Traffic Load Influence on Power Consumption of GSM and UMTS Base Stations

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Abstract: It has been shown that the base stations represent main contributor to the energy consumption of a mobile cellular network. Since traffic load in the mobile networks significantly varies during a working or weekend day, it is important to quantify influence of this variations on the base station power consumption. Therefore, this paper investigates changes in the instantaneous power consumption of the GSM (Global System for Mobile Communications) and UMTS (Universal Mobile Telecommunications System) base stations according to their respective traffic load. The real data in terms of the electric current draw and traffic load have been obtained from continuous measurements performed on a fully operated base station site. Measurements show existence of direct relationship between base station traffic load and power consumption. This paper also gives an overview of the most important concepts which are being proposed to make mobile networks more energy-efficient.

1. INTRODUCTION

As mentioned in [1], approximately 3% or 600 TWh of the worldwide electrical energy is consumed by information and communication technology (ICT) sector. It is estimated that energy consumption of the ICT will grow to 1700 TWh by 2030. Therefore, it is necessary to find new solutions to reduce energy consumption of the ICT sector and thus make telecommunication systems more "greener". Since cellular networks constitute significant part of the ICT sector, reducing consumption of the cellular access networks will contribute to the energy consumption reductions of the whole ICT sector.

The growing interest for new and reliable services in the mobile telecommunications results with increased number of installed base stations (BSs) worldwide. In addition, traditional concept of BSs deployment assumes its continuous operation in order to guarantee the quality of service anywhere and anytime. All mentioned contributes to the significant upgrowth of the total network energy consumption during last decade. It is well known that the main source of the energy consumption in the cellular mobile networks is BS with a share in total network consumption greater than 50% [2]. Therefore, reducing energy consumption of BSs as the main energy consumers in the cellular networks recently becomes important research topic.

To reduce energy consumption of the cellular networks, precise knowledge about BS energy consumption and influence of the traffic load on BS energy consumption can be of great importance. Hence, this paper tackles mentioned issues through presentation of the measuring results obtained from a real, fully operated BS site.

The rest of the paper is organized as follows: Section 2 presents an overview of the most important approaches dedicated to improving energy-efficiency of the mobile networks. Description of the BS site on which measurements have been performed with explanation of measuring setup has been given in Section 4. In Section 5, obtained measuring results have been presented and discussed. Finally, Section 6 gives some concluding remarks.

2. OVERVIEW OF ENERGY SAVING APPROACHES

Since BSs have the largest share in the energy consumption of cellular networks, it is necessary to identify those elements of BS which considerably contribute to the overall energy consumption. From the power consumption point of view, elements of BS can be divided in two groups: radiofrequency equipment (which includes power amplifiers and transceivers, whose roles are to serve one or more sectors), and support system (which includes AC/DC power conversion modules, air condition elements, analogue and digital signal processors, battery backup etc.).

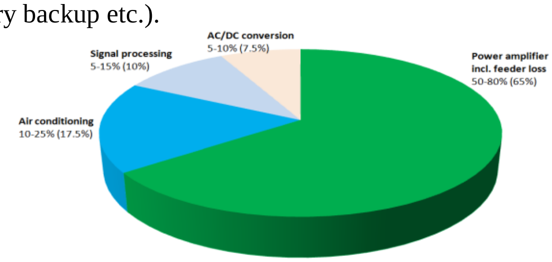

Figure 1 – Structure of BS energy consumption [3]

As shown in Fig.1, the largest energy consumer in the BS is power amplifier which has a share of around 65% in total energy consumption [3]. Of the other base station elements, significant energy consumers are air conditioning (17.5%), digital signal processing (10%) and AC/DC conversion elements (7.5%) [4].

New researches aimed at reducing energy consumption in the cellular access networks can be viewed in terms of the three levels: component, link and network. At the component level, investigations are primarily focused on improving linearity and efficiency of the power amplifier. Efficiency can be improved using specially designed power amplifier like Doherty, or special materials for power amplifier transistors, like high-frequency materials such as Si, GaAs or GaN. Efficiency can also be improved using techniques such as Envelope Tracking [5], or by using one of the techniques for Crest Factor Reduction, like peak windowing or amplitude scaling. Digital Pre-Distortion technique can be used in the power amplifier for cancelling the distortion, and therefore achieving better linearity [6].

