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Femtocell Deployment in 3rd Generation Networks

Master’s Thesis submitted in partial fulfilment of the requirement for the degree of
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Abstract

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Femtocells are small mobile telecommunication network basestations using the customers' DSL or cable modem connections as backhaul. In addition, femtocells are self-configuring and do not require a professional for installation. The devices themselves are approximately of the same size as the current Wi-Fi access points.

The growing capacity expectations and intensive competition between operators is constantly driving vendors to come up with new solutions. In 2100 MHz 3G UMTS networks, indoor and rural coverage are not at the level customers are used to with 2G networks. Femtocells are a cheap and fast way to offer capacity and coverage to homes and offices. First large scale UMTS femtocell implementations are predicted to happen during the year 2009.

Many researchers have studied the femtocell business model, and simulated the performance and co-operation with the macro layer network. These studies, however, have been often done in a very theoretical honeyconb simulating environment. This thesis will study the possible problems in femtocell rollouts and evaluate the status of current standardization and available devices. The femtocell specified in 3GPP standards, known as the Home NodeB, and other new components needed to integrate the solution with the current networks are presented together with the different possible deployment configurations.

Performance of femtocells was examined by simulations with a widely used radio network planning tool and simulator. The simulations studied service coverage and throughput. This thesis shows how the coverage is improved by femtocells and how the total network capacity gains can be up to 5 times, compared to the current macro layer network. This can be achieved with femtocells implemented on a dedicated carrier.

Furthermore, it is shown how the femtocells do not cause serious problems to the macro network, on the contrary, by careful planning macro layer performance can even be enhanced. Nevertheless, everything can not be evaluated by simulations. Piloting is the next natural step to learn more about femtocell functionality.

Key words: Femtocell, HNB, Home NodeB, UMTS, WCDMA

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Femtosolulla tarkoitetaan pientä matkapuhelinverkon solua, jonka liitäntäyhteytenä operaattorin verkkoon käytetään kuluttajan omaa laajakaistaliittymää. Femtosolut ovat itsestään asentuvia eli niiden käyttöönottoon ei tarvita ammattitaitoisen asentajan erillistä käyntiä. Kooltaan femtosolut ovat nykyisten langattomien lähiverkkojen tukiasemien kokoisia.

Kova kilpailu ja kuluttajien jatkuvat odotukset entistä nopeammista datayhteyksistä saavat laitevalmistajat jatkuvasti kehittelemään uusia, entistä edullisempia, ratkaisuja. 2100 MHz taajuudella toimiville 3G UMTS verkoille on ollut ongelmallista saavuttaa niin hyvää peittoa sisätiloissa ja haja-asutusalueilla, mihin asiakkaat ovat tottuneet toisen sukupolven matkapuhelinverkoissa. Femtosolut tarjoavat edullisen ja nopean tavan kapasiteetin ja peiton parantamiseen sekä koti että yritysympäristöissä. Ensimmäisiä laajamittaisia UMTS femtosolu verkkojan odotetaan toteutuvaksi jo vuoden 2009 aikana.

Femtosoluja on aiemmin tutkittu lähinnä liiketoimintamallina sekä niiden tuomaa etua on simuloitu yksinkertaisina hyvin teoreettisina hahmotelmina. Tämän diplomityön tarkoituksena on tutkia femtosolujen käyttöönottoa nykyisten 3G verkkojen rinnalla ja siihen liittyviä mahdollisia ongelmia. Työssä tullaan esittelemään femtosolut tekniikkana ja 3GPP:n standardisoima femtosoluratkaisu Home NodeB. Lisäksi esitellään verkkoon tarvittavat lisäelementit ja femtosoluverkon erilaiset mahdolliset toteutustavat.

Femtosolujen tehokkuutta tutkittiin simuloimalla olemassa olevaa ympäristöä kuvaavaa verkkoa. Simulointityökaluna käytettiin laajamittaisessa tuotantokäytössä olevaa kaupallista radioverkkosuunnittelutyökalua. Simulaatioiden tuloksina nähtiin peiton parantuvan femtosolujen ansioista kaikissa tilanteissa, sekä verkon kokonaiskapasiteetin jopa viisinkertaistuvan, femtosolujen ollessa omalla kanavallaan. Femtosolujen käyttöönotto ei merkittävästi huononna makroverkon suorituskykyä. Päinvastoin, huolellisesti suunniteltuna makroverkon suorituskyky voi jopa parantua. Simulaatiot eivät voi antaa vastausta kaikkiin mahdollisiin femtosolujen ongelmiin ja kokeiluprojektit ovat tarpeen.

Avainsanat: Femtosolu, HNB, Home NodeB, UMTS, WCDMA

Preface

I would like to thank Professor Jyri Hämäläinen for the supervision of this thesis and for having a real enthusiasm for femtocell studies.

As this thesis was funded by Omnitele Ltd, I would like to thank the whole company for providing the resources and an extremely educating working environment for both the thesis and other subjects related to the mobile telecommunication industry. Almost everyone at Omnitele has helped me somehow with the thesis, either by asking questions and bringing up new areas of research, or by offering their help with a specific technical problem. In addition, everyone has participated in keeping up a relaxed and humor-rich working environment. For the environment I thank everyone, especially the guys at the corner office.

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Finally, I want to express my gratitude to my mother and father, Anja and Pekka, and to my grandmother Meeri for the all their support during the years. I also wish to thank all my friends and Ida for all the great experiences outside work and university life.

In Helsinki, 3 June 2009

Mikko Järvinen

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List of Abbreviations

2G	2nd Generation
3G	3rd Generation
3G	3rd Generation Partnership Project
AAL2	ATM Adaptation Layer 2
AAL5	ATM Adaptation Layer 5
ATM	Asynchronous Transfer Mode
BS	Base Station
CAPEX	Capital Expenditure
CDMA	Code Division Multiple Access
CN	UMTS Core Network
CS	Circuit Switched
CSG	Closed Subscriber Group
CPICH	Common Pilot Channel
DAS	Distributed Antenna System
DL	Downlink
DSL	Digital Subscriber Line
DVB	Digital Video Broadcasting
E1	European Telecommunication Standard for 2,048Mbit/s link
Ev-Do	Evolution Data Only
FDD	Frequency Division Duplex
FUE	Femto UE
GAN	Generic Access Network
GANC	GAN Controller

GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communications
GTP-U	GPRS Tunneling Protocol – User layer
HeNB	Home enhanced NodeB
HLR	Home Location Register
HMS	HNB Management System
HNB	Home NodeB
HNB-GW	HNB Gateway
HSDPA	High Speed Downlink Packer Access
HSUPA	High Speed Uplink Packer Access
IMS	IP Multimedia Subsystem
IP	Internet Protocol
Iu	UMTS interface between RNC or HNB-GW and CN
Iu-b	UTRAN interface between NodeB and RNC
Iu-h	UTRAN interface between HNB and HNB-GW
KPI	Key Performance Indicator
LOS	Line Of Sight
LTE	Long Term Evolution
MSC	Mobile Switching Center
MUE	Macro UE
NSN	Nokia Siemens Networks
OA&M	Operations, Administration and Management
OPEX	Operational Expenditure

P-CPICH	Primary Common Pilot Channel
PG	Processing Gain
PICH	Paging Indicator Channel
PS	Packer Switched
QoE	Quality of Experience
QoS	Quality of Service
RAB	Radio Access Bearer
RAN	Radio Access Network
RANAP	Radio Access Network Application Part
RAT	Radio Access Technology
RF	Radio Frequency
RNC	Radio Network Controller
RSCP	Received Signal Code Power
RTP	Real Time Protocol
RUA	RANAP User Adaptation
RX	Receive
SCTP	Stream Control Transmission Protocol
SeGW	Security Gateway
SF	Spreading Factor
SGSN	Serving GRPS Support Node
SIM	Subscriber Identity Module
SINR	Signal to Interference and Noise Ratio
SIP	Session Initiation Protocol
TR	Technical Research
TS	Technical Specification

TX	Transmit
UARFCN	UMTS Absolute Radio Frequency Channel Number
UDP	User Datagram Protocol
UE	User Equipment
UL	Uplink
UMA	Unlicensed Mobile Access
UMTS	Universal Mobile Telecommunications System
USIM	Universal Subscriber Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
Uu	UTRAN air interface between UE and NodeB
VCC	Voice Call Continuity
VDSL2	Very High Speed Digital Subscriber Line 2
VoIP	Voice over IP
WCDMA	Wideband CDMA

List of Symbols

λ	Wavelength
$\mu_{kM}^{unloaded}$	Unloaded Cell Service Rate
c	Speed of light
d	Distance between nodes
f	Frequency
$f_{separation}$	Separation frequency
BW	Bandwidth
G_{RX}	Receiver gain
G_{TX}	Transmitter gain
h_{eff}	Base station effective antenna height
h_{ms}	Mobile height
k_1	Propagation model intercept parameter
k_2	Propagation model slope parameter
k_3	Propagation model correction factor for UE antenna height
k_4	Propagation model multiplying factor for UE antenna height
k_5	Propagation model multiplying factor for NodeB height
k_6	Propagation model multiplying factor for $\log(h_{eff})\log(d)$
L_{diff}	Diffraction loss
$L_{clutter}$	Clutter loss
M	Number of bits per symbol in modulation
N	Number of HSDPA codes used for bearer
N_0	Background Noise
P_{RX}	Received powed
P_{TX}	Transmission power
R	Cell radius
R	Channel air interface bitrate
$TP_{\max}$	Maximum throughput
W	Channel chiprate

1 Introduction

Capacity demands of modern mobile telecommunication networks are increasing year by year. People all over the world are using not only more voice call services but also a growing amount of data services with their cell phones. Many of these services, including Web surfing, downloading emails, video streaming and video calls require high speed connections and generate large amounts of data traffic to the network. The customer expectations are rising and soon the mobile terminals will have to achieve the same bitrates as the current fixed internet connections.

Coverage has always been an important issue in mobile telecom networks. It has traditionally been a problem in rural areas due to the long distance between base stations and in indoor and underground locations due to the wall attenuations.

The vendors have to constantly come up with solutions to make the best of the limited radio resources: space and spectrum. Smaller cell sizes such as microcells and nanocells have been used to gain more capacity in urban hotspots like shopping centers and office buildings. Microcells and nanocells as well as distributed antenna systems (DAS) have also been used to improve coverage inside buildings, basements and subway tunnels. These solutions are effective but also expensive. They generate capital expenditure in planning, building the sites, equipment costs and expensive backhaul connections. Also operational expenditures are substantial due to equipment room rents, leased backhaul connections and increased electricity bills.

Femtocells offer a different approach to these problems. Femto is a factor denoting one thousandth of nano. Femtocells are very small, low cost base stations and their maximum allowed transmit power level is low. Femtocells are even smaller than nanocells but the biggest difference is not the size of the cell. The devices are integrated to small plastic desktop or wall mount cases and are installed to the customers’ premises by the customers themselves. The customers’ existing internet connections are used as backhaul connections and the devices are powered from the customers’ electricity sockets.

As the femtocells are installed indoors they will certainly help in achieving better indoor coverage at least in their close proximity. People living in rural areas can use them in to gain better coverage. Femtocells will also give some additional network capacity due to the small cell size and reduce the load of the macrocells. On the other hand they will also use the same radio resources as macrocells and interfere the macro layer as any other base stations. There are also numerous other challenges in implementing an efficient solution and many of them are presented in this thesis. The key question of the thesis is "*What will be the effect on the total network performance when using femtocells together with the current network elements*?"

The mobile operators like any other private companies are always interested in increasing their profits. Increasing the total network capacity by deploying femtocells will save in future macrocell investments. Users that have installed a femtocell are unlikely to change their subscription to the competitor if they are satisfied with the service. Operators will probably also offer special femtocell billing schemes which will furthermore help in retaining customers.

Deploying femtocells, on the other hand, is not free of charge either. Even though the devices are relatively low-cost the operators will have to spend large amounts of money on marketing and device distribution. In addition, many users will need helpdesk phone lines or some other means of support in installing the device.

In this thesis we will first give the reader an overview to the femtocell concept in Chapter 2. The current standardization is presented in Chapter 3 with a description of the 3rd Generation Partnership Project (3GPP) Home NodeB architecture and requirements. Co-operation with the macro layer is studied by presenting different interference scenarios and evaluating the terminal mobility between the femtocells and macrocells in Chapter 4.

The total network performance and throughput are discussed in a theoretical study in Chapter 5. To provide more detailed results a case study simulation with a radio network planning tool is performed in a real mobile network with and without femtocells deployed. The simulation setup and workflow is first described in Chapter 6 and the simulation results are evaluated in Chapter 7. Chapter 8 concludes the thesis with the most important results.

2 Way to femtocells

Growing capacity and coverage demands are driving operators to use smaller and smaller cell sizes to offer better service to higher number of users. Large portions of the phone calls people make and especially the high data rate services they use, are used at home or in the office.

The continuous development in manufacturing electronics and especially integrated circuits has made it possible to include enough processing power and functionality to a low-cost consumer device to make it operate as a cellular network base station. Many of the parts needed in a femtocell are already included in a normal 3G mobile phone.

There have been similar services as the femtocell service already in the market for some time now. For instance Finnish telecom operator Saunalahti is providing the so-called UMA (Unlicensed Mobile Access) service through their customers' Wi-Fi access points and through their own Wi-Fi access network in central Helsinki. This solution, even though looking like a femtocell network, is not one because it needs both the Wi-Fi hardware and client software in the phone to get connected to the network and to handle the calls and choose between the macro layer and the Wi-Fi access points.

The Femto Forum, a non-profit membership organization focused on standardization and promotion of the femtocell solutions, defines femtocells [73] to be low-powered wireless access points that:

- Operate in licensed spectrum and are controlled by the operator.
- Can be connected with existing handsets
- Use residential DSL or cable connection for backhaul

In this chapter we discuss the challenges in implementing femtocell service. Then we briefly introduce the elements of the 3G UMTS network so that we can understand the meaning of the new network elements and functionality that have to be added to the network in order to provide femtocell service. After that, we discuss three different network topology options for integrating femtocells to the current 3G network. Lastly in Section 2.4 some of the current implementations are presented. The chapter will end with a chapter summary in Section 2.5.

2.1 Challenges

In order to keep the expenses low femtocells should require very little for installation and setup. This means that the devices should be auto-configuring so that the user only needs to plug in the cables for the internet connection and electricity and everything else would be taken care of automatically.

The fact that the user does the installation raises some other issues. The femtocell will have to negotiate with the network to setup all necessary parameters and to find out its neighbors. The exact location of the femtocell can never be known in beforehand and the user might even change its location occasionally. This makes it impossible for radio network planners to exactly plan the layout of the network.

The device has to adapt to the surrounding radio environment and possibly share the same bandwidth with other femto- and macrocells. The environment changes constantly if the femtocell density is high and new femtocells are deployed and removed all the time. Even opening doors can change the environment so that the power levels need to be temporarily adjusted.

Adding femtocells will cause dead-zones in the macro layer coverage if they operate on the same band. This will especially be a problem if the use of the femtocell is limited to a Closed Subscriber Group (CSG) and only some of the users near the femtocell can access the network using it. This issue will be examined more thoroughly in Chapter 4.

Because the femtocells operate in a licensed spectrum, the scarce location of the device needs to be verified and the femtocell needs to be authenticated to ensure that it’s operating according to the regulations and that the device is authorized to join the network. Location information is also important to provide tracking for emergency services.

Location can be verified for instance with GPS positioning and SIM card authentication thus creating a more complex and expensive device. Furthermore, acquiring a GPS position indoors is a problem.

The backhaul connection over packet switched IP is Best Effort-type. The Service Providers network or any link in the connection to the telecom operators' network could be congested or even broken. There are no guaranteed maximum levels for delay and jitter. This might require a more flexible interface between the femtocell and the core than in the case of a macrocell base station.

Scalability will also cause challenges. When femtocells are deployed in a large scale the overall number of base stations in the networks might hundred fold. The network must be able to somehow manage this. Also the number of handovers will increase substantially. Current radio network controllers (RNCs) and interfaces aren't originally designed to manage this.

Despite all of the challenges above, femtocells still need to provide all the same as well as better voice and data services as the macro layer network and even with higher bitrates and Quality of Service (QoS). In addition, handovers to other cells need to be managed seamlessly. Only the number of users per cell is smaller, current femtocell solutions support approximately 4 to 8 users.

2.2 UMTS architecture overview

The aim of this section is to give the reader a short introduction to the basic UMTS architectural elements and the interfaces between them. In UMTS system the main components are: the User Equipment (UE), the Universal Terrestrial Radio Access Network (UTRAN) and the Core Network (CN). This thesis focuses mainly on UE, UTRAN and changes in connecting to CN.

UE is the user terminal. It may contain a lot of features, including radio terminals for several radio access technologies (RAT). When UTRAN is used for radio access the UE connects to the base stations known as NodeBs. NodeBs are in charge of the physical radio interface and two low level interfaces: Uu towars the user over the radio link, and Iu-b towards the radio network controller (RNC). RNC is charge of the radio network and its resources on a higher level. RNCs connect to the Mobile Switching Center (MSC) and Serving GPRS support node (SGSN) in the core network. Interfaces Iu-CS and Iu-PS are used for circuit switched and packet switched connections, respectively. The operators CN is connected to the Internet for data services and to the Public Switched Telephone Network for calls outside the operators own network. The essential UMTS elements are presented in Figure 1.

