Far East Journal of Electronics and Communications

Published Online: January 2016
http://dx.doi.org/10.17654/EC016010147
Volume 16, Number 1, 2016, Pages 147-165 **ISSN: 0973-7006**

SIMULATION STUDIES OF THE POWER CONSUMPTIONS OF A BASE TRANSCEIVER STATION

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Abstract

Telecommunications power systems have seen an increasing energy demand in the last few years, with an exponential growth of base transceiver stations, due to the development of new mobile telephony technology and the continuous evolution of mobile services. "Power saving" is one of the most important approaches to reduce energy consumption, in particular for transmission devices; it entails switching off unused channels during low traffic periods, such as nights or weekends. In this paper, a Monte Carlo simulation algorithm that implements power saving features on transmission systems has been developed and tested by using base transceiver stations

Received: January 8, 2015; Accepted: February 25, 2015

Keywords and phrases: power consumption, telecommunication, radio base stations, sustainable development, Monte Carlo algorithm.

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Communicated by Peter Han Joo Chong

with different characteristics and typologies (GSM, DCS) and with different traffic load conditions. The research outcomes concern the optimization of algorithm parameters and energy saving performances as a function of the traffic load and the BTS typology.

1. Introduction

The development of the mobile phone network and the relevant demand for mobility services has led to a constant increase in signal transmission systems (base transceiver stations - BTS), which are necessary to ensure the quality and the territorial coverage of the services. The reduction of energy consumption of a BTS represents one of the critical factors of the telecommunications systems, both to allow a considerable saving of economic resources for the mobile phones management and to operate a “sustainable” development.

In a previous paper, we showed that the total yearly consumption of the Italian BTS system is ca. 2.1 TWh/year and the average yearly consumption of a single BTS is ca. 35500kWh, split in 65% for transmission functions and 35% for air conditioning [1]. In terms of economic and environmental impact, the yearly data corresponds to ca. 300 M€ energy costs and ca. 1.2 Mton of CO2eq emitted in the atmosphere.

BTS’s energy efficiency is one of the most important goals for operators and suppliers, that are developing guidelines and directives to this effect [2]. For example, the European Telecommunications Standards Institute (ETSI) produces globally applicable standards for the Information and Communications Technologies (ICT) sector; one of its scopes is to define target values for the energy efficiency of equipment or wireless networks, useful to assess and compare the efficiency of mobile radio network equipment with different technical and economic features.

Many innovative technical and economic solutions are being evaluated to implement energy efficiency and energy saving actions [3-17] such as the production of more energy parsimonious equipment [17], air conditioning consumption optimization [4], temperature control system efficiency [15, 16] and software solutions based on the dynamic turn off of BTS useful to make the network consumption proportional to traffic load [3, 5-14].

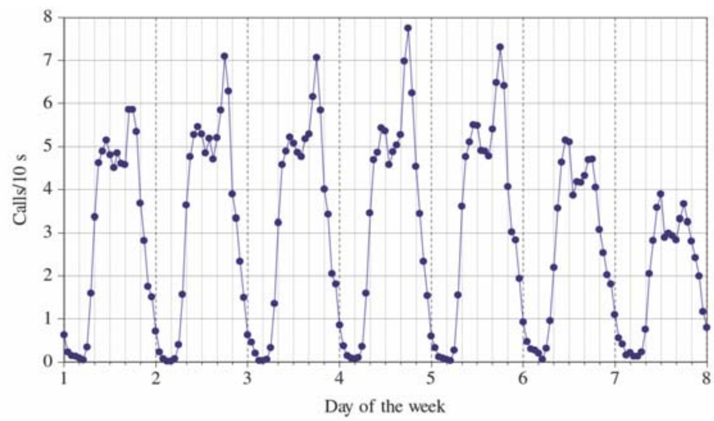
Moreover, previous literature has evaluated and developed actions and technical solutions based on renewable energy production (e.g., photovoltaic (PV) or wind plants) [18], on the infrastructures themselves or for power systems located in areas not reached by the electricity grid [19] (e.g., hybrid solutions PV-diesel or PV-wind) [20-22].

Particular attention should be paid to lowering the power consumption for transmission functions. This is an important goal to achieve, because it also grants an indirect benefit related to a lower heat production from the devices, and thus a lower need for conditioning energy to provide a suitable operating temperature to the equipment. The present paper shows power saving results obtained with a Monte Carlo simulation algorithm that implements the “power saving” features on transmission systems of BTSs with different traffic loads (amount and length of calls), characteristics and typologies (GSM, DCS).