Regarding the other BS components, the power consumption of the signal processing can be reduced using ASIC, DSP or FPGA architectures of integrated circuits, which are often combined to achieve better efficiency [7]. AC/DC conversion in BSs can be improved using highly efficient converters that can increase their efficiency even in high traffic load situation. Power consumption caused by air conditioning can be reduced by expanding operational temperature of base station models, or by using additional elements like heat exchangers, membrane filters and smart fan or heater modules [8].

Additionally, at the component level, energy savings can be achieved by implementing distributed BS architecture, where the radiofrequency equipment is placed near the antennas to minimize the losses in cables [9]. The possibility of installing photovoltaic panels and wind turbines on the base station sites are also investigated. Even combining these two renewable energy sources can lead to potential reduction in the power consumption by 50% [10].

The potential for energy savings at the link level are in the transmission techniques on the air interface, while the network level potential lies in energy-efficient management of network resources. The link level considers possible sleep modes of some BS components (micro and macro sleep), where some of them are being switched off for a certain time. In that case, BS must provide a certain differentiation between transmissions by scheduling traffic load in the uplink and downlink [4]. The 4G systems are considering the possibility of dynamic allocation of frequency spectrum depending on a traffic load [11]. The cancellation of the interference in cellular systems using distributed antenna systems and algorithms such as: linear zero forcing, minimum squared error and successive interference cancellation also contributes to the reduction of energy consumption [12].

At the network level, one of the most important approaches for reducing energy consumption is in the dynamic management of BS resources, which allows shutting down of the entire BS during a low traffic load. In such scenario, neighboring BSs must provide coverage and take over the traffic load of those BSs that are turned off [4]. This can be can be combined with dynamic Tx power selection, antenna tilting, multihop relaying or by coordinated multipoint transmission and reception [13]. The cellular network configuration itself represents the potential for reducing energy consumption, where the possibility of using heterogeneous cellular architecture is explored. In this type of cellular network, macro cells are complemented with low transmit power cells like micro, pico and femto cells [11]. The possibility of applying techniques such as cell zooming, where cell can adjust its size according to traffic load situation, is also explored [14]. Some initiatives are based on possible energy savings by cooperation between competing operators who provide services in the same area of coverage (usually in the cities). The point is that one of the operators can completely switch off its BS during the low traffic load, where the BS of the second operator accepts the subscribers of the both operators. According to the authors in [15], such approach can offer reductions in energy consumption by 20%. Most of the mentioned approaches will be practically implemented, what will result in significant reductions in energy consumption of the cellular access networks. Actually,

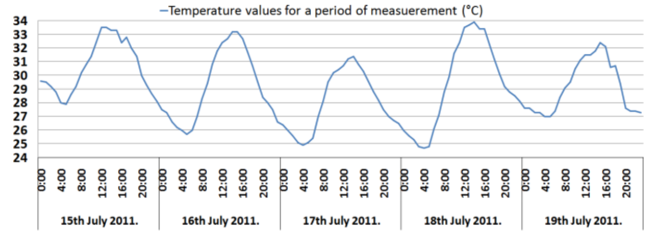

Figure 2 – Temperature values for the measuring period

the concurrent use of different approaches will have a synergistic effect that leads to completely energy-efficient mobile networks of the future.

3. SITE DESCRIPTION AND MEASUEREMENT SETUP

In order to show interdependence between BS energy consumption and traffic load, extensive on-site measurements were performed on fully operated BSs site located in an urban-dense area of a medium sized city. Selected BS site is one of the most loaded city sites in terms of a voice and data traffic flows. Information's considering: name of a mobile operator, BS site location, model and manufacturer of BSs will not be provided in order to guarantee operator confidentiality.

BSs of the three different cellular access technologies: GSM 900, GSM 1800 and UMTS have been allocated on the measuring site. Each BSs cabinet is indoor type of the cabinet located inside protected room dedicated solely for keeping site equipment. Antenna lines connect each BS cabinet with corresponding antennas located on the top of the building. Site is connected with backbone network using optical lines over gigabit switch. Overview of the site properties regarding installed BSs have been shown in Table 1.

For proper functioning of each BS cabinet, declared voltage values of DC power supply ranges from 43 V to 56 V. Additionally, site contains redundant DC battery supply of 48 V connected by means of a buffer coupling with the site AC/DC electricity converter. In the most common mode of site operation, characterized with non-interrupted energy supply form electricity grid, AC/DC converter gives time invariant DC voltage equal to 53,6 V. Also, complete site is air conditioned and site cooling consumes approximately 2 kWh.

