

Master Thesis

Comparison of energy efficiency between macro and micro cells with energy saving schemes.

By

Koustubh Sharma

Department of Electrical and Information Technology Faculty of Engineering, LTH, Lund University

SE-221 00 Lund, Sweden

# Abstract

Cellular networks are among the main energy consumers in the ICT field. They were responsible for 10% of world’s total energy consumption in 2010 and the figures are doubling in every 10 years.

To have an environment friendly transit into the new era of internet of things, we need to focus on energy consumption by these networks. There are various approaches for densifying the present network that we have; we will compare the approaches to cater to the traffic demands with macro cells versus micro cells deployments.

In the project, we had set up a dense urban real like scenario and compared energy efficiencies between macro cells centric deployment versus a micro cells centric deployment, we made use of energy saving schemes like micro DTX, lean carrier and MBSFN to reduce the power consumed in the network. We deployed these cells in the city center where the traffic demand was set to highest.

With results presented in this thesis, we will contribute to the understanding of how these cells behave in a realistic traffic scenario and how much gains can we achieve by implementing the above-mentioned energy saving schemes. To keep the results more generic and not specific to any particular set of radio base stations we implemented EARTH power model to calculate power consumption.

The energy saving schemes proved out to save a lot of energy in the operations of both macro and micro cells. It was observed that using the discontinuous transmission around 20% to 30% of energy could be saved. The amount of savings from these energy saving schemes depend upon the utilization and sleep time of these nodes, we saw that using energy saving schemes in macro cell deployment can give savings as much as 17% and 33% in micro cell deployment. Comparing macro without energy saving scheme to micro with lean carrier energy saving scheme results in 55% of energy savings. So, from an energy saving point of view, it would be much better to implement a heterogeneous network with more micro cells and small cells with energy saving features than just macro cells.

# Acknowledgments

Thanks to everyone who extended their support during the master thesis and to my parents for their constant support and motivation.

Koustubh Sharma

# Table of Contents

[Abstract 2](#_Toc498623818)

[Acknowledgments 4](#_Toc498623819)

[Table of Contents 5](#_Toc498623820)

[1 Introduction 7](#_Toc498623821)

[1.1 Introduction 7](#_Toc498623822)

[1.2 Background and Motivation 7](#_Toc498623823)

[1.3 Previous Work 9](#_Toc498623824)

[1.4 Purpose of the Project 10](#_Toc498623825)

[1.5 Outline of the thesis 11](#_Toc498623826)

[2 Theory 13](#_Toc498623827)

[1.6 Heterogeneous Networks 13](#_Toc498623828)

[1.6.1 Macro Cells: 14](#_Toc498623829)

[1.6.2 Micro Cells 14](#_Toc498623830)

[1.6.3 Pico Cells 14](#_Toc498623831)

[1.6.4 Femto cell 15](#_Toc498623832)

[1.7 LTE Basics 15](#_Toc498623833)

[1.7.1 OFDM (Orthogonal Frequency Division Multiplex) 15](#_Toc498623834)

[1.7.2 MIMO (Multiple Input Multiple Output) 16](#_Toc498623835)

[3 Power Model 17](#_Toc498623836)

[1.8 Power distribution in base station 17](#_Toc498623837)

[1.9 Power consumed at maximal load 18](#_Toc498623838)

[1.10 Variable load power consumption of BS 22](#_Toc498623839)

[1.11 Energy consumption references 23](#_Toc498623840)

[1.11.1 Energy per bit 23](#_Toc498623841)

[1.11.2 Power per unit area 24](#_Toc498623842)

[1.12 Average power consumption 24](#_Toc498623843)

[1.13 Average power consumption over a day 24](#_Toc498623844)

[1.14 Energy Saving schemes 25](#_Toc498623845)

[1.14.1 Lean carrier 25](#_Toc498623846)

[1.14.2 Micro TX sleep 26](#_Toc498623847)

[1.14.3 MBSFN 26](#_Toc498623848)

[4 Methodology 28](#_Toc498623849)

[1.15 The Simulator 28](#_Toc498623850)

[1.16 Setup 28](#_Toc498623851)

[1.17 Deployment 29](#_Toc498623852)

[1.18 Traffic 30](#_Toc498623853)

[5 Results and Discussions 31](#_Toc498623854)

[1.19 Comparison macro v/s micro without energy saving schemes 32](#_Toc498623855)

[1.20 Comparison macro with and without energy saving schemes 38](#_Toc498623856)

[1.21 Comparison micro with and without energy saving schemes 41](#_Toc498623857)

[1.22 Comparison macro v/s micro with energy saving schemes 44](#_Toc498623858)

[1.23 Daily power consumption 47](#_Toc498623859)

[6 Conclusions 49](#_Toc498623860)

[7 Future Work 51](#_Toc498623861)

[References 51](#_Toc498623862)

[List of Figures 58](#_Toc498623863)

[List of Tables 59](#_Toc498623864)

# 

# 1 Introduction

## Introduction

Energy plays an important role in our lives, almost every industry depends heavily on energy. In recent times with the rising global temperature and climate change, it is importance to save the energy. With the rapid development of Information and Communication Technology (ICT) 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 [1]. With increased need for broadband speed, the demand for energy and density of the networks is likely to increase. High energy efficiency is becoming a mainstream concern for the design of future wireless communication networks.

## Background and Motivation

The global mobile data traffic grew by 63 percent in 2016 [2]. 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.

In 2016 almost half a billion new mobile devices got added. According to the Ericsson’s forecast there will be 50 billion connected devices by 2020.

Since the mobile networks got introduced; the focus has often been on optimizing the network to fulfil the coverage, capacity and quality requirements. On these key requirements; products got developed and network were deployments. But, the focus has shifted a bit during recent years, operators have started to investigate how energy gets consumed in mobile networks. The understanding has increased on how to cut the energy consumption 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 [3]. In mobile networks, base stations are the ones which 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. A lot of research has been done to make mobile more efficient with consuming battery power but, base stations stay behind their counterparts. Radio access network consumes around 80% of the total energy in mobile networks and majorly in base stations which comes around to be 60% of all [3]. Which stresses on call for reducing this energy consumption at the base station side.

Figure 1. Breakdown of energy consumption in cellular networks [4].

Figure 2. The operational and the embodied CO2 emissions by base stations and mobile phones per subscribers per year [4].

## Previous Work

There had been various studies related to improvement of the base stations energy consumption. In 2010-2012 under Energy Aware Radio and neTwork tecHnologies (EARTH) project a study project; where researchers from around the world tried to get the deliverables [5] which proved to become standardized principles for working on energy efficiency concepts for base stations.

The EARTH project gave the mathematical power model for calculating the energy consumption in the base stations in various scenarios of rural, sub-urban and dense urban. The project developed a linear power model. This model does the simulations. It also gives the internal breakdown of energy consumed within different sizes of nodes such as macro, micro, pico and femto.

The study [6] showed to break up the energy consumed by different components of the BS in macro, pico and other cells that support the 3GPP LTE standard. It supports the Earth Project’s state of the art (SoTA) power model.

In [7] a “Manhattan-type city grid” is analyzed for energy performance in which macro cells were off-loaded with indoor cells. It was proven that indoor cells are more energy-efficient.

The dense urban scenario was studied in the study [8] wherein it was discovered that the indoor nodes were worse than the macro BS grid.

A dense network was [9] studied. In which; it was found out that the transmit power of the large base stations (BS’s) is less with the smaller cells. The idle time and the backhaul were the energy wasters.