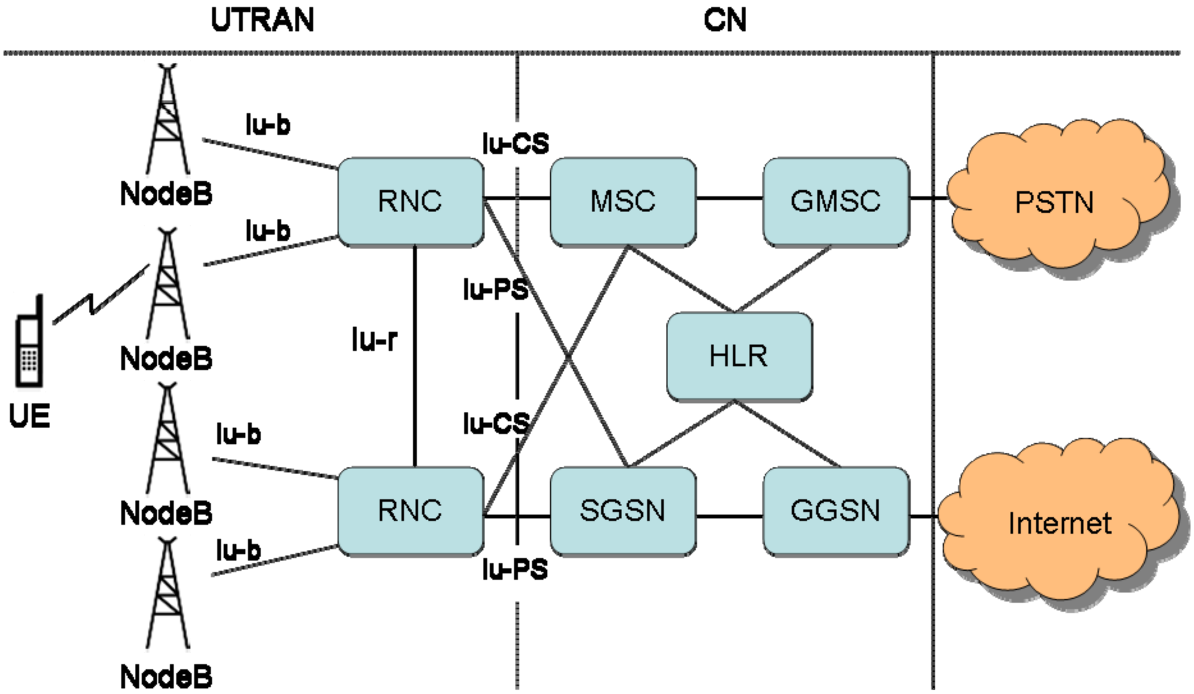


Figure 1. UMTS basic architecture

2.3 Different infrastructure options.

In this section we will discuss three different possible ways to integrate femtocells to the current UMTS networks.

The first way is to change as little as possible and to use the existing standard CS and PS interfaces tunneled over the internet to connect the femtocell and the RNC. This is called the **Iu-b over IP.** This saves expenses due to the less extra hardware is needed on the operator side. Handovers are also possible between femtocells and macrocells, just like between the current macro NodeBs.

There are challenges in using the current macro network interfaces over a Best Effort consumer grade internet connection. The existing Iu-b interface is not designed to work over an unspecified connection. There are also problems if we want to reduce traffic in the core network and route some of the user’s data, e.g. packets to the user’s local area network, without circulating it through the operator’s network. If the Iu-b interface is used, as such, all the data is the routed via the operators core network.

The second approach in femtocell implementation is to use Internet Media Sub-System/Session Initiation Protocol (**IMS/SIP)** interface. The IMS interface is used to convert the user traffic to packet switched Voice Over IP (VoIP) traffic. Session Initiation Protocol (SIP) is used in the VoIP call initiation.

This solution is very scalable because the femtocell doesn’t have to be managed like a real NodeB. The load of the CS core network is reduced, because all the femtocell bound traffic is only on the IMS core. The VoIP call is already designed to be transmitted over a packet switched connection. This doesn’t remove all the jitter and delay requirements of the backhaul connection but makes things easier.

The IMS approach will require a lot of functionality in the femtocell device itself, if support for existing handsets is provided. The PS VoIP calls must be converted to CS calls for existing handsets and a new solution called Voice Call Continuity (VCC) must be used instead of current handovers.

Implementing and maintaining the separate IMS core will create substantial expenses. We must, however, remember that the IMS core will probably be used for other packet switched traffic in the future too.

The third option is the Unlicensed Mobile Access / Generic Access Networks (**UMA/GAN)** based approach. This is a solution that has been standardized by the 3GPP for GAN such as Wi-Fi or WiMAX to integrate their traffic to the UMTS via a GAN Controller (GANC) which will provide a standard Iu interface towards the UMTS CN.

In the femtocell UMA/GAN based solution the UMA/GAN client is not integrated to the UE like in traditional solutions using UMA for the radio link. There’s no need for an extra transceiver in the UE and existing handsets are served.

In this case the UMA/GAN client is integrated in the femtocell. The femtocell has to have the functionalities of both the NodeB and the RNC when it connects to the MSC via the GANC. It is possible for the femtocell to negotiate handovers with the MSC. For operators that already provide UMA services, this option is relatively easy to implement.

2.4 Current devices and deployments.

There are several companies developing femtocell solutions at the moment. The companies can be divided into two categories. The traditional telecommunications hardware manufacturers like Alcatel Lucent, Huawei, Motorola, Samsung and Nokia Siemens Networks. Second, the companies specialized to femtocells, like ip.access, Ubiquisys and Radioframe. Most of these companies have a specified femtocell solution available. Some companies like Nokia Siemens Networks are more concentrated on offering a femtocell gateway solution, which could be used to connect standard femtocells from different vendors to the network.

Currently WCDMA 3G is the dominating technology for radio access in femtocell development, although there are solutions based also on 2G GSM and CDMA. Most vendors have a solution that provides an Ethernet connection for IP backhaul but many have models also including a DSL modem.

Femtocell manufacturing is based on co-operation of many suppliers. British company picoChip is specialized on manufacturing a femtocell solution on a single-chip. Their product is a solution for 3GPP WCDMA standard femtocells and it supports both HSDPA and HSUPA. The chip includes a 400Mhz ARM processor for processing and it includes an interface for connecting common mobile phone radios. Ethernet and full security features are supported for backhaul. The same chip is used in femtocells made by companies including ip.access, Ubiquisys, Alcatel Lucent and Motorola.

Airave by Sprint USA is the largest commercial femtocell deployment so far. The full scale commercial launch was in August 2008. Airave can be used in the Sprint Nationwide network which is a CDMA2000 network with Evolution – Data Only (Ev-DO), a feature that enables high data rates.

2.5 Chapter summary

An overview of femtocells was given in this chapter. The main challenges were laid out in Section 2.1 to give the reader a view of the main requirements for this new technology. In Section 2.2 a brief introduction on macrolayer UMTS architecture was given to make the reader familiar with the current elements for understanding the options for the femtocell infrastructure presented Section 2.3. Lastly, a quick look into the currently available devices and deployed networks was presented in Section 2.4.

3 The 3G Home NodeB

In this thesis, the femtocell architecture we mainly concentrate on is the 3G Home NodeB (HNB) solution specified in the 3GPP standards. In the beginning of this chapter, the status of HNB standardization is described (Section 3.1). Section 3.2 presents the architecture specified in the 3G HNB standards.

Even though the standards specify a certain architecture there are still different configurations available for deployment. These configurations are discussed in Section 3.3. Section 3.4 introduces the most important technical requirements related to the 3G HNBs and their deployment in the near future. Chapter 3 will also end with a chapter summary in Section 3.5.

3.1 Status of standardization

The 3rd Generation Partnership Project (3GPP) is setting the standards on the 3G Home NodeBs. The industry group Femto Forum is playing a key role in making and promoting joint agreements and proposals even though the actual standards are set in the 3GPP meetings.

The 3GPP started a femtocell feasibility study in March 2007. This raised proposals from manufacturers such as Alcatel-Lucent, Nokia Siemens Networks (NSN), Kineto, NEC, Motorola and Huawei. The feasibility study was completed at a 3GPP RAN plenary meeting held May 30th 2008 and the reference architecture for the Home NodeB was agreed on. The agreed architecture is based on a UMA/GAN based joint submission by Kineto, NEC and Motorola blended with an approach by Alcatel-Lucent. The UMA/GAN architecture is the last one of the three options we already described in Section 2.3.

The feasibility study is described in the 3GPP Technical Report (TR) 25.820 [12] which is a part of UMTS release 8. Its main purpose is to determine the HNB feasibility and to outline possible obstacles. It defines the basic architecture and characterizes the different RF- and interference issues and lists the mobility and access control scenarios. Some of the requirements are also listed. However, it has to be reminded that they are not yet complete.

This document is also used to benefit the LTE femtocell, known as Home eNodeB (HeNB), standardization.

In the same meeting two work items were set. Stage 2 to specify the architecture and Stage 3 to specify the protocols. The stage 2 UTRAN architecture is specified in the 3GPP release 8 Technical Specification (TS) 25.467 [8]. Release 8 Stage 2 was frozen in June 2008. It was agreed that there will be two new network elements the Home NodeB (**HNB**) and the Home NodeB Gateway (**HNB-GW**) and a new interface between them named **Iu-h**. Also logical elements Security Gateway (**SeGW**) and HNB Management System (**HMS**) were specified.

TS 25.467 specifies the requirements in the communication between the elements but the protocol is specified in the Stage 3 document TS 25.468 [9]. TS 25.468 specifies the RANAP User Adaptation (RUA) between the HNB and HNB-GW and fulfils the requirements specified in the stage 2 TS 25.467. Release 8 Stage 3 was frozen December 11th 2008.

In Release, 8 service requirements for Home NodeBs and Home eNodeBs are specified briefly in Chapter 8 of TS 22.011 [1] which is a specification of roaming, national roaming and regionally provided services in UMTS. In release 9, which is not yet complete, these specifications have been moved to a separate document *Service requirements for Home NodeBs and Home eNodeBs* TS 22.220 [3].

In TS 25.104 [5], which is a specification for Base Station radio transmission and reception (FDD), a new base station class of Home Base Station is introduced in release 8. Release 8 TS 25.104 specifies the requirements for transmitter and receiver characteristics, some of them vary from the older BS classes.

The Release 8 HNB specifications set in December 2008 describe a full femtocell solution for UMTS. A lot of features will probably need some re-writing and additional specifications. However, the standards are ready for vendors and operators to go forward with their development and rollouts.

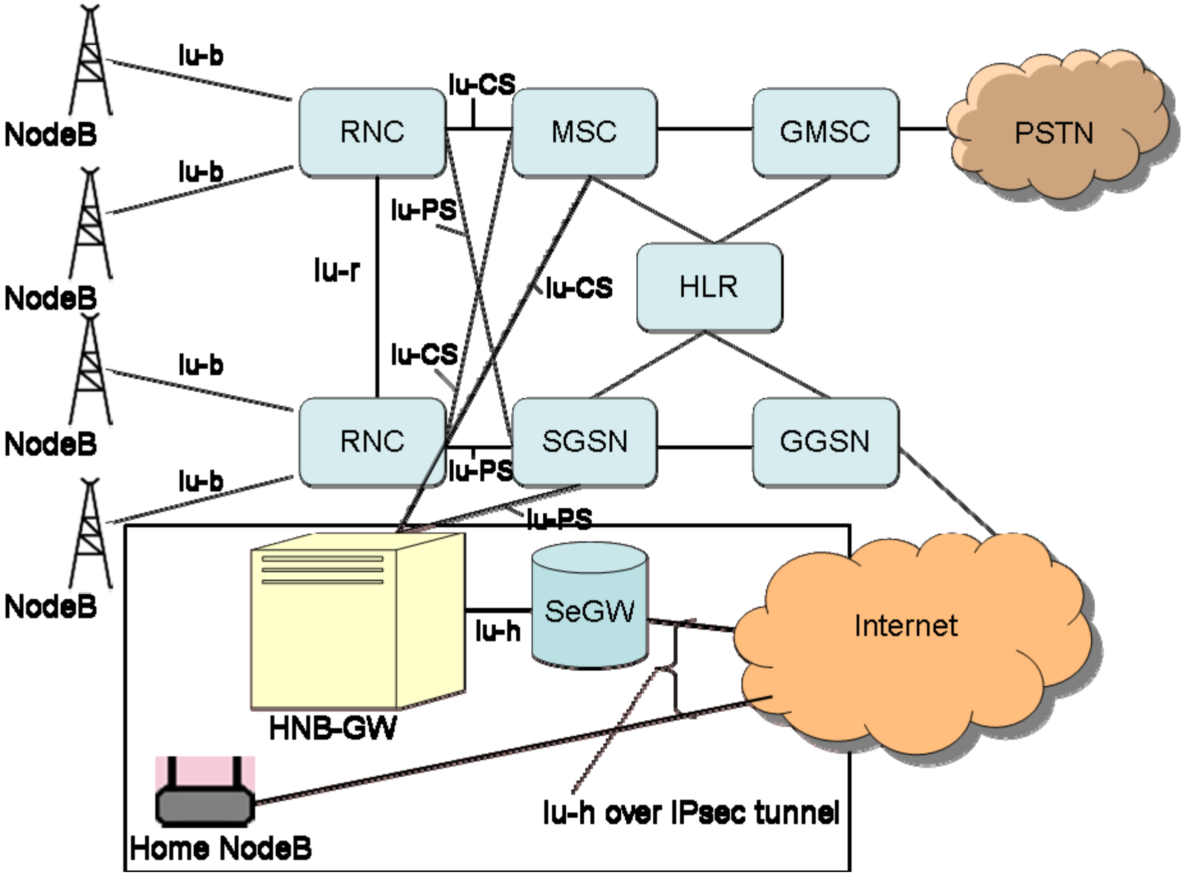
3.2 Architecture

This section deepens the overall architecture description of the 3G UMTS network we already discussed in Section 2.2. Here we present the new network elements and interfaces specified in the 3GPP standards and discussed in the previous section. We also look in to the different possible UTRA deployment configurations.

3.2.1 New network elements

The new essential network elements in the femtocell solution are the femtocell, itself, known here as the 3G Home NodeB (HNB), the 3G Home NodeB Gateway (HNB GW), Security Gateway (SeGW) and the 3G Home NodeB Management System (HMS). These new elements will be introduced and discussed in this section.

This section also introduces the interface called Iu-h defined in the 3GPP HNB standards. The Iu-h interface operates between the HNB and the HNB GW.



3.2.1.1 Home NodeB

The 3G Home NodeB is the device that is installed to the user premises, serving as a femtocell. The HNB is able to operate with 4 to 8 existing UEs and offer them the same services as if they were operating under a regular NodeB. The device is low cost and relatively small in size and can be installed to the user's home or office to the location he/she chooses. The operator has no exact control of the location. The HNB is powered from the user's electric network using most likely an external power adapter.

3.2.1.2 Home NodeB Gateway

The Home NodeB Gateway is the device used to connect the HNBs to the UMTS network. It's needed because it has been agreed not to use the standard Iu-b interface for the connection to the HNB. The HNB-GW concentrates connections from a large amount of femtocells. The new Iu-h interface is used between HNB and HNB-GW. HNB-GW is connected the CN using the standard Iu interface and the network sees it as a standard RNC. The HNB-GW can be located anywhere at the operators premises.

3.2.1.3 Iu-h interface

The Iu-h is the interface between the HNB and HNB-GW. Iu-h provides transport for the control and user plane messages. RANAP user adaptation (RUA) is used over Iu-h to provide transparent transfer for the RANAP messages and another control plane protocol called the Home NodeB Application Protocol (HNBAP) is as well introduced. HNBAP is used to carry the HNB specific control information between the HNB and HNB-GW. Transparent transport is also provided for the Iu user plane protocol layer, which is terminated at the CN, not at the HNB-GW.

The Iu-h interface is tunneled over the residential internet connection of the customer and over the public internet. Stream Control Transmission Protocol (SCTP) over IP is used to carry the control plane protocols. In the user plane Real Time Protocol (RTP) is used for real time services such as, voice and video calls, and GPRS User Data Tunneling Protocol (GTP-U) for packet data transport. UDP over IP is used for the lower layer transport. All this is carried over an encrypted IPsec tunnel.

3.2.1.4 Home NodeB Management System

The Home NodeB Management System (HMS) uses an interface based on the TR-069 standards widely used in DSL modem and DVB set-top-box management and updates. The management system sends the configuration data to the HNB and helps the HNB in HNB-GW and SeGW discovery. It can also initiate HNB software updates and perform HNB location verification.

3.2.1.5 Security Gateway

The Security Gateway (SeGW) is a logical element which can be physically implemented separately or as an integrated solution with the HNB-GW. SeGW terminates the IPSec tunnels for TR-069 and Iu-h protocols and acts as a firewall between the operator’s core network elements and the public internet.

