Introduction

* 1. Introduction

Energy plays an important role in our lives, almost every industry depend heavily on energy. In recent times with the rising global temperature and climate change, the importance of saving energy is ever important. With the rapid development of ICT (Information and Communication Technology) industry the demand for power has also increased. ICT tends to play a significant role in global greenhouse gas emissions. Cellular networks are among the main energy consumers in the ICT field. It was responsible for 10% of world’s total energy consumption in 2010 and is doubling in every 10 years(Dufková, Bjelica, Moon, Kencl, & Le Boudec, n.d.). With increased need for broadband speed the demand for energy and densification of networks is likely to increase. High energy efficiency is becoming a mainstream concern for the design of future wireless communications.

* 1. Background and Motivation

Since the introduction of mobile networks the focus has often been on optimizing the network to fulfil the coverage, capacity and quality requirements. Products have been developed and network deployments have been designed, focusing mainly on these key requirements. During recent years, operators have started to investigate how energy is consumed in mobile networks. The understanding has increased on how energy consumption can be reduced, and environmental awareness has gained importance in the mobile telecom industry. The challenge with designing an energy efficient network is to avoid reducing quality or coverage and hence reducing the performance.

About 0.5% of the world energy consumption is from mobile radio networks.(Fehske, Richter, & Fettweis, n.d.) In mobile networks, base stations are the ones who consume the most amount of energy. Comparing the life cycle of a mobile and base station, a mobile would contribute to green-house gases the most at the time of its manufacturing while for the base station, it is during its life time as a serving node[17]. A lot of research has been done in order to make mobile more efficient at consuming battery power but, base station remain behind their counterparts. Around 80% of the total energy in mobile networks is consumed in radio access network and majorly in base station which comes around to be 60% of the whole (Fehske et al., n.d.). Which stresses on call for reducing this energy consumption at the base station side.



Fig 1. Breakdown of energy consumption in cellular networks (Source Vodafone)(Han et al., 2011)



Fig 2. The operational and the embodied CO2 emissions of base stations and mobile phones per subscribers per year (Han et al., 2011)

Winner and traffic model

Poisson distribution user setup and

Ericsson also did it(Falconetti, Frenger, Kallin, & Rimhagen, 2012)

Quote Mills paper and cisco paper from Maria’s research paper. (teen paper yahin mil gaye refs ke liye) Quote Sibel Tombaz ka paper introduction from it.

5G bhi qingbi

Cite all the 10 top google paper on the Heterogenous networks Energy Efficiency a nad earth power model

Intro from A game theory analytics paper

Follow Intro background Motivation Theory Base Stations macro pico Energy/Power Model Earth Previous work (Fettweis, Henrik forssell, Gunther how much power, Laetitia ka paper, saare paper jo tu padhe unka result conclusion quote kar, feature saving Kihl ki quote kar, )

Simulation (explain Axcel, network Earth power long term short term Gunther ke paper se, Laetitia , Fethweiss se)

Result and Conclusion

Future Work

1.1 Introduction (Auer et al., n.d.)

The global mobile communication industry is growing rapidly. Today there are already more than 4 billion mobile phone subscribers worldwide [1], more than half the entire population of the planet. Obviously, this growth is accompanied by an increased energy consumption of mobile networks. Global warming and heightened concerns for the environment of the planet require a special focus on the energy efficiency of these systems [2]. The EARTH1 project [3] is a concerted effort to achieve this goal and as part of its objectives, a holistic framework is developed to evaluate and compare the energy efficiency of several design approaches of wireless cellular communication networks. For the quantification of energy savings in wireless networks, the power consumption of the entire system needs to be captured and an appropriate energy efficiency evaluation framework (E3F) is to be defined. The EARTH E3F presented in Section 1.2 provides the key levers to facilitate the assessment of the overall energy efficiency of cellular networks over a whole country. The E3F primarily builds on well-established methodology for radio network performance evaluation developed in 3GPP; the most important addendums, introduced in Sections 1.3 and 1.4, are to add a sophisticated power model of the base stations 1 EU funded research project EARTH (Energy Aware Radio and neTwork tecHnologies), FP7- ICT-2009-4-247733-EARTH, Jan. 2010 to June 2012. https://www.ict-earth.eu 1 2 Chapter 1. How Much Energy is Needed to Run a Wireless Network? Global Metric (long term, large scale) Large scale area & Long term traffic load Metric (short term scenario specific) S ll l (short term, scenario specific) system SmallͲscale, shortͲterm system level evaluations BS power P model Pin performance evaluations mobile channel P model out mobile Figure 1.1 EARTH Energy efficiency evaluation framework (E3F). (BSs) as well as a large-scale long-term traffic model extension to existing 3GPP traffic scenarios. Then, using the metrics defined in Section 1.5, in Section 1.6 the E 3F is applied in order to provide an assessment of the BS energy efficiency of a 3GPP LTE network deployed within an average European country. The energy efficiency of LTE is compared to that of already deployed networks is discussed in Section 1.7, and targets for the energy efficiency of future wireless networks are given.

