# Enhancing Energy Efficiency in LTE with Antenna Muting

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*Abstract— The concept of antenna muting for reducing energy consumption in LTE is presented and system level evaluation results are provided. The results indicate that antenna muting can reduce the energy consumption with up to around 50% in a low load scenario without significantly affecting the user throughput. Results for 4TX, 2TX, and 1TX cell configurations are presented. The system level simulator used includes detailed models of UE pre-coder selection and feedback and we show in this paper that these algorithms performs well also when antennas are muted in a way that was not considered during the design of the algorithms. Antenna muting is a promising technique that operates on a rather short time scale in order to reduce the energy consumption of an LTE cell.*

***Keywords: Energy Efficiency, Mobile Networks, Energy Consumption, Radio unit de-activation, antenna muting, MIMO adaptation, 3GPP Long Term Evolution, LTE, EARTH.***

## I. INTRODUCTION

Undoubtedly, communication technology can contribute significantly to the target to decrease the $CO_2$ emissions, e.g., by avoiding travel. Today there is a general consensus in the industry that it is theoretically possible to drastically decrease the energy consumption of telecommunication equipment, see e.g. [1]. To actually achieve this in practice is essential for all telecom equipment vendors, not only from a societal perspective in order to contribute to a sustainable world, but also for being able to offer attractive and competitive products in a future carbon lean economy.

Already today the energy costs to run a mobile network is on a comparable level to the personnel costs, and hence it is obvious that these costs move into the focus of operators. While OPEX reductions have been on the agenda for quite a while, increasing energy costs for the operators has lead to an increased attention on energy efficiency.

When scrutinizing the energy consumers in the network, it turns out that in cellular networks the access network dominates the energy consumption and in the access network the base stations are the main consumers [2]. Traditionally, the mobile terminals have been designed with energy efficiency in mind due to their battery limitations. In addition, core networks are in absolute terms only marginal consumers, because compared to the number of base stations there are only few core network nodes.

In this paper we examine a method of reducing the energy consumption in LTE networks by means of antenna muting. The outline of this paper is as follows: in section II the models and assumptions used in this paper are presented, numerical evaluation results are found in section III, and section IV summarizes the conclusions of the paper.

## II. MODELS AND ASSUMPTIONS

### A. 3GPP Long Term Evolution

LTE Rel-8 supports multi-antenna transmission in the downlink using so-called *antenna ports* where each antenna port is defined by an associated reference signal. An antenna port thus corresponds to a transmit antenna as seen from the UE. Transmissions from multiple antenna ports to a single UE is in LTE Rel-8 based on cell-specific reference signals. For each of the up to four cell-specific antenna ports (0-3), there is a cell-specific reference signal transmitted [3].

The downlink physical control channels in LTE Rel-8 (PDCCH, PCFICH, PHICH) always use the cell-specific antenna ports as demodulation reference. In order to demodulate these downlink control channels the UE need to obtain knowledge about the number of cell-specific antenna ports the cell has. This information is obtained by blindly decoding the physical broadcast channel (PBCH). The PBCH is transmitted on the same set of antenna ports ({0}, {0, 1}, or {0, 1, 2, 3}) as the cell-specific reference signals in the cell. Different error detection coding (cyclic redundancy check (CRC) masks) is used for the data transmitted on the PBCH, depending on the number of cell-specific antenna ports. Thus, in practice, UEs determine the number of cell-specific antenna ports by the corresponding successful CRC check when it succeeds to decode the PBCH.

As the number of cell-specific antenna ports is static according to Rel-8 of the LTE specifications, the UE is only required to determine the number of cell-specific antenna ports upon initial connection to the cell. The UE is not required to ever re-evaluate the number of antenna ports of a cell.

One problem with this approach is that it does not directly support discontinuous transmission (DTX) of antenna ports for low traffic scenarios. If the cell uses four cell-specific antenna ports, all the downlink control signalling and system broadcast also need to use four antenna ports irrespective of the traffic situation. This also requires cell-specific reference signals (CRS) to be transmitted on all antenna ports all the time since they are used by the UE when they perform coherent demodulation of the PBCH.

