Energy saving potential of integrated hardware and resource management solutions for wireless base stations

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Abstract: With the rollout of LTE networks the energy consumption of wireless networks will further increase. We study the impact of power amplifier improvements in combination with scheduling strategies for traffic profiles expected around 2015. We compare a scheduling policy with adapted bandwidth (capacity) using a power amplifier with adaptive operation point vs. a micro DTX scheduler using a power amplifier with a deactivation mode. In times of low traffic up to 30% of energy saving can be achieved, over a day 13% to 24% are achieved.

Keywords: energy efficiency, LTE, macro base station, scheduler, power amplifier, power model, EARTH

1. Introduction

Wireless applications have gone from voice communication to data transmission, requiring more bandwidth, new air interfaces (HSPA, LTE) and new base station rollouts. All of these tend to increase the power consumption, the operator's OPEX and the CO_2 footprint of the networks. The extrapolation of current trends [2][3], as undertaken by the EARTH project [1], reveals that for a sustainable growth of wireless communications an improvement of LTE energy efficiency is required. Single improvements can consider hardware components, whole network nodes as well as the link level, however higher gains are expected for an integrated approach. Network analysis shows that the base stations (BS) are the most significant part in overall energy consumption [4]. A good deal of this is spent for providing system capacity designed for busy hour, even when the traffic demand is currently much lower. In this paper we investigate on an integrated approach for lowering energy consumption of macro base stations by improved hardware and by "green" resource management adapting the system capacity to the daily duty cycle of traffic demand.

A base station consists of different components like baseband (BB) processors, transceiver (TRX) (comprising power amplifier (PA), RF transmitter and receiver), feeder cable and antennas, main supply, voltage converters, and cooling units. In macro BSs the PA is the component with the highest energy consumption. Even when no data is transmitted the PA requires a DC power supply holding its fixed operation point designed for low distortion amplification. At present, the DC power supply is fixed independently of the traffic load and thus, for a major part of the day, power is wasted. Power reduction can be achieved twofold. The first concept is to adapt the operating point of a PA when signal load does not reach the maximum level. The second approach deactivates the PA whenever no data or signalling is transmitted. In chapter 3 we compare the energy savings of both approaches achieved at low traffic load and over a day. Also the BB signal processing significantly contributes to energy consumption. In current macro BS the BB power is a rather small constant, while in smaller BSs it may even be the dominating term. Advanced scalable signal processing algorithms can reduce the consumed power in low load situations. Another relevant improvement is possible in the BS cooling. For more efficient BSs, especially with the PA mounted close to the antenna ("remote radio head", RRH), even passive cooling by air convection can be sufficient. In this paper we concentrate on efficiency achievements of the PA. Possible improvements of other parts of the BS hardware [5], as pursued by the project EARTH [1], are optionally included in our power model (see Figure 2).

Also on link level energy efficiency improvements are possible. They could be achieved by transmit power control in the Radio Resource Management (RRM), but 3GPP LTE standards do not support per-user power control for higher modulation schemes. Furthermore, in high load situations with many users the RRM scheduler can instead use the frequency diversity in channel conditions in order to allocate resources more efficiently ("Max. C/I scheduler" [6]), but this strongly impacts fairness. We here propose very promising gains possible in low load situations by making the scheduler aware of power saving modes of the PA. This may require a control interface between RRM protocol layer and the PA hardware. In this paper, we compare different scheduling schemes, i. e., Bandwidth Adaptation (BW), Capacity Adaptation (CAP), and Micro Discontinuous Transmission (micro DTX) [7].

The BW adaptation approach is based on adjustment of the bandwidth to the required traffic load. During medium or low traffic the bandwidth is stepwise downscaled, and so lower numbers of physical resource blocks (PRBs) are allocated. The PA can adapt to lower supply voltage and also less reference signals ("pilots") have to be sent. This, however, requires a reconfiguration of BS system parameter and signalling to mobile terminals or the usage of carrier aggregation procedures. In contrast, for the CAP adaptation method the cell bandwidth and the number of pilots remain unchanged and adaptation to lower load is performed by scheduling only a part of the LTE subcarriers, i. e., limiting the number of scheduled LTE PRBs. This approach also allows lowering the PA supply voltage, but it is transparent to the mobile terminals and maintains frequency diversity.

BW and CAP adaptation play on the frequency axis of radio resources. Micro DTX scheduling strategy creates empty transmission time intervals (i. e., LTE subframes) at low traffic load. During an empty symbol the PA on the network site could be deactivated. The required transmission for the pilots limits the duration of micro DTX sleep intervals to only two or three OFDM symbols[1].