*A. Power consumption model* (Falconetti et al., 2012)

To evaluate and compare the power consumption of the

reference network and the heterogeneous network, the power

model developed by the european project EARTH for year

2010 state-of-the-art base stations has been used [5]. Note that a micro node in EARTH corresponds to a pico node here.

In the EARTH model, the power consumption consists of a

fixed part that is consumed in idle mode and a variable part

based on the traffic load served by the base station. The output

RF power *Pout* scales with the number of frequency resources

scheduled at the given time. If all frequency resources are

scheduled at a certain time, *Pout* reaches the maximum power

*Pmax*. This power model is an approximation of the measured

power consumption of a BS transceiver [5] as depicted in Fig.

1 for a macro BS that handles three sectors.

The modelled power consumption *Pin* of a node is expressed

as

*Pin* =

􀀀\_\_

*P*0 +Δ*p ・ Pout* if 0 *≤ Pout ≤ Pmax*

*Pμ* if *Pout* = 0 and micro DTX on

*Ps* if *Pout* = 0 and sleep mode on

The power model parameters are given in Table I. The values

for the micro DTX mode were obtained from [9]. For the pico

node sleep mode, a remaining power consumption of 10W is

assumed at the pico node. This is aligned with [10].

III. ENERGY EFFICIENCY SCHEMES (Falconetti et al., 2012)

A radio access node, i.e. a base station, is composed of

different components: power amplifier (PA), radio frequency

(RF) transceiver, the base band (BB) unit and finally the

power supply (DC) and cooling (CO). Basically in current

base stations, all components contribute to the overall power

consumption of the node even during the idle time when there

is no data nor signalling transmission to perform, as shown

in Fig. 1 [5]. The two energy efficiency features considered

here are based on the deactivation of certain base station

components during the idle time of a BS. Thus, a lower power

consumption in idle mode can be achieved. This puts however

new requirements on the hardware of a BS that may not be

met by current BSs but could be taken into account when

designing future base stations.

Macro and pico nodes have different roles in the network

and therefore shall meet different requirements concerning

their availability. Consequently different kinds of sleep mode

can be applied to them.

Macro nodes provide the basic coverage meaning they must

be always reachable by potential users. For that purpose,

even if there is no active user in a macro cell and no

data transmission is scheduled, the macro node still needs

to broadcast regularly cell-specific signalling information and

monitor the uplink to identify if a user wants to establish a

connection. A sleep mode based on the complete shut down of

a macro base station is thus hardly conceivable. Even if several

RATs are implemented at a macro node, the radio components

0 0*.*2 0*.*4 0*.*6 0*.*8 1

0

250

500

750

1*,*000

1*,*250

1*,*500

Resource utilization

Power consumption [W]

PA

CO

DC

BB

RF

Fig. 1. Power consumption breakdown of a 3-sector macro BS

related to at least one RAT should remain active so as to supply

mobile communication coverage.

Pico nodes are redundant nodes deployed to help the macro

node handle high traffic demand at certain points in time. A

larger variety of sleep mode mechanisms are hence applicable

to pico nodes.

*A. Micro DTX*

Micro Discontinuous Transmission (DTX) is a sleep mode

technique, introduced in [6] and [3], and which is suitable

for an Orthogonal frequency-division multiplexing (OFDM)

based system such as LTE. The idea is to deactivate the power

amplifier of a LTE base station (BS) during empty OFDM

symbols. In LTE an OFDM symbol with a normal cyclic prefix

length lasts 71.4*μ*s. So, the micro DTX assumes a quick

reactivation of the power amplifier in the order of less than

one OFDM symbol according to [6], [3].

