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opportunities and potentials

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Published in:
75th Vehicular Technology Conference (VTC Spring), 2012 IEEE

DOI (link to publication from Publisher):
10.1109/VETECS.2012.6240298

Publication date:
2012

Document Version
Accepted author manuscript, peer reviewed version

Energy savings in mobile broadband network based on load predictions: opportunities and potentials

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***Abstract*—The deployment of new network equipment is resulting in increasing energy consumption in mobile broadband networks (MBNs). This contributes to higher CO_2 emissions. Over the last 10 years MBNs have grown considerably, and are still growing to meet the evolution in traffic volume carried in wireless networks. To save energy in MBNs, one of the options is to turn off parts of the network equipment in areas where traffic falls below a specific predefined threshold. This paper looks at a methodology for identifying periods of the day when cells or sites carrying low traffic are candidates for being totally or partly switched off, given that the decrease in service quality can be controlled gracefully when the sites are switched off. Based on traffic data from an operational network, potential average energy savings of approximately 30% with some few low traffic cells/sites reaching up to 99% energy savings can be identified.**

I. Introduction

About 1 percent of global energy is consumed by mobile network providers, making MBNs one of the biggest energy consumers [Roy08]. Between 1996 and 2008, the number of mobile devices rose from 145 million to more than 4 billion [Uni09]. Many of these devices requires a continuously active mobile data connection. During 2010, data traffic generated on mobile networks increased by about 80%; according to [Cis11], network traffic growth of 130% is estimated in countries worldwide. In addition, each user is constantly consuming more data, with more dedicated, interactive, and multimedia based content being available on mobile devices. To support traffic growth in MBNs, more base station sites and higher baseband processing power are required. The prospect of increased energy consumption in the MBNs has already led to improvements in the construction of base station equipment. Various component improvements, their respective energy consumption, and potential savings are discussed in further details in [Uni08]. According to [Roy08], in 2008, one of the main energy consumer in MBN was active cooling. Development of technical MBN hardware that can operate at higher temperatures allows switching to passive cooling [Uni09]. MBNs are planned and deployed in order to guarantee a specific Quality of Service (QoS) during the busy hour. Over a 24 hour period this is the single hour during which the network experiences the highest amount of traffic. However, over a 24 hour period, network load varies between high, normal, low, and idle (no traffic, but still transmitting synchronization and control information). In order to fulfill increasing requirements at existing and next generation MBNs during high load periods, new solutions that include deployment of smaller cells are being considered. Mobile network operators (MNOs) deploy new sites, concentrating the capacity of each on a smaller geographical area. This leads to overlapping coverage areas where multiple base stations may serve the user. Traffic load trends in MBNs can be forecasted and predicted based on past network data. Load predictions can be carried out for different network layers, considering individual cells, entire site or groups of sites. The possibility of predicting low traffic periods will result in energy savings given that it is technically possible to turn off base station equipment during the predicted low traffic periods. As an alternative to network optimization, forecasting and prediction can also help in identifying network areas where mobile network operators (MNO) will require deployment of new equipment in order to maintain a specific QoS level during the busy hour. The interest in energy optimization has spurred an interest in the research community over the past few years; commitments to reduce CO_2 emissions presented in [Eri08], energy saving solutions replacing the old MBN equipment [Eri07]. Energy consumption problems have been noticed by the European Commission [Gor07] as well. In 2010, the European project EARTH [con10] started researching energy consumption issues in the wireless infrastructures. One of their goals is energy efficient deployment strategies. Energy related optimization questions at MBN are presented in different studies. [Cis11], [JWfCy10] discuss increasing traffic and energy use in MBN without considering energy saving policies. [MCCM09] presents energy optimization strategies given the assumption that traffic patterns are identical in each cell. However, in the real networks, traffic is more dynamic. [ZGY+09] introduces dynamic base station optimization using simulated data.