Furthermore, it is necessary to emphasize temperature characteristics of the analyzed BS site located in a Mediterranean climate region. Figure 2 shows the daily temperature variations during measuring period which are typical for that part of a year. According to Figure 2, there was no significant oscillation in the temperature during measuring period. Hence, they did not significantly affect the measuring results and due to presence of cooling device influence of these oscillations on measuring results can be neglected.

For measuring the energy consumption of the individual BSs installed on site, the following equipment ware used: laptop with specialized measuring software, multi-channel measuring instrument, current clamps and corresponding cables. Photography of measurement setup has been presented in Figure 3. Used multi-channel instrument is Handyscope HS4

Table 1 – Characteristics of on-site base stations

CHARACTERISTICS OF ON-SITE BASE STATIONS	BASE STATION MODEL		
	GSM 900	GSM 1800	UMTS
Year of base station model production	2002.	2009.	2010.
Frequency band	900 MHz	1800 Mhz	2100 MHz
Number of base station racks	3	1	1
Number of transcievers in base station rack	7 – Sector 1 7 – Sector 2 4 – Sector 3	12	3
Number of sectors covered by one rack	1	3	3
Number of transcievers per sector	7 – Sector 1 7 – Sector 2 4 – Sector 3	4	1
Number of antennas per sector	2	1	1
Number of combiners in rack	3	3	integrated in radiofrequecy module
Number of antenna cables per antenna	2	2	2
Output power per sector	50 W	25 W	25 W
Antenna cable diameter	7/8"		
Average power consumption of site	7.5 kW		

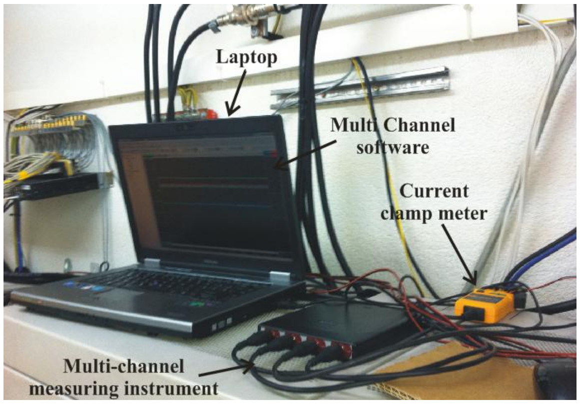

Figure 3 – Measuring devices used on site

of manufacturer TiePie Engineering. This instrument has capability of mapping up to four input measuring signals. In our case, measuring signals have been generated by Fluke i30s current clamps. They are used for precise detection of DC current which flows through electric supply cable of BS cabinets. Measured signals are concurrently transferred through USB cable to the laptop on which the Multi Channel software of the corresponding multi-channel instrument has been installed. Such software enables graphical presentation of measured results with many processing options.

In our research, we take into consideration two GSM 900 BS cabinets dedicated for transferring Sectors 1 and 2 traffic. Residual GSM 900 BS cabinet covering Sector 3 has not been analyzed due to significantly smaller average traffic load. In addition, measurements have been performed for GSM 1800 and UMTS BSs having in the single cabinet equipment for covering all three sectors (Table 1). During measuring period, we measure in parallel current draw of four BS cabinets (GSM 900 Sectors 1 and 2, GSM 1800 and UMTS) on each of four channels of the multi-channel instrument.

Frequency of measuring samples has been set up to 5 kHz on each of the measuring channels. Furthermore, samples have been filtered using low-pass filter of 1 Hz and finally re-sampled to 10 Hz, what results with 1 measuring sample every 10 seconds. Due to slow changes of the BS power consumption during a day, it is reasonable to believe that such approach guarantees acceptable measurement accuracy.

Continuous four-day measurements were performed in the period from 15th July starting at 12:00 until 19th July ending at 10:00. It is worth to emphasize that measuring period starts at Friday and finishes at Tuesday, taking into account not only working but also weekend days. We select such measuring period in order to notice possible differences in the BSs power consumption among working and weekend days.