A heterogeneous network scenario was [10] studied. In the study; how to save the power by increasing the network density studied. To prove that the network density successfully increased without increasing the energy requirements; micro DTX and pico node sleep modes was used. 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.

We will make use of these energy-saving features like micro DTX, lean carrier and MBSFN in the nodes.

We will use 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 uses ray-tracing propagation models like BEZT.

## Purpose of the Project

With the outset of 5G, many cities will use small cells. The networks density will increase at a very fast pace. The internet of things (IoT) would need more dense network with lower latency and higher throughput for self-driving cars, buses etc. New technologies like augmented reality and virtual reality are bound to demand higher data rates. These advancements will call for a strengthened mobile broadband network.

To have a good balance between environment and the Internet of Things, it is important to focus on energy consumption by these networks. There are various approaches to increase the present network density; we will compare the approaches to cater to the traffic demands with macro cells versus micro cells deployments.

We will setup a dense urban real like scenario in our simulator and compare the energy efficiencies between macro cells centric deployment versus a micro cells centric deployment, and we will make use of energy- saving schemes like micro DTX, lean carrier and MBSFN to cut the power consumed in the network. The traffic demand is highest in the city center; we will deploy these cells there.

With results presented in this thesis, we will contribute to the understanding of how these cells behave in a realistic traffic scenario and how much gains can we achieve by implementing the above-mentioned energy-saving schemes. To keep the results more generic and not specific to any particular set of radio base stations we will carry out EARTH power model.

## Outline of the thesis

In this thesis; chapter 1 deals with the introduction, background and motivation of this project, chapter 2 is about the theory of BSs which describes about various cells used in a typical LTE heterogeneous deployment and the transmission techniques used by these BSs like MIMO and OFDM, chapter 3 is where we explain about the Earth Power model and the energy-saving schemes, chapter 4 deals with the simulation setup, followed by chapters on results and discussions, conclusion and future work.

# 2 Theory

## Heterogeneous Networks

With the onset of 5G, there will be a lot of deployment of dense networks to satisfy the demand for increased traffic. High traffic centers like downtown of an urban city [11] [12] will have most of the mobile traffic around 70%. 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 smaller cells will have a small coverage area which will enable frequency to reuse possible being close to each other; which will provide large capacity improvement [7].

With the incoming 5G spectrum allocation; speculations are that frequency spectrum for 5G will lie in a very high frequencies of the order 30 GHZ, according to a study done with coverage and penetration of these waves in indoor environment will be very problematic. “Achieving indoor coverage at 30 GHz is highly problematic for all cases, and it is concluded that smaller base stations are necessary if frequencies of 10 GHz and above are to be used in future mobile networks.” [13].

Here are some details about the cells which constitute a heterogeneous network.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Specification** | **Femtocell** | **Picocell** | **Microcell** | **Macrocell** |
| **Transmit Power** | 20 dBm | 30dBm | 30dBm | 45dBm |
| **Power Consumption** | Low | Low | Moderate | High |
| **Coverage distance** | Less than 30m | Less than  100 m | Less than 500m | Several kms |
| **Deployment** | Indoor | Indoor and Outdoor | Outdoor and Indoor | Outdoor |
| **Backhaul connectivity** | DSL, cable, fiber | Microwave, mm | Microwave, Fiber | Microwave, Fiber |
| **Installation** | User | Operator | Operator | Operator |

Table 1. Comparison between different types of nodes in a heterogeneous network.

**PICOCELL**

Picocells can support up to 100 users at a time in areas less than 250 yards. Often used in indoor applications, picocells can be used to improve coverage in an office building or retail space.

Often self-installed, femtocells are the smallest of handling few users at a time. These units are autonomous and can provide “5-bar” signal within a small area.

FEMTOCELL

**MICROCELL**

Microcells cover areas less than a mile in diameter and can often be seen mounted on signs, traffic lights, etc. They can be used temporarily during large events for additional coverage.

SMALL CELL BASICS

**MACROCELL**

Comparatively, the traditional cell towers you are used to seeing cover about 20 miles.

Figure 3. Small cells pictorial representation.

### Macro Cells:

These cells are the base stations that provide coverage to a large area with Inter Site Distance (ISD) from hundreds of meters to several kilometers. depending upon the density. They fulfill the baseline coverage for any LTE network, providing connectivity and up all the time. The power consumption varies from 100W to 300W; they have sectored antennas normally covering 120 degrees per sector.

### Micro Cells

Micro cells have lower transmit power than macro BSs, they are smaller base stations with full features that used to cover both indoor and outdoor crowded areas. It can typically cover a range of few metres to one or two kilometers. The power consumption ranges from 10W to 40W. They are generally used for indoor purposes as well as outdoor such as hot-spots. [12]

### Pico Cells

Pico cells have lower transmit power than macro BSs, they have omnidirectional antennas unlike macro BSs which are sectored. The transmit power ranges from 250mW to 2W. They are generally used for indoor purposes around hot-spots like offices, railway stations etc. Pico cells are connected over X2 interface [12].

### Femto cell

Femto cells are also known as HeNBs are deployment for small rooms and home requirements generally for a very small range coverage less than 30m. They have omnidirectional antennas, transmit power is around 100 mW. They could be plugged in using a DSL line or modem cable [12].

## LTE Basics

### OFDM (Orthogonal Frequency Division Multiplex)

In LTE, OFDM modulation technique produces the orthogonality between the sub-carriers in frequency domain. A sub-carrier is of 180 kHz. The OFDM provides resistance to interference in between LTE sub-carriers, the LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) in down link radio access and Single Carrier Frequency Division Multiple Access (SC-OFDMA) in uplink radio access. OFDM provides high data rates and tightly spaced orthogonal sub-carriers provides high spectrum efficiency. 

Figure 4. Comparison between conventional FDM modulation technique and OFDM modulation technique.

### MIMO (Multiple Input Multiple Output)

A key radio access feature for LTE is MIMO. The data streams going in and out of antenna in radio channel forms beam and transmit diversity. The diversity will result in low correlation of fading and this could be used for receive and transmit diversity. Better reception could be generated by sending simultaneously the copies of the same data through the channel and receiving using multiple antennas. MIMO provides spatial multiplexing i.e. sending different data streams transmitted in parallel over separate antennas. MIMO could be used to increase the throughput. As per the need 2 x 2, 4 x 2, or 4 x 4 antennas could be used in LTE deployment.



Figure 5. Representation of MIMO scheme.

# 3 Power Model

## Power distribution in base station

This section defines how could we breakdown and understand comprehensively the energy consumed by the BSs. As per the findings of the Earth Project, power amplifier (PA) remains by far the major contributor to energy consumption. Understanding the root cause of this consumption can help us to eradicate the problems and nip the issues which lead to high energy consumption.

|  |
| --- |
| Mains Supply  DC-DC  Cooling  P**in**  P**out**  BB  PA  RF  feeder  PA  RF |

Figure 6. A typical transceiver structure of Base Station.

Figure 6 shows how the block diagram of a typical BS, it could be macro, micro, pico or femto. This model was taken into consideration for developing the Earth Project’s state of the art (SoTA) BS power model. There could be multiple transceivers in a BS. Each transceiver contains the baseband (BB) module, radio frequency module (RF module), power amplifier (PA), DC to DC power converter, cooling system and a power supply connected to the mains. For macro BS the sector antenna is at large distance from the PA which leads to large feeder losses and which is compensated by PA [14].