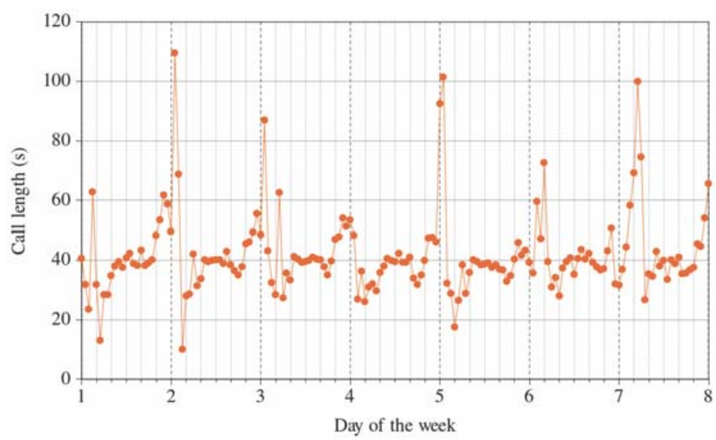
A previous research from this group has already shown the agreement between on-field measurements and simulation algorithms [23]. The current work goes further in that direction, pointing out the details of the algorithm and the original results.

2. Description of the Operating Parameters of a BTS

Here are considered BTSs used for mobile communication, utilizing GSM and DCS technologies. A BTS is composed by cells, covering different areas (sectors) around the station; every cell has many transceivers (TRXs), which perform the sending and reception of the signals. In any TRX, there is a number of time slots (TSs) that are utilized as control channels, carrying service information, or as traffic channels. Usually, the first TRX includes a broadcast control channel (BCCH) and other control channels; it is always switched on, even when there are no calls. Communication channels are used to convey calls: each TS corresponds to a single channel and conveys just one call at full rate mode and two calls at half rate mode. The cell traffic is measured as the cumulative number of calls available per hour and is indicated in Erlangs (Erl) (i.e., one Erl corresponds to a one-hour call, two half-hour calls, 10 six-minute calls, etc.). Note that the term “call” is used herein to indicate the time when the channels are occupied.



(a)



(b)

Figure 1. Hourly averages of new calls every 10 seconds (a) and hourly averages of call length (b) of a typical BTS cell (Agliana, first GSM cell, see below) for a one-week period. Day of the week 1 corresponds to Monday, etc.

A perfect mobile communication system would have infinite capacity, providing access to every call request, also during periods of maximum demand. However, in real systems, only a finite number of calls is possible, set by the number of TSs available. This number is chosen at the design stage, starting from the maximum number of forecast calls. Figures 1(a) and 1(b) show the weekly profile of number and length of calls of a typical Italian BTS cell, that was monitored for this study [1]. In detail:

- The hourly average number of new calls every 10 seconds (Figure 1(a)) and the hourly average call length (Figure 1(b)). They fluctuate statistically and depend on the traffic profile of the area, time of day, period of the week/year, etc. Concerning the daily fluctuation of the number of calls, it is evident that, during the night hours, they are almost down to zero, while there is a relative maximum in the morning hours and a sharper one in the evening hours. This behavior is also confirmed by other studies on the subject matter [24]. Moreover, there are also weekly fluctuations, with a lower traffic level in the weekend (e.g., on Sundays, day 7 in the figure, when there are fewer calls and less fluctuations during the daylight hours).

On the other hand, the average call length is almost constant, except at around midnight, with far longer average call duration and more fluctuations, due to the low number of calls during these periods. There are no clear weekly fluctuations of the average call length.

The network designer sets the best grade of service (GoS), i.e., the minimum amount of technical issues for the customer, while maintaining technical and economical sustainability, by planning for a suitable number of TS channels in the cells and fine-tuning the transmission parameters. Figure 2(a) is a schematic view of a typical cell, with 3 TRXs (the rectangular rows) and 8 TSs (squares) per TRX. In the first TRX, there are 2 control TSs, labeled “C”, and 6 more TSs, three of which are occupied by a call, indicated with an “X”.

In general, the control channels must be always switched-on to provide the continuous visibility of the cell, so the whole TRX is always on. This provides the uninterrupted availability of the six remaining call channels.