The main advantage of this technique is to exploit very

short idle periods of the BS. These are expected to occur more

often in the future as there will be an increased amount of

traffic generated by means of regular small packets, e.g. social

networking type of traffic.

To enable a quick return to the normal operation mode, the

cell should remain visible to the legacy users. Therefore the

cell-specific signaling still need to be transmitted in certain

OFDM symbols even when there is no data transmission. In

particular the cell-specific reference symbols (CRS) which are

transmitted regularly limit the time where micro DTX can

be applied. Basically, a BS can go to the micro DTX mode

and reduces its power consumption only between two CRS

transmissions. For LTE, the highest possible micro DTX ratio

would be of 10/14, since from the 14 OFDM symbols that

compose each normal subframe, 4 OFDM symbols contain

CRS in case of a transmission with up to two antenna ports.

*B. Pico node sleep mode*

In addition to the micro DTX, the pico nodes introduced

in a heterogeneous network can be subject to a deeper sleep

mode technique, in which not only the PA but also the RF and

BB components of a pico node are deactivated. The inactive

state here is assumed to last in the order of a few hundred

milliseconds.

When applying this mode the control signaling can not be

transmitted by the pico node anymore, and therefore the pico

cell becomes invisible to the user. So all remaining users must

be handed over to another cell before entering the sleep mode.

This kind of deep sleep mode is possible for a pico node

in a heterogeneous network, as the overlaid macro cell that

provides the basic coverage can take care of remaining users.

Several implementations of the pico node sleep mode are

possible depending on the criteria used to trigger the reactivation,

and also on the level of integration of the pico nodes

into the macro network. For instance one could think of a

pico node sleep mode in which an uplink (UL) signal strength

sensor remains active and triggers the pico node reactivation

when the measured UL signal strength exceeds a threshold.

This indicates the presence of a user in the surroundings of

the pico node.

In this paper we consider a heterogeneous network in which

the pico nodes are able to tightly cooperate with the overlaid

macro node. A good connection between the macro and its

pico nodes is thus required. But such a setup offers a more

flexible pico node reactivation that can be based on more

elaborate criterion. In the following the macro node controls

the activation and deactivation of its underlaid pico nodes and

takes its decision based on the traffic load in the different

cell layers. This enables to react quickly to the traffic demand

variation and avoids the re-activation of pico nodes for users

that would not benefit from a higher available bitrate, e.g.

VoIP users. Moreover, compared to the pico node activation

based on uplink signal measurement, the present scheme does

not require long measurement filtering before triggering the

activation.

As shown in Fig. 2, the macro node regularly checks the

traffic load level in its cell. If the traffic load exceeds a certain

threshold, all pico nodes under its control are activated. An

activation delay of 100ms is assumed here. Note that a macro

node equipment is serving all sectors (or cells) of a site.

Here we assume that the macro node activates the pico nodes

located in the macro sector where the load is increasing. After

triggering the pico node activation, the macro node requests all

users to measure the signals from neighboring cells. This may

result in a handover of some users towards the pico nodes.

The activated pico nodes regularly monitor the served traffic.

If the traffic load remains low after a certain delay, *δactive*,

these pico nodes autonomously go back to sleep, see Fig. 3.

* 1. Previous Work by Henrik Forssell

The Energy Aware Radio and netWork tecHnologies (EARTH) project was during

the years 2010-2012 investigating the energy efficiency of mobile communication

systems. The project was documented in a series of deliverables which,

together with more information about the project can be found on the on the

web-site [1]. There they state that: “The goal of the project was to address the global environmental challenge

by investigating and proposing effective mechanisms to drastically reduce energy

wastage and improve energy efficiency of mobile broadband communication

systems, without compromising users perceived quality of service and system

capacity.”

As a part of the EARTH project, mathematical models for the power consumption

of various BS types were developed. These power models were used in

simulations so as to be able to study the energy consumption at network level.

Several types of deployment areas, e.g.rural, suburban, urban and dense urban

were considered.