The energy saving potential of the approaches and their combination with new PA solutions is studied by implementing a detailed power model. First fundamental BS power consumption results are achieved by considering an average interference situation in a macro cellular network.

2. Framework for power consumption analysis and optimisation

The performance and power consumption of a BS and of potential improvements have to be simulated including the user density, their mobility and of the interference situation. However, a wireless network cannot be simulated on a country wide scale. Instead, the EARTH Energy Efficiency Evaluation Framework (E^3F) [9][10] proposes a set of representative small-scale, short-term use cases ("snapshots") comprising different deployment areas (e. g., dense urban or rural areas) and different times of the day (e. g., busy hour or night time). Given the daily traffic profile and the distribution of deployment types, the power consumption of a network over a day can be calculated by a weighted sum of short-term evaluations.

It is important to note, that energy saving of a technique like BW adaptation is not to be judged for its effect on the large scale network, but for each individual snapshot. A technique that provides good gain in dense urban scenarios may not be attractive for the rural case. For each different deployment type a different hardware can be selected. For the different times of day management methods can be used to switch between different scheduling strategies.

2.1. Modelling of hardware components

The energy consumption of a BS is described as function of traffic load. We use the detailed BS power model provided by the EARTH E^3F for 2012 [9][10], thus ensuring realistic power characteristic of state-of-the-art (SOTA) hardware and of BS components with energy efficiency improvements. Figure 1 shows the PA power consumption, depending on the RF output power. The SOTA characteristic (upper curve) describes the energy consumption of a SOTA Doherty PA with over 100 W DC input power at full load, where a 10 MHz macro BS site typical radiates up to 40 W output power per cell. The lower curves show an improved PA [5] with adaptability of the operation point by changes in the DC power supply. However, the use of a lower DC supply limits the maximum output power due to saturation of the PA. Finally, PA deactivation enables a micro sleep mode that allows very low power consumption of only 4.4 W during OFDM symbols with zero load (not containing any data or pilots).

We consider a sectorised BS with three cells, each with a RRH feeding one antenna emitting up to 40 W RF power. Next to the PA, the other components per cell are the BB processing and the RF signal generation, which consume about P_{other} = 25 W for SOTA. Further, the limited efficiency η of DC/DC conversion, AC/DC power supply, and cooling causes additional power consumption. For SOTA the total overhead power is around 70 W and nearly independent of load (Figure 2).

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[1] An exception is possible by introduction of "almost blank subframes" designed for MBSFN broadcast services, which is not considered in this paper

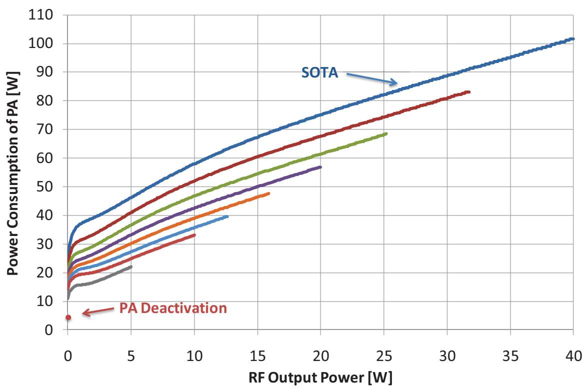

Figure 1: PA characteristics over RF output, depending on operation point settings

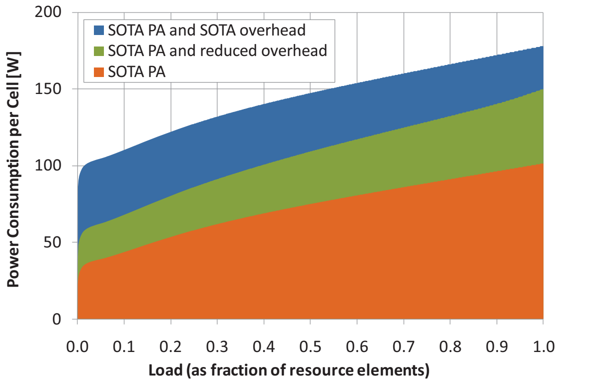

Figure 2: Power consumption per cell depending on the scheduled load

For energy calculation of a cell with improved hardware we assume that the overhead can be made proportional to the load and no active cooling is required any more. The total power consumption of a cell can be computed as $P_{cell} = (P_{PA}+P_{other})/\eta$. Roughly speaking, $P_{other} \sim 0.25*P_{PA}$ and the two power supply efficiencies each approach 90%, yielding a total power of (1.0+0.25)/(0.9*0.9), i. e., the PA consumes 65% of the total power.

