# Reducing Energy Consumption in LTE with Cell DTX

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### Abstract

**This paper discusses how energy consumption can be significantly reduced in mobile networks by introducing discontinuous transmission (DTX) on the base station side. By introducing DTX on the downlink, or cell DTX, we show that it is possible to achieve significant energy reductions in an LTE network. Cell DTX is most efficient when the traffic load is low in a cell but even when realistic traffic statistics are considered the gains are impressive. The technology potential for a metropolitan area is shown to be 90% reduced energy consumption compared to no use of cell DTX. The paper also discusses different drives for the increased focus on energy efficient network operation and also provides insights on the impact of cell DTX from a life cycle assessment perspective.**

### Introduction

Energy consumption in cellular networks has rapidly moved from an area of low priority to a focus area of the whole telecommunication community. When analysing the energy consumption of wireless access networks it becomes clear that in order reduce the total energy usage it is important to concentrate the efforts on the most abundant network nodes namely the base stations (BS). The two most important drives for improved energy efficiency for mobile-networks operation are: a number of operators experiencing increased electricity costs for network operation; and an increased awareness in the society of how energy use relates to green-house gas emissions and global warming. Today all major actors agree that human activities are impacting the global climate and there is a strong consensus among leading economies to limit the future temperature increase to 2$^o$C, see e.g. [1]. In addition there are also increasing concerns about future energy availability and cost as many researchers predict that oil and coal production will peak and then decline during the coming decades, see e.g. [2] and references there in.

Consequently, in a newly started research initiative called EARTH, (*Energy Aware Radio and neTwork tecHnologies*) industry and academia have joined forces in addressing energy consumption in mobile systems [3]. The EARTH project is part of the Seventh Framework Programme of the European Community and is scheduled to last until June 2012. The consortium consists of 15 partners and includes operators, network providers, component manufactures, research institutes and universities. The project primarily concentrates on energy efficiency in the base stations but is also addressing wider network and system aspects. The Focus of the EARTH project is on 3GPP mobile broadband technologies, in particular LTE and its evolutions. However, the topics to investigate span from near future component research and development to long term academic research and determination of theoretical limits of investigated concepts.

In this context it is important to remember that the global carbon footprint of the mobile telecommunication industry today accumulates to less than 0.5% of the estimated total emissions from human activities [4]. However, despite this moderate contribution it can be concluded that reducing energy consumption of cellular systems is today a primary concern for the mobile communication industry, for reasons discussed above.

The challenges in reducing mobile network energy consumption look differently in different markets, depending on current energy consumption patterns. In the more mature mobile-broadband markets the primary focus is rather on how to accommodate an expected traffic growth of 1000 times in terms of mobile data [5] with maintained or even strongly reduced $CO_2$ emissions. In expanding emerging market it is found that many base stations are powered by off-grid diesel generators with significant maintenance costs. Grid connections are often expensive and up to $30,000 per site have been reported; they may have long installation lead times, in extreme cases up to 2 years; and the reliability can be problematic with outages of many hours per day [6]. Today a typical off-grid base station consumes in the order of 20 m$^3$ of diesel per year. The cost of delivering the diesel to remote sites on poor roads and protecting it from theft is often found to be more expensive than the fuel itself. In the light of this background it is unfortunate that solar-powered base stations are often not an economically feasible option yet. The main reasons are the amount of solar panels required (typically 50-60 m$^2$ per site) as well as the large capacity of the backup batteries required. However, if the power of a future mobile-broadband site could instead be provided with less than 5m$^2$ of solar panels it is likely that the market segment would dramatically increase. Such a product would be an important step toward providing affordable and near-emission-free mobile broadband on a global scale. Fortunately, the reduction in base station energy consumption of about a factor 10 to make that possible is, as shown in this paper, definitely within reach.

The needs of the different market segments can benefit from the same technical solutions for decreased energy consumption in the network operation. Until today cellular radio systems have been designed to be always on. This paper shows that a consequence of this design paradigm is that the main part of the energy consumed in mobile networks is actually spent when no user is accessing that specific part of the network. Examining the traffic in a cellular network with a short enough time resolution, e.g. on millisecond level, it is

978-1-4244-8331-0/11/$26.00 ©2011 IEEE

found that no user is served in most of the cells most of the time. However, on a longer time scale, e.g. 15 minutes, only very few cells carry no traffic. Consequently, there is a large energy saving potential for fast dynamic mechanisms that allow for a cell to switch off cell specific signalling whenever there is no user data transmitted or received in the cell. In order to meet the outlined challenges we argue that the time has come to change the default radio network design paradigm from *always on* to *always available*.