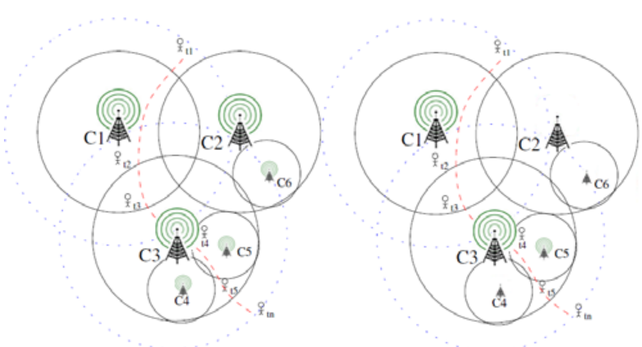
In our paper the possibilities of dynamic base station optimization, based on the identification of day periods when cells or sites carrying low traffic are candidates for being totally or partly switched off are discussed. A simple traffic load threshold for selecting candidates for optimization is presented. We assume that the decrease in service quality from switching off sites or cells can be controlled gracefully. The possibilities of using forecasting and prediction on traffic data obtained from an operational HSDPA network and optimization are presented.

The paper is organized as follows. Section II starts with the background information on network configuration and energy consumption in MBNs. Section III presents an overview of the network data traffic, load and traffic prediction. Section IV the results in terms of energy saving. Section V presents interpretations and discussions. Finally, Section VI concludes the paper with conclusions and future work.

II. Mobile networks and energy savings

A. Network construction

A mobile network is composed of a grid of base station sites. A site is composed of a number of cells, generally three, co-located and sharing partly the same site equipment. Cells within the site are arranged for maximum cell coverage, nominally with an angle of 120 degrees between two neighboring cells. The site equipment consists mainly of antennas, radio frequency amplification and conversion, baseband signal processing, cooling and power supply (see Section II-B for details).



(a) No optimization (b) With optimization

Fig. 1. Network structure

A simplified network structure assumed in this paper is illustrated in Figure 1. A fully operating network with no optimization is shown in Figure 1a, and a network with energy optimization is shown in Figure 1b. Lines over the sites show, see Figure 1b, that sites are active, e.g., **C1**, **C4**, and sites with no lines are inactive, e.g., **C2**, **C6**. Black circles represent the covered area within which a user would normally connect to the site. Dotted lines define the coverage of sites **C1** and **C3**, in the absence of **C2**. The coverage cannot be strictly defined, since in general it depends on propagation conditions and interference between cells. Within the overlapping areas, the user performs handover, i.e., the mobile user is disconnected from the operating site and connected to the new site. Dashed line presents a users trip over time.

The MBN is constructed of different layers, where every layer provides different network coverage. The three sites **C1**, **C2**, and **C3** presented in Figure 1 construct a macro layer. Macro sites cover large areas and in general produce bigger overlapping regions.

The micro layer consists of cells with smaller network coverage - micro sites. Micro sites can serve smaller areas, low coverage or hot spot areas with high capacity demand. Due to the requirements for higher peak data rates and increased network capacity, smaller micro sites such as **C4**, **C5** and **C6** are required in future mobile networks.

Allocation of new sites in covered areas produce further overlappings that can be optimized by turning off parts of the network equipment and can result in energy savings. In Figure 1b, micro site **C4** could be turned off during low traffic periods, since macro site **C3** fully covers the area of site **C4**. By the same principle the area of **C2** and **C6** could be partly supported by neighboring sites. The same strategy of turning on and off could be used within different network layers, as well as with individual cells and sites.

B. Energy savings in MBNs

The energy consumption of a base station site is typically, [Roy08], divided according to:

- Antenna 1.2%
- Feeder 1.2%
- RF conversion & amplification 21.2%
- Baseband processing 40.1%
- Power Supply 11.3%
- Cooling 25%

Only a small fraction of the total consumption is radiated as Radio Frequency (RF) energy and by far most of the electrical energy is turned into heat, thereby necessitating cooling. Some of the network equipment is shared, therefore turning off some of it can cause either cascading effects on all the other active equipment or give very small savings. For example turning off one cell in a three sector site will give less than 33% of energy savings, since cooling, power supply are shared with a large fixed and a smaller load dependent part. Maximum energy savings will only be achieved if the whole site is turned off, leaving only equipment required for turning the site on.