4. MEASURING RESULTS

4.1 Instantaneous power consumption

Changes in the instantaneous power consumption of GSM 900 (Sector 1 and 2), GSM 1800 and UMTS BSs have been presented on Figures 4, 5, 6 and 7, respectively. This power consumptions of the individual BSs have been obtained by multiplying the measured values of the instantaneous BS electric current consumption with constant DC voltage (53,6 V). Very short but rapid decline of the power consumption in the early morning hours on the last day of measurements can be perceived in Figures 4 – 6. Due to extremely short duration, this unexpected decline caused by short instability of some BS components will not influence on overall measurement results and can be neglected. According to Figures 4 - 7, it is obvious that the power consumption of each BS is not constant in time. Actually, instantaneous power consumption of the BSs varies during a day and these variations are inherent for all analyzed mobile technologies (GSM 900, GSM 1800 and UMTS).

From Figures 4 - 7 can be noticed that the highest power consumer is the GSM 1800 BS. When compared with the BSs consumption of the other technologies, this BS has more than twice higher instantaneous power consumption in any moment. This is because GSM 1800 cabinet serves concurrently all three sectors through configuration with 4 transceivers (TRXs) per sector (4/4/4). Since each TRX has separate power amplifier and in Section 2 we show that the power amplifier has the highest share in the BS power consumption, number of TRXs have important influence on the total BS power consumption. Therefore, when compared with the number of TRXs in GSM 900 (7/sector) and UMTS (1/1/1) cabinets (Table 1), higher total number of TRXs (12) in GSM 1800 BS cabinet is the main reason for higher power consumption.

In addition, influence on the power consumption will be somewhat contributed with the fact that GSM 1800 BS has been selected for maximal capacity utilization. This means that GSM 1800 BS first accepts voice and textual massaging communication. Other three GSM 900 BSs serves as redundant BSs in case when GSM 1800 is fully loaded or when level of received signal strength drops below a predefined threshold. Nevertheless, GSM 900 BSs execute call setup establishment and start of the conversation, what preserves high activity level of BSs. From Figures 4 and 5 can be noticed that Sectors 1 and 2 of the GSM 900 BS have similar power consumption pattern. BS serving Sector 1 traffic has somewhat higher power consumption during every moment of a day because of the