In the example of Figure 2, two transceivers are devoted only to calls; moreover, two TSs are occupied in the second TRX and three in the last TRX. Each active TRX and TS consumes a fixed amount of power.

Usually, many BTSs are always switched on, leading to a power wastage that can be considerable in low traffic periods. A suitable algorithm to switch off the unused channels can bring to a significant power saving [1, 6, 17]. The chosen power saving (PS) algorithm achieves this by:

- merging the active channels on the same TRXs;
- disabling the unused TRXs;
- providing the needed TRX at once when necessary. Figure 2(b) depicts the situation after applying the PS algorithm to the status depicted in Figure 2(a): the calls were moved to the first and second TRXs, leaving the third TRX free, so that it can be turned off.

It is possible to operate in a similar way on individual time slots [6, 17].

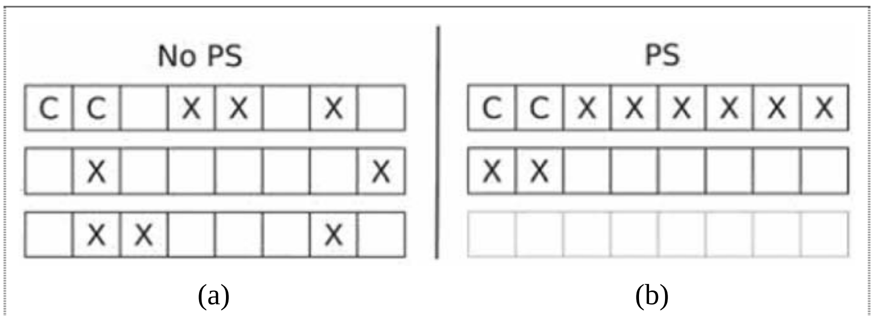


Figure 2. Schematic representation of the management of incoming calls with and without power saving. Each row represents a TRX and each square a TS. Thus, this scheme represents a cell with 3 TRXs and 8 TSs per TRX. Controls occupied by TSs are indicated with C, and TSs occupied by transmission are indicated with X. (a) No PS: new calls are randomly occupied. (b) PS: occupied TS are re-allocated in the first TRX. The last TRX remains unused and can thus be switched off.

3. Material and Methods

3.1. The Monte Carlo simulation algorithm

As discussed above, BTSs telecommunication channels are always operational, even during low traffic time intervals (for example, at night or at the weekend); therefore, a power saving optimization is possible with the “PS feature” [1, 8, 11, 13, 16, 25], entailing every transmitting channel appropriately on or off, depending on the traffic load.

The practical activation of the PS presents some issues to be addressed: the minimization of power consumption must be carried out without affecting the quality of service and the availability of the transmission channels; that means that the needed number of channels should be, ideally, available at once, in every traffic condition. Various operating PS parameters can be set and influence both the energy consumption and the service quality. The choice of the best set, which depends on the specific technical and statistical characteristics of the site (number and capacity of the channels, average number of calls and call length), can be done via direct experimental check.

However, the test for every available parameter is long and cumbersome: it should last a fair amount of time to allow a result that is independent of the statistical fluctuations of the number and length of the calls, i.e., not less than two weeks for every parameter set. Moreover, this should be repeated for every cell, due to the uniqueness of the technical and traffic parameters.

In this framework, we developed a Monte Carlo (MC) algorithm [1, 26], in order to simulate the “power saving features” required to maximize the savings in the BTS transmission, without altering the grade of service, defined as the percentage of correctly handled incoming calls to the BTS. In the MC simulations, input data coming from real collected traffic is used.

To perform the Monte Carlo simulations, time slots (*cycles*) of ten seconds were considered. The number of new calls for each time slot was supposed to have a Poisson distribution, while the call length was simulated with an exponential distribution.

The algorithm provides a number of new calls for every cycle and a call length for every call. The allocation of the calls in the available time slots is casual in the normal (no power saving - NOPS) regime. However, in the PS regime, they are allocated in the free channel in the lower order TRX, while the active calls are reallocated in the lower order channels vacated by the finished calls. A TRX is switched off if it remains unused for a suitable number of cycles. This is done via a counter that is decreased by 3 if the free slots are below a fixed value (indicated as BTSPSHYST + 9) and increased by 1 otherwise. A TRX is switched off when the counter reaches a fixed value (TRXOFFTARGET) and a new counting begins after TRXOFFDELAY cycles [6].

