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

The global mobile data traffic grew by 63 percent in 2016.(“Cisco Visual Networking Index: Forecast and Methodology Cisco Visual Networking Index: Cisco Visual Networking Index: Forecast and Methodology,” 2015) it stood at 7.2 billion giga bytes per month during the ending of 2016. And by 2021 it will be 49 billion giga bytes.

Almost half a billion new mobile devices were added in 2016 and according to the Ericsson’s forecast there will be 50 billion connected devices by 2020.

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)

* 1. Previous Work

There has been studies related to improvement of the base stations energy consumption, and in 2010-2012 a study was conducted under Energy Aware Radio and netWork tecHnologies (EARTH) project in which researchers from around the world tried to achieve some deliverables(Domenico & Petersson, 2012) which proved to be a standardized principles for working on energy efficiency concept for base stations.

In the the executive summary of their final deliverable they state that: “The Energy Aware Radio and neTwork tecHnologies (EARTH) project had the ambitious overall goal to derive solutions that together can decrease the radio access network energy consumption by 50 % with preserved quality of service. These solutions act all the way from more efficient components in the base station, over improvements affecting individual radio links, up to solutions acting on the radio network level such as deployment strategies. Furthermore, the project not only developed and proposed energy efficient solutions in all these areas, but also combined them into an overall EARTH energy efficient integrated concept. In addition, EARTH is committed to have a real impact on networks in operation; hence the target was not only to carry out theoretical studies in this aspect, but also to provide trustworthy proof-of-concepts of the individual solutions and in particular of the overall EARTH energy efficient integrated concept.”(Domenico & Petersson, 2012)

The EARTH project gave the mathematical power model for calculating the energy comsumption in the base stations for various different scenarios of rural, sub-urban and urban, the linear power model is used in generic simulations. It also gives the internal breakdown of energy consumed within different sizes of nodes such as macro, mico, pico and femto.

In(Yunas, Valkama, & Niemelä, 2015) a “Manhattan-type city grid” is analysed for energy performance in which off-loading the macro cells with indoor cells prove to be more energy efficient.

In (Forssell & Auer, 2015) The study was conducted to find if in a dense urban scenario the indoor nodes would prove to be energy efficient or not but, to the contrary they proved to be worse than keeping only the macro BS grid in the scenario.

In (Tombaz, Sung, & Zander, 2012) study was conducted on densification of network in which it was found out that the deployment of smaller cells reduces the transmit power of large BSs and the idle time and backhaul becomes energy wasters

In(Falconetti, Frenger, Kallin, & Rimhagen, 2012) a heterogeneous network scenario was considered in which network desification strategies were introduced and to save the power micro DTX and pico node sleep modes were utilized to prove that the network desification could take place successful without

increasing the energy requirements. The heterogeneous network was composed of macro nodes and pico nodes. At high traffic energy could be saved a lot by smaller nodes handling large traffic, thereby increasing user performance and decreasing energy consumption at the same time. In one of the deliverables of EARTH Project DTX scheme was also presented.

We will make use of these energy saving features like short term DTX and long term sleep modes in the nodes. We will make use of a Ericsson’s static network simulator which will present us a realistic three dimensional model of a city with buildings, pavements and open spaces. The simulator makes use of ray-tracing propagation models.

* 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

With the onset of 5G there will be use of a lot of HetNets and densified networks to satisfy the demand for increased traffic. Most of the mobile traffic will be concentrated indoor around 70 percent of the traffic will come from indoor users in shopping malls, airport teminals etc.(Ericsson white paper, 2014). There will be small cells which would be deployable as ‘plug and play ’ which is going to save a lot of CAPEX for the operators and as these small cells will have a small coverage area which will enable frequency reuse possible being close to each other which will provide large capacity improvement (Yunas et al., 2015).

Achieving indoor coverage at 30 GHz is highly problematic

for all cases, and it is concluded that indoor base stations are

necessary if frequencies of 10 GHz and above are to be used in future mobile networks.(Rydén, 2016)

2.1 Macro Cells

2.2 Pico Cells

PICOCELLS Picocells are regular eNBs with the only difference of having lower transmit power than traditional macro cells. They are, typically, equipped with omni-directional antennas, i.e., not sectorized, and are deployed indoors or outdoors often in a planned (hot-spot) manner. Their transmit power ranges from 250 mW to approximately 2 W for outdoor deployments, while it is typically 100 mW or less for indoor deployments. Since picocells are regular eNBs from the architecture perspective, as can be seen in Fig. 2, they can benefit from X2-based intercell interference coordination (ICIC).

