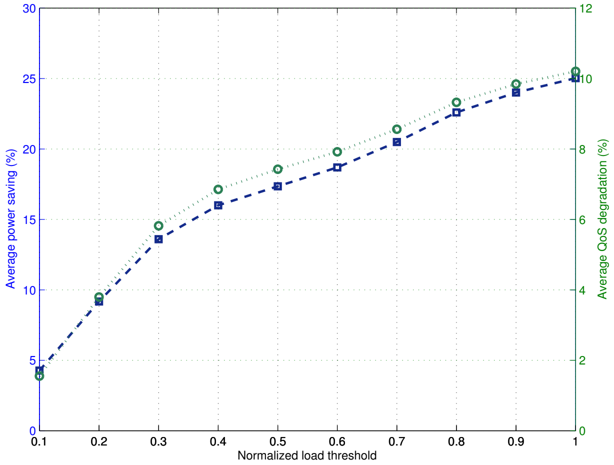

Fig. 8. Average power savings and QoS by varying threshold on normalized load of Type I sites

V. Conclusion

In this paper, we proposed site sleep mode schemes for LTE networks. The idea is to switch off completely cell sites when their carried traffic is low and their neighbors are able to offload their traffic. We showed that networks are usually over-dimensioned, in capacity and in coverage, in order to carry the traffic at busy hours, and operate almost at 0 load during the rest of the day. Based on an online identification of sites that are candidate to sleep mode as those whose coverage area is completely overlapping with neighbors, we proposed a simple online activation/deactivation algorithm. In this algorithm, each candidate site exchanges periodically its traffic load with its neighbors and goes into sleep mode if it estimates that its neighbors are able to offload all its traffic. We showed that this simple algorithm is able to achieve high energy savings with acceptable QoS in terms of user throughput. As of future works, we aim at enhancing our sleep mode scheme by an appropriate traffic prediction in order to reduce the ping pong effect between ON and OFF states that is observed on some sites.

References

[1] GSMA, Mobile Energy Efficiency: An Overview, August 14, 2013.

[2] Ericsson, Sustainable energy use in mobile communications, August 2007, White paper.

[3] G. P. Fettweis and E. Zimmermann, ICT energy consumption - trends and challenges, in Proceedings of the 11th International Symposium on Wireless Personal Multimedia Communications, Lapland, Finland, September 2008.

[4] G. Micallef, P. Mogensen, H. O. Scheck, Cell Size Breathing and Possibilities to Introduce Cell Sleep Mode, European Wireless Conference 2010, pp.111-115, April 2010.

[5] M. Etoh, T. Ohya, and Y. Nakayama, Energy consumption issues on mobile network systems, Proc. Internat. Symp. on Applications and the Internet (SAINT 2008), Turku, Finland, 2008, pp. 365-368.

[6] J. Palicot, Cognitive Radio: An Enabling Technology for the Green Radio Communications Concept, IWCMC, June 2009.

[7] L. Saker, S-E. Elayoubi and H.O. Scheck, System selection and sleep mode for energy saving in cooperative 2G/3G networks, IEEE VTC-fall 2009, Anchorage, September 2009.

[8] F. Richter, A. J. Fehske, G. P. Fettweis, Energy Efficient Aspects of Base Station Deployment Strategies for Cellular Networks, IEEE Vehicular Technology Conference (VTC09), Anchorage, USA, September 2009.

[9] B. Badic, T. o'Farrell, P. Loskot, J. He, Energy Efficiency Radio Access Architectures for Green Radio: Large versus Small Cell Size Deployment, IEEE Vehicular Technology Conference (VTC09), Anchorage, USA, September 2009

[10] T. Bonald and A. Proutière, Wireless Downlink Data Channels: User Performance and Cell Dimensioning, ACM Mobicom 2003, April 2003.

[11] Auer, Gunther, et al. How much energy is needed to run a wireless network?, Wireless Communications, IEEE 18.5 (2011): 40-49.

[12] L Saker, SE Elayoubi, L Rong, T Chahed, Capacity and energy efficiency of picocell deployment in LTE-A networks, IEEE VTC-spring 2011.