III. Forecasting and predicting network traffic

A. Data traffic

Historical information is a good source for making future predictions. In this study traffic data generated by an actual European MBN is used for making predictions and forecasts. The data set was collected in 2009, during two different weeks for 334 cells located in 112 sites. Data measurements were logged hourly and contained the data logging date, the amount of users served by the cell, and the data traffic throughput in kilobits that was generated during the single hour. Actual traffic throughput would be higher these days but traffic trends should remain the same (temporarily and spatially). Figure 2 shows the average traffic for a weekday, calculated using past data for all cells during weekdays. In the morning around 7AM, traffic growth starts. Throughout the day traffic varies but shows a steady increase. In the evening around midnight, traffic reaches the highest volume. This increase shows that on average people request most network resources in the evening, most likely from their homes. After the busy

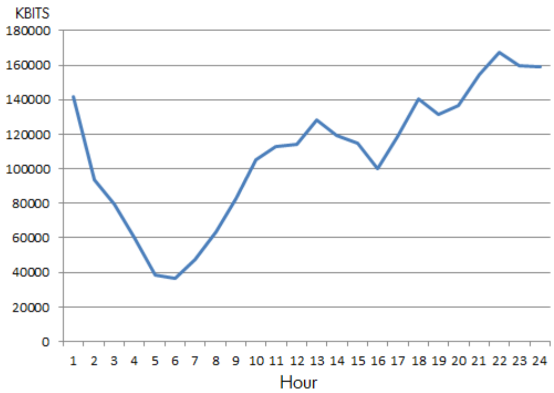


Fig. 2. Average MBN traffic Mon-Fri

hours traffic decreases and during the early morning hours it reaches a minimum. The night period with low traffic gives the highest potential for energy saving. Therefore, the first obvious optimization is to turn off the equipment during the early morning hours, from 4AM to 7AM, see Figure 2. However the average traffic curve does not show how traffic varies at cell (site) level, making it difficult to select the candidates and the periods for turning on and off network equipment. A comparison of three typical cell profiles is shown in Figure 3. The lines in the figure shows differences between very low

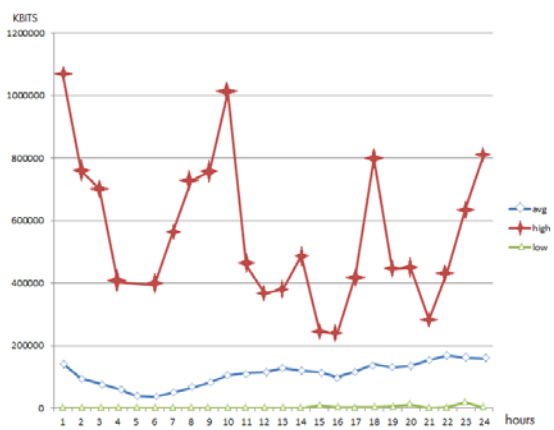


Fig. 3. 3 different traffic profiles at cells

(triangle), average (diamond), and high (star) traffic cells. It can be noted that the high traffic cells generally stays loaded, while some cells have low traffic all 24 hours.

B. Forecasting and predicting

The main parts of forecasting and prediction are shown in Figure 4. Forecasting is a solution for estimating numbers based on the past data. On the other hand, prediction is used to make statements about the events that might occur in the future based on past traffic data. In this study forecasting is presented as a method to estimate future traffic trends in MBN, with prediction applied on forecasted data when defining two traffic profiles: low (the network has high potential for savings) and high (the network has no potential for savings).

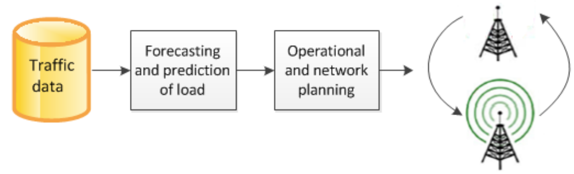


Fig. 4. Forecasting applications and use in MBNs

Various forecasting techniques and methods have been developed and used in different areas. A number of articles present forecasting ideas for MBNs. In [GPP+09] authors present a traffic forecasting model based on autoregressive integrated moving average (ARIMA). In [TN07] Holt-Winter's method is proposed as a solution for making forecasts with MBN data. The articles outline the possibility of detecting periods of high traffic based on the MBN traffic forecasting.