The PA connects to the antennas of the base station after providing the required power gain. The PA has poor power efficiency; as it works in a non-saturated region. Which means to avoid nonlinear distortion from channel interference. The PA efficiency [8] is better in the macro BS digital due to pre-distortion.

Radio Frequency module is used to convert analog signals to digital signals. Base Band module serves as digital signal processor for digital up and down conversion of signals, it also does OFDM modulation of the signal. Typical functionalities for BB are filtering, FFT for OFDM modulation and IFFT for OFDM demodulation, signal detection, channel estimation, it is the brain of transceiver [14].

The total power consumed within a BS as given in the EARTH power model [14] is:

(3.1)

## Power consumed at maximal load

The EARTH power model [5] breaks down the power consumption in a BS at maximum load, which could be given as:

 (3.2)

Where PPA = Pout / ηPA is for the power consumption in PA. As we know that, the efficiency is η = Pout / Pin, and the loss is defined by; σ = 1 – η. The power increases linearly with the number of transceiver chains, NTRX.

Below table lists the energy consumed in different parts of BS in different cells [15].



Table 2 SoTA estimation of power consumption in different LTE BSs.

Figure 7 Power consumption in different components of BSs.

The Figure 7 [15] shows the breakdown of power consumption in various base stations. We can see over here that the macro base station consumes the most energy in PA in macro cells; whereas base band becomes the major component in small cells.

## Variable load power consumption of BS

As we have seen earlier that power amplifier amounts to the most part of energy consumption in BSs. It amounts to approximately 60% of the total power consumption in macro BS whereas, in smaller cells it consumes lesser than 25%. It is because power amplifier’s energy consumption depends upon the traffic load; higher the traffic load is higher the power consumption will be.

The relation between the RF output power and the power consumed by base stations are roughly linear in nature [5]. The mathematical equation of this relation could be represented as:

(3.3)

This represents the linear approximation of the power model. Here *P* would represent the power consumed in the BS and *Pout* is the RF output power, at maximum load the output power would be *Pmax*. Power consumption at zero load is given by *P0*, *Δp* represents the slope of the curve. *Psleep* represents the sleep mode power consumption in the BS when the load is low and *NTRX* is the number of transceiver chains. Table 3 provides parameters of power model for different BSs [15].

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **BS type** | ***NTRX*** | ***Pmax[W]*** | ***P0[W]*** | **Δ*p*** | ***Psleep[W]*** |
| **Macro** | 6 | 20 | 130.0 | 4.7 | 75.0 |
| **RRH** | 6 | 20 | 84.0 | 2.8 | 56.0 |
| **Micro** | 2 | 6.3 | 56.0 | 2.6 | 39.0 |
| **Pico** | 2 | 0.13 | 6.8 | 4.0 | 4.3 |
| **Femto** | 2 | 0.05 | 4.8 | 8.0 | 2.9 |

Table 3 This table provides parameters of power model for different BSs.

## Energy consumption references

Power per unit area and Energy per bit are the standard units for comparison of energy performance; thus we will use these units to compare the energy consumption in different scenarios.

### Energy per bit

It is the amount of energy consumed in delivering a single bit from the transmitter. Dividing the total energy consumed, E over a time interval of, T by the total number of transmitted bits, B during that duration will gives the Energy per bit. It is expressed in [W/bps].

 (3.4)

### Power per unit area

It is the amount of power consumed in the network divided on average by the coverage area. It is expressed in [W/m2].

 (3.5)

## **Average power consumption**

The simulator used in the project is a static simulator which runs from *0 – T* and takes the average of the power consumed during that time period. This confirms our model as power consumption is a function, u(t) which depends upon the traffic generated at a time instant *t*. The average power consumed over the time interval is:

 (3.6)

So, by applying eq. 3.3 in 3.6 we get

 (3.7)

 (3.8)

 (3.9)

## Average power consumption over a day

Above equation defines the instantaneous power consumption at a moment *t*. To get an idea of the power consumption over the entire day, we need to average the power consumed over a day. The simulator which we have uses statistical tools to model a dynamic traffic. It measures the networks parameters for a small period of time while keeping the total traffic to be constant. Therefore, to know the network performance over a varied load, we sweep the total traffic value over a sufficient range.

In real scenario the traffic values change over the day in a pattern which is given in [15]. By taking the traffic profile as described in [15] we can estimate the traffic for every hour as a fraction of the peak throughput. Here we take the case of an urban traffic scenario which shows the average pattern of traffic over a day on hourly scale.

Figure 8. The figure shows the variation of peak throughput percentage over the whole day.

## Energy Saving schemes

We will consider the following energy-saving schemes in our deployment of macro and micro nodes. These energy schemes are supposed to be implemented in future mobile networks on a large scale.

### Lean carrier

The Lean carrier make use the sleep modes and switching off the cell when there is no transmission of data. It makes use of different features like transmitting the signal only when required, transmitting faster with higher modulation scheme, effectively utilizing the carrier aggregation to have large spectrum and making use of beam forming antennas. These features reduce extraneous signaling and interference.

Minimizing the overhead cell specific reference signaling and using the spectrum flexibility it reduces energy consumption. With lean carrier design, it is possible to achieve fraction of sleep at no load condition to 100%. More details about lean carrier can be found in [16].

### Micro TX sleep

The radio’s RRU component does not transmit all the time. There are time slots when the radio can be put to sleep mode depending upon the traffic handled and the scheduled transmission. When this point comes then the biasing of the final stage amplifiers is turned off, which can be achieved by sending a strobe signal based on the information of the data that the DU needs to send. This information is sent in a message that gives the symbols which will be sent over the radio during the transmission time interval. [17]

An LTE RRU transmits 140 OFDM symbols per radio frame consisting of cell-specific radio signal (CSRS) and physical downlink control channel (PDCCH). Assuming a no load situation when there is no scheduled users out of 140 OFDM symbols power amplifier could be put in sleep mode for 73 of them with 37 wake up events, this equals to 4.1 ms of sleep time during each radio frame or 41% of time.

### MBSFN

In a LTE radio frame six out of ten sub-frames can be Multicast and Broadcast Single-Frequency Network (MBSFN) for FDD system [18]. The MBSFN sub-frames are used to predict the future traffic load for a base station. Using these MBSFN a base station could calculate the load it needs to handle in subsequent frames and the resources required to cater to the traffic. This load prediction is made based on the previously served load information exchanged between the base stations over X2 interface. This load prediction is used to turn off the idle resources and setup the switch off intervals. Moreover, the MBSFN sub-frames have less number of reference signals than normal sub-frame, which gives an opportunity to turn off these sub-frames when there is no data available. [19]

Using MBSFN scheme in no load condition we get 91 OFDM symbols with 19 wake up events per radio frame. Which gives a window of 5.9 ms or 59% with sleep mode enabled.

Figure 9. LTE OFDM radio frame structure.Figure 9 below shows the LTE OFDM radio frame structure.