Linear power models for BSs is widely used for simulation studies of energy

efficiency and energy savings. In [9] the energy consumption of HetNets consisting

of macro and pico BSs are studied. Linear power models from the EARTH

project are used in a generic 3rd generation partnership project (3GPP) simulation

scenario were pico nodes are placed randomly within 100 m from each macro

BS. Furthermore, in [16], the energy performance of LTE HetNets is studied in

relation to the user experience by utilizing linear power models, again with a

3GPP simulation scenario.

In [18], different approaches to densifying urban networks are studied. Their

simulation results show that indoor deployment of small cells is more energy efficient

than densifying the macro deployment. The simulation scenario considered

is a uniform “Manhattan-type city model”.

DTX as an energy saving technique is proposed in [4] and the potential

energy savings is studied in [3, 12, 7]. In [12] a DTX enabled macro deployment

in a metropolitan area is studied through simulations.

The main contribution from this study is an assessment of the energy saving

potential from the combination of short term DTX sleep and longer sleep modes

specifically in the small cell BSs. Furthermore, the studied simulation scenario

is more specific and detailed than the previous work we know of, considering

a city with real buildings and realistic small cell deployment. The realistic 3D

environment and specific site deployment in the simulator allows for ray-tracing

propagation models that is more accurate than statistical models used in generic scenarios with random deployment.

* 1. Purpose of the Project

With the outset of 5G, many cities will be deployed with indoor cells, pico, DAS and radio dots. Therefore, it is more than required than ever that this type of research should take place to compare and find out the equivalence and power consumption of the Pico cells, micro cells and macro cells.

Out of 100% of Ericsson’s deployment of base stations cities like Beijing have 50% in indoor deployment and cities like Seoul, Dubai 80%, Shanghai have much more.

As in South Korea vendors like SKT have bought 28 GHz band for their frequency spectrum, this will be impenetrable to the buildings from outside so for base coverage indoor we would need micro, pico and radio dots and other indoor deployments at 3 GHz.

5G is going to be like HetNets in radio frequency plus high frequency base stations.

1.5 Outline of the Thesis

Theory

2.1 Macro Cells

2.2 Pico Cells

2.3 LTE Transmission Techniques

2.4 WINNER and Traffic Poisson Model

**The Framework:**

**WINNER**(Auer et al., n.d.)

Energy Efficiency Evaluation Framework (E3F) The widely accepted state-of-the-art to evaluate the performance of a wireless network is to simulate the relevant aspects of the radio access network (RAN) at system level. The computed results are, e.g. the system throughput measured in bit/s, quality of service (QoS) metrics, and fairness in terms of cell-edge user throughput. In order to ensure that the results generated by different RAN system simulation tools are comparable, well defined reference systems and scenarios are specified. This is an outcome of extensive consensus work from standardization bodies, such as 3GPP [4], and international research projects, such as the EU project Wireless World Initiative New Radio (WINNER) [5], with partners from academia as well as from industry. The most recent example is the global effort in ITU to evaluate system proposals for compliance with IMT-Advanced requirements [6]. In that direction, the EARTH E3F builds on the 3GPP evaluation framework for LTE [4].

Power Model

EARTH Power Model

Power Model (Auer et al., n.d.)

1.3 Power Model This section provides a power model for various types of LTE Base Stations. The power model constitutes the interface between component and system level, which allows quantifying how energy savings on specific components enhance the energy efficiency at the node and network level. 1.3.1 Base Station Power Consumption Breakdown Fig. 1.2 shows a simplified block diagram of a complete BS that can be generalized to all BS types, including macro, micro, pico and femto BSs. A BS consists of multiple transceivers (TRXs), each of which is serving one transmit antenna element. A TRX comprises a Power Amplifier (PA), a Radio Frequency (RF) small-signal transceiver section, a baseband (BB) interface including a receiver (uplink) and transmitter (downlink) section, a DC-DC power supply, an active cooling system, and an AC-DC unit (mains supply) for connection to the electrical power grid. In the following the various TRX parts are analyzed. Antenna Interface: The influence of the antenna type on power efficiency is modeled by a certain amount of losses, including the feeder, antenna band-pass filters, duplexers, and matching components. Since macro BS sites are often situated at different physical locations as the antennas a feeder loss of about σfeed=3 dB needs to be added. The feeder loss of a macro BS may be mitigated by introducing a remote radio head (RRH), where the PA is mounted at the same