A TRX is switched on when another counter reaches the value TRXONTARGET. This counter is increased only when the TSs are missing (i.e., if they are lesser than BTSPSHYST + 9). The algorithm provides a fast counter increase for a burst in the number of calls.

The procedure is repeated for the next cycle, until the end of the simulation period, usually one day.

The recommended parameter values are [6]:

Parameter	**Recommended range (suggested default)**
BTSPSHYST	1-16 (**2**)
TRXOFFTARGET	20-100 (**50**)
TRXONTARGET	20-100 (**49**)
TRXOFFDELAY	6-90 (**30**)

The power consumed by the BTS is calculated by adding the power consumed by the fixed device (65W), the power consumed by every channel in the control transmitter (12W/channel), and the power consumed by every channel in the remaining active transmitters (9W/channel). These power values were provided by the suppliers.

3.2. Input data

The input data used in the Monte Carlo simulations considers two scenarios:

(1) “the virtual station” scenario, in which it is constant during the whole day. This case is useful for its simplicity, when looking for the best numerical algorithm parameters;

(2) “the real scenario”, in which it varies during the day, according to the data collected for real BTSs under study.

In particular, simulations were performed using the following initial configuration and traffic data:

(i) a “virtual” BTS designed to test the algorithm in fixed conditions. The characteristics of this “virtual BTS” are reported in Table 1.

Table 1. Technical characteristics of virtual stations

Sector	TRXs	Voice time slots	Control channels
VIRTUAL1	3	21	3
VIRTUAL2	4	29	3

Concerning the traffic data used for the “virtual” BTS, one can consider different traffic load set-ups: from a low load condition, with an average of 8640 incoming calls/day to the station and an average call length of 10s, up to extreme load situations with an average of 43200 incoming calls/day and an average length of 50 seconds. In detail, the call/days and the average time calls used are:

Calls/day	8640	17280	25920	34560	43200
Average time/call (s)	10	20	30	40	50

(ii) “Real traffic data” of a BTS (belonging to the base station controller called BFID), located in Toscana (central Italy) with one cell (FID1) was used. The sampling traffic data period is from 29 November 2009 to 13 December 2009, and covers the whole sampling period. The cell has 3 TRXs with 8 time slots, 3 of which operating as a control channel. Table 2 presents the traffic data used for this BTS.

Table 2. Traffic load of BFID

Day	FID1	
	Calls/day	Average time/call
29/11/2009	9865	28,7
30/11/2009	13054	34,0
01/12/2009	12745	33,7
02/12/2009	13453	31,4
03/12/2009	13516	31,7
04/12/2009	13882	33,0
05/12/2009	12596	30,1
06/12/2009	10493	27,1
07/12/2009	13904	30,2
08/12/2009	9349	36,5
09/12/2009	13671	31,3
10/12/2009	14739	37,7
11/12/2009	14628	30,4
12/12/2009	11953	28,0
13/12/2009	9716	30,7

(iii) Another BTS, located in Agliana (Pistoia) and consisting of 3 DCS sectors and 3 GSM sectors, for which a campaign of measurements was performed [1], was considered. Table 3 reports the characteristics of Agliana BTS, in terms of TRXs, time slots and control channels.

Table 3. Characteristics of Agliana BTS

Sector	**TRXs**	**Voice time slots**	**Control channels**
DCS1	4	28	4
DCS2	3	21	3
DCS3	3	20	4
GSM1	4	30	2
GSM2	3	22	2
GSM3	2	14	2

The sampling traffic data period is from 23 March 2009 to 19 April 2009.

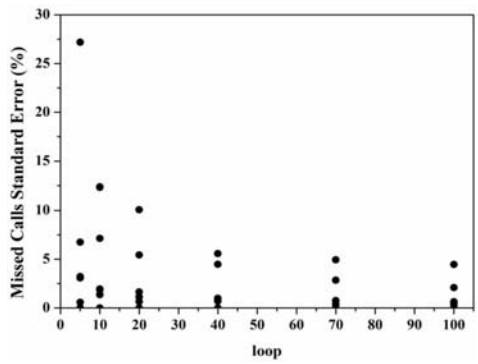
Simulations were performed with scripts written in the R language [27].