$$P_{\text{cell, SOTA}}(u) \sim P_{\text{PA}}(u) + 70\text{W} \qquad P_{\text{cell, reduced}}(u) \sim \frac{P_{\text{PA}}(u)}{65\%}$$

In the following calculations the detailed power model [9][10] of the EARTH project is used. Figure 2 shows the SOTA PA power (orange curve) and the total power of one cell as function of the relative resource utilisation level *u*, including downlink and uplink RF and BB processing, cooling (only for SOTA) and power supply losses. The blue curve shows the total power consumption of a SOTA cell. The green curve gives the total power regarding hardware improvements for reduced overhead power.

2.2. Traffic profiles

Beside the power characteristic of the components the traffic load is a significant aspect in assessment of the power consumption of a BS. The EARTH traffic model [9][10] is based on spatial and temporal statistics of European wireless data traffic. For a capacity cell in dense urban areas (inter-site distance 500 m) we consider 3000 subscriber/km² and in busy hour 2% of the users running a broadband service, which is assumed as a high resolution video streaming service with 2 Mbps. During night time activity is up to a factor of 7 lower (see Figure 3).

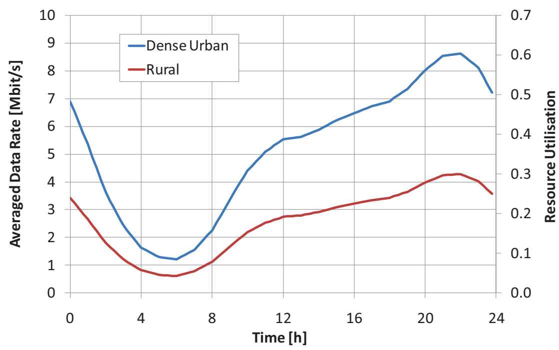

Figure 3: Traffic load scenarios

This amounts to a monthly traffic of 78 GB per broadband subscriber. These numbers are much higher than in today's network, but annual doubling of mobile data traffic is considered as for the near future. As a second example we consider a rural coverage cell (inter-site distance 1940 m) with 100 subscriber/km².

2.3. RRM Strategies

A fundamental role in the overall system performance is taken by the radio resource frame structure and by the scheduler. The scheduler sets the principal physical parameters for the transmission at each LTE subframe and, in consequence, decides about the radiated power. The LTE resources are scheduled in PRBs. Each PRB takes 1 ms time slots (subframes) and in 10 MHz bandwidth up to 50 PRBs can be supported simultaneously. Implementing different scheduling strategies, we can investigate how scheduling can leverage component innovations resulting in more energy efficient operation.

During low and medium traffic load period a significant number of resources are not used. For the BW and CAP adaptation modes the scheduler adapts resources to LTE bandwidths by equal utilisation of PRBs over a given time period. Depending on this load an optimised PA characteristic with limited output RF power (see Figure 1) can be used. On the other hand, a scheduler can reserve some of the time intervals (micro DTX) and set an energy saving deactivation mode of the PA during these times. The difference between the resource utilisation strategies is shown in Figure 4 for a 10 MHz BS at 40% of the maximum user data load (which corresponds to the average load of the dense urban cell in Figure 3).

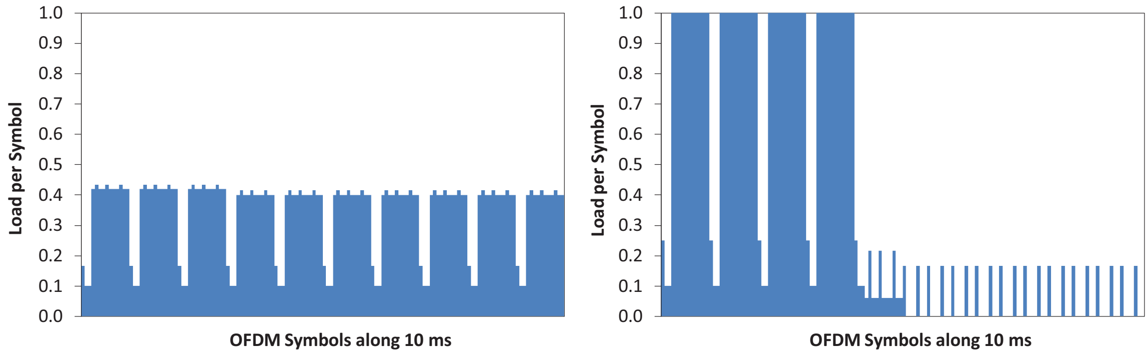

Figure 4: Resource utilisation u(t) per symbol for different RRM strategies at 40% user load (left: bandwidth adaptation, right: micro DTX)