To show energy savings potentials in the MBNs information about the next day (24 hours) traffic is required. For this task traffic forecasting and predicting is used. Forecasting consists of two phases - learning based on the initial data set and forecasting. During the first phase, the initial data set is analyzed and a forecasting model that fits the initial data set is created. Future values can be predicted using the constructed forecasting model and estimated forecasting parameters. To evaluate how good (accurately) forecasting parameters were defined, real and forecasted values have to be compared. For this task different forecasting error metrics can be used, e.g., mean absolute scaled error (MASE).

To build a good forecasting model, specific occurrences and re-occurrences that affect the model have to be discovered. Below are outlined the main factors that cause traffic variations in MBNs.

Cell variability: Traffic at the base station site is generated by different cells. Most often the site consist of 3 cells, therefore traffic forecast can be done individually for every cell or the entire site.

Spatial variability: Some areas of the network, such as specific streets or industrial areas, might have a specific type of activity that results in a characteristic traffic profile.

Temporal variability:

Daily variation: Daily changes in the traffic are mostly affected by our life style (see Figure 3).

Weekly variation: During the weekend days traffic is slightly different from week days, and generally lower.

Seasonal variation: Monthly or seasonal changes where the traffic changes overall.

Special events: Concerts or other events, that results in people gathering. In this case, the increased traffic in MBN can't be planned unless information about the event is known in advance and is taken into account.

Service variability: MBN traffic combines different types of services, e.g., short message service (SMS), voice calls, Internet and others. The knowledge of different user needs would allow to give more precise estimations how many resources will be required from the cell/site.

Data collection: The data used for making forecasting models has impact to results. If the initial data set is gathered during the summer period, forecasts made for the winter season might be inaccurate. The same problem can be faced if too small learning data set is used. Too old data sets can show patterns that were common in the past, however won't reflect the current situation (i.e., new changes on the network structure). To make the forecasting model accurate, fresh data should be combined with the historical information.

IV. RESULTS

Low traffic periods and the possibility of turning on and off network equipment are the main network optimization techniques considered in our paper. Knowledge about the network construction and traffic data (forecasted and predicted) are required for efficient energy saving. Network optimization can be performed only in dense coverage areas, where the turned off cell (or site) results in no coverage holes and QoS is maintained at an acceptable level. The threshold should be defined based on network traffic, analyzing every network individually. This amount indicates the shift when low traffic turns to high. In this study, hourly traffic measurements for all cells (based on our data set) were used. A threshold of 1000 kilobits per hour was defined. However the threshold only identifies the *potential* network parts for turning off, while QoS is used when evaluating if the selected parts can be turned off. Periods when traffic is below the threshold are considered *low traffic periods*, and periods with traffic above the threshold - *high traffic periods*.

For the following results a data set covering one week, Monday to Friday has been used.

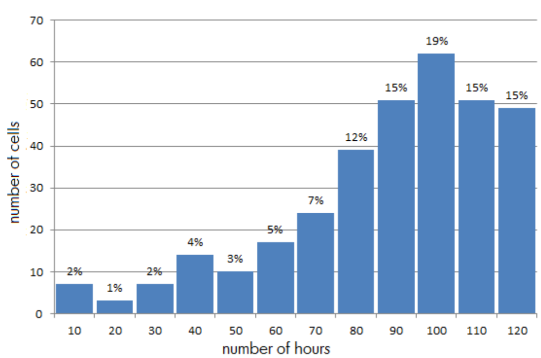


Fig. 5. Efficient (traffic above threshold) cell usage

In Figure 5, the number of cells (above the bar as % of all cells) and the number of hours when cells carry traffic above the predefined threshold are presented. From the figure it can be concluded that

- 17% of the cells have low traffic 50-99% of the time. Some cells have only 1 hour with traffic above the predefined threshold in 120 hours.
- 34% of the cells have low traffic 25-50% of the time
- 34% of the cells have low traffic 8-25% of the time
- 15% of the cells have low traffic 0-8% of the time

The figure represents accumulated data, therefore distribution of low/high traffic periods cannot be seen for the individual days. Traffic load characteristics vary for every cell; some cells has the same daily traffic pattern, while some cells have both high and low traffic periods in a random order. As it was discussed in Section II-B, energy savings in the MBN depends on the equipment that can be turned off. Length of the periods when the equipment can be turned off affects the energy savings as well. A cell turned off for 3 hours period will give better savings than a cell turned off 3 times for 1 hour. This is due to energy consumption that is required turning on and off network parts.