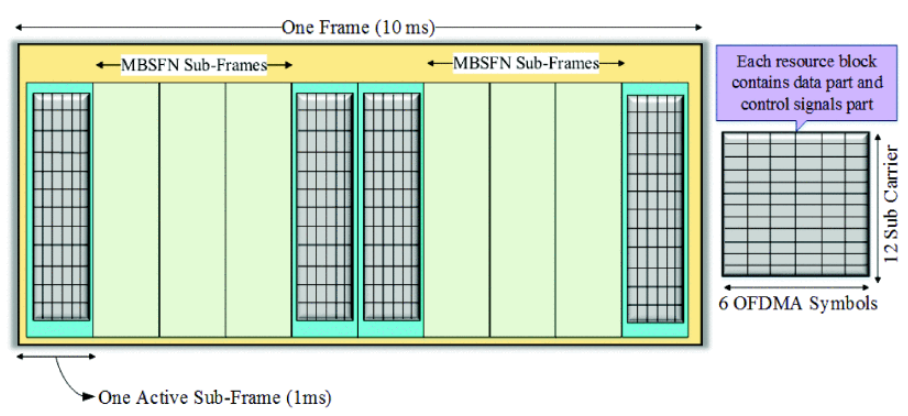


Figure 9. LTE OFDM radio frame structure.

# 4 Methodology

Here we explain the simulator and the deployment strategy used in running the simulations.

## The Simulator

The simulator used is Ericsson’s internal network simulator. The simulator is time static system level simulator implemented in Matlab. It provides various propagation models from statistical models to ray-tracing based models [13]. The model used in our thesis makes use of statistical model that determines the utilization of the base stations running on a particular load and using this we get estimate of the power being consumed by the whole network.

## Setup

The scenario that we setup makes use of a “real like” dense city network, in which we are deploying the city with streets, buildings, base stations and users. The deployment is made keeping in mind of a typical dense urban network with high-rise buildings in the center and lesser dense and low height buildings outer wards. This way we make use of a real city like scenario rather than just a statistical propagation analysis.

In our setup, we make use of the static simulator with ray-tracing propagation model called BEZT. The simulator makes use of the multipath propagation model that calculates the path gain between the user and the base station. The channel gains over these paths are stored in a huge gain matrix which is used to estimate the throughput for every user, in the central part of the map



Figure 10. The figure shows the 3D model of the city with buildings and streets, the city center has high rise buildings.

## Deployment

We are deploying a real like city scenario in which the outer layer of macro grid will provide baseline coverage for the users outside the city center, this is the surrounding macro layer. In first scenario, we deploy macro cells in the city center complemented by the surrounding macro grid and in second scenario we deploy small micro cells in the city center complemented by the surrounding macro grid.

In the first scenario setup, we have taken 21 macro cells deployed in the central grid of the city with inter-site distance of 200m surrounded by a base layer of macro cells inter-site distance of 400m.

In the second scenario setup, we have taken 28 micro cells deployed in the central grid of the city with a base layer of macro cells inter-site distance of 400m.

The system under consideration is a LTE network with carrier frequency of 2 GHz, highest modulation scheme is 64 QAM, each site has three-sectors, In the power model we have considered the *P0* = 130W for the whole macro cell including the three sectors. For the micro cell we have considered the P0 = 56W taking into account the EARTH power model. The central grid area is 1000x1000m. The max Output Power out per antenna in DL is 40 W. *Δp* = 4.7 *Psleep* = 75.0 for macro cells.

The max Output Power out per antenna in DL from the micros is 10 W and *Δp* = 2.6 and *Psleep* = 39.0 for micro cells.

.



Figure 11. The figure shows deployment of micro cells in the center of the city with macro cells in the surrounding area.

## Traffic

When we deploy a particular scenario in the simulator with buildings, streets, base stations and users. The simulator calculates the SINR between each user and node deployed on macro or micro layer, as the propagation model and the interference is known thus the gain or the propagation loss is calculated for each link. To simulate the dynamic network where the download by users happens at random; equal buffer traffic model is utilized. Each session is of fixed file size where the request comes as per the Poisson distribution. The users fully utilize the link bit rate during the file download. The total air traffic could be given by offered traffic per m2**.** Because of the capacity limitations the served traffic is lower than offered traffic. In the simulations, we sweep through varying loads of offered traffic and make use of the served traffic to compare performances.

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| Carrier frequency | 2.0 GHz |
| Bandwidth | 20 MHz |
| Modulation scheme | 64 QAM |
| Packet traffic model | Equal buffer model |
| Macro TX Power | 40 W per sector |
| Micro TX Power | 10 W |
| Macro cells in central grid | 21 |
| Micro cells in central grid | 28 |
| Feeder loss | 10 dB |

Table . Simulation parameters

# 5 Results and Discussions

## Comparison macro v/s micro without energy saving schemes

In this chapter, we discuss about the results which we got after running the simulations for the scenarios we deployed. We will compare the energy performance and the network performance of deploying the large cells of macro grid in the city center versus small cells of micro grid.



Figure 12. Comparison of Power per area unit versus System throughput

for central deployment of macro cells and micro cells.

The Power per unit area is measured for power per 1 km2 around the central area of the map. We calculate the utilization of each node which taken as a factor for calculating the total power consumed by that node for the utilization. As we can see in Figure 12, the power per unit area for micro cells is lesser than the macro cells. Here we are sweeping the simulation for various loads to test the system for varying units of system throughput. We can see that the Power per area unit increases as the throughput increases as we predicted by the earth power model.



Figure 13. Comparison of Energy per bit versus System throughput for central deployment of macro cells and micro cells.

In Figure 13, we compare the energy performance with respect to the energy per bit. For calculating the energy per bit, we divide the total energy consumed by the serving nodes by the total traffic served by them. Energy per bit tells us that how much energy is needed in the system to deliver a single bit. As we can observe that the deployment of micro cells proves out to take lesser energy per bit as the power amplifier in the micro cells do not ramp up the energy consumption with the load as much in macro units. The energy per bit is higher for lower load because the system throughput increases faster than the power consumption in the serving nodes.



Figure 14. Comparison of Energy per bit versus 10th percentile DL user throughput for central deployment of macro cells and micro cells.

In Figure 14, we do a critical analysis of quality of service down to the 10 percentiles of users, these users have the worst downlink throughput, they could be considered as edge cell users. So, to deliver a good throughput to these edge cell users say, 11 Mbps we can see the macro cells need something around 1.8 kJ/Mbit while micro cells need 0.3 kJ/Mbit. Here the macro cells come out to as winner because of they can handle a higher load than micro cells as well as the increased load compensates for the increased power consumption in macro cells.



Figure 15. Comparison of bits per unit energy versus system throughput for central deployment of macro cells and micro cells.

Bits per unit energy is the inverse of energy per bit, to calculate this, we divide the total traffic by total power consumption. In Figure 15, we can see that the micro cells can transfer more bits per unit energy than the macro cells and as the power consumption in micro cells increases less with served traffic load, the number of bits transferred in unit energy (Mbit/kJ) is higher for smaller cells than the large macro cells.



**Figure 16. Comparison of DL user throughput for 50th and 95th percentile versus system throughput.**

The DL user throughput is calculated for 10th, 50th and 95th percentile. The 10th percentile refers to the cell edge users the 50th percentile is the median user data rate for the served traffic, the 95th percentile users are the best-case users with top 5% data rates. In figure 16 the 95th percentile users have similar data rates in macros and micros. The 50th percentile users experience difference in data rates experience because the data rates at the user side increases with transmit power.

The DL data rate decreases with the increasing traffic load this is because at lower load there are enough of resources available for the cells to serve the users with high data rates but as the traffic load increases the bandwidth and the available resources reduces and hence it leads to a lowered data rate.