2.4. Modelling of power consumption

To simulate the resource utilisation and the power for a given user distribution and data rate the structure of LTE resources has to be modelled in detail. The duration of PRBs is separated into 14 OFDM symbols, 3 for control signalling and 11 for data symbols. The control signalling has many options, in our simulation we neglect persistent scheduling and assume scheduling 1 user per subframe, which requires on average 10% load during 3 symbols for the control signalling information. Some of the data symbols are reserved for pilots, broadcast and synchronisation information. We slightly simplify the modelling of Physical Broadcast Channel and synchronisation by reserving 6 PRBs in every 10^{th} subframe[2]. This leaves resources of 494 PRBs per 10 ms for scheduling of user data.

For a specific time *t* of a day the resource utilisation is calculated as a function of traffic load *R(t)* and of RRM strategy. Assuming a mean spectral efficiency[3] of 1.76 bps/Hz the maximum user data capacity of a cell is C_{LTE} = 14.3 Mbps, excluding resources used for control channels and pilots. The user resource utilisation *r(t)* is then given by $r(t) = R(t)/C_{LTE}$, which corresponds to a minimum number of required PRBs These are scheduled over 10 ms according to the applied RRM strategy. Figure 4 depicts the resource utilisation *u(t)* including additional pilots and control channels for a user resource utilisation of *r(t) = 40%*, both for BW adaptation and micro DTX. With the help of these utilisation patterns, the instantaneous power during each individual symbol is determined according to the power model described in section 2.1 and then averaged over 10 ms.

To obtain a daily power consumption profile, for every hour a resource utilisation pattern and power consumption is generated from the corresponding mean traffic as shown in Figure 3 and finally the average daily power consumption is evaluated.

For DTX intervals, we consider a realistic switching speed when the PA switches from empty active state to deactivated state and vice versa. For the SOTA case the difference in power consumption between states amounts to ΔP = 26.7 W and for the improved solution to 21.2 W (see Figure 1). Assuming a linear slope of 20 µs duration and a guard interval of 5µs the additional average power during an activation or deactivation symbol is ΔP *(20µs/2 + 5µs)/71µs = 5.6 W respectively 4.5 W.

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[2] Actually in LTE these 6 signalling PRBs are spread over subframe #0 and subframe #5

[3] Calculated by system simulations, showing a 50 percentile SINR of 6.25 dB which results in this modulation and coding rate [8]

3. Results

The evaluated daily total power consumption of a cell is illustrated for the investigated RRM strategies in Figure 5 both for a typically dense urban (left side) and rural traffic scenario (right side). During night at lowest traffic load highest energy savings can be achieved by using the BW adaptation approach. Micro DTX is more beneficial at busy hours in dense urban scenarios, because due to the traffic load BW adaptation here cannot use one of the adaptation modes. The CAP adaptation approach yields the lowest energy savings along a day as shown in Figure 6, but has the benefit compared to BW adaptation that there are no impacts on standardisation. With the integrated approach of scheduler strategy and PA hardware improvements gains up to 30% are achieved, over a full day best energy savings of 16.7% can be achieved with micro DTX in dense urban and 23.9% with BW adaptation in rural scenarios. Considering additionally also all improvements of the other components very high energy savings of 46.7% in dense urban and 57.4% in rural scenarios can be achieved by using micro DTX or BW adaptation, respectively.