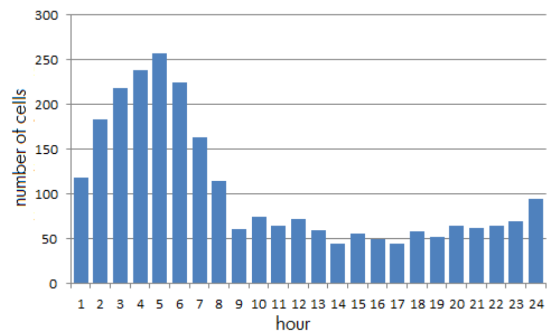


Fig. 6. Hourly savings at cell level, Monday

In Figure 6, the hours of the day and the number of cells with traffic below the threshold are presented. The highest energy saving potential is during the night hours from 2AM to 7AM, with a peak around 5AM, when more than 250 cells (74% of all cells) are potential candidates for being turned off. During the remaining hours, the network could be optimized by turning off around 50 cells every hour.

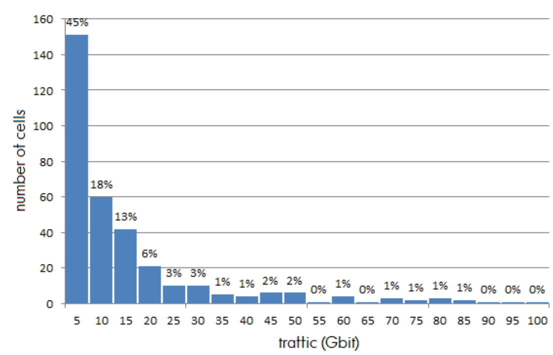


Fig. 7. Total traffic variance between cells

In Figure 7, the total traffic generated during five day period per cell and the number of cells (above the bar as % of all cells) are provided; 0% represents 1 cell. As we can see, 45% of the cells generate traffic up to 5 gigabits, while the highest traffic volume is generated by a small number of cells.

Figure 8 reflects, for how long periods different cells could be turned off. As we can see, most often cells could be turned off for 1 hour. However there are cells that could be turned off

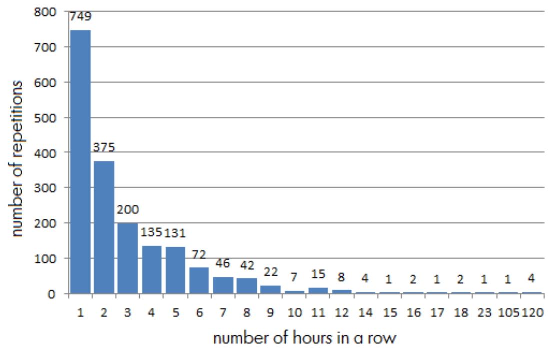


Fig. 8. Consecutive low traffic periods, cells layer

for longer periods, e.g., 2 to 9 hours. According to the data, there are 4 cells that could be turned off for the full week, provided that neighbouring cells can carry the traffic as per our assumption.

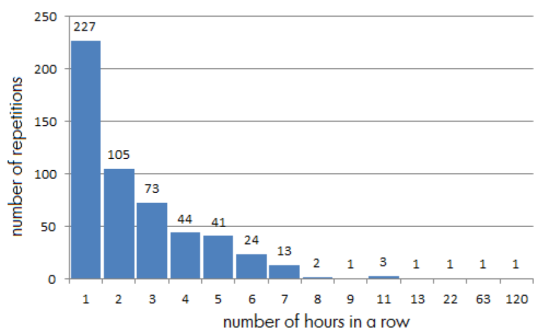


Fig. 9. Consecutive periods of low traffic, sites layer

The highest energy savings are achieved when turning off the whole site, and leaving running only the equipment required to turn on the site. An evaluation of low traffic periods and length when whole site equipment could be turned off is presented in Figure 9. There are 227 periods, when the site (with corresponding cells) could be turned off for 1 hour, 105 periods for 2 consecutive hours. One site could be turned off for 120 hours. Energy savings that can be achieved by turning whole site can be calculated using equation:

$$energy_{savings} = \sum_{i=1}^{120} x_i * i * e_{site} \tag{1}$$

where i is the length (in hours) when whole site can be turned off $1, \ldots, 120$; x_i is the number of periods of length i. Considering that a site with three cells (each cell consumes 20W) requires around 5kW, data from Figure 9 and equation (1), savings would be $energy_{savings} = 227*1h*5kW + 105*2h*5kW + \ldots + 1*120h*5kW = 7740kWh$ during five weekdays. Total energy consumption for 112 sites, during five days (120 hours) would be $energy_{total} = 112*120*5kW = 67200kWh$.

V. Discussion

The numbers provided in Section IV are only potentials. Approximately 11% savings can be achieved by turning off whole sites. Additional savings can be achieved by turning off individual cells. Optimized network has to be evaluated if the remaining active MBN can provide service with QoS guarantee. Figures 5, 6, 8, 9 show different possibilities for selecting candidates for turning off.

VI. Conclusions and Future Work

Very dynamic on/off switching is not possible with current equipment, but can be expected with the evolution of the technology and the general focus on energy efficiency. A range of related technologies also need to be in place, e.g., Self-Optimized Network (SON) features with active antenna tilting to optimize the coverage area between cells when switching off neighbouring cells or sites. Investigated data shows that there are various layers for optimization, e.g., cell or site. Accurate forecasting and prediction methods should be implemented for network layers. Estimated traffic should be used as the source for network optimization and planning. In this paper we analyzed the potential of saving energy in the MBNs using different perspectives for selecting which equipment part could be turned off, e.g., taking the most energy greedy network elements, or taking the one that can be turned off for the longest period. Development of a prototype and possibilities of evaluating network QoS with various network elements turned off are the next steps.

References

[Cis11] Cisco. Cisco visual networking index: global mobile data traffic forecast update, 2010-2015. White Paper, 2011.

[con10] EARTH consortium. Energy aware radio and network technologies, January 2010.

[Eri07] Ericsson. Sustainable energy use key facts. Report, 2007.

[Eri08] Ericsson. Energy-saving solutions helping mobile operators meet commercial and sustainability goals worldwide, June 2008.

[Gor07] B. Gorjni. Etsi work programme on energy saving. In *Telecommunications Energy Conference, 2007. INTELEC 2007. 29th International*, pages 174 –181, 30 2007-oct. 4 2007.

[GPP+09] Jia Guo, Yu Peng, Xiyuan Peng, Qiang Chen, Jiang Yu, and Yufeng Dai. Traffic forecasting for mobile networks with multiplicative seasonal arima models. In *Electronic Measurement Instruments, 2009. ICEMI '09*, pages 3–377 –3–380, aug. 2009.

[JWfCy10] Zhang Jian, Tian Wu-feng, and Cui Chun-yan. Traffic forecasting of mobile communication in call center. In *Computer Science and Information Technology (ICCSIT), 2010 3rd IEEE International Conference on*, volume 3, pages 160 –164, july 2010.

[MCCM09] M.A. Marsan, L. Chiaraviglio, D. Ciullo, and M. Meo. Optimal energy savings in cellular access networks. In *Communications Workshops, 2009. IEEE International Conference on*, June 2009.

[Roy08] Steve Roy. Energy logic for telecommunications. White Paper, 2008.

[TN07] D. Tikunov and T. Nishimura. Traffic prediction for mobile network using holt-winter's exponential smoothing. In *Software, Telecommunications and Computer Networks, 2007. SoftCOM 2007*, pages 1 –5, sept. 2007.

[Uni08] International Telecommunication Union. Ngns and energy efficiency. Technical report, International Telecommunication Union, 2008.

[Uni09] International Telecommunication Union. Icts and climate change, 2009.

[ZGY+09] Sheng Zhou, Jie Gong, Zexi Yang, Zhisheng Niu, Peng Yang, and Development Corporation. Green mobile access network with dynamic base station energy saving. *Proc of ACM MobiCom*, 9(262):10–12, 2009.