3.2.2 Functionality

The HNB architecture and the elements differ from the standard UTRAN configuration, thus does their functionality too. The things usually handled by the NodeB are divided between the HNB and HNB-GW. The functional split between the devices is specified in the Release 8 TS 25.467 which specifies the UTRAN architecture.

Because the HNB itself is the part which actually contains the radio and is located near the user, it has main responsibility on radio resource and RAB management tasks. It’s in charge of the admission control and together with the CN it manages the RAB establishments, modifications and releases. Security functions on the air interface, like ciphering, are also managed by the HNB with CN managing the key.

Most of the mobility management is also done between the HNB and CN, though the role of the HNB-GW is left for further study in some of the handover issues. Triggering and co-ordination of paging is done between the HNB and CN.

HNB-GW really becomes important in the Iu link management. It communicates with the HNB using the Iu-h interface and with the network using the standard Iu interface. HNB and HNB-GW manage the User plane transport on the Iu-h. HNB-GW is in charge of establishing and managing the ATM connection and putting the Iu-h CS and PS data on the ATM AAL2 and AAL5 layers for Iu.

3.3 Deployment configurations

There are some optional configurations in the 3G HNB architecture. The options can be chosen by the operator considering both the business case and also the technology and RF-requirements. In this section we will have a look at the different access policies, whether to grant open access to all users of the macro layer network or to limit the HNB services to a closed subscriber group. We will look at the possibilities of allocating a dedicated channel for the HNB or using a common channel with the macro layer. Lastly we'll discuss the options of using dynamic or pre-set maximum transmit power for the HNB.

3.3.1 Access policies

It is possible for the operator to configure the HNBs to work in an open access mode, where all the operators' customers and the visitors whose operators have a valid roaming agreement are allowed to access the network via the HNBs. In addition, a closed access mode is also specified. When closed access is used, the HNB only allows certain users to connect. Additionally a hybrid mode of the two is also specified.

Open access is the simple case. If a user is under a HNB coverage area, services are provided whether or not also macrocell service is available. The limiting factors here are the capacity of the HNB and the capacity of the backhaul connection. It would be unfair to the customer who has actually bought the HNB and provides the premises and connection for it to experience blocking due to traffic caused by other users just passing by. On the other hand, many users will probably want to offer the high data rates and good coverage of the HNB to their guests and when open access is used no additional configuration is needed.

Closed access is the configuration option where the HNB provides services only for a pre-configured set of users called a Closed Subscriber Group (CSG). The CSG can be configured by the customer using e.g. a http-interface. Current solutions support up to 50 USIM identities to be on the list. When CSG is used there is no one else causing traffic on the HNB or on the backhaul connection than the users approved by the customer. Security concerns for connecting the HNB to the customer's private network are not as high as with open access, due to the fact that the users allowed to connect the HNB would probably be allowed to the local area network as well.

The CSG option, however, is not without problems either. The operator has a limited amount of radio resources. When CSG is used an amount of spectrum and space is reserved only for the CSG users and the number of members in a CSG might be very small. This is especially a concern when the same carrier is used for the macro layer. This is discussed more in detail later when introducing the co-channel deployment configuration.

Hybrid access mode is a mixture of the two previous modes. Everyone is allowed to use the services like in open access mode but a CSG is defined. When the load levels in HNB rise the users belonging to the CSG get better service. It can also be configured so that the non-CSG users can only access voice and maybe some low bit rate data bearers.

It's also possible to configure temporary CSG memberships for visiting users. These memberships will expire automatically when their validity period is over. Handovers are used to move the users to the macro layer when their temporary CSG membership expires or when a HNB in hybrid mode needs to release open access users to provide service for the members of the CSG.

Future terminals will also include some intelligence related to CSGs. They will maintain a list of allowed CSG identities and be able to view the CSG identity on the screen.

3.3.2 Dedicated or co-channel

It's possible for a HNB to operate on a dedicated channel or share spectrum with the macro layer. Operating on a dedicated channel means that femto and macro layers aren't causing any intra channel interference to each other. All the equipment must naturally fulfill certain adjacent channel interference ratio requirements but, in general, a dedicated channel for HNBs makes things a lot simpler. Using a dedicated channel, though, might not be an option for many operators because of the extra spectrum it needs. Each UMTS FDD UL and DL channel uses a 5 MHz-wide-bandwidth of valuable spectrum. Operators typically have 2-3 total available carriers. Operators might have paid large sums of their available channels and the use of the radio resources needs to be carefully configured. However, there are many operators using only a single carrier for their whole current 3G service and having unused carriers for dedicated channel femtocell operation.

In co-channel operation the same frequency band is used in both HNB and macrocell operation. All the cells cause interference, which is relative to their transmitting power. Even though HNBs are relatively low-powered, they will cause interference to their close proximity and the macrocell service can become unavailable. This is not a problem if the users in this area can access all the services they want via the HNB.

Using CSG access together with the co-channel operation mode causes all other users to lose all service in the proximity of the HNB. This combination can be resolved either by using the hybrid access mode or by implementing sophisticated power control mechanisms. Different interference scenarios are more thoroughly examined in Chapter 4.

Also a partial co-channel model is listed as a solution for CSG operation in the research study TR 25.820 [12]. In this mode the HNB would only use a subset of the macro channel frequencies. This way the macro UEs suffering intolerable HNB interference could be moved to the clear part of the spectrum.

3.3.3 Transmit power configuration

It’s possible to set the maximum transmit power (TX-power) of a HNB to a predefined value or use a dynamic power control. When the dynamic power control is used the HNB must listen to the radio environment a make measurements of current noise and power levels. Based on these measurements the HNB will adjust its maximum TX-power to a level where it causes only an acceptable amount of interference. Later in this thesis it will be shown that when CSG access and co-channel modes are used, dynamic power allocation is necessary.

3.4 Operation and requirements

3.4.1 Installation and management

The HNB installation is done by the customers most of whom are non-technical people. The installation process must be straightforward and automatic. Even then the operator needs to have some means of technical support just to tell which wires are plugged where. There might be different device types connecting either to Ethernet or with an integrated DSL or cable modem. The progress of the installation can be indicated with a series of LED's showing up when each step is working. With the help of these lights problems can be determined when a customer calls the helpdesk and reports the status of these lights.

When plugged into the customer's electric outlet and internet connection the HNB needs to first determine the correct settings for the internet connection. Preferably DHCP or some other means of automatic negotiation is used to get the IP and DNS settings. When these settings are set and the backhaul is working the HNB needs to connect with the mobile operator.

It is stated in TS 22.220 [3] that the HNB shall support the automatic discovery of the Home NodeB Management System (HMS) and that the management connection needs to be secure end to end. For this it needs to connect to the SeGW with which the secure tunnel is created to transfer the TR-069 based management information. After this the operator can upload settings and possible software updates to the HNB.

The operator needs to know that the HNB is operating under all relevant regulations. To ensure that the device is transmitting on a carrier licensed to the operator, the geographical location must be known to ensure that the HNB is in-fact on the operator's territory. TS-22.220 specifies that a location check needs to be performed by the HMS, but the means for it are open. The most straightforward option is to use macrocell information, but unfortunately, if the HNB is used to gain better coverage in rural areas or indoors, macrocell service might not be available. Another possibility is to have also a 2G radio on the HNB and use it to listen to the nearby 900MHz 2G GSM cells working on lower frequencies and thus having a better coverage and indoor penetration than the 2100 MHz

3G UMTS macro layer. Using the neighboring GSM cell-IDs the operator can determine the scarce geographical location. An integrated GPS chip can as well be used, but then the HNB needs to be located above ground level and near a window to acquire satellite coverage. IP address information of the broadband connection can also be used to limit the location to a certain ISP and a certain area.

When the settings are in order, the HNB equipment id is authenticated and the location is checked, the operator allows the HNB to start transmitting and become part of the network.

When the HNB is functioning as a part of the network, the management system is used to remotely change configurations, perform software updates and manage the general Operations, Administration and Management (OA&M) tasks, such as monitoring for faults and performance. The operators needs be able to shutdown the HNB’s transmitter at any given time, if it starts operating against regulations.

The location information is also needed in emergency services. The HNB must support emergency call for all users, whether they belong to the possible CSG or not.

3.4.2 Backhaul and local IP access

The best effort consumer grade DSL or cable modem connection doesn’t offer any guaranties. The backhaul connection should offer enough capacity to handle the throughput of 4 to 8 users. It’s stated in TS 22.011 Chapter 8 that the backhaul traffic including signaling and overhead for 4 simultaneous CS voice calls or emergency calls, shall not exceed 200kbps.

Theoretically, if a single user is using for instance the 10800 kbps fifteen code HSDPA bearer there are no HSDPA codes left for other users on the same carrier and the required throughput on the backhaul is 10,8 Mbps plus IP and tunneling headers. This is achievable on the common consumer grade DSL connections available today.

For instance the VDSL2 technology offers 100Mbps downlink throughput in theory. The real achieved maximum throughputs e.g., in downtown Helsinki Finland with only few hundred meters of copper wire are somewhere between 60 and 70 Mbps. This is enough to provide backhaul for a femtocell and still leave capacity for the customers other internet usage. Currently many of the macro NodeBs especially in rural and semi rural areas are running with 2x2Mbps E1 connections as backhaul.

It can be stated that of the current consumer grade selection an average or not a low-end connection is required to offer good HSDPA service, and leave some capacity for the customers other internet use. The HNB is not necessarily the only device using the connection.

HNB users will probably be accessing a lot of data in their local area networks located in the own premises. They perform backups and download software from and to the terminals, upload photos and videos and syncronize emails with a local server. TS-22.220 specifies that for IP capable UEs a direct local IP access must be provided. This means that packets going to local IP addresses are routed straight to the destination from the HNB not causing traffic on the backhaul connection or on the operator’s core.

3.4.3 Requirements for the handsets

The HNB must provide service for legacy handsets from Release 99 onwards. Release 8 handsets will have additional features for HNB use. The UE registration process is specified separately in TS 25.467 for pre Rel-8 UEs and Rel-8 UEs. The difference is that in Rel-8 both the UE and HNB support the CSG. In Rel-8 it’s possible to for the UE to know when it’s using the CSG HNB service and a different billing scheme. This information can be displayed to the user and can also be used to trigger data transfers such as automatic backups and updates.

3.4.4 Security and charging

Security is an important issue in all mobile phone networks. Users need to be authenticated to make sure no-one else can use their identity and that the correct user is charged for his/her calls.

Mostly the same authentication methods are used with the HNB as in the UMTS in general. The UE contains a SIM card (Subscriber Identity Module), which is authenticated at the network operators Home Location Register (HLR). The current SIM authentication is a very secure procedure, and even if the authentication messages were revealed by tapping the connection, the SIM card secret would not be compromised.

The connection through the internet needs to be end-to-end secure for management connection, signaling and user data security.

Existing mechanisms are used also for charging. And the charging requirements are set to hold the existing specifications (TS-22.115). The most important issues here are that the user is charged based on the used services and the user must have cost control. He or she must be able to know how much is charged at any given time. A different charging rate can be offered for the HNB area users but there must also be a mechanism to inform the user what charging rate is used in the beginning of the call and to let the user know if the charging rate is changed when the user leaves or enters the HNB service area in the middle of an ongoing call.

3.4.5 Requirements for the transmitter and the receiver

A maximum transmit power for HNBs in the order of 20dBm is considered in the 3GPP technical report TR 25.820. The 3GPP study shows that transmit powers of this magnitude ensure that the radiated power density level for general population exposure will not be a limiting factor [12]. The value of 20dBm, when transmit diversity is not used, is specified as the maximum transmit power for a Home BS class transmitter in Release 8 TS 25.104 [5]. When transmit diversity is used the maximum value is 17dBm.

The interference scenarios analyzed in the TR 25.820 [12], which we will discuss further in Chapter 4, show that a single maximum limit for transmission power doesn’t provide good performance in all of the deployment options. As mentioned in Section 3.3.3, a dynamic control for the maximum TX-power is needed at least when the HNBs are used in a co-channel configuration. It is stated that it should be possible to set the maximum output power from 0 dBm to the maximum TX power limit [12].

A lower frequency error limit is given to the HNB than in to standard NodeB. TS 25.104 specifies the frequency error limit of 250 ppb for the Home BS class transmitter versus the previously specified NodeB base station classes of 100ppb for the Local and Medium Area and 50 ppb for the Wide Area BS class. This is justified because the UEs using HNB services will likely move only with relatively low speeds resulting in lower frequency offsets caused by Doppler shift. The lower Doppler shift lowers the risks of demodulation and handover errors. This together with very good expected signal conditions makes it possible to allow some more frequency error.

A set of new requirements for output power adjustment for adjacent channel protection are defined in TS 25.104. These new requirements are only applicable for the Home BS class. It's stated than when an adjacent channel is licensed to another operator it is mandatory for the HNB to monitor the pilot power received on this channel and limit its own transmit power to 7 or 10dBm for operation with and with out transmit diversity if certain conditions for other operator pilot power and noise are met.

On the receiver side some new requirements have been given to the Home BS class receiver to increase the receiver dynamic range. This will help to keep the downlink and uplink in the same order of magnitude even in extreme conditions. We will return to study this deeper in Chapter 4.

Most of the requirements related to transmitter and receiver are the same as for a Local Area BS Class NodeB.

3.4.6 Mobility and handovers

HNBs will increase the amount of total cells and decrease the average cell size substantially. For seamless service, the UEs need to be able to move between HNBs and macro layer cell service. Cell reselection and handovers need to be implemented to and from HNBs. All types of handovers do not need to be available. It is possible for instance to handover all calls leaving a HNB coverage area to 2G. This is not yet fully specified in the 3GPP standards. Mobility and handover issues in femtocell service are discussed further in Chapter 4.

3.5 Chapter summary

Chapter 3 introduced the concept of 3G HNB. Section 3.1 discussed the HNB standards' status. Subsequently, Section 3.2 presented the architecture specified in the already discussed standards. However, it was noted that the standards leave many configuration options for deployment open for the operator to decide. The different configurations were discussed in Section 3.3. Finally, Section 3.4 introduced the most important technical requirements related to HNBs and their deployment. It can be stated that a great part of the HNB features are specified but various challenges still remain for the operators and vendors to solve.

4 Co-operation with Macro Layer

Femtocells will be used in co-operation with the macro layer network. They will provide additional rural and indoor coverage and improved capacity by better spatial reuse of spectrum. It’s clear that a single static femtocell user (FUE) will experience good network performance because of the short distance to the serving cell. However, for efficient operation a femtocell must really be integrated to the network. Terminals need to be able to move between femto- and macrocell service without noticeable problems.

Sharing the same radio resources without any planning on the femtocell deployment side creates problems that need to be solved. The increased number of cells causing interference is especially an issue when the macro and femto layers are in co-channel operation. Co-channel operation is essential to many operators to achieve maximum gain out of spatial reuse. Moreover, when the femtocells are in co-channel CSG mode there are a number of interference scenarios that need to be carefully investigated to mitigate problems.

In this chapter we will first introduce the results of studies by the 3GPP and Femto Forum on different worst case interference scenarios (Section 4.1). The likelihood of these scenarios and possible mitigation techniques are also evaluated. Section 4.2 explains the terminal mobility between femto- and macrocells and the different possible femto - macro handover implementations. A short chapter summary is presented, as always, in Section 4.3.

4.1 Interference

The Femto Forum [24] and 3GPP [12] have studied many femtocell to macrocell, macrocell to femtocell and femtocell to femtocell interference scenarios. These studies have been particularly focused on the co-channel operation because of its importance. The required adjacent channel selectivity of 33dB in terminals is enough to prevent the most extreme interference scenarios if the femtocells are on a dedicated carrier.

In this thesis we are not going to go through the calculations already done in the previous studies. However, the results and the likelihood of the most important co-channel scenarios are explained to provide a clear view of what’s important to understand in the following chapters when discussing performance and the simulation results of the thesis. It needs to be pointed out that these are all worst case scenarios and their likelihood to occur is small.

4.1.1 Interference in WCDMA UMTS

UMTS uses Wideband Code Division Multiple Access (WCDMA) as a multiple access method. In WCDMA a large amount of users use the same frequency channel, known as a carrier. Most operators are currently using only a single carrier for both downlink and a corresponding carrier for uplink in their macro layer operation.

In WCDMA, the different transmissions on a single carrier are separated by using orthogonal scrambling and spreading codes. Different NodeBs and different UEs use different scrambling codes to separate their transmissions. Spreading codes are used to separate different physical layer channels in a single nodes transmission.

When the scrambling and spreading codes are known in the receiving end, the wanted channel can be separated from all other channels. The separation is described by Processing Gain (PG). The calculation process done to separate the channels can raise the channels signal level by the amount of PG. Value of PG can be calculated from the ratio of the WCDMA chip rate *W* (a known network parameter, usually 3,84 Mchips/s for UMTS) and the air interface bit rate of the channel *R* [37].

$$PG = 10\log\left(\frac{W}{R}\right) \tag{1}$$

Transmission sent with other scrambling codes than the code of the channel we want to receive, in other words transmission from other users or other than the serving NodeB, appears as noise in the receiver. Spreading codes are orthogonal and in an ideal situation, different channels sent with different spreading codes but same scrambling code, do not create interference. In reality, where the spreading codes do not stay perfectly orthogonal due to multipath propagation between the transmitting and receiving end, some interference exists between the different channels.