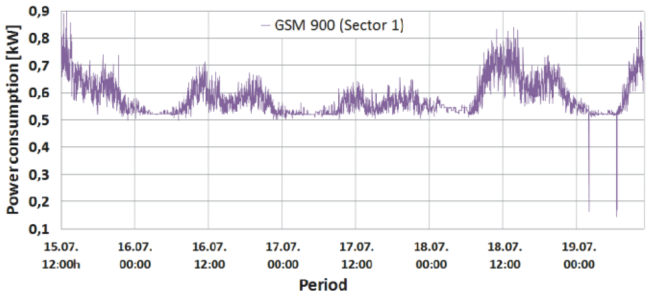

Figure 4 – Power consumption of GSM 900 (Sector 1) BS cabinet

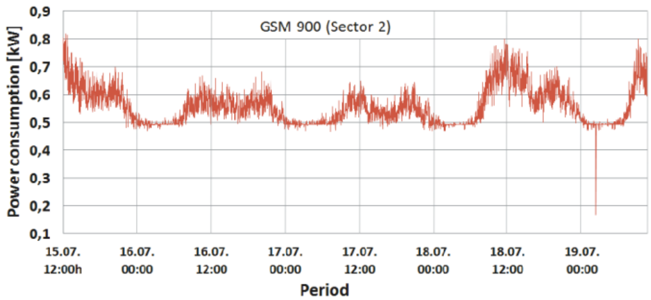

Figure 5 – Power consumption of GSM 900 (Sector 2) BS cabinet

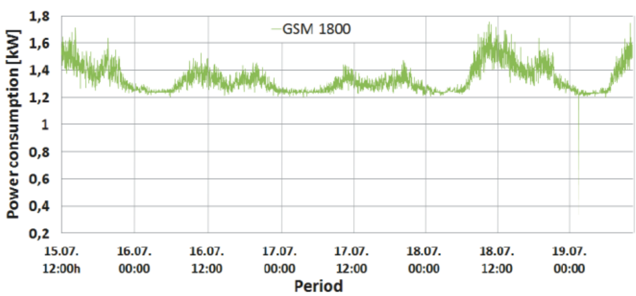

Figure 6 – Power consumption of GSM 1800 BS cabinet

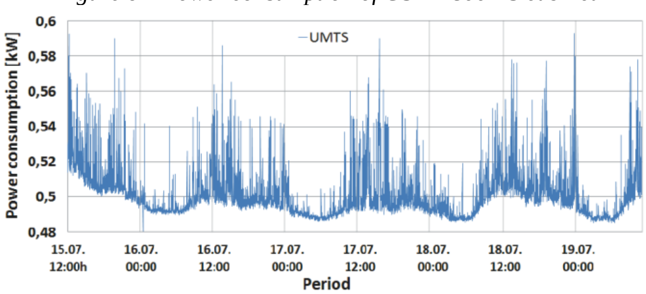

Figure 7 – Power consumption of UMTS BS cabinet

higher traffic activity of the users located inside Sector 1. Of all the on-site BSs, UMTS BS has the lowest power consumption. This can be explained with minimal TRX configuration (1/1/1) and the newer technology characterized with BS hardware which is generally more energy-efficient.

Conformation to this can be found in Table 2 containing minimal and maximal daily power consumptions with percentile ratio between them for weekend days and one working day. Based on Table 2, the lowest oscillations in the daily power consumption have been recorded for UMTS

Table 2 – Power consumption statistics for working and weekend days

Period	Parameter	GSM 900 (Sector 1)	GSM 900 (Sector 2)	GSM 1800	UMTS
Saturday, July 16, 2011	Min. daily power consumption [kW]	0,5545	0,5188	1,3450	0,5289
	Max. daily power consumption [kW]	0,8435	0,7822	1,7175	0,6581
	Min./Max. power consumption ratio	66%	66%	78%	80%
	Total energy consumption [kWh]	**15,0385**	**14,4913**	**34,9149**	**13,4191**
Sunday, July 17, 2011	Min. daily power consumption [kW]	0,5509	0,5202	1,3415	0,5422
	Max. daily power consumption [kW]	0,7560	0,7449	1,6819	0,6626
	Min./Max. power consumption ratio	73%	70%	80%	82%
	Total energy consumption [kWh]	**14,6812**	**14,2074**	**34,4789**	**13,3499**
Monday, July 18, 2011	Min. daily power consumption [kW]	0,5607	0,5176	1,3452	0,5419
	Max. daily power consumption [kW]	0,9892	0,9139	1,9739	0,6994
	Min./Max. power consumption ratio	57%	57%	68%	77%
	Total energy consumption [kWh]	**16,4551**	**15,5838**	**36,9737**	**13,4769**

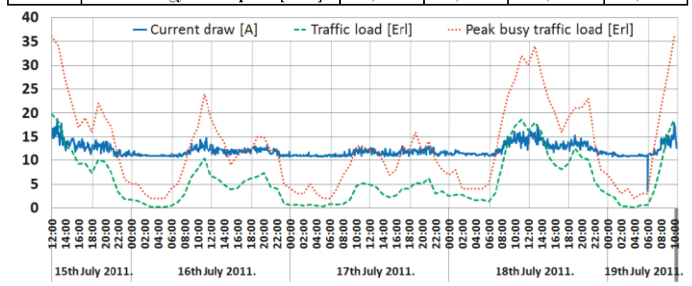

Figure 8 – Comparison between electric current draw and traffic load for GSM base station (Sector 1)

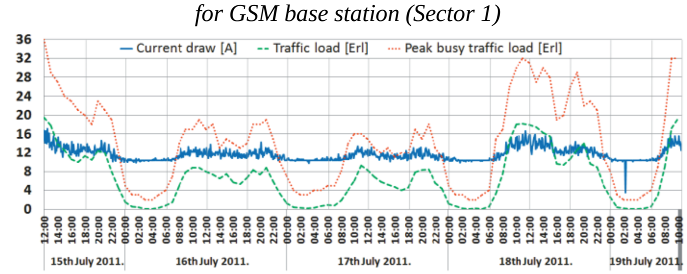

Figure 9 – Comparison between electric current draw and traffic load for GSM base station (Sector 2)