4. Results and Discussion

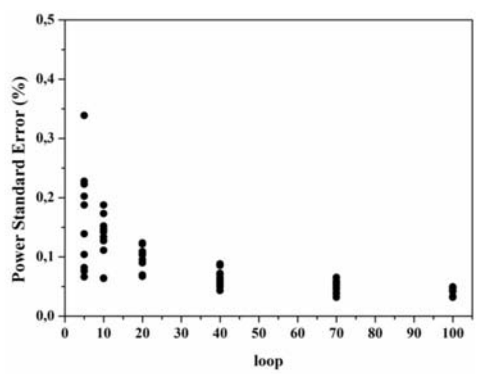
4.1. Tuning of numerical algorithm parameters

In order to tune the algorithm parameters of the simulations, different numerical checks were carried out. In particular, this study focused on the number of simulation cycles useful to minimize the fluctuation of the results and the choice of the algorithm parameters that maximize the energy savings.

To locate the number of simulation cycles needed for a suitably low fluctuation of the output values, it was necessary to set the standard error of the simulated power distribution below 0.1% of the average and the standard error of the distribution of the number of missed calls below 5%.



(a) Missed calls standard error.



(b) Simulated power standard error.

Figure 3

The test was performed by selecting certain days of the week, with various traffic situations (different number and incoming calls length) and by taking the number of simulation loops equal to 5, 10, 20, 40, 70 and 100. The simulations were carried out in both cases, i.e., with and without power saving. The results, presented in Figures 3(a) and 3(b), respectively, show that it is possible to use a number of loops of 70, in order to have standard errors below the chosen threshold.

To find the values of the PS parameters that maximize energy savings, simulations were performed on the data collected in the Agliana BTS, on the first GSM cells. The researchers looked for parameters offering a power consumption as low as possible (keeping the same GoS), which translated into greater savings. For the algorithm parameters, a series of values was used. The results were obtained using the following quantities:

Parameter	**Values**								
BTSPSHYST	1	2	4	6	8	10	12	14	16
TRXOFFTARGET	20				100				
TRXONTARGET	20				100				
TRXOFFDELAY	6				90				

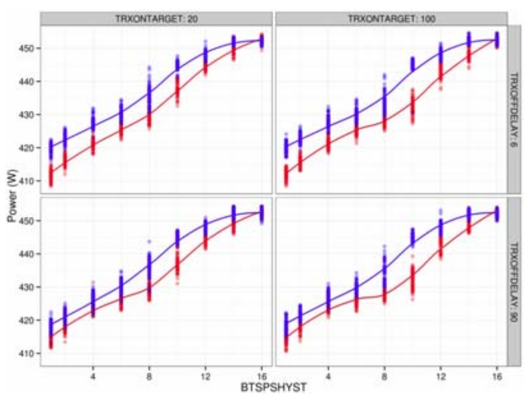


Figure 4. Calculated power consumption vs. parameters of the PS algorithm. Color codes of the TRXOFFTARGET parameter: red = 20 and blue = 100. A smoothed line is shown as a visual aid.

The results of the simulations are shown in Figure 4 where, varying all parameters, the average values of the calculated powers are reported. On the *x*-axis, there are BTSPSHYST values, on the *y*-axis, the power (in Watt) calculated with the algorithm; each group of results (joined by a curve passing through the midpoint) represents different TRXOFFTARGET values. It can be seen that the parameters affect the power produced in the following order of importance:

BTSPSHYST,

TRXOFFTARGET,

TRXOFFDELAY,

TRXONTARGET (practically irrelevant).

Given the results, it is possible to conclude that the couple of algorithm parameters, BTSPSHYST = 1 and TRXOFFTARGET = 20, is the one that presents the lowest power value, and thus the greater power savings, while variations of TRXONTARGET and TRXOFFDELAY have a small effect on power reduction. However, the difference between BTSPSHYST = 1 and BTSPSHYST = 2 is quite small, thus BTSPSHYST = 2 can be considered the suggested value.

Therefore, from now on, the following algorithm parameters are used:

Number of iterations (loops of the simulations) = 70;

BTSPSHYST = 2;

TRXOFFTARGET = 20;

TRXONTARGET = 49 (indicated by the provider as the optimal value) [25];

TRXOFFDELAY = 30 (indicated by the provider as the optimal value) [25].