Power control is an important issue in WCDMA. When multiple nodes are transmitting on the same channel and other transmission can be seen as noise, it is important to keep the transmission powers as low a possible. Thus, power control is implemented in WCDMA.

In UMTS WCDMA, two power control methods are used. Open loop power control is used to set the initial uplink and downlink transmission powers when accessing the network, and fast closed loop power control is used to maintain the given Signal to Interference and Noise Ratio (SINR) by exchanging power control information at a frequency of 1500Hz. Fast power control keeps the transmission powers as low as possible in each situation, hence limiting the interference caused to other transmissions to the minimum.

4.1.2 Macro NodeB Downlink interference to FUE RX

In this scenario it is assumed that a receiving FUE is close to a window and a fully loaded macro NodeB is in LOS with the window. The FUE is at the cell edge of the femtocell and the femtocell coverage is limited by the strong macro DL power. This scenario is marked as scenario 4 in the 3GPP studies [12] and as scenario A by the Femto Forum [24].

The likelihood of this scenario is relatively low but it will eventually happen to thousands of users and the femtocell service will be severely impacted. We must, however, remember that in this case the customers can achieve excellent macro cell service. The only issues are that the femtocell becomes almost useless and if a user has a calling plan limited to the femtocell zone, his/hers zone becomes very small. The Femto Forum study suggests that a mechanism to identify the femtocells placed very close to macro NodeBs should be implemented. In addition, a money back guarantee in this situation, would probably satisfy the users.

4.1.3 Femto UE Interference to Macro NodeB Uplink

Here it is assumed that a transmitting FUE is close to a window and a macro NodeB is in LOS with the window. If the FUE is at the cell edge of the femtocell and transmitting at full power, then FUE TX power will cause a large amount of interference in the macro NodeB receiver. This scenario is marked as scenario 1 in [12] and as scenario D in [24].

Due to the close proximity of the macro NodeB, this scenario is not extremely relevant. The uplink noise rise will most likely be less than the downlink noise rise. The femtocell downlink will be limited due to the small distance between the femtocell and the macro NodeB. The femtocell range will be so badly impaired that the FUE transmitter is not likely to cause considerably strong interference at the macro NodeB receiver.

4.1.4 Macrocell Uplink interference to femtocell RX

In this scenario a femtocell is located inside a building in an area where there is a weak macrolayer indoor coverage. A terminal using high TX power due to the weak macro NodeB signal (MUE) is located in the same room next to the femtocell. Another terminal (FUE) is using the femtocell at the same time. This scenario is marked as scenario 3 in the 3GPP studies [12] and as scenario B by the Femto Forum [24]. This scenario is only relevant when CSG access is used in the femtocell and MUE is not part of the allowed group.

The impact of the scenario is dependent on the femtocell receiver capabilities. An extended dynamic range of the receiver will ensure that the MUE transmitting at full power doesn’t block the femtocell receiver in the same room. In the Femto Forum studies a blocking level of 2 meters with new dynamic range requirements is described. This leads to a very low overall probability for the blocking to occur.

4.1.5 Femtocell Downlink interference to MUE RX

A femtocell is located inside a building in an area where there is a weak macrolayer indoor coverage. A terminal using the weak macro NodeB signal (MUE) is located in the same room next to the femtocell. The femtocell has possibly many users and it’s downlink is fully loaded. This scenario is marked as scenario 2 in the 3GPP studies [12] and as scenario C by the Femto Forum [24].

The femtocell transmitting at full power is causing interference to the MUE receiver, thus creating a hole in macrolayer coverage around the femtocell. The holes will only be a serious problem in the CSG case described in the previous subsection. It’s shown in the

Femto Forum study that adaptive power control for the maximum transit power and pilot power are needed to avoid this problem. Other possible mitigation technique is to handover the MUE to another carrier or RAT.

The interference in this scenario will also lower the co-channel macro capacity inside and possibly outside of the building in question. The lowered capacity is not a serious problem due to the possible hundredfold areal capacity increase offered by the femtocells.

4.2 Mobility

To provide good Quality of Experience (QoE) in mobile telecom networks the users need to be able to seamlessly move inside the network and still be available to make, sustain and receive calls and data sessions. This includes cell re-reselections and a functioning paging scheme while moving in idle mode and handovers between cells while a call is in progress.

The normal cell re-selection and handover procedures in UMTS are triggered when there is another cell available with a signal level exceeding the currently used by a pre-configured threshold. This is the main principle with femtocells also, but there are certain situations that need to be avoided. In addition, scalability raises issues in the current mechanisms due to the very large possible number of femtocells.

In idle mode the UE periodically measures the Ec/Io of the Primary Common Pilot Channel (P-CPICH) and listens to the physical Paging Indicator Channel (PICH) for possible paging messages. Pilot signals of the neighbors are measured too and if there is a cell with a better Ec/Io the UE starts to listen that cell. When a location area border is crossed a location area update is sent to the network. This mechanism is to avoid sending paging messages to the whole network. The size of the location area is a tradeoff between paging traffic in the network downlink and power consumption of the UE.

A handover occurs in a mobile network when a user has an ongoing call and moves from a coverage area of one cell to a coverage area of another cell. Normally in UTRAN handovers between NodeBs are soft. Soft handover means that the active UE is connected to more than one participating cell at the same time. At least one active radio link is kept at all times and the link is released only after there is another working connection to another cell. If the operator is using more than one carriers in its network, the handovers between carriers are implemented as hard handovers i.e. the previous radio link is released before the new one is established. Even though there are no multiple simultaneous connections to several cell, hard handovers are usually fast enough not to be noticed by the user.

All femtocell handovers are implemented as hard, whether they are intra- or inter-frequency. In a hard handover, only one radio link is active at a time. The hard handovers make the system more scalable and are also easier to implement over the IP backhaul.

Femtocells will be located indoors, thus the change in signal levels may vary suddenly when entering or leaving for instance a concrete building or even when walking by a window where a macrocell is in LOS. These sudden changes in a small area may result to a situation where the phone is constantly moving between macrocell and femtocell service. In idle mode this creates unnecessary power consumption and during a call the extra handovers create unnecessary overhead traffic in the network.

GSG femtocells add complexity to the situation. An idle-mode-terminal moving between cells listens to CSG femtocells the terminal is not a member of. This listening and camping on the cells, which in reality cannot be used, is futile and a waste of the terminals limited power resources.

The 3GPP [8] has specified that release 8 terminals will have support to recognize CSGs and functionality to avoid futile camping. Unnecessary handovers can also be avoided by prioritizing the femtocell connection over macrocell while the femtocell is still well within range.

Femtocell coverage area can be adjusted via adaptive power control, when Common Pilot Channel (CPICH) power is adjusted the area on which the terminals camp on the cell is altered too. This can be used to balance traffic between the femto- and macrolayers. If a femtocell is already serving the maximum number of users or the IP backhaul is congested, the CPICH power can be decreased so that some of the terminals will handover to the macrolayer or to other femtocells.

In the normal mobility situation between macro NodeBs the terminal receives a lot of information of the neighboring cells from the network. This information is necessary for soft handovers and makes the transitions between the cells a lot faster.´Adding all femtocells to the macrocells' neighbor lists is not a scalable solution for the network. There could be potentially hundreds of femtocells in that area and the maximum number of cells in the neighbor list is 64. In addition this would create challenges to the femtocell self-configurability and interface towards the network. On the other hand, neighboring macrocell can be added to the femtocells neighbor lists. There aren't that many macrocells available for handover and the femtocell can figure out the neighboring macrocells by listening.

To reduce the price and complexity of femtocells, all different types of handovers don't need to be implemented. The highest priority is on the handovers from the femtocell to the macro layer. This ensures call continuity in locations where macro coverage exists. If the femtocells are only added to the network for capacity reasons a voice call can very well be finished in the macro layer too. Handover from the femtocell to a macrocell is absolutely necessary for call continuity when for instance leaving the building.

Different handover modes have been explained by David Chambers in [19, p. 40]. A prioritization of the different handover modes is introduced and the order of importance is the following:

1. Femto 3G to Macro 2G
2. Macro 2G to Femto 3G
3. Macro 3G to Femto 3G
4. Femto 3G to Macro 3G

When voice calls are concerned, the customer does not easily notice what technology is used to carry the call. 2G GSM macro base stations can be used as well as UMTS macro NodeBs. In many areas the 2G indoor coverage is better due to the typically lower frequency. Letting the call handover to 2G on macro layer and making a handover to a 3G femtocell only after that, if necessary, would be a feasible solution on the coverage viewpoint.

However, the 3G to 3G handovers will be important in the future for capacity and for continuity when the current 2G networks will be shut down. Additionally, the new UMTS 3G implementations on the lower 850 and 900MHz bandwidths are raising the 3G indoor coverage up to the same level with the 2G coverage.

3G femtocell to 3G femtocell handovers will not most probably be implemented at all and handovers looks to always happen via a 2G or 3G macrocell.

In good coverage conditions femtocells are added mainly to increase data transmit capacity. It’s important that also the data connection handovers work seamlessly. Critical data shouldn’t be lost and there shouldn’t be noticeable delay or jitter in real time applications.

All in all, handover is a basic function of mobile telecommunication network and the main thing is that it works without any significant problems. Actual difficulties in the future networks cannot be seen yet. This is probably one of the main issues operators will need to investigate in their pilot projects. Possible problems after a commercial launch can cause serious difficulties in selling femtocells to the public.

4.3 Chapter summary

In Section 4.1 we introduced the results of studies by the 3GPP and Femto Forum on different worst case interference scenarios. As a conclusion, the likelihood of the worst scenarios is extremely small and even if they occur, mitigation techniques can be implemented to still offer macrocell or femtocell service.

Section 4.2 discussed the terminal mobility between femto- and macrocells and the different possible femto - macro handover implementations. The elements for a working solution exist. However, it is extremely difficult to predict all the possible problems in the operations. This cannot be done by simulation, therefore pilot projects and first commercial deployments are needed to gain experience.

5 Network performance

In this chapter we will evaluate the theoretical aspects of femtocells' impact on performance and how it could be predicted. The aim of this chapter is also to provide a significant amount of background information to help understand the setup and results of the simulations presented in chapters 6 and 7.

Section 5.1 briefly presents some basic radio propagation theory. Using that theory we then show by some calculations in Section 5.2 how cell size affects to the network performance. The key performance indicators to analyze improvements brought by femtocells are discussed in Section 5.3. Finally, Section 5.4 summarizes the chapter.

5.1 Radio propagation theory

In a mobile telecommunications network the distances and the dimensions of the radio propagation environment are very large compared to the used wavelength. This makes it possible to model the propagation as rays instead of waveforms. A simple equation can be presented for the propagation loss in free space. In terms of transmitted and received power

$$P_{RX} = \frac{G_{RX} G_{TX} \lambda^2}{(4\pi d)^2} P_{TX} \tag{2}$$

Where P_{RX} and P_{TX} are the received and transmitted powers, respectively. G_{RX} and G_{TX} are the antenna gains, d is the distance between the receiving and transmitting station and $\lambda = c / f$ is the wavelength, where c is the speed of light and f is the frequency.

Free space propagation, however, is only valid for free space. In a real nature and man made environment every obstacle and surface affects the propagation of the wave. The waves reflect from surfaces, diffract from obstacles in the path and scatter from the small irregularities in the surfaces and in the propagation path.

The propagation environment is extremely complex and it's almost impossible to construct an exact mathematical model. Therefore, it's necessary to use a model based on educated approximations. There are a number of widely used empirical models for wave propagation in urban, suburban and rural environments. These models are based on measurements and are typically accurate only in certain types of environments. They're also usually only suitable for a certain band of frequency (e.g. from 1GHz – 2 GHz).

The models' accuracy can be improved by taking into consideration also some location specific data, like terrain types and the heights of individual buildings. For smaller cells and indoor environment raytrace models are used. In a raytrace model the path of the wave is followed and virtual sources are created in the reflection and diffraction points.

We will return to the radio propagation aspects in Section 6.2 considering the models used in the simulation case of this thesis.

5.2 Cell size impact to the performance

Network performance and the available capacity are closely related to the signal level and noise, namely Signal to Noise and Interference Ratio (*SINR*). As we learned in Section 4.1, in WCDMA systems, all transmissions to and from other users can be seen as noise.

Theoretical maximum link capacity in an Average White Gaussian Noise (AWGN) channel can be derived from the Shannon capacity theorem. When also the interference from other users is considered as White Gaussian Noise, the maximum theoretical throughput for a radio link is.

$$TP_{\max} = BW \log_2(1 + SINR)\,, \tag{3}$$

where *BW* is the bandwidth of the used channel. From equation (3) we find that improving the SINR also improves the maximum achievable throughput. When looking at a whole mobile telecommunication system the capacity is about spectral efficiency. The valuable bandwidth needs to be used efficiently over a certain area.

Let us define a theoretical radio network, with an average cell radius of *R* km and free space propagation. If the cells' coverage areas are pictured as ideal hexagons, the average terminal distance *d* from a cell is

$$d = R(\sin 60^\circ - \frac{1}{2}\tan 60^\circ) = \frac{1}{\sqrt{3}}R. \tag{4}$$

d can be calculated by assuming a center line for the coverage hexagon and by simple trigonometry.

And from a neighboring cell the average distance is $d = \frac{5}{2\sqrt{3}}$.

If the same average power levels are used in all the cells and only neighboring cells are considered, to simplify the equation, and thermal noise $N_0 = 0$, *SINR* is formulated as

$$SINR = \frac{P_{RX}^{own}}{\sum_i P_{RX}^i + N_0} = \frac{\frac{1}{d_1^2}}{\sum_i \frac{1}{d_i^2}} = \frac{\frac{1}{3}}{\sum_1^6 \frac{6}{5}} = \frac{5}{108}, \tag{5}$$

where P_{RX}^{own} is the received power of the signal we want to receive, $\sum_i P_{RX}^i$ is the sum of all other signal powers, d_1 is distance from the serving cell and d_i is the distance from the neighboring cells.

When we want to continue receiving at the same power levels P_{RX} while using a smaller cell radius R', we can see by looking at equation (2) in Section 5.1, how also the transmitted power levels P_{TX} can be set on lower level while *SINR* stays the same. This works both for uplink and downlink, terminals and base stations can use lower average transmission powers.

Thus, when we can maintain the same *SINR* and use smaller cell sizes, we can achieve higher total throughputs per certain area while keeping the maximum link level throughputs the same. In a real world situation when the smaller cells, like femtocells in this thesis, are isolated by building walls and have lower antenna heights, the situation is even better. This is why better spectral efficiency and better *SINR* values for individual terminals can be achieved.

5.3 Performance indicators

To be able to see what we gain by adding femtocells to a mobile telecom network we need a set of indicators to monitor. There are numerous ways to evaluate a network's performance. Measurements can provide raw numeric data like throughput values and error rates. In addition, quality can be evaluated on a more humane level by measuring Quality of Experience (QoE).

The traditional Key Performance Indicators (KPI) for mobile telecommunication networks, including call success and drop rates, service availability, signal strength and quality, call setup times, data connection setup times and throughputs cannot be investigated in the limits of this thesis, because many of these cannot be known until the actual physical devices are tested.

The indicators we cannot measure are very much related to achieved quality and radio environment error rates. Possible problems in the backhaul and the new interfaces and network elements cannot either be predicted. Instead of modeling everything we concentrate on the limitations of the radio interface and the enhanced capacity gained by introducing a large number of small cells and creating good indoor coverage. The KPIs of this thesis are capacity and coverage. Coverage is estimated by looking at the received pilot channel strengths and capacity is estimated by evaluating throughputs and *SINR*. The results are gained by means of simulation in chapters 6 and 7.

5.4 Chapter summary

In this chapter we first presented a brief overview on radio propagation in Section 5.1. The propagation loss in free space was presented in equation (2). Using the previously presented theory we then showed by some calculations in Section 5.2 how using smaller cell sizes improves the network performance. Section 5.3 evaluates the key performance indicators to analyze the improvements brought by femtocell deployment. Coverage and throughput are selected to be the most important KPIs to be simulated in the following chapters.

Case: Femtocells deployed on Helsinki

6 Simulation setup

It's extremely challenging to examine the true performance gain from adding femtocells. The true interoperability with the macro layer can only been seen through piloting and actual rollout. Since actual devices are not available for the research, simulation is the second best alternative.

Many researchers, such as Choi *et al* [21] and Claussen [22], have simulated femtocell deployment scenarios. These simulations, however, have very often been implemented in very theoretical radio propagation environments. A typical simulation setup [22] consists of a honey-cone model of macrocells with randomly positioned femtocells added. The femtocells are typically placed inside small residential buildings with outer walls, a few windows and inner walls. All femtocells in a simulation are usually placed inside a similar building model.

It can be seen that everything cannot be taken into account in the simulations. One major issue is the functionality and efficiency of the backhaul solution. Typically a DSL or cable modem connection cannot guarantee any specific bitrates. The maximum throughput depends on the quality of the, sometimes very old, copper phone line or coaxial TV-cable and even the connection in the ISP's core can get congested. Therefore it's impossible to reliably predict the operation of for instance the 3GPP Iu-h interface in live action.