## A Closer Look at Energy Use in Cellular Networks

When operating a typical cellular network, such as GSM, WCDMA, or LTE, around 80% of the energy is normally used by the base stations. Traditionally, the mobile terminals have been designed with energy efficiency in mind due to their battery limitations. In addition, core network nodes are in absolute terms only marginal consumers, simply because they are outnumbered by the base stations. Furthermore, within a single base station the power amplifiers (PAs) are the dominating energy consumers. Typically 80% of the total energy use at a base station site is consumed by the PAs.

A simple, but still surprisingly accurate, model of the energy consumption in a typical WCDMA or LTE cell is shown in Figure 1. Please note that a site typically can host several cells, e.g. three cells per site is a common configuration. The power use of a cell typically increases linearly with the utilization of the PA. Typically the fixed energy consumption part (*C*) is in same order as the variable part (*V*). A cell can be put into sleep mode or discontinuous transmission (DTX) mode where the energy consumption is reduced to a lower value (*D*). In this paper we make the assumption that the cell can enter a sleep mode with zero time delay while going back from a sleep mode to the active transmission mode requires a certain delay and a certain amount of energy which both depend on the sleep level. In the deepest sleep level the power use can be arbitrarily close to zero Watt. However to wake up from this low power mode may require some 10-20 seconds or more. In a more light sleep mode, only some well selected parts of the cell hardware may be inactivated and the activation process is much faster, however, at the expense of somewhat reduced power savings. In this study we will only consider a single sleep mode level consuming 10 Watt with a wake up time of 30 µs, which is in the order of one half OFDM symbol in LTE. By introducing a delay in the order of one OFDM symbol in the radio unit we can ensure that the PA is automatically activated in due time before transmission of a non-empty OFDM symbol starts. These requirements are challenging but not impossible if DTX performance is prioritized properly when the hardware is designed.

Please note that the model in Figure 1 only considers the transmitted signal power and that the bandwidth of the transmitted signal is not included in the model. This is motivated by the assumption that the PA is designed to support a certain maximum bandwidth (e.g. 20 MHz) and even if we feed the PA with a more narrow band signal (e.g. 5 MHz) this will not significantly affect the energy use of the amplifier. This does not rule out that another PA designed for a lower maximum bandwidth (e.g. 5 MHz) might result in lower energy use for the same narrow band signal; however in this study we do not consider such potential power reductions.

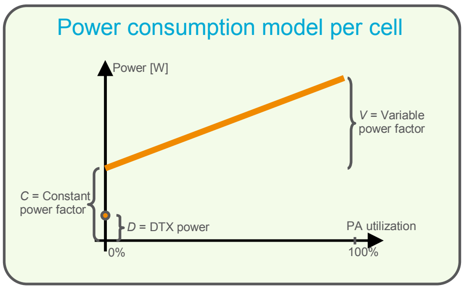


Figure 1: Illustration of the power consumption model used in the implementation.

## Feasibility of Cell DTX in LTE

In the previous section we discussed the potential for significant power savings by putting the cell into some sort of sleep mode. However, even when no user data is communicated in the cell the cellular standard that the base stations must comply with still often stipulate some minimum amount of transmissions, and such mandatory idle-mode transmissions can significantly limit the feasibility of cell DTX. In a WCDMA system, for example, each cell needs to continuously transmit a common pilot channel (P-CPICH) and a common control channel (P-CCPCH) and therefore the PA utilization never goes below 10%, leaving no time at all for cell DTX. In this section we will examine how the LTE standard supports cell-DTX behaviour.