**Figure 17. Comparison of DL user throughput for 10th percentile versus system throughput.**

The 10th percentile users represents the cell edge users; the figure 17 compares the data rates for the cell edge users between the micro grid and the macro grid. When the data throughput drops to zero then it represents that the total traffic in the area is so high that the cell edge user could not be served. The data rates for these users decreases rapidly for micro case which proves that it is not the best choice for coverage purpose. This clearly shows that the capacity of macro cells is more than micro cells.

## Comparison macro with and without energy saving schemes



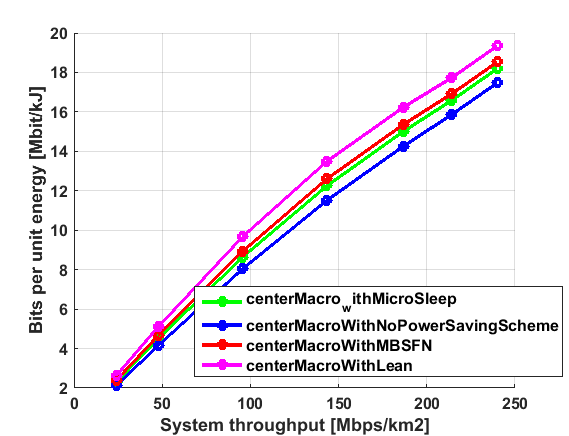
**Figure 18. Comparison of power per area unit versus system throughput for central deployment of macro cells.**

As we can see in figure 18, the power per unit area for micro cells with energy saving schemes is lesser than micro cells without energy saving schemes. Here we can see that as the traffic load increases the power required to serve that traffic also goes up. The Lean energy saving scheme seems to be more energy efficient than MBSFN and micro sleep. We can easily save around 10-15% energy using any of the energy saving schemes. Lean scheme proved to be the most energy efficient with 17% savings on energy.



**Figure 19. Comparison of energy per bit unit versus system throughput for central deployment of macro cells.**

From fig 19 we can derive that there is some difference in energy needed to transmit a bit for lower traffic load in different schemes but, as we gradually move towards higher loads this difference comes close together because at higher traffic loads there will be less idle time for the cells to save energy.



**Figure 20. Comparison of bits per unit energy versus system throughput for central deployment of macro cells.**

In the continuation to figure 19 we plot the bits per unit energy versus traffic demand in figure 20 and we encounter that there are more number of bits which could be transferred per unit energy where we make use of energy saving schemes.

## Comparison micro with and without energy saving schemes



**Figure 21. Comparison of Power per area unit versus System throughput for central deployment of macro cells.**

As we can see in figure 21, the Power per area unit variation for micro cells also follows the similar pattern as in the power per unit area for macro cells. The energy saving schemes can save upto 2 kW/km2 for varying traffic load lesser than micro cells without energy saving schemes. Here we can see that as the traffic load increases the power required to serve that traffic also goes up. The Lean energy saving scheme seems to be more energy efficient than MBSFN and micro sleep. We can see over here that deployment with lean power saving scheme can save 23.5% energy compared with when deployment without any energy saving scheme.



**Figure 22. Comparison of energy per bit unit versus system throughput for central deployment of micro cells.**

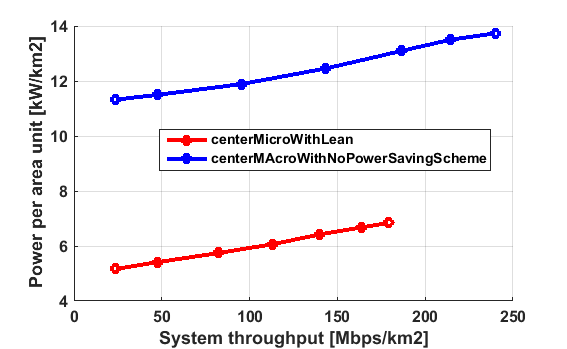
The follows the same pattern as the one we saw in central macro deployment case however the energy per bit needed in micro is lesser than that of macros. The energy schemes can save upto 25% on energy per bit for micro deployment.



**Figure 23. Comparison of bits per unit energy versus system throughput for central deployment of macro cells.**

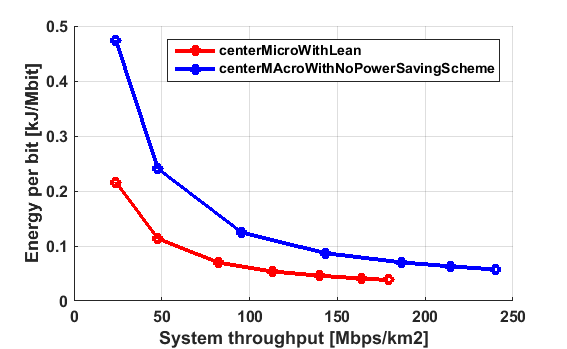
In figure 23, we see the behaviour as expected, deployment with enegy saving schemes have potential to fit in upto 30% more bits per unit energy than deployments without energy saving schemes.

## Comparison macro v/s micro with energy saving schemes



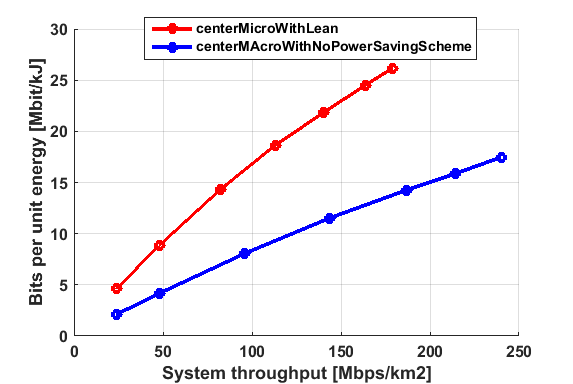
**Figure 24. Comparison of Power per area unit versus System throughput for central deployment of macro cells versus micro cells.**

In figure 24, we can compare the amount of energy savings we can achieve by having a micro cell with lean carrier energy saving scheme against a macro cell with no energy saving schemes. For 100 Mbps/km2 of system throughput the micro consumes 6 kW//km2 whereas macro consumes double than that 12 kW//km2 . So, implementing a scheme like this one reduce power consumption to half.



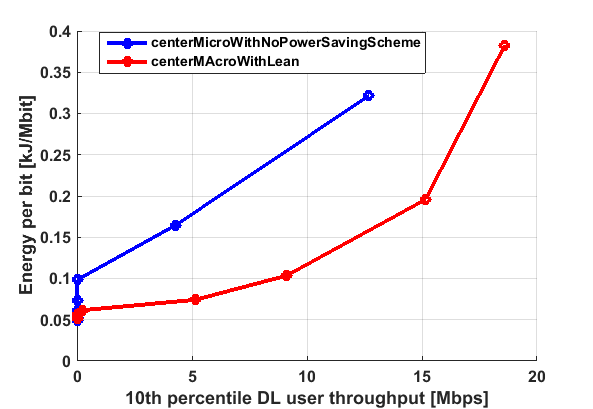
**Figure 25. Comparison of energy per bit unit versus system throughput for central deployment of micro cells versus macro cells.**

Now let’s consider the energy per bit, we see in figure 25, the energy per bit requirement for micro cells with energy saving scheme is much less than that of macro counterpart. The energy per bit is high for low traffic load because the total served traffic is low for low load and hence, the energy per bit increases.



**Figure 26. Comparison of bits per unit energy versus system throughput for central deployment of micro cells versus macro cells.**

The bits per unit energy for micro cells with lean carrier energy saving scheme is almost double than that of the macro cells without energy saving schemes as seen in figure 26.