In the beginning of this thesis one of the objectives was to examine how a radio network planning tool and simulator, currently used for every day planning of macro networks, can be adjusted to simulate femtocell network properties including coverage and capacity. Using an existing tool means, in this case, also using the existing map data, such as, building vectors and terrain clutters. The macrocells were also placed on existing locations.

The radio network planning tool and simulator used in this thesis is ASSET 6.0 by Aircom International. ASSET is part of the Aircom ENTERPRISE suite. It's a well known tool in the mobile telecommunication industry and widely used by operators for planning around the world. ASSET can be used in planning and analysis of all the main mobile telecommunication technologies.

The simulation case was performed in an area in central Helsinki. The case and the network elements are presented in Section 6.1. In this thesis, three scenarios were selected for simulation. First a set of 77 macrocells was simulated for reference. Then 300 femtocells were added to the scenario. The two femtocell cases were 300 femtocells on a dedicated carrier and 300 femtocells in a co-channel configuration with the macro layer.

The throughput studies in this case will be focused on the downlink. High Speed Downlink Packet Access (HSDPA) will be implemented but for the uplink direction only basic Release 99 bearers are supported. The selected terminal category for HSDPA is category 10. Even though such devices are not on the market yet, we need to look in to the future as the whole femtocell architecture is still at its early steps. Category 10 will enable better throughputs and really benefit from good SINR values.

Before the simulations could be performed the case needed to be planned and configured to the software. In this chapter the configurations of different elements in the simulator are discussed as well as the compromises that had to be done between the simulated scenario complexity and the real world situation. The basic workflow in ASSET consists of network planning (Section 6.1), selection and tuning of the propagation model (Section 6.2), selection of used services and available radio resources (Section 6.3), generation of traffic (Section 6.4) and configuring the Monte Carlo simulator (Section 6.5). We will present these steps together with various pictures and tables to clarify the case and the parameters to the reader. The concept of Monte Carlo simulations will be presented in Section 6.5. The chapter will end with a brief chapter summary in Section 6.6.

6.1 Sites and cells

6.1.1 The scenarios

The simulation area of the case is a 1,537 km² area in central Helsinki. The basic macro layer setup contains 77 cells in 32 sites. The 32 individual sites contain 1-5 cells per site.

The 300 femtocells added to the network are randomly placed to the area. They are, however, placed so that they're in a building and not next to each other. An overview of the simulation area is shown in Figure 2.

Figure 2. Overview of the sites and cells

Three different simulations will be performed. To make identifying easier, the simulation scenarios are numbered in the following way:

- Scenario 1: Only 77 macrocells in use.
- Scenario 2: 77 macrocells and 300 femtocells in co-channel operation
- Scenario 3: 77 macrocells and 300 femtocells on dedicated carriers.

The amount of 300 femtocells is close to the maximum that can easily be fitted to the simulation area in ASSET. The amount is relatively low because there are no floors or inside walls in the building data. In a real world situation a considerably larger amount of femtocells could be placed in the same building and still maintain the same amount of attenuation between the femtocells. They could be for instance on top of each other in different floors separated by a concrete floors

6.1.2 Carriers

Two carriers are used in the simulations. Carrier with a Downlink Universal Absolute Radio Frequency Channel Number (UARFCN) of 10738 is used for the macro layer in all scenarios and for the femto layer in scenario 2. Carrier with DL UARFCN number of 10763 is used for the femto layer in scenario 3. A carrier is usually expressed with it’s Dowlink UARFCN, but both the downlink and uplink frequencies can be calculated from it. The DL UARFCN number tells us directly the center frequency of the downlink channel. The frequencies of the downlink and uplink can be calculated when the definition of the UARFCN number is known and when the duplex channel separation is known. The calculations are the following.

$$f_{DL} = \frac{1}{5} UARFCN_{DL} (MHz) \tag{6}$$

$$f_{UL} = \frac{1}{5} UARFCN_{DL} - f_{separation} (MHz) \tag{7}$$

With given DL UARFCN numbers and knowing the duplex channel separation in UMTS is 190MHz, we can calculate the uplink and downlink center frequencies for the simulated carrier. The frequencies for the carrier 10738 are 1957,6 MHz and 2147,6 MHz for uplink and downlink, respectively. The center frequencies for carrier 10763 are 1962,6 MHz (UL) and 2152,6 (DL). It is best to choose the higher frequencies for femtocells if possible, due to the higher wall and distance attenuations with higher frequency transmissions.

6.1.3 Node types and resources

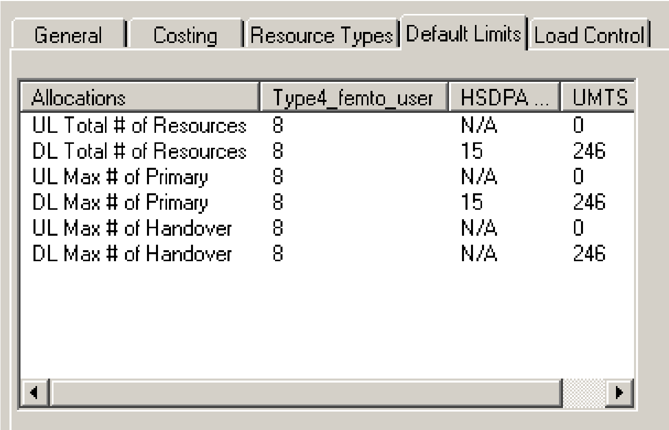
In ASSET some of the parameters for cells and sites are defined in base station node types. ASSET allows the setting of three resource types for each node type and the available resources need to be set so that they correspond to the available radio resources in a real life situation. This depends on the amount of resources available in the node type and the amount of resources consumed by a radio access bearer (RAB). We will return to the consumption of resources in Section 6.3.1 discussing the different bearers**.**

For this thesis, two node types were defined. *Node Type 1* for the macrocells and *Femto Node* for the femtocells. Two resource types were defined for the *Node Type 1*, including resource types *UMTS codes* and *HSDPA codes*. Limits are defined for the downlink only, due to the fact that we are focusing mainly on downlink performance and the uplink traffic in the scenarios will be low.

The allocation of *UMTS codes* resource elements is based on the assumption that there are 256 total codes available when the WCDMA spreading factor (SF) is 256. When the amount of codes used in signaling is subtracted the amount left for user bearers is 246, when it is also assumed that HSDPA is used in the cell [28].

The allocation of *HSDPA codes* is based on a total of 16 codes (SF=16), of which maximum of 15 can be used for user bearers. The amount of available resource elements can be configured per network, site or cell. In this case the simulated resources are radio resources and they are configured per cell.

For *Femto Node*-type one additional resource type is added. Since the current femtocell solutions have a limited maximum number of users, an additional resource limit is added to represent this. Eight simultaneous users is the maximum for the higher capacity office type femtocells and can be considered as a good estimate for the available capacity in the near future. This limitation is set by adding a third resources type called *Type4_femto_user* which has a total of 8 elements available per cell. The resource types *UMTS codes* and *HSDPA codes* are given the same values as in *Node Type 1* configuration. The resources configured for node type *Femto node* are presented in Figure 3. Uplink codes are not limited for this case, since the simulations are concentrated on downlink only.



Allocations	Type4_femto_user	HSDPA ...	UMTS
UL Total # of Resources	8	N/A	0
DL Total # of Resources	8	15	246
UL Max # of Primary	8	N/A	0
DL Max # of Primary	8	15	246
UL Max # of Handover	8	N/A	0
DL Max # of Handover	8	N/A	246

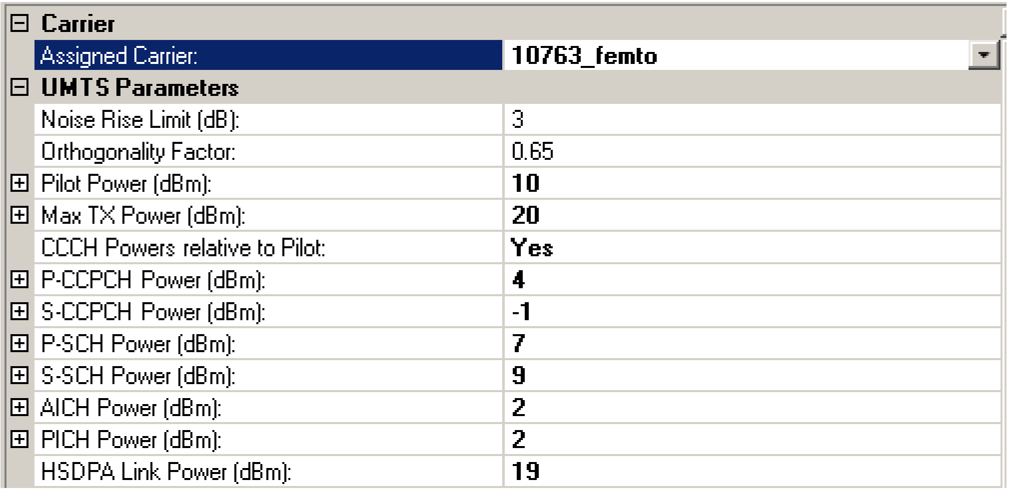
Figure 3. Resource limits for node type Femto node

6.1.4 Cells

In ASSET the network elements are configured in the site database. For the macro layer sites, used in all scenarios, there are one to three cells per site and a total of 77 cells in 32 sites. The configurations for the macrocells vary. Maximum transmit powers are between 38 and 44dBm. Different antennas and as well as tilt angles are used. The Equivalent Isotropically Radiated Power (EIRP) levels are from 55 to 62,5 dBm. Having different cell sizes is normal in a macro layer network, especially in a dense urban environment. The sites are in different kind of locations, affecting the possible antenna heights and types. Distances between sites are not the same either. The parameters in ASSET as well as the real world settings need to be set site by site according to the situation and needs.

For the femtocells the situation is different. In a real network, adaptive power control would most probably be used and femtocells would try to adapt themselves to the surrounding radio environment. However, ASSET doesn’t support this feature and thus a static value for the maximum transmit power is used. However, HSDPA dynamic power allocation is used in both macro- and femtocells. HSDPA transmit power is set dynamically according to the traffic needs and signal conditions.

All parameters for all femtocells are set to the same values. They all have the same antenna heights of 5 meters relative to the ground and all the radio interface parameters are the same. The height of 5 meters is considered a good average value for varying building heights. Only parameter changed between scenarios 2 and 3 is the carrier allocation as discussed in Section 6.1.2. The power level settings of the femtocells are presented in Figure 4.



⊟ **Carrier**	
Assigned Carrier:	**10763_femto**
⊟ **UMTS Parameters**	
Noise Rise Limit (dB):	3
Orthogonality Factor:	0.65
⊞ Pilot Power (dBm):	**10**
⊞ Max TX Power (dBm):	**20**
CCCH Powers relative to Pilot:	**Yes**
⊞ P-CCPCH Power (dBm):	**4**
⊞ S-CCPCH Power (dBm):	**-1**
⊞ P-SCH Power (dBm):	**7**
⊞ S-SCH Power (dBm):	**9**
⊞ AICH Power (dBm):	**2**
⊞ PICH Power (dBm):	**2**
HSDPA Link Power (dBm):	**19**

Figure 4. Femtocell power parameters

6.2 Propagation models

6.2.1 ASSET standard macrocell model

The standard macrocell propagation model in ASSET is based on the COST231-Walfish Ikegami empirical macrocell propagation model. The COST 231-Walfish Ikegami model is an improved version of the empirical Okumura-Hata model based on measurements done in the 1960’s around Tokio. It’s designed to model situations where the antenna heights are at the rooftop level or below. It also takes the building heights into consideration.

The ASSET standard macrocell model contains additional features and calibration options to enhance its accuracy. It takes position specific map data, including height contours, terrain clutters and building heights, into consideration when predicting path losses.

There are several different methods available to use for diffraction calculation in the standard macrocell model. In this thesis we are using the Epstein-Peterson model which is originally based on studies made in 1953 [23]

The standard macrocell model uses the following equation for pathloss prediction

$$\begin{aligned} L_p(d) &= k_1 + k_2 \log(d) + k_3 h_{ms} + k_4 \log(h_{ms}) + k_5 \log(h_{eff}) \\ &+ k_6 \log(h_{eff}) \log(d) + k_7 L_{diff} + L_{clutter}, \end{aligned} \tag{8}$$

where d is the distance between the UE and the NodeB in kilometers, h_{ms} is the height of the UE antenna, h_{eff} is the efficient height of the NodeB antenna, L_{diff} is the diffraction loss calculated by using the Epstein-Peterson model, and $L_{clutter}$ is the clutter loss. Parameters *k1* and *k2* are the intercept and slope, respectively, for the distance attenuation, *k3* is the correction factor for the effective UE antenna height, and *k4* is the multiplying factor for the UE antenna height. *k5* is the effective NodeB antenna height gain multiplying factor and *k6* is the multiplying factor for $\log(h_{eff})\log(d)$.

6.2.2 Maps and clutters

A network plan in ASSET can contain several layers of map information. Usually a normal city or roadmap is used as a background to keep track of location. Layers of ground and building height data are used in propagation predictions. Building vectors are used by raytrace models to calculate reflections and diffractions.

Clutter types are used to categorize different types of terrain, building and population environments. Clutters are used to weight the propagation loss more over some type of terrain than another and in addition to distribute simulated users on a certain area. Clutters used to model the simulation area of this thesis are presented in Figure 5. The clutter resolution is 5m.

Figure 5. Clutter model of central Helsinki

Clutters are taken into account in the propagation model as clutter loss $L_{clutter}$ which is, in a basic situation, calculated out of three parameters through-loss, through-loss-distance and offset-loss. The through-loss models the loss per distance and it is set as decibels per kilometer. The offset-loss is a single loss value, which is added when a new type of clutter comes upon in the propagation path. Through-loss-distance is used to linearly scale down the affect of through-loss while distance from the UE grows.

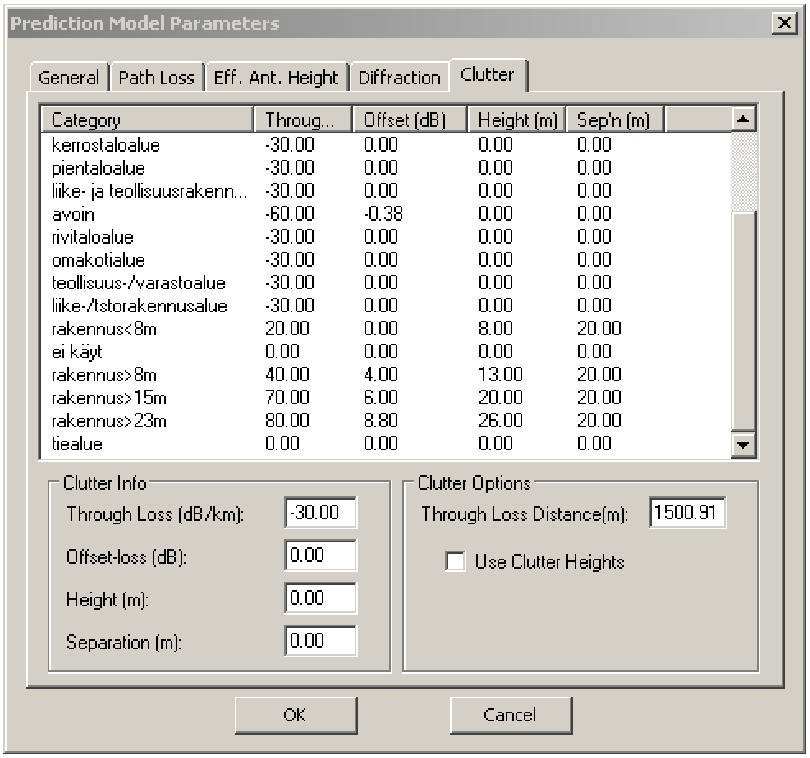
Wall attenuations are not used by the standard macrocell mode and that is why indoor users and losses in ASSET are also based on clutters. Percentage of users indoor, the indoor-loss and the fading standard deviation are set for each clutter type. The loss is taken in to account in the total propagation loss if the UE is inside a building in the simulation.

6.2.3 Models used in the simulations

Although Aircom gives recommended starting parameters for the different frequencies, it’s heavily recommended to calibrate the model for the specific type of area. All the k-factors in equation (8), as well as the clutter parameters can be used for tuning the model. The configuration of the standard macrocell model we’re using in this thesis, to predict the macrocell propagations, is called *macro_urban_5m*. The model has been calibrated with measurements in the central Helsinki and to be used with a 5m clutter resolution. The equation for the model *macro_urban_5m* is.

$$\begin{aligned} L_p(d) &= 170,61 + 66,75\log(d) - 2,55h_{ms} - 13,82\log(h_{eff}) \\ &\quad - 6,55\log(h_{eff})\log(d) + 0,65L_{diff} + L_{clutter} \end{aligned} \tag{9}$$

The clutter parameters for *macro_urban_5m* are presented in Figure 6. The model has been tuned to model also street canyon propagation to some extend. Thus, some of the clutter loss values are negative.