The transmission format specified for the LTE downlink is known as orthogonal frequency division multiplexing, OFDM. Since OFDM is a multi-carrier transmission technique the physical radio resource can conceptually be described as a time-frequency grid where each resource element consists of one sub-carrier during one symbol. In Figure 2 we show an example of a downlink radio-frame in LTE that consists of 10 sub-frames of 1 ms duration each, numbered from 0 to 9. Each sub-frame begins with a downlink control region spanning between 1 to 3 OFDM symbols. The primary and secondary synchronization signals (PSS and SSS, respectively) are transmitted in sub-frame 0 and 5 and the (physical) broadcast channel (PBCH) is transmitted in sub-frame 0.

In the circled close-up we see one resource block pair containing 14×12 resource elements (assuming normal cyclic prefix). The blue resource elements are used to transmit cell specific reference signals (CRS) related to one antenna port in LTE. The LTE Rel-8 standard supports up to four such cell specific reference signals that are used by the mobile stations as demodulation reference, for channel quality estimates, and for mobility measurements. The white resource elements can be filled with user specific data.

Beside the normal (unicast) data subframes, LTE Rel-8 also provides a special type of sub-frames, i.e. the multi-cast and broadcast single frequency network (MBSFN) sub-frame, as illustrated in Figure 2. This type of sub-frame consists of a short control region at the beginning of the subframe, similar to the normal sub-frames, while the rest of the sub-frame may be empty. Six out of the ten sub-frames in a radio frame can be configured as such MBSFN sub-frames (1, 2, 3, 6, 7, and 8).

Thus when the traffic load is low we can, in order to reduce energy consumption, configure a cell with up to 6 MBSFN sub-frames that are not used. Hence, in Figure 2 we see the minimum amount of signals that need to be transmitted in a cell with no traffic at all (in addition higher layer system information is required on a less frequent time scale than a radio frame, not shown in Figure 2). In contrast to e.g. WCDMA, where the cell is required to transmit continuously, there is a significant possibility to reduce energy consumption with cell DTX in LTE Rel-8. When counting the actually transmitted OFDM symbols in a radio frame with 6 MBSFN sub-frames and assuming a PA wake up time of 30 μs it becomes apparent that the PA can be in low power DTX mode in 74% of the time when there is no traffic in the cell. This simple calculation alone gives some indication that cell DTX is an effective method for reducing energy consumption in LTE when there is no or very little traffic. In order to determine in more detail how the network energy consumption depends on the traffic we have performed system simulations that are presented in the following section.

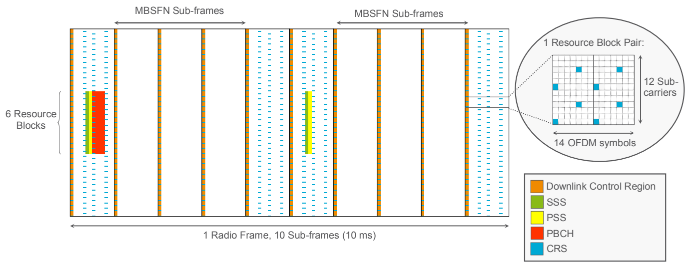


Figure 2: One example of a downlink radio frame in LTE with 6 MBSFN sub-frames showing cell reference symbols (CRS) for one antenna port, downlink control region with a size of one OFDM symbol, primary and secondary synchronization signals (PSS and SSS), and physical broadcast channel (PBCH).

## NUMERICAL RESULTS

In this section we will start by presenting system simulation results analysing the RAN power use as function of the traffic load, with parameter settings according to Table 1. Please note that the power values in Table 1 that are used in this study correspond to relatively modern hardware and that many existing base stations use significantly more power than this.

TABLE 1: SIMULATION SETTINGS AND PARAMETER VALUES (THE VARIABLES *D*, *C*, AND *V* REFER TO FIGURE 1).

| Parameter | Value/Description |
|---|---|
| Deployment | 27 hexagonal cells, default cell radius: 400 m |
| Traffic | Uniform user distribution. A user downloads one 1 MB file and leaves the system |
| DTX schemes | *No DTX;* *Micro DTX* (30 μs off → on switching time)*;* *Short DTX* (UEs measure on synch channels)*;* *Tech. potential* (no broadcast transmitted at all) |
| DTX cell power (*D*) | 10 W |
| Fixed cell power factor (*C*) | 170 W |
| Variable cell power factor (*V*) | 275 W |
| Bandwidth | 20 MHz |
| DL maximum power | 80 W |
| MBSFN allocation | Between 1 and 8 sub-frames (Rel-8 allows 6) |
| Logging interval | Cell average power logged every 100 ms |