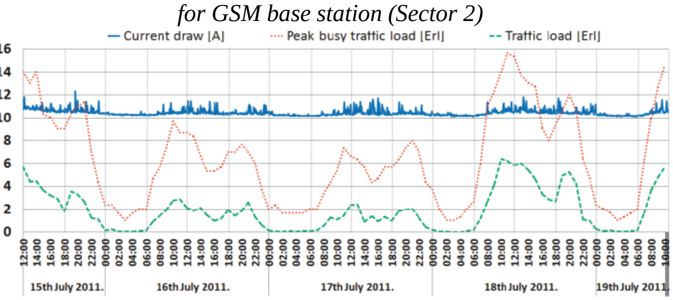

Figure 10 – Comparison between electric current draw and traffic load for UMTS base station

technology (~20 %) while the highest variations have been obtained for GSM 900 BSs (34 % - 43 %). Although GSM 900 and 1800 BSs are of the same technology and manufacturer, GSM 1800 BS with even higher number of TRXs has lower variations in the daily power consumption (22% - 32%). This is direct result of hardware improvements built in newer GSM 1800 and UMTS BSs manufactured in 2009 and 2010 (Table 1), respectively.

In a many recent analyses dedicated to improving energy-efficiency of the cellular networks, these variations are neglected; assuming constant power consumption of BSs. This assumption is obviously incorrect, but it ensures significant simplification when expressing BS power consumption. On the other hand, such simplification can lead to wrong estimation of BSs monthly energy consumption. This is because daily energy consumptions of BSs have been different for every day in a week (Table 2). Generally, higher energy is consumed during the working day (Monday) and small differences in the energy consumption can be even noticed between weekend days.

4.2 Interdependence of power and electric current

Shape of the power consumption pattern presented in Figures 4 – 7 is basically identical for all BSs and does not depend on the transmission technology. This means that the highest power consumption has been recorded between 10:00 and 14:00 (peak hours) for every of the analyzed days. In addition, increased consumption is recorded in the period from 19:00 to 22:00, while lowest consumption has been observed between 01:00 and 08:00. Also, during peak hours, for each BS differences in the power consumption between working (15th, 18th and 19th July) and weekend (16th and 17th July) days can be clearly perceived. Figures 4 – 7 shows that BSs during the peak hours of the working days have higher power consumption when compared with consumption during the peak hours of the weekend days (Table 2).

Such shape of the power consumption pattern is direct consequence of a daily traffic pattern variation. It can be said that increase in a user activity during a day results with increase in the instantaneous power consumption of a BSs and vice versa. Conformation of this can be found in Figures 8, 9 and 10, presenting comparison between measured traffic load and electric current consumption for GSM 900 Sector 1, Sector 2 and UMTS BSs, respectively. Information's regarding average traffic load and peak (maximal) traffic load recorded on hourly bases have been obtained from specialized monitoring system of the operator. In the case of UMTS BS traffic load, it is worth to emphasize that we present in Figure 10 averaged traffic load of all three sectors.

Graphs presented in Figures 8 – 10 shows that changes in the instantaneous electric current closely pursue variations of the peak and average traffic loads. Hence, direct correlation between the electric current draw and variations in the traffic pattern can be perceived. Somewhat lower level of correlation can be noticed in Figure 10 for UMTS current draw, due to minimal number of TRXs in the BS configuration (1/1/1) and only one year old equipment which is less prone to traffic variations. Although level of correlation in Figures 8 – 10 might seem negligible; it is consequence of presentation approach which uses the same axes to present different measuring parameters. On the other hand, influence of the correlation is highly reflected on the power consumption (Fig. 4 – 7), what explains its daily variations which are not negligible.

In terms of generating voice or data traffic, activity of the users during first quarter of a day is low and current draw of the BSs will be lower. On the other hand, during peak hours, users activity is high and BSs consumption of the electric current becomes higher. Explanation of such behavior can be found in additional hardware and processing resources that must be activated by a BS in order to accommodate increased traffic load. Therefore, typical day/night variations in the user's activity have influence on the BSs power consumption.

5. CONCLUSION

In this paper, we investigate impact of the traffic pattern variations on the power consumption of BSs. Analyses have been performed on a real BS site containing BSs of GSM 900, GSM 1800 and UMTS access technologies. After four days of continuous measurements we obtained results which confirm that the instantaneous power consumption of all BSs varies in accordance with the traffic load. This is consequence of direct correlation which exists between the BS electric current draw and traffic load pattern. According to the obtained power consumption pattern, higher power consumption of the BSs has been recorded during working days due to higher user activity. In addition, measurements show non-negligible daily oscillations among peak values of the instantaneous power consumption reaching up to 40 %. Also, in this paper we give an overview of the latest research activities focused on improving energy-efficiency in the cellular access networks.

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