Category	Throug...	Offset (dB)	Height (m)	Sep'n (m)
kerrostaloalue	-30.00	0.00	0.00	0.00
pientaloalue	-30.00	0.00	0.00	0.00
liike- ja teollisuusrakenn...	-30.00	0.00	0.00	0.00
avoin	-60.00	-0.38	0.00	0.00
rivitaloalue	-30.00	0.00	0.00	0.00
omakotialue	-30.00	0.00	0.00	0.00
teollisuus-/varastoalue	-30.00	0.00	0.00	0.00
liike-/tstorakennusalue	-30.00	0.00	0.00	0.00
rakennus<8m	20.00	0.00	8.00	20.00
ei käyt	0.00	0.00	0.00	0.00
rakennus>8m	40.00	4.00	13.00	20.00
rakennus>15m	70.00	6.00	20.00	20.00
rakennus>23m	80.00	8.80	26.00	20.00
tiealue	0.00	0.00	0.00	0.00

Clutter Info

Through Loss (dB/km): -30.00

Offset-loss (dB): 0.00

Height (m): 0.00

Separation (m): 0.00

Clutter Options

Through Loss Distance(m): 1500.91

☐ Use Clutter Heights

Figure 6. macro_urban_5m-model clutter parameters

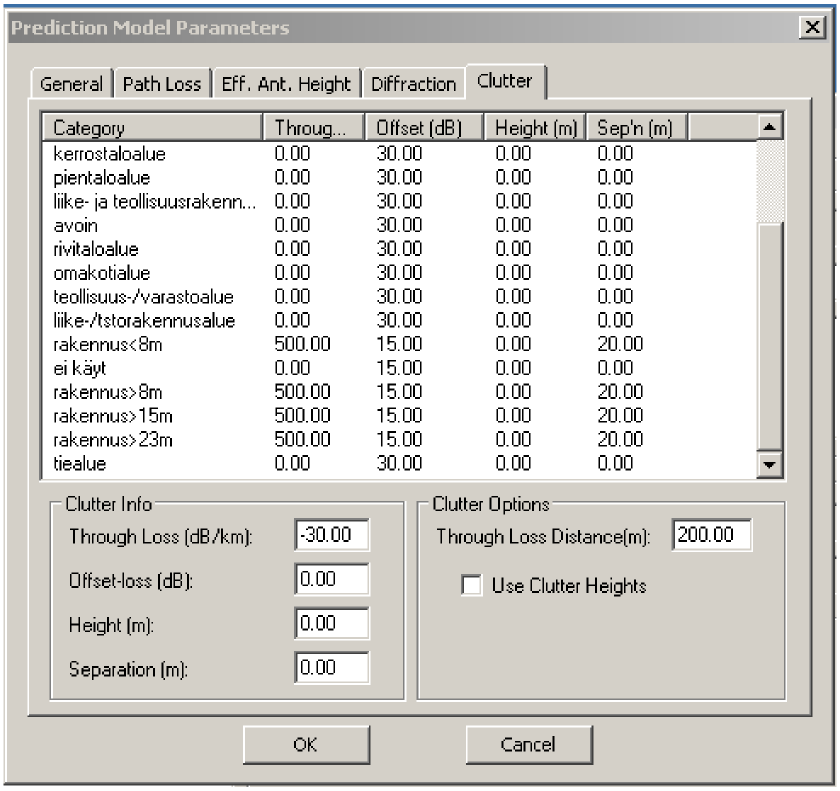
As usual, femtocells in this thesis are located indoors. If available, a full three dimensional raytrace microcell propagation model would be best suited for the femtocell propagation calculations. However, there were no 3D models available of the simulation area and ASSET does not contain such a propagation model as a default. There is a two dimensional microcell model available in ASSET 6.0 and it was first considered as the best candidate for this thesis. There were, however, several software based problems with the model and Aircom stated that the whole model will be removed from ASSET version 6.1. As a result, a decision was made to modify the standard macrocell model to calculate also the femtocell predictions.

The macrocell model was never intended to be used when the cells are located indoors. The main problem is that the indoor losses by clutter type (see Section 6.2.2) are defined globally to the plan, while different propagation models can be used for different cells. The macrocell model doesn’t support a wall penetration loss to be implemented to the building vectors either. The clutter-loss parameters, nevertheless, are defined individually to each propagation model. Thus, it is possible to edit the parameters in a way that the overall situation represents the reality.

The indoor losses for the different building clutters are on average 15dB. This value is accounted for in the femtocell propagation loss for an indoor UE even though the UE is located inside the same building. Thus, to get the situation in line with the *macro_urban_5m* model we need to the subtract this 15dB from the intercept value *k1* of the pathloss equation (9), as a result we get

$$\begin{aligned} L_p(d) &= 155{,}61 + 66{,}75\log(d) - 2{,}55h_{ms} - 13{,}82\log(h_{eff}) \\ &\quad -6{,}55\log(h_{eff})\log(d) + 0{,}65L_{diff} + L_{clutter}. \end{aligned} \tag{10}$$

In the case of femtocells it’s extremely important to have wall attenuation in the model when going out of the building. This is done by editing the clutter offset-loss values. The offset-loss for all the clutter types surrounding the building clutters is set as 35dB to compensate for both the 15dB wall attenuation and the indoor loss value no longer subtracted from the total pathloss when the UE is outside the building clutter. To model the wall attenuation when entering other buildings, the building clutter types are given a 15dB offset-loss value. The buildings in ASSET do not have inside walls, therefore the in-building attenuation is modeled by setting a through-loss value for the building clutters. 500dB/km equaling 0,5dB/m is used as the through-loss value. This value is the default parameter for the ASSET microcell model indoor loss. All other height and through-loss values are set as zero. The clutter values of the femtocell propagation model *jarvinen_femto_5m* are presented in Figure 7.



Category	Throug...	Offset (dB)	Height (m)	Sep'n (m)
kerrostaloalue	0.00	30.00	0.00	0.00
pientaloalue	0.00	30.00	0.00	0.00
liike- ja teollisuusrakenn...	0.00	30.00	0.00	0.00
avoin	0.00	30.00	0.00	0.00
rivitaloalue	0.00	30.00	0.00	0.00
omakotialue	0.00	30.00	0.00	0.00
teollisuus-/varastoalue	0.00	30.00	0.00	0.00
liike-/tstorakennusalue	0.00	30.00	0.00	0.00
rakennus<8m	500.00	15.00	0.00	20.00
ei käyt	0.00	15.00	0.00	0.00
rakennus>8m	500.00	15.00	0.00	20.00
rakennus>15m	500.00	15.00	0.00	20.00
rakennus>23m	500.00	15.00	0.00	20.00
tiealue	0.00	30.00	0.00	0.00

Clutter Info
Through Loss (dB/km): -30.00
Offset-loss (dB): 0.00
Height (m): 0.00
Separation (m): 0.00

Clutter Options
Through Loss Distance(m): 200.00
☐ Use Clutter Heights

Figure 7. jarvinen_femto_5m-model clutter parameters

Despite the model not being extremely sophisticated, it serves its purpose. The properties of the model can best be understood when looking at Figure 8 and Figure 9.

In Figure 8 and Figure 9, a zoomed view of three femtocells is presented. Figure 8 is a best DL cell by RSCP plot, which tells us the cell with best pilot power received at each pixel. The green, light yellow and the reddish brown colors represent the three femtocells and other colors are surrounding macro and femtocells not visible in the plot. It can be clearly seen how the femtocell signal propagates better inside the buildings than on the outside. However, there is some noticeable propagation to the outside as well.

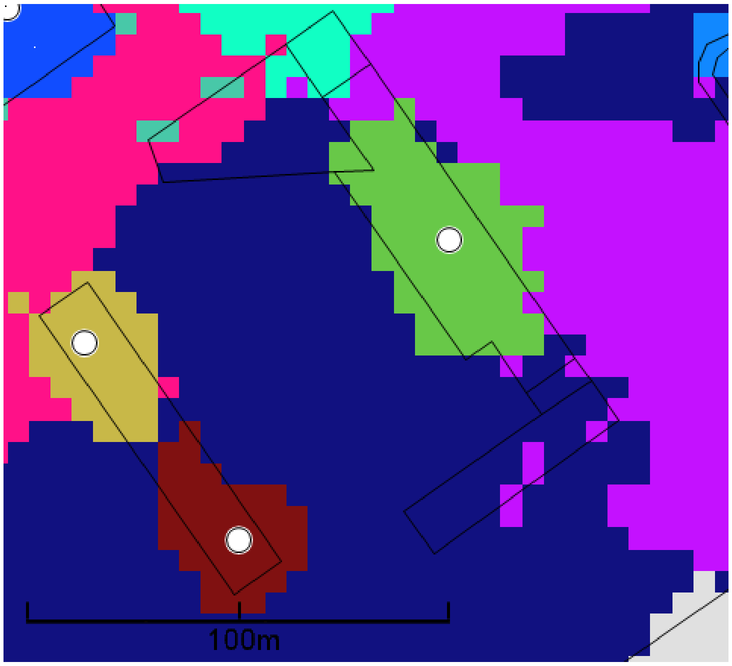


Figure 8. Best DL cell by RSCP, plot of three femtocells

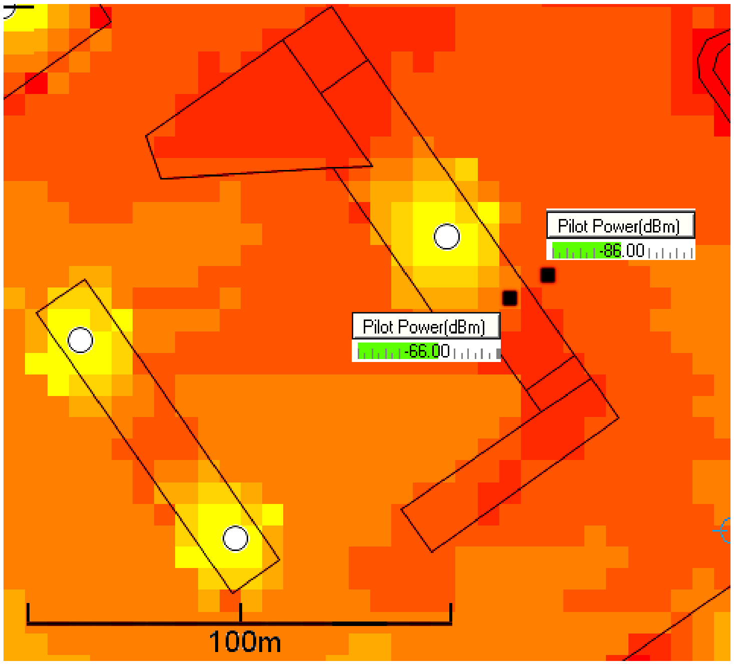


Figure 9. Best RSCP, plot of three femtocells

To see how the propagation model works, it was examined with the ASSET pixel analyzer tool. Figure 9 shows the same zoomed area of a best RSCP level plot. There are two pixel values of received pilot power emphasized in the figure, the other is a pixel value inside a building and the other is a pixel value outside the same building. It can be seen that while the outside pixel is only slightly further away from the nearest femtocell and the pixels are only ten meters apart, the received pilot power is 20dB lower outside.

6.3 Terminal type, services and bearers

6.3.1 Radio access bearers

In UMTS, it is possible to allocate different amount of capacity to each user according to the user's needs and the radio conditions. This is done by dividing the different transport characteristics into radio access bearers. A bearer is negotiated or renegotiated on the basis of the service and the signal to noise and interference ratio (SINR).

In ASSET, the bearers represent the air interface connections of the real UTRAN. They have the task of representing the voice and data transport. To support high data rates most bearers in this thesis are related to HSDPA and known as HSDPA bearers.

Bitrate and link quality requirements are set for each bearer in ASSET. The minimum acceptable link quality is set as the minimum energy per bit over noise E_b / N_0 value which can be directly calculated from the SINR and vice versa. In ASSET the required SINR for a HSDPA bearer is calculated by [14]

$$SINR_{ASSET} = \frac{E_b}{N_0} MN \ . \tag{11}$$

Where, M is the number of bits per symbol in the used modulation. $M = 2$ for Quadrature Phase Shift Keying (QPSK) and $M = 4$ for 16 Quadrature Amplitude Modulation (16QAM). N is the number of HSDPA codes used for the particular bearer. HSDPA bearers are presented in Table 1.

Table 1. HSDPA bearers

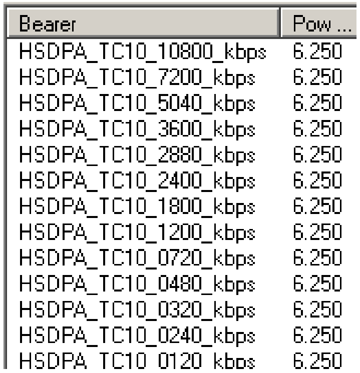
Bearer	**Bitrate (kbps)**	**Coding rate & modulation**	**HSDPA codes**	**UMTS codes**	**Eb/N0 (per code) (dB)**	**SINR (asset) (dB)**
HSDPA_TC10_0120_kbps	120	QPSK 1/4	1	17	-1,97	1,04
HSDPA_TC10_0240_kbps	240	QPSK 1/2	1	17	0,83	3,84
HSDPA_TC10_0320_kbps	320	QPSK 1/3	2	33	-0,88	5,14
HSDPA_TC10_0480_kbps	480	QPSK 1/2	2	33	1,12	7,14
HSDPA_TC10_0720_kbps	720	QPSK 1/2	3	49	0,56	8,34
HSDPA_TC10_1200_kbps	1200	QPSK 5/8	4	65	0,97	10
HSDPA_TC10_1800_kbps	1800	16QAM 3/8	5	81	-1,11	11,9
HSDPA_TC10_2400_kbps	2400	16QAM 1/2	5	81	0,32	13,33
HSDPA_TC10_2880_kbps	2880	16QAM 3/5	5	81	1,49	14,5
HSDPA_TC10_3600_kbps	3600	16QAM 3/4	5	81	2,99	16
HSDPA_TC10_5040_kbps	5040	16QAM 3/4	7	113	4,53	19
HSDPA_TC10_7200_kbps	7200	16QAM 3/4	10	161	7,31	23,33
HSDPA_TC10_10800_kbps	10800	16QAM 3/4	15	241	24,22	42

Each bearer is set to consume resources to simulate the use of the WCDMA and HSDPA code tree. The configured resource consumptions for all bearers are listed in Appendix A. For all the HSDPA bearers the amount of *UMTS codes* resource units they use is a multiplication by 16 of the used *HSDPA codes* resource units. Each used bearer uses also one *Type4_femto_user* resource.

6.3.2 Terminals, services and bearer activity factors

To setup how the different bearers are used, services need to be configured to ASSET. A service contains a list of supported bearers and carriers and bearer power activity factors. The activity factors determine how much each bearer is used.

Five different services are allocated and each of them supports a different set of bearers. The services are: packet switched 384 kbps web browsing data; packet switched 64 kbps data; circuit switched 12,2kbps outdoor voice; HSDPA category 10 data with 384 kbps uplink; and HSDPA category 10 data with 64 kbps uplink. The bearers for all the services and their activity factors are listed in Appendix A. The activity factors are configured for each bearer in each service. As an example, activity factors of the bearers supported by HSDPA cat 10 64 kbps UL are shown in Figure 10. The same activity factors are used also for the HSDPA service with 348kbps UL.



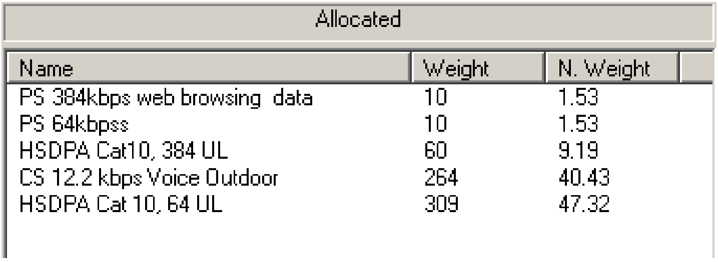
Bearer	Pow ...
HSDPA_TC10_10800_kbps	6.250
HSDPA_TC10_7200_kbps	6.250
HSDPA_TC10_5040_kbps	6.250
HSDPA_TC10_3600_kbps	6.250
HSDPA_TC10_2880_kbps	6.250
HSDPA_TC10_2400_kbps	6.250
HSDPA_TC10_1800_kbps	6.250
HSDPA_TC10_1200_kbps	6.250
HSDPA_TC10_0720_kbps	6.250
HSDPA_TC10_0480_kbps	6.250
HSDPA_TC10_0320_kbps	6.250
HSDPA_TC10_0240_kbps	6.250
HSDPA_TC10_0120_kbps	6.250

Figure 10. HSDPA bearers' activity factors

A round-robin type of scheduling is used between the different bearers in the HSDPA services. Round-robin means that activity time is shared equally between the bearers. All achievable bearers are active 1/16th of the time, thus the 6,25% activity factors in Figure 10. Weighting the bearers' activity factors by their user bitrate would give a more real value for best possible individual user bitrates. Nevertheless, the round-robin solution is recommended by Aircom when the total cell capacity is measured. Asset doesn't support the proportional fairness scheduling actually used in HSDPA but the results can be estimated by adding 40%-60% more throughput to the round-robin simulation results [14].