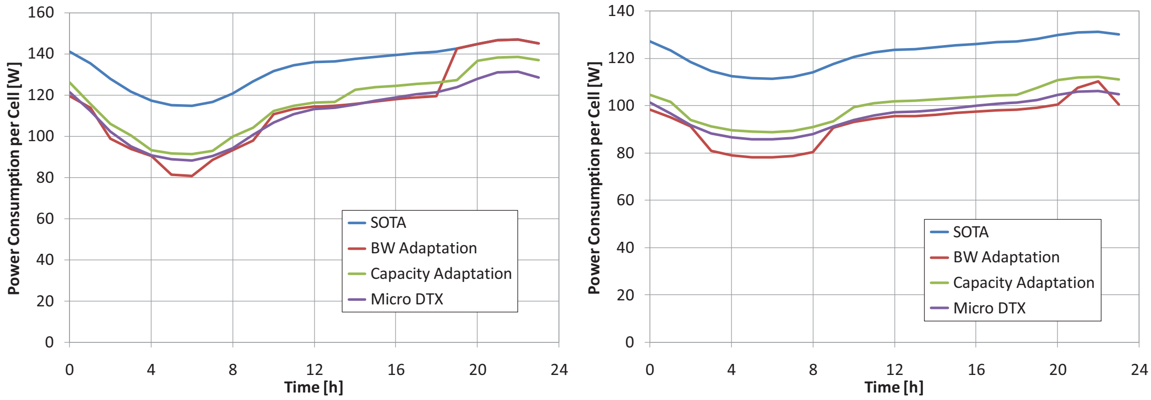

Figure 5: Power consumption for different RRM strategies in dense urban (left) and rural scenario (right)

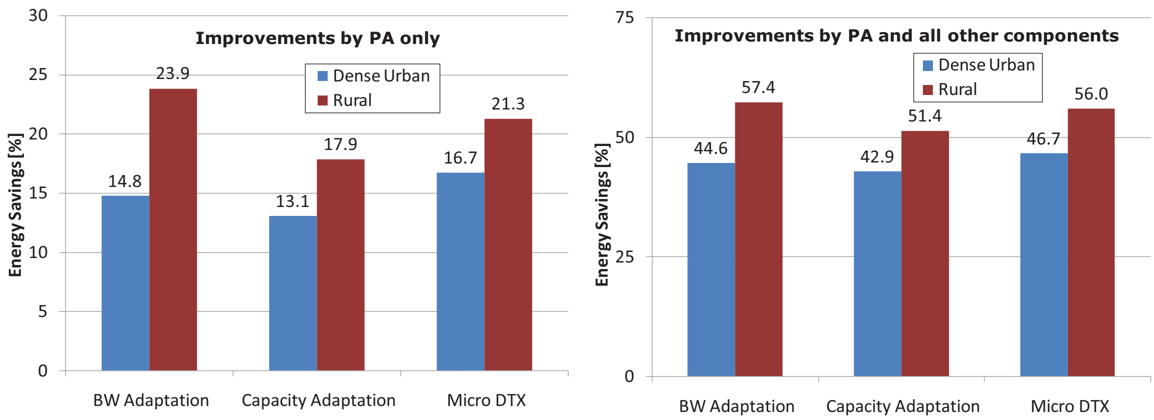

Figure 6: Energy savings for different RRM strategies based on PA only improvements (left) and improvements of all components (right)

4. Conclusions

We have applied the EARTH power model and traffic profile to compute energy consumptions of LTE deployments. Even for future high traffic per user for large part of the day less than 40% respectively 20% of cell resources are used for dense urban capacity cells and for rural coverage cells. Two integrated energy saving approaches are compared: a scheduling policy with adapted BW (CAP) using a PA with adaptive operation point vs. a micro DTX scheduler using a PA with a deactivation mode. Further savings can be achieved by considering other BS hardware (BB, cooling) improvements.

At rather high resource utilisation micro DTX can more flexibly utilise the void resources, where the fixed steps of BW and CAP adaptation limits the saving potential. For low utilisation BW adaptation has the highest saving because rather low efficiency for sending pilots limits the saving for micro DTX. CAP adaptation is the most flexible approach but also is limited by the pilot transmission power.

For all strategies higher savings are achieved in the rural cell, because the lower resource utilisation leaves more scheduling potential for energy saving. Based on a typical static SINR level, we show up to 30% of gain, achieved in the early morning hours. Over day 13% to 24% energy saving can be achieved by the proposed combinations of improved PA hardware and a matching scheduling strategy. With corresponding improvements in other parts of the BS hardware savings around 50% are achievable as targeted by the EARTH project.

In future work we will study if a combination of both approaches can achieve even higher gains. Further, the implemented power model will be applied to system level simulations to include the dynamic impact of inter-cell interference. Other approaches like MBSFN "almost blank subframes" and management scenarios, where underlaying small capacity cells (HetNet) are switched off, are also of interest because such solutions could further improve energy savings of a radio access network at the currently lower traffic per user.

Acknowledgements

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