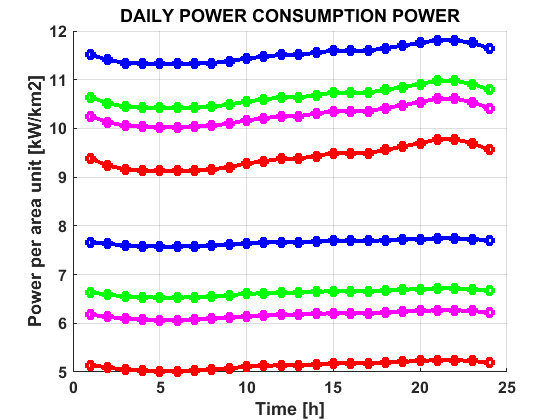
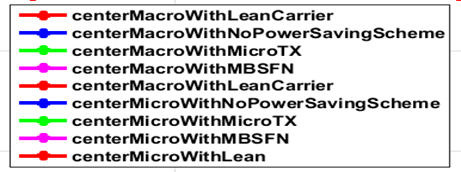


**Figure 27. Comparison of energy per bit unit versus system throughput for central deployment of micro cells versus macro cells.**

When it comes to reaching the last mile of user throughput, the micros could not provide as good user throughput as macros do. That’s why the energy per bit needed for providing high through for the edge cell users is high in case of micro cells.

So, the macro cells are needed to provide a good coverage area and decent throughput to the bottom 10th percentile users.

## Daily power consumption



**Figure 28. Comparison of daily power consumption in central deployment of micro cells versus macro cells.**

For calculating the daily power consumption we kept a threshold of 10 DL Mbps for 10th percentile users during the peak hours. The figure 28 shows the power consumption of macro and micro with different energy saving schemes.

At peak load for macro deployment we can see there is a possibility of 17% saving using the lean carrier energy saving scheme and 20% energy saving could be achieved at low load.

In case of micro deployment, at peak load we can see 29% saving using the lean carrier energy saving scheme and a good 33% energy saving at low load. This is because lower utilization of nodes at lower loads gives more scope for energy saving schemes to be implemented.

From these patterns we can verify that the traffic demand is low during early morning hours and is high during the evening hours.

# 6 Conclusions

We used 28 center micro cells and 21 macro cells in the center grid which is a third time more number of micro units used to cover the central city area and provide an acceptable throughput performance to the users in the area.

As the number of resources is limited with macro cells so, as the traffic load goes up these resources need to be shared among the UEs. This leads to reduced data rate per UE and longer time to receive a file. So, it is advantageous to complement macro cells in the network with micro cells for increased quality of service and improved data rates. The results on the energy savings were much better by using the micro only base stations as they saved almost half of the energy required to run the network when implemented with energy saving schemes. The energy saving features does not affect the resultant data rates to the users. The data rates remain the same regardless of using the energy saving schemes

The energy saving schemes proved out to save a lot of energy in the operation of both macro and micro cells. It was observed that using the discontinuous transmission around 20% to 30% of energy could be saved. The amount of savings from these energies saving schemes depend upon the utilization and sleep time of these nodes.

1. For Macro deployment, the power consumption for a day without using any energy saving scheme is 283.44 kWhr/km2 which is 103455.6 kWhr/km2 for a year. Using micro TX energy saving scheme it is 263.52 kWhr/km2 which is 96184.8 kWhr/km2 for a year. Using MBSFN energy saving scheme it is 254.64 kWhr/km2 which is 92943.6 kWhr/km2 for a year. Using lean carrier energy saving scheme it is 234.62 kWhr/km2 which is 85637.76 kWhr/km2 for a year.
2. For Micro deployment, the power consumption for a day without using any energy saving scheme is 185.80 kWhr/km2 which is 67819.92 kWhr/km2 for a year. Using micro TX energy saving scheme it is 161.23 kWhr/km2 which is 58849.68 kWhr/km2 for a year. Using MBSFN energy saving scheme it is 150.24 kWhr/km2 which is 54837.6 kWhr/km2 for a year. Using lean carrier energy saving scheme it is 125.85 kWhr/km2 which is 45937.44 kWhr/km2 for a year.

So, we can see that using energy saving schemes in macro cell deployment can give savings as much as 17% and 33% in micro cell deployment over a year.  
  
And comparing the macro without energy saving scheme to micro with lean carrier energy saving scheme results in 55% of energy saving. So, from an energy saving point of view, it would be much better to implement a heterogeneous network with more micro cells and small cells with energy saving schemes than with more number of macro cells.

This sort of heterogeneous cell deployment would help the network engineers in analyzing which type of cells are better suited for energy efficient deployment.

Here we can also see that macro grid performs much better when it comes to coverage, as the performance of the big macro cells is better than micro cells for the 10th percentile users for this reason we need to deploy the small cell networks complemented by the macro cells for coverage purposes. To provide sufficient coverage to the edge cell users.   
  
So, at last I would like to conclude that it would be more efficient to substitute macro cells with micro cells especially in the parts of the city which require higher data rates and this will be a backbone of 5G deployments.

Applying these energy saving schemes in across thousands of sites in a mobile network will accumulate to tens of millions of kilowatt hours (kWh) in power savings annually. However, it would be the responsibility of the network planners to ensure that these cells are placed in the areas where they are needed the most otherwise adding small cells on top of the macro cells will only result in higher energy consumption.

# 7 Future Work

As the simulation was carried out in a realistic dense urban scenario there is scope of finding out the energy efficiency gains in other scenarios as well such as sub-urban and rural. These scenarios are equally important because there is a huge amount of diesel energy consumed for fueling up the cells in rural environments.

As the results are dependent over the deployment of the cells one could might as well deploy the cells on other buildings to analyze the energy and throughput efficiencies.

The propagation model used in this study was BEZT however, there are various other propagation models like WINNER II etc. that could be used to calculate propagation losses in a real city like environment.

As the simulator which was used is a static, one can also make use of dynamic simulators to analyze the traffic and latency in each of the energy saving schemes.