4.2. Energy saving versus traffic load

With the aim of understanding the role played by the number of TRXs and the traffic load on energy saving, even with respect to the grade of service, this study performed simulations by using the algorithm parameters specified above and a “virtual BTS” station (see Table 1). Figure 5 reports the results obtained through simulations carried out for energy saving with different traffic load set-ups and different numbers of TRXs.

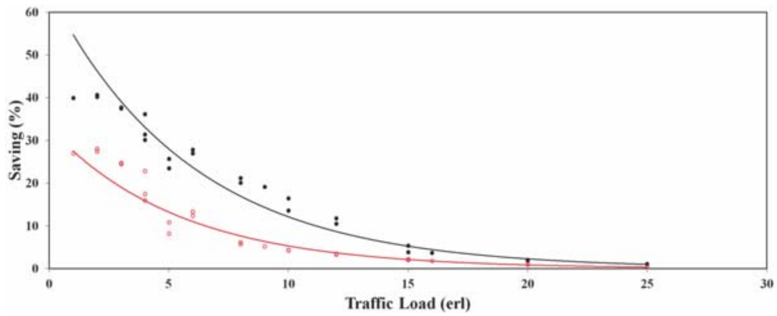


Figure 5. Power saving versus traffic load for two virtual BTSs. Black dots and the related line correspond to a 4 TRXs cell, while red dots and the related line correspond to a 3 TRXs cell.

It can be concluded that power saving depends on the number of TRXs and the traffic load conditions. The percentage of power saving ranges from a minimum of near zero, in situations of heavy telephone load (25 erl), up to a saving of 27% (for station with 3 TRXs) and 40% (for the station with 4 TRXs) for low traffic loads.

In the same simulation, the grade of service (GoS) was also evaluated, calculating it as the complement to 100 of the percentage of missed calls. The GoS is practically the same with and without PS regimes, and indeed the GoS falls to 72% for 3 TRXs station and 91% for 4 TRXs station both with power saving OFF and ON. This behavior is caused by the overloading of the available channels; therefore, the quality of service offered by the station does not depend on the energy saving algorithm, but mainly on the technological structure of the station itself, at least in the parameters range analyzed.

Then, in order to evaluate the energy saving as a function of the number and length of the calls, simulations were performed on the stations FID1, whose results are presented in Figure 6. In this graph, the squares show the daily calls and the dots the average daily length of incoming calls, as a function of the percentage of achieved power saving.

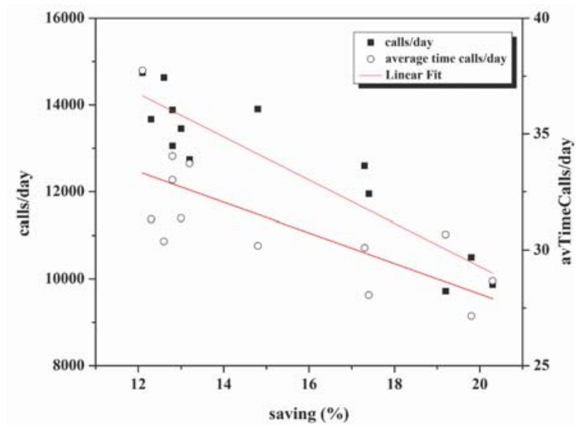
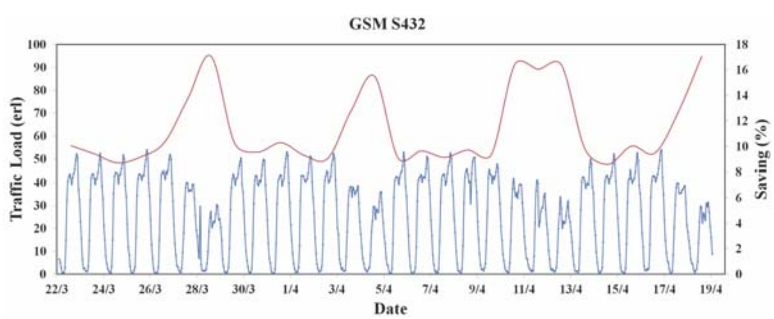