Hence, even if the load and/or required data-rate is low and a single antenna port would be sufficient, reference signals on all cell-specific antenna ports need to be transmitted. This is

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unfortunate as multiple power amplifiers need to be active even when not motivated by the data rates used in the cell. From a power-savings perspective, it is desirable to activate multiple power amplifiers only when motivated by traffic load and/or data rate. This is illustrated in Figure 1.

### *B. Antenna Muting in LTE Rel-8*

Since LTE is designed to operate reliably on a fading radio channel there is a great deal of robustness built into the design. Therefore, if an LTE Rel-8 cell has two antenna ports then we may mute (i.e. DTX, or turn off) one antenna port when there is no, or only low traffic. This will have a negative effect on the decoding of primarily the PBCH and on system information transmitted on the PDSCH, but in most cases the system will still continue to operate properly [4].

The PBCH uses a transmit diversity scheme known as space frequency block coding (SFBC). The 2 transmit (TX) SFBC code that is used for PBCH and PDCCH is shown in Figure 2. It is clear that by muting antenna port #1 we are effectively un-doing the SFBC encoding. The PBCH, and also the PDCCH, are often over designed for robustness so that it is possible to reach the cell edge even in the largest cells when the inter-cell interference is high. Clearly, during non-peak hours the inter-cell interference level is often low. Thus the additional TX-diversity gain provided by the two base station antennas might not be always needed. In addition, when the load is low all radio units operate far below their maximum output power level and it is possible to boost the power on the remaining radio units in case some radio units are muted.

When muting one antenna port we also suffer from a power loss. Assuming each antenna contributed with $\gamma$ W of power then we have reduced the transmission power from $2\gamma$ W down to $\gamma$ W. If the maximum output power of each PA is at least $2\gamma$ W then this power loss can easily be compensated for. This is in general always possible if the power spent on the common channels is just a small fraction of the total available power.

It should be noted however that this type of power boosting is best suited for relatively wide bandwidths. In case the system has a total bandwidth of only 6 resource blocks (RBs); 6 x 180 kHz is the minimum bandwidth specified for LTE Rel-8, then it is not possible to boost the BCH power further (assuming full PA power is required for PBCHS transmission when antennas are not muted) as power can only be borrowed in the frequency domain, not in the time domain. For the 6 RB case all resource elements are used when transmitting the PBCH and hence the corresponding OFDM symbols are already transmitted with the maximum output power. When 4TX antennas are used (see Figure 3) then we can mute


**Figure 1: Adaptive multi-antenna discontinuous transmission (DTX).**

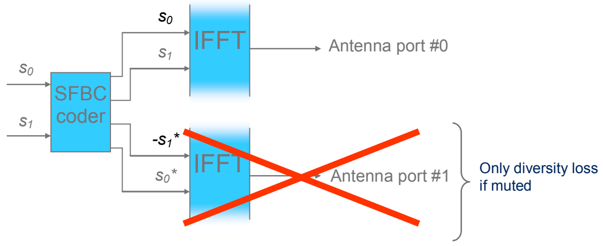


**Figure 2: Antenna port #1 can be muted if common channels (PBCH and PDCCH) can reach the cell edge without the additional diversity gain provided by the 2TX SFBC scheme.**

antenna ports #2 and #3 and only suffer from a diversity loss and potentially also a power loss from using 2 PA instead of 4 (that we can compensate for by boosting the power of the remaining antennas if needed).

If we also mute antenna port #1 then we are loosing half the channel code redundancy, and this will further reduce the performance. The PBCH[1] and the PDCCH are encoded with tail-biting convolutional codes with parent code rate 1/3 and constraint length 7 [5]. The effective code rate after rate matching is ~0.013 for PBCH and in the approximate range of 0.1 to 0.7 for PDCCH[2], one can conclude that by muting antenna ports 1, 2, and 3 we are effectively left with a channel code having twice the code rate, which offers significantly reduced performance. However, if we assure the initial code rate was well below ½ then the UEs would in many scenarios be able to decode the PBCH and the PDCCH even if 3 out of 4 antenna ports were muted. This could be the case e.g. for situations where there is little inter-cell interference, or when the SINR of the common channels is sufficiently large for other reasons. To (partially) compensate for the performance impact from the muted antenna port, one could e.g. boost the transmission power from the remaining antenna(s) (a single PA at high power is typically more efficient than multiple PAs running at a lower power) or by using a lower initial code rate of the PDCCH and on the PDSCH (both the PDCCH code rate as well as the PDSCH code rate can be dynamically adjusted by the scheduler in Rel-8).