Before traffic can be created for the simulator, a terminal type needs to be configured. It was decided to use only a single terminal type and create a set of services the terminal will use. Terminal type *HSDPA terminal (OT) mikko 10* is created for this thesis. For the terminal type services and service weights, according to which the use of services is divided by, are configured.

The terminal uses the set of services to present the average situation in the network, in other words, the service set is not something a single user would use instead it models the average data and voice load from the operator viewpoint. The used set of services and weights is taken from a known situation of an international telecommunications operator having more data service users and a more congested network than the Finnish operator operating the macrolayer network of this thesis. There will most probably be a similar situation in Helsinki in the near future. The allocated services and their weights for terminal type *HSDPA terminal (OT) mikko 10* are presented in Figure 11.

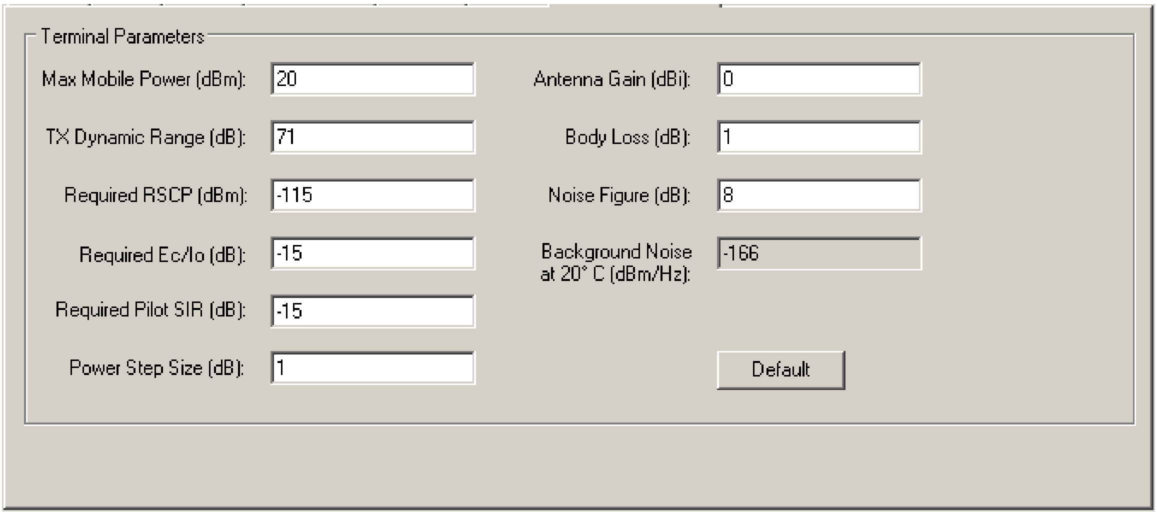


Allocated

Name	Weight	N. Weight
PS 384kbps web browsing data	10	1.53
PS 64kbpss	10	1.53
HSDPA Cat10, 384 UL	60	9.19
CS 12.2 kbps Voice Outdoor	264	40.43
HSDPA Cat 10, 64 UL	309	47.32

Figure 11. Allocated services for the terminal type HSDPA terminal (OT) mikko 10

The radio technical parameters for terminal type *HSDPA terminal (OT) mikko 10* are presented in Figure 12. ASSET uses the required signal level values to calculate coverage and the noise parameters to calculate the total noise in the receiver. The values are widely used nominal values [35].



Terminal Parameters

Max Mobile Power (dBm): 20

TX Dynamic Range (dB): 71

Required RSCP (dBm): -115

Required Ec/Io (dB): -15

Required Pilot SIR (dB): -15

Power Step Size (dB): 1

Antenna Gain (dBi): 0

Body Loss (dB): 1

Noise Figure (dB): 8

Background Noise at 20° C (dBm/Hz): -166

Figure 12. HSDPA terminal (OT) mikko 10 parameters

6.4 Traffic

Traffic is created by adding a number of terminals to the simulation area. The distribution of terminals is determined by clutter types and is the same at all scenarios throughout the thesis. Each clutter has a traffic weight value and a percentage of indoor users. The values can be seen in Appendix B.

The number of terminals is a variable used in the simulations to see the effects of demanding more capacity. It’s configured by changing the number of terminals inside the polygon limiting the simulation area. The number is changed manually and for each user amount the simulations are re-run. An example of the generated traffic at 6000 total terminals is shown in Figure 13.

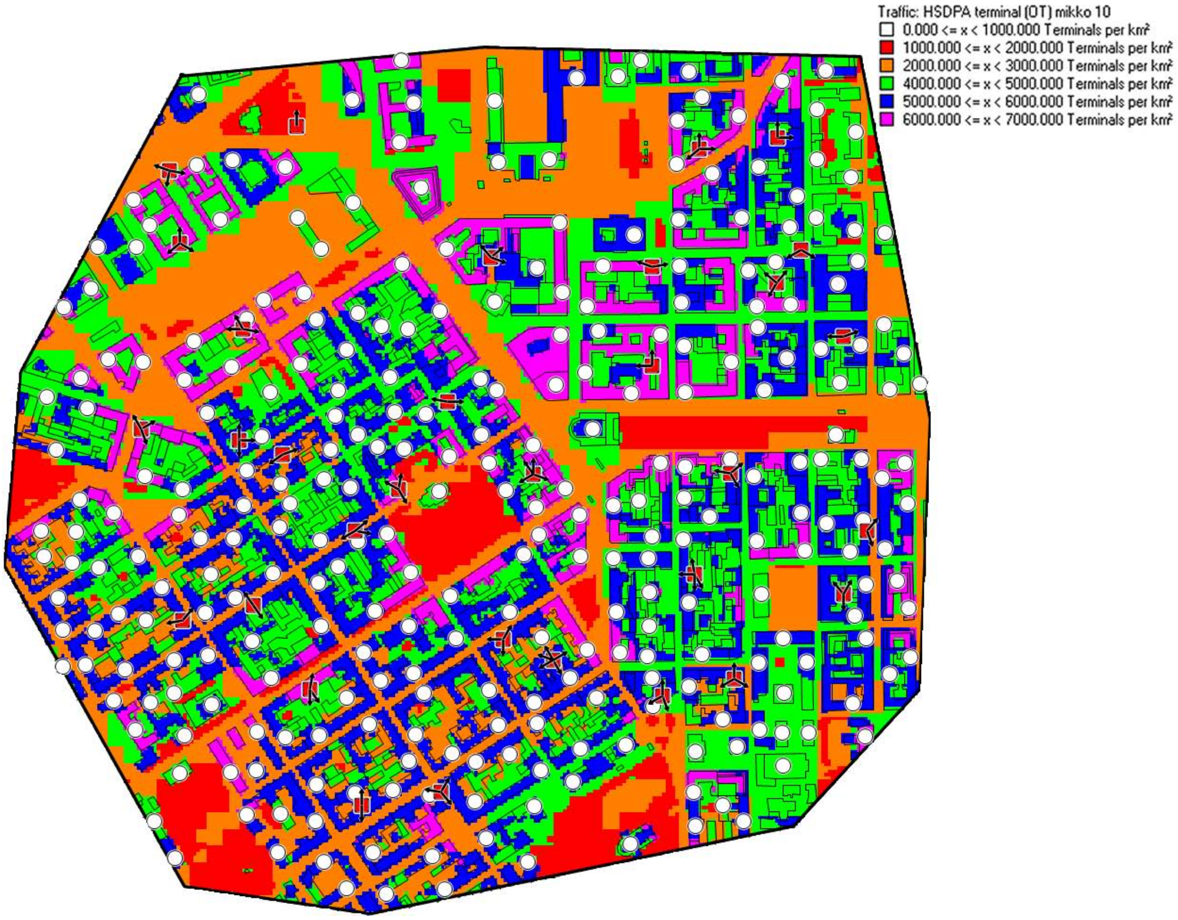


Figure 13. Traffic distribution at 6000 total terminals

6.5 Monte Carlo simulations

Due to the amount and randomness of users and their behavior in a cellular network a continuous simulation with moving users would be very complex. It's easier to use a static approach. Users are distributed randomly in to static locations and a simulation is performed. A more reliable view of the situation is achieved when more than one of these static *snapshots* is simulated. This process of repeating a number of static simulations, with redistribution of the terminals between the steps, is called a Monte Carlo simulation.

ASSET uses Monte Carlo simulations to evaluate network performance. In each snapshot terminals are randomly distributed in the simulation area according to the created traffic distribution. User can select the number of snapshots in a simulation sequence. After each snapshot the radio conditions for each terminal and the amount of shared resources available is calculated using and iterative process. The calculation is continued to a user configured precision. After all the snapshots have been performed, average values of the snapshot results can been used to evaluate overall performance the network.

At first an amount of 500 total terminals was used and a decision was made to use a widely used value of 50 snapshots for all the simulations. As it was noticed after the preliminary results that the amount of traffic had to be substantially increased for the total network throughput studies, 50 snapshots meant that the simulations with the largest amounts of total terminals had to be run overnight on a high end PC workstation. The simulations were run at total terminal amounts of 3000, 6000, 9000, 12000, 15000, 18000 and 21000 terminals. Figure 13 in Section 6.4 showed the traffic distribution in the case of 6000 terminals.

6.6 Chapter summary

This chapter introduced the simulator and the workflow of setting up a femtocell network simulation in ASSET. The three scenarios, and the network elements were presented in Section 6.1. Thereafter, the propagation models were introduced in Section 6.2. Different models were used for the femtocells and macrocells. The femtocell propagation model had to be tuned to represent the situation where the cell is located inside a building. Thus, the reliability of the model was also investigated by plotting coverage on a small selected area.

Selection of used services and available radio resources were evaluated in Section 6.3 and generation of traffic in Section 6.4. The concept of Monte Carlo simulations and snapshots as well as the actual simulator parameters were described in Section 6.5.

7 Simulation results

In this chapter, the simulation results from the three scenarios listed in the previous chapter are presented. First, in Section 7.1, we present the network coverage with and without the femtocells. Next the HSDPA SINR in all three scenarios is shown in Section 7.2. As it is known, the achievable HSDPA bearer is very closely related to the SINR conditions. Thus, the HSDPA achievable bearer in all scenarios is presented in Section 7.3. Thereafter, we present the cell service rates for individual users (Section 7.4) and finally the total network throughput results (Section 7.5). As always a chapter summary is presented last in Section 7.6.

7.1 Coverage

Coverage is presented in best Received Signal Code Power (RSCP) plots in Figure 14 and Figure 15. In a best RSCP plot the power of the best received common pilot channel is plotted. In Figure 14 the best RSCP of the pure macrocell scenario, scenario 1, is shown. It can be clearly seen that while the coverage is mainly very good there are clear problems in indoor coverage. The received RSCP is very low inside some buildings further away from macrocells.

In Figure 15, there is noticeably less area of -115 to -90 *dBm* (plotted as red in the figure). The femtocells will help in poor coverage areas especially indoors. However, it is also noticeable how a single femtocell enhances the coverage only in a relatively small area. Thus, a great number of femtocells is needed to really affect the overall operator coverage area.

However, in a real deployment scenario, customers would more probably acquire a femtocell when suffering from very bad coverage. In urban environment the few problem areas would be fast covered. Femtocells could be used in many places currently covered with repeaters. The coverage of a single femtocell can best be understood by looking at the previous Figure 8 and Figure 9.