physical location as the transmit antenna. Likewise, feeder losses for smaller BS types are typically negligible. Power Amplifier (PA): Typically, the most efficient PA operating point is close to the maximum output power (near saturation). Unfortunately, non-linear effects and OFDM modulation with non-constant envelope signals force the power amplifier to operate in a more linear region, i.e., 6 to 12 dB below saturation [7]. This prevents Adjacent Channel Interference (ACI) due to non-linear distortions, and therefore avoids performance degradation at the receiver. However, this high operating back-off gives rise to poor power efficiency ηPA, which translates to a high power consumption PPA. Digital techniques such as clipping and digital pre-distortion [8, 9] in combination with Doherty PAs [7] improve the power efficiency and linearizes the PA, while keeping ACI under control, but require an extra feedback for pre-distortion and significant additional signal processing [9]. While these techniques are necessary in macro and micro BSs, they are not used in smaller BSs, as the PA power consumption accounts for a smaller percentage of the power breakdown, allowing for a higher operating back-off. The Small-Signal RF Transceiver (RF-TRX) comprises a receiver and a transmitter for uplink (UL) and downlink (DL) communication. The linearity and blocking requirements of the RF-TRX may differ significantly depending on the BS type, and so its architecture. Typically, low-IF (Intermediate-Frequency) or super-heterodyne architectures are the preferred choice for macro/micro BSs, whereas a simpler zero-IF architecture are sufficient for pico/femto BSs [10]. Parameters with highest impact on the RF-TRX energy consumption, PRF, are the required bandwidth, the allowable Signal-to-Noise And Distortion ratio (SiNAD), the resolution of the analogue-to-digital conversion, and the number of antenna elements for transmission and/or reception. Baseband (BB) Interface: The baseband engine (performing digital signal processing) carries out digital up/down-conversion, including filtering, FFT/IFFT for OFDM, modulation/demodulation, digital-pre-distortion (only in DL and for large BSs), signal detection (synchronization, channel estimation, equalization, compensation of RF non-idealities), and channel coding/decoding. For large BSs the digital baseband also includes the power consumed by the serial link to the backbone network. Finally, platform control and MAC operation add a further power consumer (control processor). The silicon technology significantly affects the power consumption PBB of the BB interface. This technology scaling is incorporated into the power model by extrapolating on the International Technology Roadmap for Semiconductors (ITRS). The ITRS anticipates that silicon technology is replaced by a new generation every 2 years, each time doubling the active power efficiency but multiplying by 3 the leakage [11]. The increasing leakage puts a limit on the power reduction that can be achieved through technology scaling. Apart from the technology, the main parameters that affect the BB power consumption are related to the signal bandwidth, number of antennas and the applied signal process-

ing algorithms. While the consumed power scales linearly with the bandwidth; MIMO signal detection scales more than linearly with the number of antennas. Power Supply and Cooling: Losses incurred by DC-DC power supply, mains supply and active cooling scale linearly with the power consumption of the other components, and may be approximated by the loss factors σDC, σMS, and σcool, respectively. Note that active cooling is only applicable to macro BSs, and is omitted in smaller BS types. Moreover, for RRHs active cooling is also obsolete, since the PA is cooled by natural air circulation, and the removal of feeder losses σfeed allow for a lower PA power consumption, PPA = Pout ηPA·(1−σfeed) , where ηPA denotes the PA power efficiency. Assuming that the BS power consumption grows proportionally with the number of transceiver chains NTRX, the breakdown of the BS power consumption at maximum load, Pout=Pmax, amounts to Pin = NTRX · Pmax ηPA·(1−σfeed) + PRF + PBB (1−σDC)(1−σMS)(1−σcool) (1.1) The efficiency is defined by η = Pout/Pin, whereas the loss factor is defined by σ = 1−η. Note that the maximum RF output power per transmit antenna, Pmax, is measured at the input of the antenna element, so that losses due to the antenna interface (other than feeder losses) are not included in the power breakdown. Table 1.1 summarizes the state of the art power consumption of various LTE BS types as of the year 2010. By introducing RRHs in macro BS sites, so that feeder losses σfeed and active cooling are avoided by mounting the PA close to the transmit antenna, the power savings exceed 40%.