FEMTOCELLS Femtocells or HeNBs are typically consumer deployed (unplanned) network nodes for indoor application with a network backhaul facilitated by the consumer’s home digital subscriber line (DSL) or cable modem. Femtocells are typically equipped with omnidirectional antennas, and their transmit power is 100 mW or less. Depending on whether the femto cells allow access and hence usage of the consumer’s home DSL or cable modem to all terminals, or to a restricted set of terminals only, femto cells are classified as open or closed. Closed femtos restrict the access to a closed subscriber group (CSG), while open femtos are similar to picocells but with the network backhaul provided by the home DSL or cable modem. A femtocell can also be hybrid, whereby all terminals can access Picocells are regular eNBs, with the only difference of having lower transmit power than traditional macrocells. They are, typically, equipped with omnidirectional antennas (i.e., not sectorized) and are deployed indoors or outdoors, often in a planned (hotspot) manner. DAMNJANOVIC LAYOUT 6/6/11 10:56 AM Page 13 14 IEEE Wireless Communications • June 2011 but with lower priority for the terminals that do not belong to the femto’s subscriber group. Since closed femtos do not allow access to all terminals, they become a source of interference to those terminals. Co-channel deployments of closed femtos therefore cause coverage holes and hence outage of a size proportional to the transmit power of the femtocell. Figure 2 shows the architecture of LTE femtocells (HeNBs), and, as can be seen, no X2 interface is defined for HeNBs in Rel-8/9. The absence of an X2 interface for closed femtos does not make ICIC possible for this type of node. Instead, OAM-based techniques in conjunction with possibly autonomous power control techniques are the only viable interference control techniques for Rel-10. These techniques seek to minimize the outage these network nodes cause around them by enabling reception of the signal from the closest macrocell in close proximity to the closed femto.