### *C. Evaluation Assumptions*

The evaluations presented here are based on the case 1 of the 3GPP LTE evaluation assumptions [6]. That is, the evaluations are performed assuming an urban three-sectorized macro cellular network, deployed with inter-site distance (ISD) of 500 m and operating at a carrier frequency of 2 GHz. Users are located indoors and slowly moving (3 km/h). Only the downlink performance is analyzed and the traffic comprises file downloads, following the FTP traffic model [6] where each user downloads a single file of size 0.5 MB. An overview

[1] The payload on PBCH (MIB) is 24 bits (of which 10 are padding and reserved for future use) and the number of coded bits is 1920 for normal CP and 1728 for extended CP.

[2] The actual rate depends on DCI-format and number of control channel elements (CCEs); the higher code rates are mainly for dual-layer transmission to a UE and the lowest are used to schedule system information.

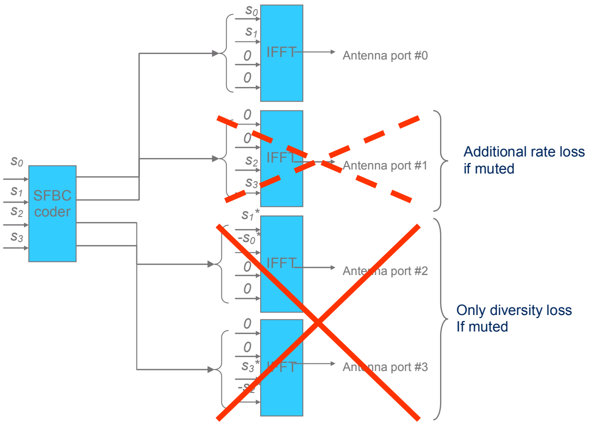


**Figure 3: For 4 TX diversity transmission antenna ports #2 and #3 can be muted without any rate loss. In addition, antenna port #1 may be muted at the cost of loosing half the redundancy of the channel code.**

of the employed models and assumptions is provided in Table I.

A 10 MHz LTE FDD Release 8 network with four, two, or a single transmit antenna per sector is assumed. For the multi-antenna cases, the performance has been evaluated either with all antennas active or using the adaptive antenna activation and muting scheme described above in Section II.B. The single antenna case is included for reference purposes. At the UE side, a dual antenna MMSE receiver is assumed. At both the UE and the base station side cross-polarized antenna setups are employed and for the four transmit antenna case, the two cross-polarized antenna groups are placed with a separation of ten wavelengths.

Based on periodic PMI and CQI reports from the UE to the network, proportional fair scheduling, adaptive modulation and coding, and code-book based pre-coding with rank adaptation is applied in order to adapt the transmissions to the channel conditions.

Different antenna muting algorithms were evaluated and for the 4TX case we found that it was better to switch directly between only one antenna active and all four antennas active rather than trying to adaptively mute or un-mute one antenna at the time. This is not surprising considering that the studied traffic is of bursty nature; typically, there is either quite a large number of bits awaiting transmission in the transmit buffer or the cell is empty. In the simulations we used the average downlink resource block utilization during a 10 ms radio frame as a load measure. All antennas in a cell were immediately activated when the load was above 90% while if the load was below 10% for ten consecutive radio-frames then all except one antenna were muted.