# References

|  |  |
| --- | --- |
| [1] | K. Dufková, M. Bjelica, B. Moon, L. Kencl and J.-Y. Le Boudec, "Energy Savings for Cellular Network with Evaluation of Impact on Data Traffic Performance". |
| [2] | "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update The Cisco ® Visual Networking Index (VNI) Global Mobile Data Traffic Forecast Update," 2016. |
| [3] | F. Richter, A. J. Fehske and G. P. Fettweis, "Energy Efficiency Aspects of Base Station Deployment Strategies for Cellular Networks," 2016. |
| [4] | C. Han, T. Harrold, S. Armour, I. Krikidis, S. Videv, P. M. Grant, H. Haas, J. S. Thompson, I. Ku, C. X. Wang, T. A. Le, M. R. Nakhai, J. Zhang and L. Hanzo, "Green radio: Radio techniques to enable energy-efficient wireless networks," *IEEE Communications Magazine,* vol. 49, no. 6, pp. 46-54, 2011. |
| [5] | A. D. Domenico and S. Petersson, "Final Integrated Concept," 2012. |
| [6] | C. Desset, B. Debaillie and F. Louagie, "Towards a Flexible and Future-Proof Power Model for Cellular Base Stations". |
| [7] | S. Yunas, M. Valkama and J. Niemelä, "Spectral and energy efficiency of ultra-dense networks under different deployment strategies," *IEEE Communications Magazine,* vol. 53, no. 1, pp. 90-100, 2015. |
| [8] | H. Forssell and G. Auer, "Energy Efficiency of Heterogeneous Networks in," pp. 53-58, 2015. |
| [9] | S. Tombaz, K. W. Sung and J. Zander, "Impact of densification on energy efficiency in wireless access networks," *2012 IEEE Globecom Workshops,* pp. 57-62, 2012. |
| [10] | L. Falconetti, P. Frenger, H. Kallin and T. Rimhagen, "Energy efficiency in heterogeneous networks," *Online Conference on Green Communications (GreenCom), 2012 IEEE,* pp. 98-103, 2012. |
| [11] | E. A. – Chenguang Lu, M. Berg, E. Trojer, P.-E. Eriksson, K. Laraqui, O. V. Tidblad and H. Almeida, "Connecting the dots: small cells shape up for high-performance indoor radio," 2014. |
| [12] | S. Landström and F. Anders, "Ericsson Review: Heterogeneous networks-increasing cellular capacity," 2011. |
| [13] | V. Rydén, "Outdoor to Indoor Coverage in 5G Networks," 2016. |
| [14] | G. Auer, V. Giannini, I. Gódor, M. Olsson, M. Ali Imran, D. Sabella, M. J. Gonzalez, O. Blume, A. Fehske, J. Alonso Rubio, P. Frenger and C. Desset, "How Much Energy is Needed to Run a Wireless Network ?". |
| [15] | O. Blume, V. Giannini and I. Gódor, "D2. 3: energy efficiency analysis of the reference systems, areas of improvements and target breakdown," *EARTH Deliverable 2.3,* pp. 1-69, 2010. |
| [16] | Ericsson AB, "5G energy performance," *Ericsson White Paper,* no. Uen 284 23-3265, 2015. |
| [17] | K. O. Mecklenburg and A. Blomgren, "Energy Optimization of Radio," Lund, 2016. |
| [18] | D. Migliorini, G. Stea, M. Caretti and D. Sabella, "Power-Aware Allocation of MBSFN Subframes Using Discontinuous Cell Transmission in LTE Systems," in *2013 IEEE 78th Vehicular Technology Conference (VTC Fall)*, 2013. |
| [19] | K. Kanwal, G. A. Safdar, M. Ur-Rehman and X. Yang, "Energy Management in LTE Networks," *IEEE Access,* vol. 5, pp. 4264-4284, 2017. |
| [20] | Z. Zhao, S. Kuendig, J. Carrera, B. Carron, T. Braun and J. Rolim, "Indoor Location for Smart Environments with Wireless Sensor and Actuator Networks". |
| [21] | J. Wu, Y. Zhang, M. Zukerman and E. K.-N. Yung, "Energy-Efficient Base-Stations Sleep-Mode Techniques in Green Cellular Networks: A Survey," *IEEE Communications Surveys & Tutorials,* vol. 17, no. 2, pp. 803-826, 22 2015. |
| [22] | J. Wu, S. Zhou and Z. Niu, "Traffic-aware base station sleeping control and power matching for energy-delay tradeoffs in green cellular networks," *IEEE Transactions on Wireless Communications,* vol. 12, no. 8, 2013. |
| [23] | L. Wang, K.-K. Wong, S. Jin, G. Zheng, R. W. Heath, L. Wang and K.-K. Wong, "A New Look at Physical Layer Security, Caching, and Wireless Energy Harvesting for Heterogeneous Ultra-dense Networks," 2017. |
| [24] | TAO CHEN, "NETWORK ENERGY SAVING TECHNOLOGIES FOR GREEN WIRELESS ACCESS NETWORKS," *TECHNOLOGIES FOR GREEEN RADIO COMMUNICATION NETWORKS.* |
| [25] | M. H. Tafsir, "Energy Efficiency through Virtual Machine Redistribution in Telecommunication Infrastructure Nodes," no. September, 2013. |
| [26] | C. Ribordy, "Small Cell backhaul Canada East Commtech Show," 2014. |
| [27] | E. Oh, K. Son and B. Krishnamachari, "Dynamic base station switching-on/off strategies for green cellular networks," *IEEE Transactions on Wireless Communications,* vol. 12, no. 5, 2013. |
| [28] | C. Liu, B. Natarajan and H. Xia, "Small Cell Base Station Sleep Strategies for Energy Efficiency," *IEEE Transactions on Vehicular Technology,* vol. 65, no. 3, 2016. |
| [29] | C. Hoymann, D. Larsson, H. Koorapaty and J.-F. Cheng, "A Lean Carrier for LTE," *IEEE Communications Magazine,* vol. 51, no. 2, pp. 74-80, 2 2013. |
| [30] | K. Hiltunen, "Total power consumption of different network densification alternatives," *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC,* pp. 1401-1405, 2012. |
| [31] | T. Han and N. Ansari, "Powering mobile networks with green energy," *IEEE Wireless Communications,* vol. 21, no. 1, 2014. |
| [32] | X. Ge, S. Tu, G. Mao, C.-X. Wang and T. Han, "5G Ultra-Dense Cellular Networks," 2015. |
| [33] | M. D. G and A. Soysal, "Nonoverlay Heterogeneous Network Planning for Energy Efficiency," vol. 2017, 2017. |
| [34] | M. Fallgren, M. Olsson and P. Skillermark, "Energy saving techniques for LTE: Integration and system level results," in *2013 IEEE 24th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, 2013. |
| [35] | Ericcson, "Heterogeneous Network (Hetnet)". |
| [36] | P. Ek, "Examensarbete 30 hp Oktober 2013 Deployment of Indoor Small-Cells for 4G Mobile Broadband". |
| [37] | D. D. E. L. U. E and A. D. Domenico, "Energy Efficient Mechanisms for Heterogeneous Cellular Networks," 2012. |
| [38] | K. Dufková, M. Popovi, R. Khalili, J.-Y. Le Boudec, M. Bjelica and L. Kencl, "Energy Consumption Comparison Between Macro-Micro and Public Femto Deployment in a Plausible LTE Network \*". |
| [39] | C. Desset, B. Debaillie, V. Giannini, A. Fehske, G. Auer, H. Holtkamp, W. Wajda, D. Sabella, F. Richter, M. J. Gonzalez, H. Klessig, I. Godor, M. Olsson, M. A. Imran, A. Ambrosy and O. Blume, "Flexible power modeling of LTE base stations," in *2012 IEEE Wireless Communications and Networking Conference (WCNC)*, 2012. |
| [40] | M. Deruyck, W. Joseph and L. Martens, "Power Consumption Model for Macrocell and Microcell Base Stations," *EUROPEAN TRANSACTIONS ON TELECOMMUNICATIONS Eur. Trans. Telecomms,* vol. 00, pp. 1-14, 2011. |
| [41] | B. Debaillie and C. Desset Imec, "Power Modeling of Base Stations," 2014. |
| [42] | A. Damnjanovic, J. Montojo, Y. Wei, T. Ji, T. Luo, M. Vajapeyam, T. Yoo, O. Song and D. Malladi, "A SURVEY ON 3GPP HETEROGENEOUS NETWORKS," 2011. |
| [43] | G. Cong, F. Kronestedt and M. Xiao, "Pico Cell Densification Study in LTE Heterogeneous Networks". |
| [44] | G. cong, "Pico cell densification". |
| [45] | X. Chu, Heterogeneous cellular networks : theory, simulation, and deployment, p. 460. |
| [46] | T. Bohn, D. Ferling, P. Jüschke, A. Ambrosy, S. Petersson, M. Olsson, P. Frenger, Y. Jading, A. Erdem, P. Maugars, S. Pla, D. Büthker, S. Mizuta, G. Dietl, M. Boldi, M. Crozzoli, D. Disco, M. Fodrini, E. Calvanese-Strinati, R. Gupta, A. Giry, L. Dussopt, Y. Qi, V. Giannini, C. Desset, M. Li, B. Debaillie, R. Torrea, F. Cardoso, L. Correia, C. Peixeiro, J. Leinonen and M. J. Gonzalez, Most Promising Tracks of Green Radio Technologies, 2010. |
| [47] | G. Biczok, "CONFIDENTIAL, EARTH PROJECT INFSO-ICT-247733 EARTH Deliverable D2.3 Energy efficiency analysis of the reference systems, areas of improvements and target breakdown". |
| [48] | J. Bengtsson and J. Nilsson, "Energy Optimization of Radio". |
| [49] | E. A. - Sara Landström, A. Furuskär, K. Johansson, L. Falconetti and F. Kronestedt, "Heterogeneous Networks (HetNets) – an approach to increasing cellular capacity and coverage". |
| [50] | X. Zhang, Z. Su, Z. Yan and W. Wang, "Energy-efficiency study for two-tier heterogeneous networks (HetNet) under coverage performance constraints," *Mobile Networks and Applications,* vol. 18, no. 4, pp. 567-577, 2013. |
| [51] | K. Wang, M. ;. Kihl, A. ;. Gavler, M. Du, C. Lagerstedt, A. Gavler and M. Kihl, "Power Consumption Analysis of FTTH Networks Power Consumption Analysis of Energy-aware FTTH Networks," 2015. |
| [52] | S. Tombaz, M. Usman and J. Zander, "Energy efficiency improvements through heterogeneous networks in diverse traffic distribution scenarios," *Proceedings of the 2011 6th International ICST Conference on Communications and Networking in China, CHINACOM 2011,* pp. 708-713, 2011. |
| [53] | E. Ternon, P. Agyapong, L. Hu and A. Dekorsy, "Energy Savings in Heterogeneous Networks with Clustered Small Cell Deployments". |
| [54] | H. Tabassum, M. Z. Shakir and M. S. Alouini, "Area green efficiency (AGE) of two tier heterogeneous cellular networks," in *2012 IEEE Globecom Workshops, GC Wkshps 2012*, 2012. |
| [55] | F. Richter, A. J. Fehske and G. P. Fettweis, "Energy Efficiency Aspects of Base Station Deployment Strategies for Cellular Networks". |
| [56] | M. P. Mills, "THE CLOUD BEGINS WITH COAL BIG DATA, BIG NETWORKS, BIG INFRASTRUCTURE, AND BIG POWER AN OVERVIEW OF THE ELECTRICITY USED BY THE GLOBAL DIGITAL ECOSYSTEM". |
| [57] | Y. Mao, X. Li and L. Chen, "Energy-efficient area coverage in heterogeneous energy wireless sensor networks," in *2008 International Conference on Wireless Communications, Networking and Mobile Computing, WiCOM 2008*, 2008. |
| [58] | C. Khirallah, J. S. Thompson and D. Vukobratovic, "Energy efficiency of heterogeneous networks in LTE-advanced," *2012 IEEE Wireless Communications and Networking Conference Workshops, WCNCW 2012,* pp. 53-58, 2012. |
| [59] | K. Huq and S. Mumtaz, "Frequency Allocation for HetNet CoMP: Energy Efficiency Analysis," *Wireless Communication Systems (ISWCS 2013), Proceedings of the Tenth International Symposium on,* 2013. |
| [60] | M. Haddad, P. Wiecek and O. Habachi, "A Game Theoretic Analysis for Energy Efficient Heterogeneous Networks". |
| [61] | A. J. Fehske, F. Richter and G. P. Fettweis, "Energy Efficiency Improvements through Micro Sites in Cellular Mobile Radio Networks". |
| [62] | Ericsson, "Energy-saving solutions helping mobile operators meet commercial and sustainability goals worldwide". |
| [63] | A. A. Eisenblätter, R. Pisz and S. Stefański, "White Paper". |
| [64] | P. Cunningham, M. Cunningham, O. Arnold, F. Richter, G. Fettweis and O. Blume, "Future Network and MobileSummit 2010 Conference Proceedings Power Consumption Modeling of Different Base Station Types in Heterogeneous Cellular Networks," 2010. |
| [65] | boswarthick, "HetNetEnergyPerformance\_Dianat\_Auer\_Forssell\_Ericsson". |
| [66] | A. Atiyah Abd, T. Sieh Kiong, J. Koh, D. Chieng and A. Ting, "Energy Efficiency of Heterogeneous Cellular Networks: A Review," *Journal of Applied Sciences,* vol. 12, no. 14, pp. 1418-1431, 1 12 2012. |
| [67] | M. W. Arshad, A. Vastberg and T. Edler, "Energy efficiency gains through traffic offloading and traffic expansion in joint macro pico deployment," in *IEEE Wireless Communications and Networking Conference, WCNC*, 2012. |
| [68] | A. A. Abdulkafi, S. K. Tiong, D. Chieng, A. Ting, A. M. Ghaleb and J. Koh, "Modeling of Energy Efficiency in Heterogeneous Network," *Research Journal of Applied Sciences, Engineering and Technology,* vol. 6, no. 17, pp. 3193-3201, 2013. |
| [69] | "Cisco Visual Networking Index: Forecast and Methodology Cisco Visual Networking Index: Cisco Visual Networking Index: Forecast and Methodology," *Forecast and Methodology,* pp. 2015-2020, 2015. |
| [70] | "A GLOBAL VIEW ON MOBILE COMMUNICATION NETWORKS". |