2.3 LTE Transmission Techniques

LTE OVERVIEW The first release of LTE was published in March 2009 and is referred to as LTE Rel-8 [18]. 3GPP has developed the LTE standard for fourth-generation (4G) cellular networks based on orthogonal frequency-division multiplexing (OFDM) waveform for downlink (DL) and single-carrier FDM (SC-FDM) waveform for uplink (UL) communications mainly to improve the user experience for broadband data communications. Compared to 3G technologies, such as 3GPP’s HSPA,1 LTE Rel-8 offers higher peak data rates due to larger system bandwidth (up to 20 MHz was allowed) and higher-order multiple-input multiple-output (MIMO) spatial processing techniques (up to 4 Tx × 4 Rx open and closed loop MIMO schemes are supported in the DL of LTE Rel-8). Figure 2 illustrates the LTE network [18] nodes and the interfaces among them. The base stations are denoted eNode-B (eNB) and the mobile stations or terminals as UE. The lowpower nodes include picocells, femtocells, home eNBs (HeNBs), and relay nodes (RNs). The eNB serving the RN (i.e., scheduling RN backhaul traffic) is denoted donor eNB (DeNB). The same eNB can be the DeNB for one RN and the regular serving cell for UE, as shown in Fig. 2. The mobility management entity (MME) and serving gateway (S-GW) serve as local mobility anchor points for the control and data planes, respectively. The X2 interface defined as a direct eNB-toeNB interface allows for inter-cell interference coordination (ICIC). The Rel-8 ICIC techniques can be summarized as: • Proactive: Techniques that facilitate fractional frequency reuse (FFR) or “soft reuse” operation in the DL and UL with the goal of reducing interference experienced in certain Figure 2. LTE heterogeneous network nodes and their interfaces. RN UE UE UE Pico Pico HeNB HeNB HeNB HeNB GW E-UTRAN UE UE eNB DeNB MME / S-GW MME / S-GW X2 X2 S1 S1 S1 X2 S1 S1 S1 S1 S1 S1 S1 S1 S1 X2 Un S11 1 HSPA Rel-10 supports carrier aggregation mode, where four 5 MHz can be aggregated offering broadband wireless communication to a single UE over 20 MHz bandwidth. Compared to 3G technologies, such as 3GPP’s HSPA, LTE Rel-8 offers higher peak data rates due to larger system bandwidth (up to 20 MHz was allowed) and higher-order MIMO spatial processing techniques. DAMNJANOVIC LAYOUT 6/6/11 10:56 AM Page 12 IEEE Wireless Communications • June 2011 13 frequency subbands in order to increase the cell edge user throughput • Reactive: Techniques that respond to highinterference conditions and enable tight control of the interference-over-thermal (IoT) level in the UL These ICIC techniques are expanded in Rel-10 to enable efficient support of co-channel heterogeneous network deployments, discussed later. S1 and S11 interfaces support transfer or user and data traffic between the corresponding nodes and are not utilized for ICIC. The Un interface refers to an air interface between DeNB and RN. Un is based on a modified interface between the eNB and UE in order to allow half duplex operation for the RN. As mentioned above, the LTE air interface is based on OFDM in the DL and SC-FDM in the UL. The basic time and frequency unit in the DL (UL) is one OFDM (SC-FDM) symbol and one subcarrier (virtual subcarrier), respectively. The subcarrier spacing is 15 kHz and therefore, the OFDM symbol duration is 66.67 us. Each OFDM/SC-FDM symbol is pre-appended with a cyclic prefix (CP) to suppress the inter-symbol interference and mitigate multi-path. Two CP durations are defined; the normal CP has a duration of 4.7 us and the extended CP has a duration of 16 us. One resource element corresponds to one subcarrier (virtual subcarrier) in one OFDM (SC-FDM) symbol. OFDM (SCFDM) symbols are grouped in subframes of 1 ms duration. Each subframe is composed of two 0.5 ms slots. In order to limit the signaling overhead of data allocations, the minimum scheduling unit for the DL and UL of LTE is referred to as a resource block (RB). One RB pair consists of 12 subcarriers in the frequency domain (i.e., 180 kHz) and one subframe in the time domain (i.e., 1 ms). In the DL, all the control information is time-division multiplexed (TDM) with the data transmission. The DL control information is concentrated in the first slot of the first subframe, and dynamically spans the first one, two, or three OFDM symbols of the subframe. Subframes are further grouped in 10 ms radio frames. Figure 3 illustrates the physical layer frame structure for FDD. Each radio frame has two 5 ms halves containing the signals necessary to obtain the physical identity of the cell. These signals are what we call the acquisition channels, which are the primary and secondary synchronization signals, providing the physical cell identity (PCI) of the cell, and the physical broadcast channel (PBCH), which provides some critical system information such as the DL transmission bandwidth and the number of DL antenna ports. The acquisition channels share the property of spanning the middle six RBs of the system bandwidth. This enables having the same acquisition channels irrespective of the actual system bandwidth (up to 20 MHz is supported for Rel-8). LTE defines a reference or pilot signal in Rel-8, referred to as a common reference signal (CRS), which is used for mobility measurements as well as for demodulation of the DL control and data channels. The CRS transmission is distributed in time and frequency, as shown in Fig. 3, to enable adequate time and frequency interpolation of the channel estimates for the purpose of coherent reception of the transmitted signals in time- and frequency-selective channels. As discussed later, co-channel deployments of heterogeneous networks rely on the coordination of almost blank subframes. Almost blank subframes are intended to reduce the interference created by the transmitting node while providing full legacy support. For that reason, on almost blank subframes, eNB does not schedule unicast traffic while transmitting acquisition channels and CRS to provide legacy support. 3GPP has been working on further improving the spectral efficiency of LTE as part of its Rel- 10 version. LTE Rel-10 is being developed to meet ITU requirements for IMT-Advanced technology. LTE Rel-10 [19], also termed LTEAdvanced (LTE-A), supports improved MIMO operation as DL MIMO support is enhanced (8 Tx × 8 Rx is supported), and UL MIMO (4 Tx × 4 Rx) is introduced to improve link spectral efficiency. Signaling mechanisms enabling aggregation of multiple carriers are also introduced in LTE Rel-10, offering improvements in peak user data throughput. Up to five 20-MHz component carriers can be aggregated, offering a peak data rate of more than 1 Gb/s. However, these improvements, while significant from the link perspective and for users in good coverage, or in terms of the peak data rates for lightly loaded systems, do not translate into significant improvements in terms of system spectral efficiency in bits per second per Hertz. System gains are only achievable through increased node density and deployment of low-power nodes, such as pico, femto, and relay base stations.

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%.

*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* =

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*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 r educes 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.

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

(Rydén, 2016)Methodology

This chapter is organized as follows: section 3.1 briey describes the Ericsson simulator

and the simulation parameters used. Section 3.2 further describes the propagation models

used by the simulator, before the new outdoor to indoor model is presented in section 3.3.