In addition to the reference case without any cell DTX we will examine both an LTE Rel-8 compliant DTX scheme, where all signals in Figure 2 are transmitted even in sub-frames with no traffic, as well as a non LTE Rel-8 compliant DTX scheme where we assume that only the synchronization signals and the broadcast signal are mandatory. In the sequel these two DTX schemes will be denoted *cell micro DTX* and *enhanced cell DTX* respectively. As a lower bound on achievable energy consumption we will also consider a system where no synchronization and broadcast overhead signals are transmitted from any cell, corresponding to an ideal case that shows the *technology potential* of cell DTX.

The blue curve in Figure 3 shows the average power consumption for an eNB without capability of cell DTX. We see that with increasing traffic load the average power also increases. However without cell DTX the power usage scales badly, i.e. it is not proportional, to the traffic load. The red curve shows the average power consumption with the Rel-8 compatible *cell micro DTX* scheme. Note that the most significant gain in reduced average power comes at low load, since here the probability of having empty sub-frames is higher, while at the highest load point the curves for no DTX and cell micro DTX coincide since there are basically no empty sub-frames left where DTX can be enabled.

Also shown in Figure 3 are the results for the enhanced cell DTX scheme in which CRS are only transmitted in resource blocks that carry data (black curve) and where only PSS, SSS, and PBCH transmissions are mandatory in the cell. This solution has been discussed for E-UTRA in 3GPP [7] but was not included at this stage due to the timing of the proposal and issues with terminal backward compatibility. The final curve (magenta) in Figure 3 shows the results obtained when no overhead is considered, i.e. we assume that synchronization, system broadcast, mobility measurements etc. can be supported at zero additional cost.

No implementation of cell DTX can achieve lower energy consumption than this and hence this curve serves as a lower bound on energy consumption in our scenarios. The curves show that with the enhanced cell DTX scheme it is possible to further reduce the low load power use substantially compared to the case when only micro DTX is used. Also, with enhanced cell DTX we can achieve power levels fairly close to the technology potential curve. Note, however, that there is still room for around 40% further reduction of the average power at the lowest load point.

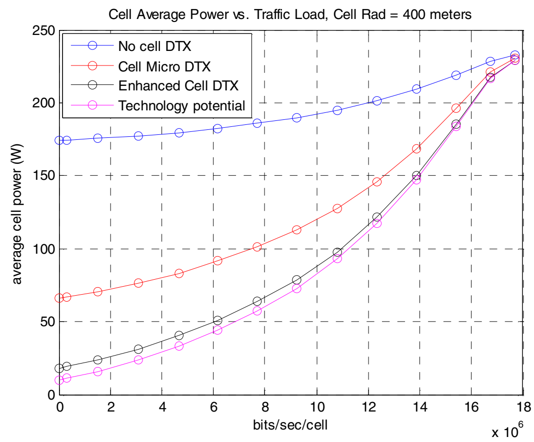


Figure 3: Average power as a function of increasing load, for different DTX schemes. The enhanced cell DTX configuration comes fairly close to "technology potential".

### Energy saving potential of MBSFN sub-frames

As mentioned above, one Rel-8 compatible method to improve the cell micro DTX scheme is to introduce one or several MBSFN sub-frames. This can reduce the average cell power use at low load since fewer cell-specific reference symbols need to be transmitted. Figure 4 shows the average power use in a network with four different MBSFN configurations, and the reference case with no MBSFN sub-frames. All configurations support cell micro DTX to various degrees. Note that the LTE standard does not support configuration of 8 MBSFN sub-frames currently, so this curve is mainly for comparison. Two characteristics can be highlighted from Figure 4. Firstly, that the more MBSFN sub-frames that are introduced the lower the average power used at low load. Secondly, the maximum supported traffic load in a network with MBSFN sub-frames is reduced significantly. More MBSFN sub-frames imply fewer sub-frames for data transmission, reducing cell capacity. Basically the cell capacity reduction scales linearly with the number of allocated MBSFN sub-frames.