# List of Figures

Figure 1. Breakdown of energy consumption in cellular networks (Source Vodafone) (Han et al., 2011) 8

Figure 2. The operational and the embodied CO2 emissions by base stations and mobile phones per subscribers per year (Han et al., 2011) 9

Figure 3. Small cells pictorial representation. 14

Figure 4. Comparison between conventional FDM modulation technique and OFDM modulation technique. 15

Figure 5. Representation of MIMO scheme. 16

Figure 6. A typical transceiver structure of Base Station. 17

Figure 7 Power consumption in different components of BSs.[2] 22

Figure 8.The figure shows the variation of peak throughput percentage over the whole day**.** 25

Figure 9. LTE OFDM radio frame structure. 27

Figure 10. The figure shows the 3D model of the city with buildings and streets, the city center has high rise buildings. 29

Figure 11. The figure shows deployment of micro cells in the center of the city with macro cells in the surrounding area. 30

Figure 12. Comparison of Power per area unit versus System throughput 32

Figure 13. Comparison of Energy per bit versus System throughput for central deployment of macro cells and micro cells. 33

Figure 14. Comparison of Energy per bit versus 10th percentile DL user throughput for central deployment of macro cells and micro cells. 34

Figure 15. Comparison of bits per unit energy versus system throughput for central deployment of macro cells and micro cells. 35

# List of Tables

Table 1. Comparison between different types of nodes in a heterogeneous network. 13

Table 2 SoTA estimation of power consumption in different LTE BSs. 20

Table 3 This table provides parameters of power model for different BSs. 23

Table 4. Simulation parameters 31