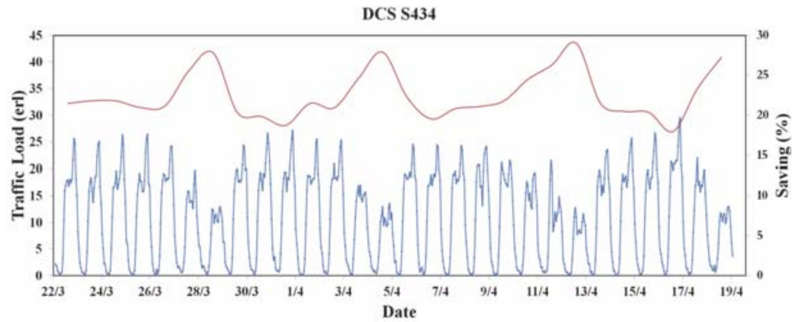
Figure 6. Variation of the percentage of energy saving compared to calls per day and average calls duration in the site FID1.

A decreasing “quasi-linear” relationship between the number of calls per day and the average calls duration versus the percentage of energy saving is found.

Finally, to evaluate the behavior of the energy saving as a function of the traffic load in real life, simulations were carried on the Agliana BTS, whose results are presented in Figure 7, showing the percentage of energy saving (red) and the traffic load (blue), as a function of the date of sampling (days).



(a) Variation of the percentage of energy saving (red line) compared to GSM traffic load (blue line) in the Agliana BTS.



(b) Variation of the percentage of energy saving (red line) compared to DCS traffic load (blue line) in the Agliana BTS.

Figure 7

A clear correlation between energy saving and BTS traffic load can be noticed: an increase of around 10% in energy saving is found during days with less traffic that, in this specific case, is the weekend.

The results found for the energy savings are consistent with those found with similar approaches in the literature [8, 11, 13].

5. Conclusions

This paper outlines a new "power saving features" Monte Carlo (MC) algorithm, useful to define the maximum achievable saving in the BTS transmission, without altering the grade of service (GoS), which was developed and tested for different BTS characteristics and traffic load conditions. The main remarkable facts are:

- The appropriate number of simulation cycles, needed to achieve an acceptably low fluctuation of the output values, was achieved. Moreover, we showed that for each set of parameters, it is possible to identify the best values for the PS features parameters with the goal to maximize energy savings.

- A linear dependence of the energy saving as a function of the number and length of the calls was found.

• Energy saving of BTS depends on the number of TRXs, the different technologies (GSM, DCS) and the traffic load: an energy saving of 27% and 40% for BTS, with 3 and 4 TRXs, respectively, was estimated.

• Finally, the GoS does not show a difference between the PS simulation and NOPS simulation, and it does not depend on the number of TRXs and traffic load, at least in a given range of parameters. This means that the quality of service offered by the station does not depend on the energy savings algorithm, but mainly on the technological structure of the station itself.

Thus, it can be concluded that the PS can and should be activated in the BTS for a substantial saving of the consumed energy, without affecting the GoS of the BTS itself.

The best numerical and operating parameters can successfully be addressed with a suitable MC algorithm, which also provides the expected saving.

Acknowledgement

We kindly acknowledge Italian mobile telecommunications providers (H3G, Vodafone, Telecom and Wind) and their technological partners (Ericsson). This study was partially funded by Regione Campania through European funds (POR Campania FSE 2007-2013) for the “Dottorato in azienda” project.

References

[1] C. Lubritto, A. Petraglia, C. Vetromile, S. Curcuruto, M. Logorelli, G. Marsico and A. D’Onofrio, Energy and environmental aspects of mobile communication systems, Energy 36(2) (2011), 1109-1114.

[2] ETSI-ITU, Measurement Method for Energy Efficiency of Wireless Access Network Equipment, Guideline, 2013.

[3] J. T. Louhi, Energy efficiency of modern cellular base stations, Presented at Telecommunications Energy Conference, 2007, INTELEC 2007, 29th International, 2007, pp. 475-476.

[4] X. Sun, Q. Zhang, M. A. Medina, Y. Liu and S. Liao, A study on the use of phase change materials (PCMs) in combination with a natural cold source for space cooling in telecommunications base stations (TBSs) in China, Appl. Energy 117 (2014), 95-103.

[5] M. Sorrentino, G. Rizzo, F. Genova and M. Gaspardone, A model for simulation and optimal energy management of telecom switching plants, Appl. Energy 87(1) (2010), 259-267.

[6] Ericsson, Sustainable Energy Use in Mobile Communications, White Pap., 2007.