The evaluations generally focus on how the cell energy consumption and the data channel (PDSCH) performance are affected by antenna muting. Throughout the evaluation it is assumed that the physical control channels, such as the PBCH, the PHICH, the PCFICH, and the PDCCH, continue to work properly when one or several antennas are muted during

TABLE I: MODELS AND ASSUMPTION

| | |
|---|---|
| **Traffic Models** | |
| User distribution | Indoors with uniform distribution |
| User speed | 3 km/h |
| Traffic model | File transfer (file size 0.5 MB) |
| **Radio Network and Deployment Models** | |
| Deployment | Hexagonal grid with wrap-around, 3 sectors/site, 21 sectors in total |
| Inter-site distance | 500 m |
| Distance attenuation ($L$) | $L(d) = \beta + 10 \cdot \alpha \cdot log_{10}(d)$ $\alpha = 3.76$, $\beta = 15.3$ |
| Indoor penetration loss | 20 dB |
| Shadow fading | Log-normal, 8 dB standard deviation |
| Small-scale fading | 3GPP SCM urban macro 15 [7] |
| **LTE System Model** | |
| Spectrum allocation | FDD, 10 MHz downlink at 2 GHz carrier frequency |
| Base station output power | 46 dBm (40 W) |
| Number of base station transmit antennas | 1, 2, or 4 |
| Number of UE receive antennas | 2 |
| UE receiver | MMSE |
| Scheduling | Proportional fair in time and frequency domains |
| Transmission scheme | Code-book based precoding with rank adaptation using the LTE Rel-8 codebook |
| Modulation and coding schemes | QPSK, 16QAM, 64QAM; Turbo coding with rates according to LTE Rel-8 standard |

low traffic periods. For a detailed analysis of the LTE control channel performance with antenna muting we refer to [4].

The power models used in this paper are derived from the models presented in the EARTH project [10]. For a 10 MHz macro cell with 4TX configuration and 40 W total transmission power model used is shown in Figure 4. The power model for $n$ active antenna elements is linear between the power consumption at 0W RF output power ($P_{0,n}$) and the maximum power for all $n$ antenna elements ($P_{\max,n}$). The power model values for a 4TX cell are shown in Figure 4 and they are: $\{(P_{0,4}, P_{\max,4}), \ldots, (P_{0,1}, P_{\max,1})\} = \{(414, 663), (356, 543), (296, 428), (233, 312)\}$. The corresponding values used in this study for a 2TX cell are: $\{(P_{0,2}, P_{\max,2}), (P_{0,1}, P_{\max,1})\} = \{(259, 443), (185, 284)\}$; and for a 1TX cell we used the values $\{(P_{0,1}, P_{\max,1})\} = \{(169, 334)\}$.

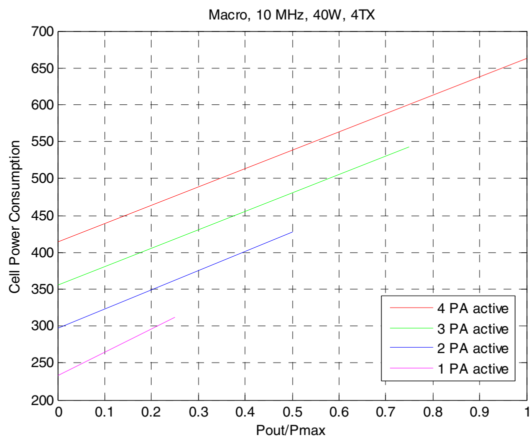


**Figure 4: Power model of the 4TX, 10 MHz, 40W macro cell used in this study.**

## III. NUMERICAL EVALUATION RESULTS

The evaluation results are generally presented as a function of the system throughput and for stable operational points only, i.e., for operational conditions in which users (packets), over time, enter and leave the system at the same rate [7]. We have here chosen to measure the system throughput per area unit, and not per cell that is otherwise commonly used. As a point of reference one may note that when using an ISD of 500 m and a three-sectorized deployment, an area throughput of 100 Mbps/km$^2$ corresponds to a cell throughput of around 7.2 Mbps/cell. Figure 5 depicts the average physical resource block utilization, which is a measure of the system load, as a function of the system throughput. As data rates increase when more transmit antennas are employed, packets can be transmitted using fewer resource blocks, and the average resource block utilization decreases. Note further that the "adaptive" schemes use slightly more physical resource blocks than the corresponding "all active" schemes. This is due to the antenna activation delay that causes the initial part of some packet transmissions to be performed with only one active antenna.