Short-Term Model

## Long-Term Model

## Other Paper Models

3.4.1 Eric Sibel Tombaz Mohd. Usman

D. Power Consumption Model In our power consumption analysis of different heterogeneous deployment strategies, we have used the power consumption model proposed in [2]. Here, power consumption of a base station is modeled as a linear function of average radiated power per site as below: Pi = L.(aiPtx + bi) (6) where Pi and Ptx denote the average consumed power per base station and radiated power respectively. The coefficient ai accounts for the power consumption that scales with the transmit power due to RF amplifier and feeder losses while bi models the power consumed independent of the transmit power due to signal processing and site cooling. Here L reflects the activity level of the base stations. In [2], it is noted that small, low power base stations have the ability to scale their power consumption with activity level of the network. For simplicity, we assume the network is fully loaded, L is equal to one, i.e., each base station has at least one mobile requesting data with all resources allocated. TABLE I POWER CONSUMPTION PARAMETERS Base Station Type ai bi Macro 21.45 354.44 Micro 7.84 71.50 Pico 5.5 38 WLAN 3.2 10.2 1000 1500 2000 2500 3000 3500 4000 0 500 1000 1500 2000 2500 3000 3500 Distance (m) Area Power Consumption (Watt/km2 ) macro macro + 3 macro macro + 5 macro macro + 3 micro macro + 5 micro macro + 3 pico macro + 5 pico macro + 3 wlan macro + 5 wlan (a) Area power consumption as a function of intersite distance 1000 1500 2000 2500 3000 3500 4000 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 Distance (m) Area Spectral Efficiency (bits/s/Hz/km2 ) macro macro + 3 macro macro + 5 macro macro + 3 micro macro + 5 micro macro + 3 pico macro + 5 pico macro + 3 wlan macro + 5 wlan (b) Area spectral efficiency as a function of intersite distance Fig. 2. Performance metric functions of different network deployments for uniformly distributed traffic. It should be noted that each kind of base station has different model parameters. For macro and micro base stations, the parameters stated in [2] are used. If it is not stated otherwise, for pico base stations and WLAN, the parameters are chosen as in Table I. Total power consumption of each heterogeneous network, P, is calculated as follow: P = $m i NiPi (7) where m is the number of base station types in the network, Ni is the number of i. type of base station and Pi is the power consumption of that base station which is calculated via (6). To be able to make a fair comparison, area power consumption is used as a performance measure which is given by 710 P = P A = %m i NiPi A ∼ f(Dα) f(D2) (8) Here A is the total area of the network

Simulation setup

Deployment

We will deploy a layer of outer grid comprising of Macro cells and a layer of inner indoor cells for high traffic requirements and then we will measure the Energy performance with keeping only the Macro layers outside the central grid keeping the base stations inside inside cover the traffic and the outside layer of macro cells for coverage purposes.

Traffic

## 4.3. Energy Saving Features

Results and Discussion

Conclusion

Future work

References

Abdulkafi, A. A., Tiong, S. K., Chieng, D., Ting, A., Ghaleb, A. M., & Koh, J. (2013). Modeling of Energy Efficiency in Heterogeneous Network. *Engineering and Technology*, *6*(17), 3193–3201.

Auer, G., Giannini, V., Gódor, I., Olsson, M., Ali Imran, M., Sabella, D., … Desset, C. (n.d.). How Much Energy is Needed to Run a Wireless Network ?

Dufková, K., Bjelica, M., Moon, B., Kencl, L., & Le Boudec, J.-Y. (n.d.). Energy Savings for Cellular Network with Evaluation of Impact on Data Traffic Performance.

Falconetti, L., Frenger, P., Kallin, H., & Rimhagen, T. (2012). Energy efficiency in heterogeneous networks. *Online Conference on Green Communications (GreenCom), 2012 IEEE*, 98–103. https://doi.org/10.1109/GreenCom.2012.6519623

Fehske, A. J., Richter, F., & Fettweis, G. P. (n.d.). Energy Efficiency Improvements through Micro Sites in Cellular Mobile Radio Networks.

Han, C., Harrold, T., Armour, S., Krikidis, I., Videv, S., Grant, P. M., … Hanzo, L. (2011). Green radio: Radio techniques to enable energy-efficient wireless networks. *IEEE Communications Magazine*, *49*(6), 46–54. https://doi.org/10.1109/MCOM.2011.5783984

Appendix A: Extended material

Some extra information for readers who would like more.