[7] N. Faruk, A. A. Ayeni, M. Y. Muhammad, L. A. Olawoyin, A. Abdulkarim, J. Agbakoba and M. O. Olufemi, Techniques for minimizing power consumption of base transceiver station in mobile cellular systems, Int. J. Sustain. 2(1) (2013), 1-11.

[8] M. A. Marsan, L. Chiaraviglio, D. Ciullo and M. Meo, Optimal energy savings in cellular access networks, IEEE International Conference, 2009, pp. 1-5.

[9] M. Ajmone Marsan, L. Chiaraviglio, D. Ciullo and M. Meo, On the effectiveness of single and multiple base station sleep modes in cellular networks, Comput. Netw. 57(17) (2013), 3276-3290.

[10] L. Chiaraviglio, D. Ciullo, M. Mellia and M. Meo, Modeling sleep mode gains in energy-aware networks, Comput. Netw. 57(15) (2013), 3051-3066.

[11] S. Zhou, J. Gong, Z. Yang, Z. Niu and P. Yang, Green mobile access network with dynamic base station energy saving, MobiCom’09, Vol. 9, 2009, pp. 10-12.

[12] X. Wang, A. V. Vasilakos, M. Chen, Y. Liu and T. T. Kwon, A survey of green mobile networks: opportunities and challenges, Mob. Netw. Appl. 17(1) (2012), 4-20.

[13] E. Oh and B. Krishnamachari, Energy savings through dynamic base station switching in cellular wireless access networks, Global Telecommunications Conference (GLOBECOM 2010), 2010, pp. 1-5.

[14] E. Oh, B. Krishnamachari, X. Liu and Z. Niu, Toward dynamic energy-efficient operation of cellular network infrastructure, IEEE Commun. Mag. 49(6) (2011), 56-61.

[15] S. Roy, Energy logic: a road map to reducing energy consumption in telecommunications networks, Telecommunications Energy Conference, INTELEC 2008, IEEE 30th Int., 2008, pp. 90-98.

[16] R. Tu, X.-H. Liu, Z. Li and Y. Jiang, Energy performance analysis on telecommunication base station, Energy Build. 43(2) (2011), 315-325.

[17] Huawei, Energy Savings Creates Profit, Reduces OpEx, 2011.

[18] J. K. Kaldellis, I. Ninou and D. Zafirakis, Minimum long-term cost solution for remote telecommunication stations on the basis of photovoltaic-based hybrid power systems, Energy Policy 39(5) (2011), 2512-2527.

[19] J. K. Kaldellis, Optimum hybrid photovoltaic-based solution for remote telecommunication stations, Renew. Energy 35(10) (2010), 2307-2315.

[20] J. K. Kaldellis and I. Ninou, Energy balance analysis of combined photovoltaic-diesel powered telecommunication stations, Int. J. Electr. Power Energy Syst. 33(10) (2011), 1739-1749.

[21] S. Leva and D. Zaninelli, Hybrid renewable energy-fuel cell system: design and performance evaluation, Electr. Power Syst. Res. 79(2) (2009), 316-324.

[22] M. S. Okundamiya, J. O. Emagbetere and E. A. Ogujor, Design and control strategy for a hybrid green energy system for mobile telecommunication sites, J. Power Sources 257 (2014), 335-343.

[23] C. Lubritto, A. Petraglia, C. Vetromile, A. D'Onofrio, F. Caterina, M. Logorelli, G. Marsico, S. Curcuruto, L. Miglio and F. Cenci, Simulation analysis and test study of BTS power saving techniques, Presented at Telecommunications Energy Conference, 2009, INTELEC 2009, 31st International, 2009, pp. 1-4.

[24] T. Louail, M. Lenormand, O. Cantú, M. Picornell, R. Herranz, E. Frias-Martinez, J. Ramasco and M. Barthelemy, From mobile phone data to the spatial structure of cities, 2014, arXiv:1401.4540.

[25] Ericsson, Reduced power consumption in GSM RAN, User Description, 2008.

[26] C. Vetromile, A. Petraglia, A. D'Onofrio, M. Logorelli, G. Marsico, S. Curcuruto and C. Lubritto, New models for BTS energy savings strategies, Presented at Telecommunications Energy Conference, 2010, INTELEC 2010, 32nd International, 2010, pp. 1-4.

[27] The R Foundation for Statistical Computing, R Studio.