In Figure 6 we show the mean user bitrate as function of the system area throughput. The user bitrate is defined as the file size divided by the time used to transfer the entire file. As expected we see that a cell with 2TX antennas performs significantly better than a cell with 1TX antenna. Similarly, a cell with 4TX antennas performs better than a cell with 2TX antennas; however, the difference between the 4TX and the 2TX antenna cases is relatively small. Compared to the 2TX antenna scheme the 4TX antenna scheme offers additional directivity, however, as the mobile is equipped with 2RX antennas only it does not imply any improved spatial multiplexing capabilities. We also see that the adaptive schemes performs on par with the always on schemes, meaning that the adaptive antenna muting and un-muting algorithm only has a very minor impact on the user throughput.

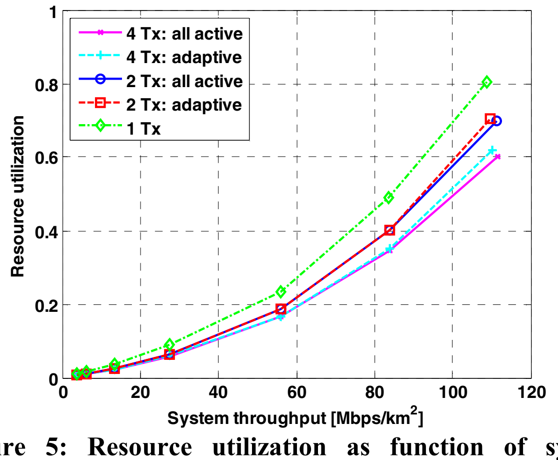


**Figure 5: Resource utilization as function of system throughput.**

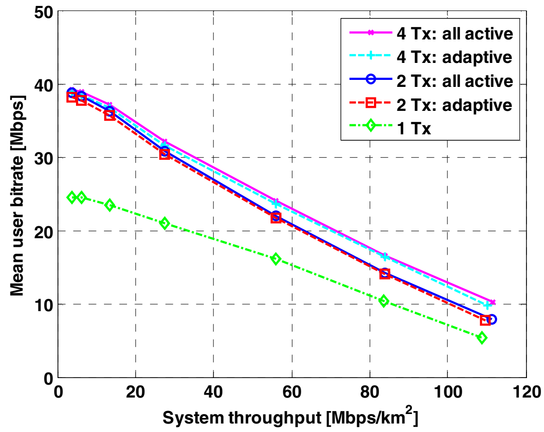


**Figure 6: Mean user bitrate as function of system throughput.**

In Figure 7 we show the 5$^{th}$ and the 95$^{th}$ percentiles of the user bit-rate as function of the system area throughput. The fact that cells with two or four transmit antennas may use dual-stream spatial multiplexing, whereas a cell with a single transmit antenna is restricted to single-stream transmission, is reflected in the 95th percentile of the user data rate. The 95th percentile user data rate, which here is limited by the peak data rate at low system throughputs, is basically double for the 2TX and the 4TX cases compared to the 1TX case. At higher traffic loads the performance is limited by the sharing of the common channel with other users in the same cell as well as inter-cell interference. Comparing the performance of the adaptive schemes to the corresponding always on schemes we note that the adaptive schemes deliver almost as good performance as the always on schemes for both high and low user data rate percentiles.

The energy consumption of the different schemes is shown in Figure 8 and Figure 9. Following the recommendation in [9], we express the energy consumption in terms of power per area unit (P/A) and energy per bit (E/B). In Figure 8 we show the power per area unit as function of system throughput. For the "all active" schemes we see that as system throughput increases the energy consumption increases rather moderately. The adaptive schemes (4TX adaptive and 2TX adaptive) have an energy consumption that is more load dependent than the corresponding all active schemes. The 4TX adaptive scheme has lower energy consumption compared to the 4TX all active scheme, and at low system throughput it is even lower compared to the 2 TX always on scheme. At low load the gain of the 4 TX adaptive scheme compared to the 4 TX always on scheme is 47% and at the highest simulated load the gain is still 13%. The corresponding gains for the 2 TX adaptive scheme over the 2 TX all active schemes are 31% at low load and 7% at high load. The size of the gains found in this paper is consistent with earlier studies on radio unit de-activation [11]. In [11] the MIMO adaptation was evaluated in a static simulator on a much slower time scale in contrast to the dynamic and much more detailed simulator used in this study. The energy consumption per bit decreases with the system