It should be clear that introducing MBSFN sub-frames can lower the power use by allowing for a more efficient DTX scheme. There are, however, also negative consequences, both in terms of reduced cell capacity and degraded user throughput. Hence, it is of importance, if not inevitable, that fast switching between MBSFN configurations can be performed in an adaptive fashion. The adaptive mechanism would switch from many MBSFN sub-frames at low activity and react to changes in the traffic situation by removing the MBSFN sub-frames when traffic increases. The current mechanism for switching between MBSFN configuration is via system information and hence not a particularly fast method; in LTE Rel-8 we may only change the information on the system broadcast channel once every six minutes on average. Therefore, in future LTE releases it is important to allow for unicast data transmission also in sub-frames that are configured for MBSFN use.

In the standardization process in 3GPP there has also been proposals to introduce sub-frames that are completely blank, i.e. where not even the downlink control region is present, although not included at this stage. Not surprisingly, blank sub-frames gives very similar results to the use of MBSFN sub-frames and is therefore not further discussed here.

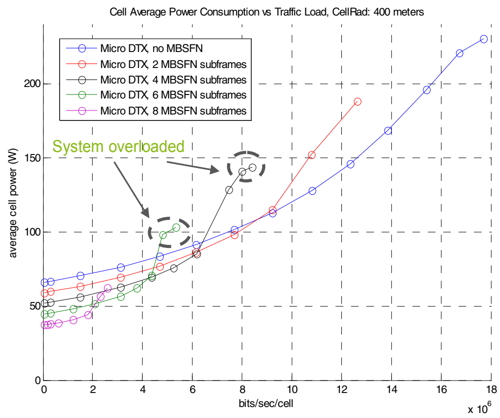


Figure 4: Average power as a function of increasing load, for different MBSFN network configurations. Note that the maximum load level per cell (capacity) reduces with increasing number of MBSFN sub-frames.

### Considering Real Network Traffic

From the simulations presented above we are able to see how much DTX we can expect for a given load and cell size, and with the energy consumption model in Figure 1 we are able to produce energy consumption versus load plots such as presented in Figure 3. However, from an energy consumption point of view it is important to also consider how often we can expect a certain load level in the network.

The traffic data shown in Figure 5 has been gathered from more than 300 cells in a big European city. The measurements were taken for several weeks in 2009 and include both circuit switched (CS) and packet switched (PS) data in an HSPA network. Measurements were gathered at RNC level over 15 minute intervals. In the graph we show the measurement data where the cells (columns) are first sorted according to the average load, and then for each column the time samples are sorted according to instantaneous load. It can be seen in Figure 5 that the load is low in most of the cells during most of the time. In this example the median traffic is 150 kbps and 83% of the samples are below 1 Mbps. Only 6% of the data samples corresponded to zero transmitted bits during a 15 minute duration.

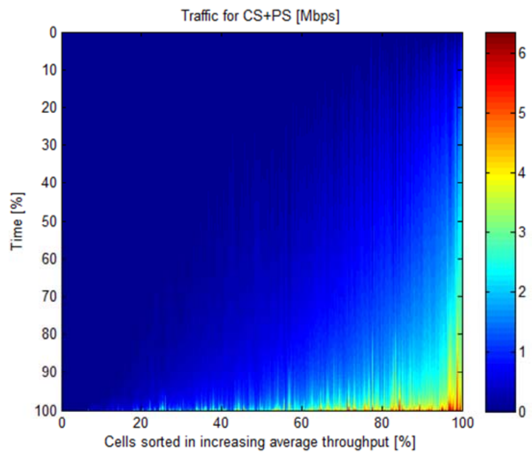


Figure 5: HSPA traffic data from more than 300 cells in a big European city measured for several weeks in 2009. The Each vertical column corresponds to data samples from one cell. The columns are first sorted according to average load on the *x*-axis and then according to instantaneous load on the *y*-axis.

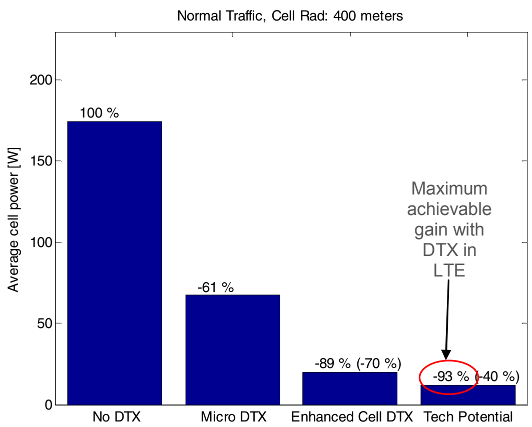


Figure 6: Average energy consumption per cell for different DTX schemes when applying the traffic measurements.