3.1 The Simulator

The simulator used in this thesis is an Ericsson internal, time static LTE system level

network simulator written in Matlab. It o\_ers support for various propagation models,

ranging from fast, statistical models to more computationally demanding, ray-tracing based

models, as will be further described in the following sections. The fact that it is time static

is not a limiting factor, as the goal of this thesis is to determine indoor coverage for

throughout a building oor plan, where users can assumed to be stationary.

3.1.1 Ray Tracing

Ray tracing is a technique to accurately model propagation of high frequency electromagnetic

waves, by tracing the wave propagation path from a base station (BS) to a user. In

particular, ray tracing may be used to model the reections with building walls in a city,

or indoor walls in an indoor environment [10]. Since this technique approximates the wave

front with particle-like ray, wave-like phenomena such as di\_raction needs to be modeled

separately. This can for instance be done by replacing the terrain pro\_le with absorbing

half-screens [11], and using a recursive model [12].

3.1.2 Simulation Parameters

Since the parameters used in future 5G networks are yet to be determined, parameter

assumptions have to be made. The most signi\_cant parameters when studying proagation

is the carrier frequency, for which a few candidates exist. For instance, 28 GHz is used

in [13]. In this work, a range of frequencies was selected in order to give an idea of how

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propagation characteristics change for various frequencies. The frequencies chosen in this

work are 2, 5, 10 and 30 GHz.

The EIRP for a 5G system is assumed to be 65 dBi, mostly by the use of large antenna

arrays to achieve a high beam forming gain. In the simulations, an antenna with 65 degrees

horizontal and vertical half power beam width is used to simulate an antenna with many

beam forming elements. As only PG is studied, and not interference between users, this

corresponds to being able to steer the beam individually to each user with a high gain.

To reach the chosen EIRP, a transmit power of 40 W and antenna gain of 19 dBi was

assumed. The actual values for a 5G systems will most likely di\_er from these, and may

also be frequency dependent. However, the EIRP remains the most important measure,

and it is assumed to be around 65 dBi for 5G systems. To reach an SNR of 0 dB, (2.9)

gives a minimum PG of -131 dB, which will be de\_ned as the threshold for whether a user

is in coverage or not. For this reason, PG will be the measure of performance in this work.

The simulation parameters are summarized in table 3.1.

Table 3.1: System parameters.

Frequency [GHz] 2, 5, 10 and 30

Transmit power, BS [dBm] 46

Antenna gain (BS) [dBi] 19

Noise \_gure, DL [dB] 9

EIRP (BS) [dBi] 65

Horizontal beam width, BS [deg] 65

Vertical beam width, BS [deg] 65

3.2 Propagation

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

(Yunas et al., 2015)In this article, we have studied the performance

of DenseNets from different deployment strategies’

perspectives covering classical macro layer

densification, the extremely dense indoor femto

layer and outdoor dynamic distributed antenna

system. The macrocell and ultra dense small cell

deployment strategies have been evaluated from

the cell spectrum efficiency, network spectrum

efficiency, and network energy efficiency perspectives

with an extreme level of densification

and under full network load conditions to investigate

and demonstrate the performance differences

of these solutions when pushed to their

capacity limits. The obtained results indicate that

dedicated indoor solutions with densely deployed

femtocells are much more spectrum-efficient

and energy-efficient approaches to address the

enormous indoor capacity demands compared to

densifying the outdoor macro layer. Hence, we

can conclude that to counter the growing concerns

of the mobile operators related to the

exponentially increasing amounts of mobile data

toward the 5G era, an appealing solution is to

deploy dedicated indoor solutions like femtocells,

which offer a cost-effective and energy-efficient

solution for indoor capacity demands. Also,

from the indoor-to-outdoor service provisioning

point of view, the mobile operators can partially

leverage indoor-based femtocells to provide certain

neighborhood coverage to low-mobility outdoor

users, thereby offloading some of the traffic

from the outdoor layer. This strategy can result

in significant cost saving for mobile operators.

Finally, from the outdoor service provisioning

point of view, we have introduced and analyzed

the dynamic outdoor DAS concept, which offers

an efficient and capacity-adaptive solution to

provide outdoor capacity on demand in urban

areas by dynamically configuring the remote

antenna units to either act as individual small

cells or distributed nodes of a common central

cell. One main purpose of this article is to raise

awareness of the full network-level energy efficiency

and spectrum efficiency potential of dedicated

indoor systems, on one side, especially

with increasing levels of wall penetration losses

observed recently in modern buildings, and the

reconfigurable capacity provisioning prospects of

dynamic DAS solutions also closely connected to

the emerging cloud-RAN concepts in the future.

Future work

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Appendix A: Extended material

Some extra information for readers who would like more.