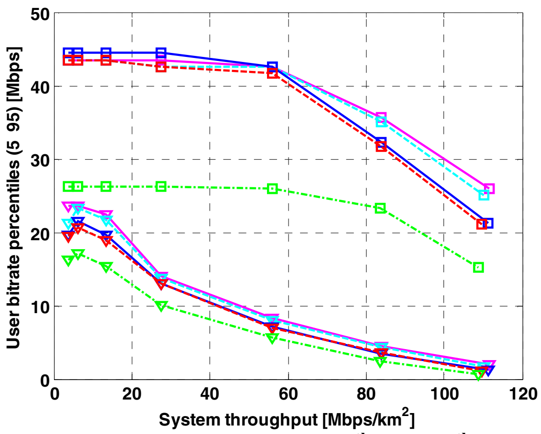


**Figure 7: User bitrate percentiles (5th and 95th) as function of system throughput (same coloring as in, e.g., Figure 6; square markers indicate the 95th percentile and triangle markers the 5th percentile).**

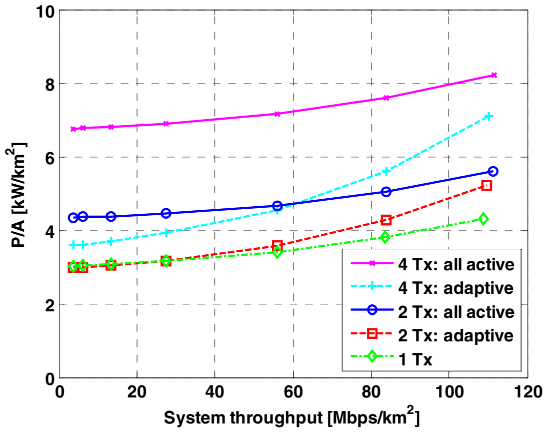


**Figure 8: Power per area unit as function of system throughput.**

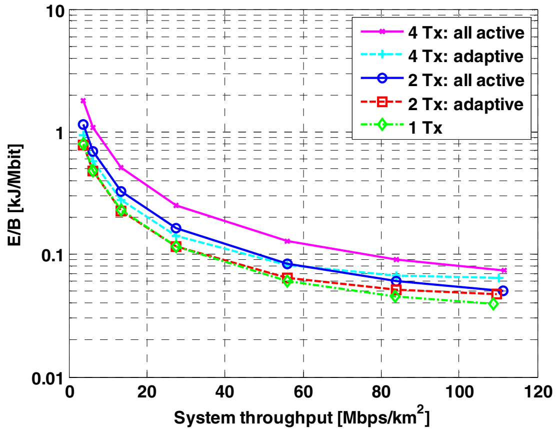


**Figure 9: Energy consumption per bit as function of system throughput.**

throughput as shown in Figure 9, indicating that in terms of the energy spent per delivered bit the network operates more efficiently at high loads than at low loads. Considering e.g. that the base station power consumption is associated with a relatively high fixed cost ($P_{0,n}$), which is divided over a larger number of bits at high traffic loads, this falling trend is in line with expectations.

## IV. Conclusion and Future Work

In this paper we have studied the system level performance with antenna muting. As expected we observe a significant gain in terms of reduced energy consumption of the schemes where adaptive antenna muting is used compared to the schemes where all antennas are always active. At the same time we showed that the performance loss was minor. Results for 4TX, 2TX, and 1TX cell configurations were presented. The system level simulator used includes detailed models of UE pre-coder selection and feedback and we show in this paper that these algorithms performs well also when antennas are muted in a way that was not considered when these algorithms were originally designed.

Antenna muting is a promising technique that operates on a rather short time scale in order to reduce the energy consumption of an LTE cell. In future studies we would like to study how to use antenna muting in combination with other energy saving algorithms based on cell and deployment reconfiguration, e.g. sector-to-omni re-configuration, cell on-off schemes, bandwidth adaptation, MBSFN adaptation, and slow MIMO adaptation.

## Acknowledgements

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