When weighting the energy consumption results from Figure 3 with the traffic measurements in Figure 5 results of the expected average power per cell for different DTX schemes are obtained, as shown in Figure 6. Without cell DTX the average energy consumption per cell is in the order of 170 W. Furthermore, the micro DTX provides an energy reduction of 61%. The resulting energy saving the enhanced cell DTX scheme is a 70% reduction compared to the cell micro DTX case, and an 89% reduction compared to the no DTX case. As a reference we show also in this section results for a "technology potential" scheme where we assume that PBCH and SSS/PSS signals contribute with no overhead cost what so ever. The Technology potential results are 40% lower energy consumption compared to the enhanced cell DTX scheme and 93% reduction compared to the no DTX scheme.

## The Life Cycle Impacts of Cell DTX

A life cycle assessment (LCA) provides a systematic approach to the impacts over the whole life cycle of products and systems, from resource extraction, through the design, manufacturing, distribution, use phase and finally end-of-life treatment including recycling [8]. The LCA methodology is specified in the ISO 1404X series of standards [9][10]. The electricity consumption of base station sites is pointed out as the single most important parameter from the very beginning and is still responsible for nearly 50% of the total life cycle $CO_2$e emissions from wireless networks, in the order of 10 – 15 kg $CO_2$e per subscription annually.

When considering the whole life cycle of a radio access network we note that during the first years of operation the traffic will be low and consequently cell DTX will reduce the energy use significantly during this phase. Eventually the traffic increases and then the gains of cell DTX become somewhat diminished, perhaps as low as 25%. However, a fully loaded system is always more energy efficient per subscriber compared to a lightly loaded system, so during this phase the $CO_{2e}$ emissions are relatively well spent. If a new system emerges in the future and the traffic moves away from the old system then cell DTX becomes more important again. Therefore, cell DTX is essential if we want to keep the energy use (or $CO_{2e}$ emissions) per subscriber low during the whole system life cycle.

## Conclusion

In this paper we show that cell DTX is of key importance when we want to reduce the energy consumption in a radio base station. For LTE we show that by turning off the radio transmitter in OFDM symbols that does not carry any data or reference symbols we can save 61% of the energy in a realistic traffic scenario.

**Acknowledgements**: The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement n° 247733 – project EARTH.

## References

[1] UNFCCC, "Copenhagen Accord," Draft decision at Conference of the parties, COP15, Copenhagen, December 7-18, 2009.

[2] K. Aleklett, M. Höök, K. Jakobsson, M. Lardelli, S. Snowden, and B. Söderbergh, "The Peak of the Oil Age: Analyzing the world oil production Reference Scenario in World Energy Outlook 2008," *Energy Policy*, vol. 38, issue 3, pp. 1398-1414, March 2010.

[3] (2010) The EARTH project website. [Online]. Available: http://www.ict-earth.eu/

[4] J. Malmodin, "Carbon Footprint of Mobile Communications and ICT," in *Proc. Joint International Congress and Exhibition Electronics Goes Green, Merging Technology and Sustainable Development*, Berlin, Germany, September 7-10, 2008.

[5] Cisco, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2009-2014," White Paper, February 9, 2010.

[6] GSMA Development Fund, "Green Power for Mobile: Top ten findings," 2009.

[7] Ericsson and ST-Ericsson, "Enabling Enhanced Cell DTX in LTE," *3GPP TSG-RAN WG1 #60*, R1-101309, San Francisco, USA, February 22-26, 2010.

[8] J. Malmodin, "The importance of energy in LCA for the ICT sector," in *Proc. SETAC Europe 14th LCA Case Study Symposium*, 2007.

[9] ISO 14040, "Environmental Management – Life Cycle Assessment – Principles and Framework," 2006.

[10] ISO 14044, "Environmental Management – Life Cycle Assessment – Requirements and guidelines," 2006.