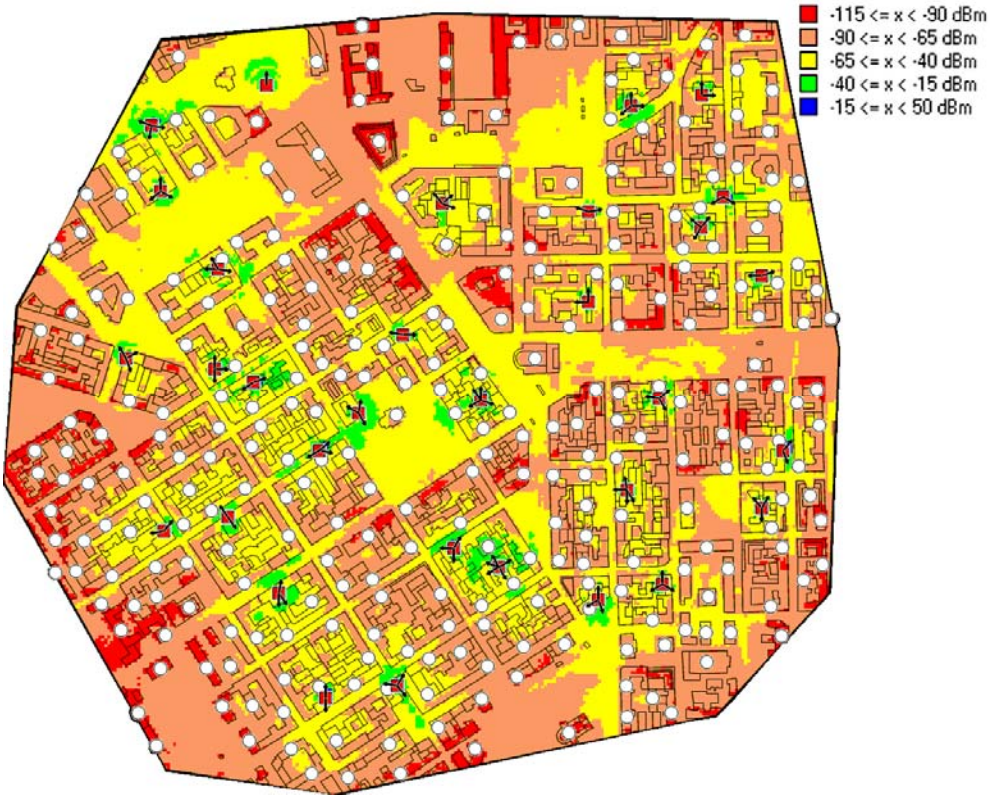


Figure 14. Best indoor RSCP, Scenario 1

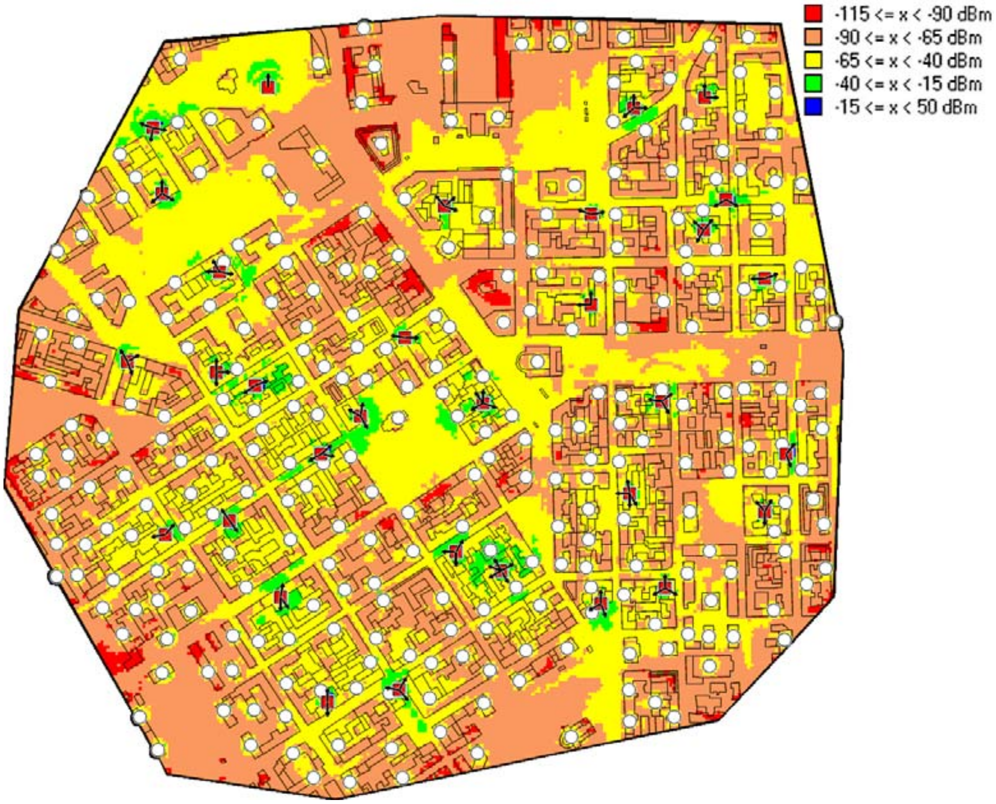


Figure 15. Best indoor RSCP, Scenarios 2 and 3

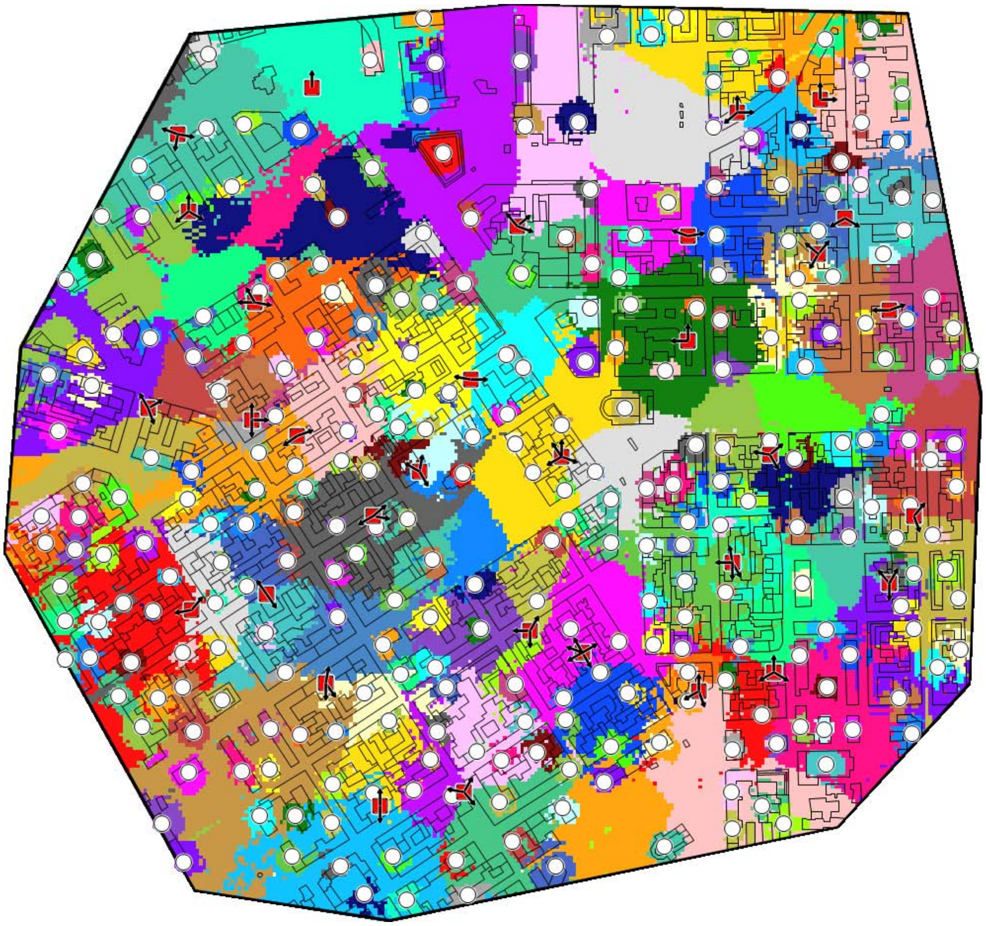


Figure 16. Best DL cell by RSCP, Scenarios 2 and 3

To examine the cell dominance areas, a best DL cell by RSCP plot of scenarios 2 and 3 is shown in Figure 16. The colors in the figure represent the areas, in which the best RSCP is received from a certain cell. It can be seen that the femtocells dominate mostly indoors and that all the cells have clear dominance area borders.

7.2 HSDPA SINR

HSDPA SINR is calculated in ASSET by the following equation

$$E_{\alpha Jk}^{SINR} = \frac{P_{\alpha J}^{HSDPA\_link}}{R_{\alpha k}^{total} L_{Jk}^{\downarrow} - \varepsilon_{\alpha J} (P_{\alpha J}^{pilot} + P_{\alpha J}^{common} + P_{\alpha J}^{UMTS}) - P_{\alpha J}^{HSDPA}} . \qquad (12)$$

In which $R_{\alpha k}^{total}$ is the time-average total DL noise power at the terminal

$$R_{\alpha k}^{total} = N_{\alpha k}^{thermal} + \sum_{\beta} \sum_{J} \frac{A_{\alpha\beta}^{\downarrow} P_{\beta J}^{total}}{L_{Jk}^{\downarrow}}. \tag{13}$$

In equation (12), the received HSDPA link power is divided by the total DL noise. Due to orthogonality own cell pilot, common channel and UMTS powers $P_{\alpha J}^{pilot}$, $P_{\alpha J}^{common}$ and $P_{\alpha J}^{UMTS}$ (the power of R99 UMTS services) multiplied by the orthogonality factor $\varepsilon_{\alpha J}$ are subtracted from the denominator. Own cell HSDPA power $P_{\alpha J}^{HSDPA}$ is not considered as interference and is also subtracted. In equation (13), the total noise at the terminal $R_{\alpha k}^{total}$ is a sum of thermal noise and received downlink powers from all cells multiplied with the adjacent carrier attenuation $A_{\alpha\beta}^{\downarrow}$. In the case of same carrier the adjacent carrier attenuation $A_{\alpha\beta}^{\downarrow} = 1$.

Besides code tree resources, SINR is the basis for deciding the achievable downlink bearer. HSDPA SINR in scenarios 1, 2 and 3 is presented in Figure 17, Figure 18 and Figure 19, respectively. The scale has been graduated to match the required SINR values for different HSDPA bearers in ASSET (see Table 1).

While looking at the figures a clear difference can be seen in scenario 3 but by bare eye scenarios 1 and 2 seem almost the same. It can be seen that the SINR is noticeably better around the femtocells in scenario 2 and that there are some differences in the edges of different SINR levels. In scenario 3 the SINR plot looks totally different and the SINR is much higher all around. To clarify the results, numerical values of the total areas of each SINR category are shown in Table 2.

It can be seen that the low SINR categories, marked with red borders in Table 2, are almost nonexistent in scenario 3 and have a share of few percents in scenario 1, scenario 2 being in the middle. The area percentages evolve to the other direction in SINR category from 19*dB* to 23,3*dB*, equivalent of the 5040 kbps HSDPA bearer. In scenario 3, 73% of area belongs to this SINR category while the percentages are 33 and 45 for scenarios 1 and 2, respectively. The use of femtocells, especially on dedicated carrier, raises the share of the higher SINR categories.

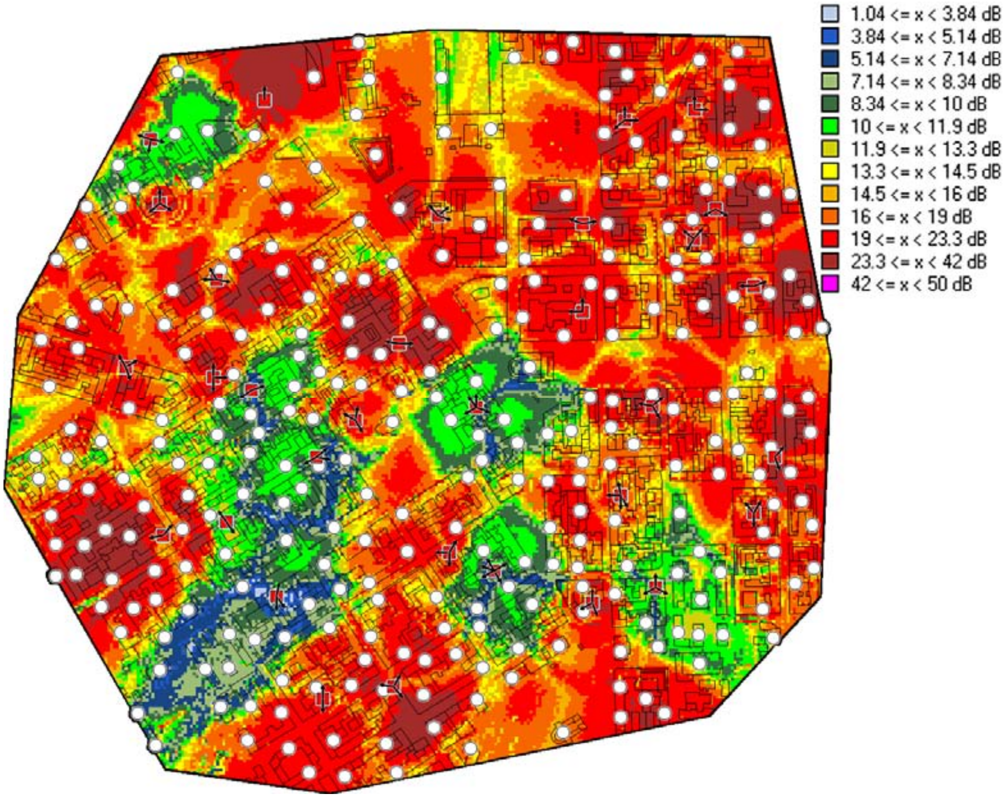


Figure 17. HSDPA SINR, Scenario 1

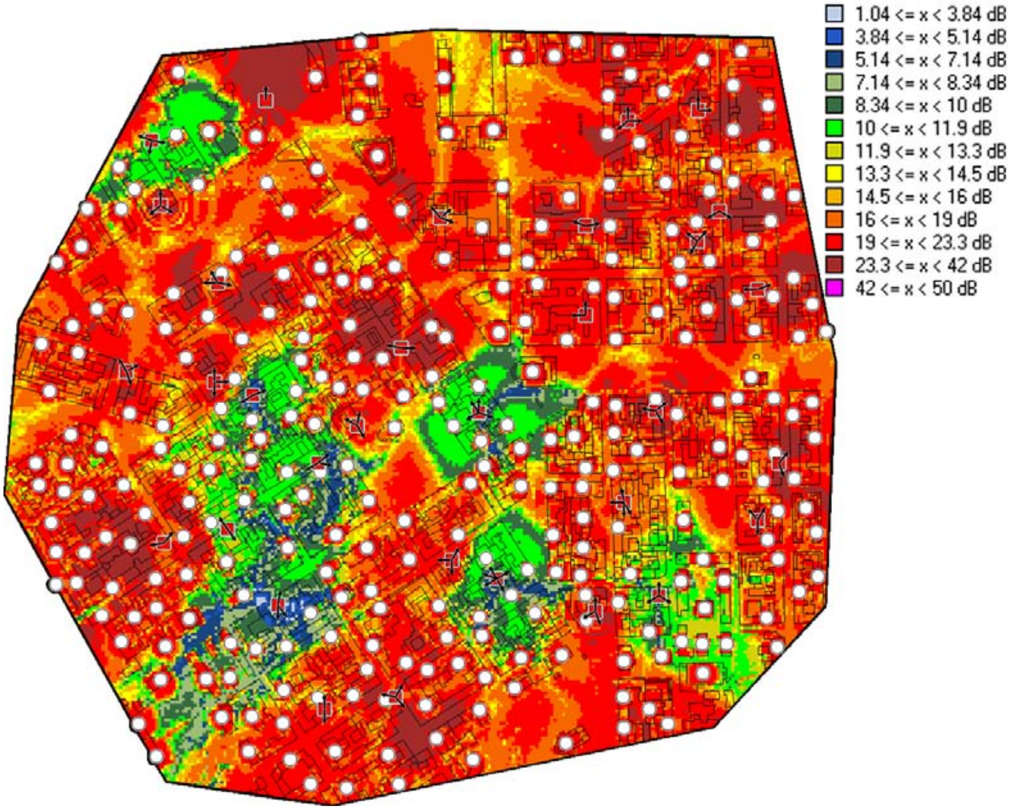


Figure 18. HSDPA SINR, Scenario 2

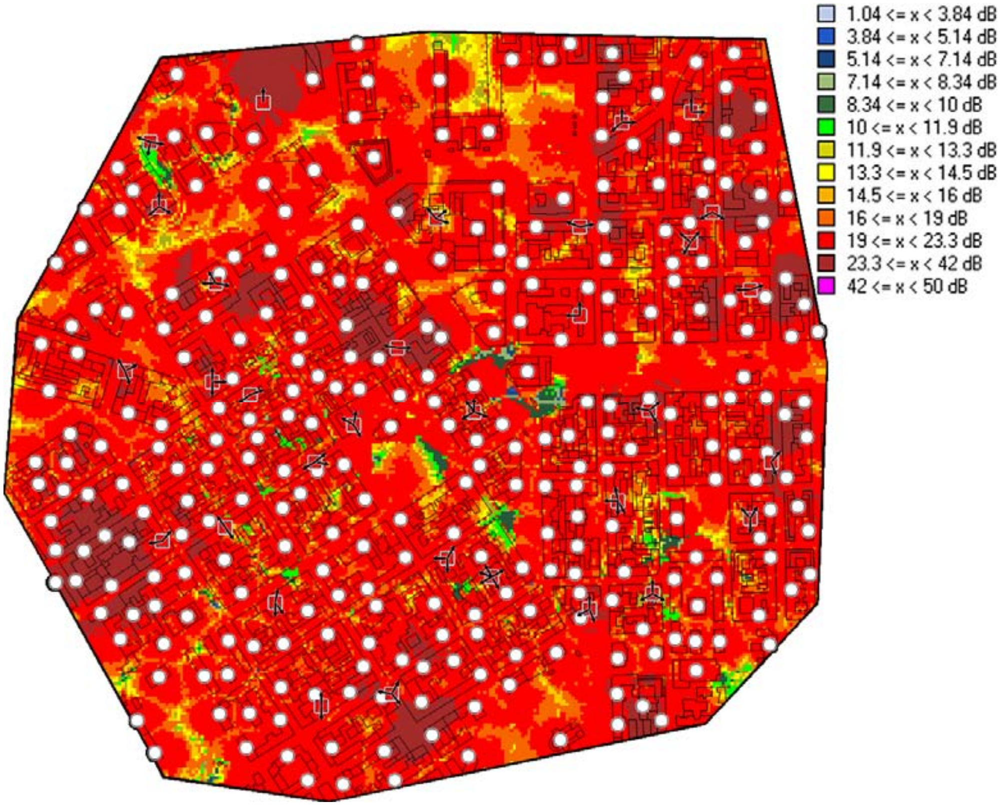
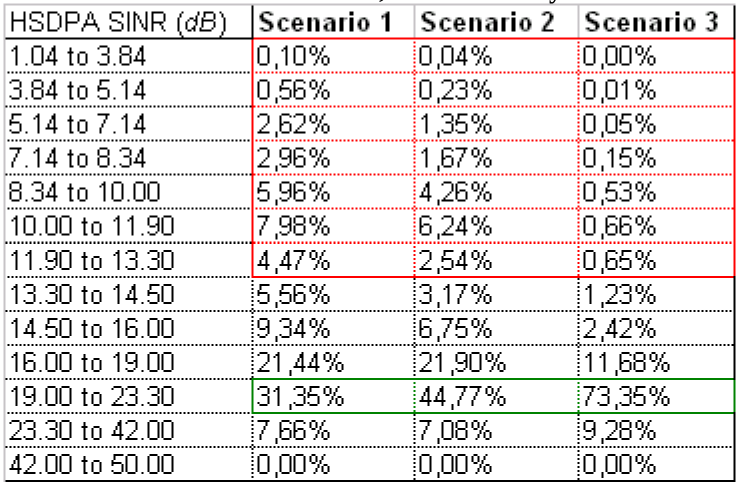


Figure 19. HSDPA SINR, Scenario 3

Table 2. HSDPA SINR, distribution by area



HSDPA SINR (*dB*)	**Scenario 1**	**Scenario 2**	**Scenario 3**
1.04 to 3.84	0,10%	0,04%	0,00%
3.84 to 5.14	0,56%	0,23%	0,01%
5.14 to 7.14	2,62%	1,35%	0,05%
7.14 to 8.34	2,96%	1,67%	0,15%
8.34 to 10.00	5,96%	4,26%	0,53%
10.00 to 11.90	7,98%	6,24%	0,66%
11.90 to 13.30	4,47%	2,54%	0,65%
13.30 to 14.50	5,56%	3,17%	1,23%
14.50 to 16.00	9,34%	6,75%	2,42%
16.00 to 19.00	21,44%	21,90%	11,68%
19.00 to 23.30	31,35%	44,77%	73,35%
23.30 to 42.00	7,66%	7,08%	9,28%
42.00 to 50.00	0,00%	0,00%	0,00%

7.3 Achievable HSDPA bearer

The achievable downlink HSDPA bearer is highly related on the SINR at each location introduced at the previous section. The SINR requirement needs to be fulfilled for a bearer to be achievable. The achievable HSDPA bearer plot in ASSET takes also other restrictions in to consideration. Shortage of HSDPA or UMTS codes can result in not achieving a certain bearer. It also takes standard deviation of shadow fading into account and chooses the achievable bearer when a connection probability of at least 90% is achieved.

The achievable HSDPA bearers in scenarios 1 and 2 are presented in Figure 20 and Figure 21. Traffic at all plots is 500 total terminals. It can be seen how the plots do not differ as much as in SINR plots. The most noticeable difference between scenarios 1 and 2 can be seen when looking at the area where no HSDPA bearer is achievable, marked as white in the plots. In scenario 1 there are significant indoor and outdoor areas with no HSDPA coverage, while in scenario 2 these areas are smaller. When looking at the higher bitrate bearers in the plots there are differences to both directions. Their coverage is better in some locations in scenario 1 and in some locations in scenario 2. Overall area for e.g. the 5040 kbps bearer seems to be better in scenario 2.

When multiple carriers are used the achievable bearer plot can only be viewed by carrier in ASSET. The plots for scenario 3 macrocarrier 10738 and femtocarrier 10763 are shown in Figure 22 and Figure 23. In the case of the macrocarrier the achievable bearers look the same to by bare eye in scenario 3 as in scenario 1. However, there is also the femtocarrier to add capacity. The femtocarrier achievable bearers seem to be coverage limited at this total amount of traffic and traffic distribution. The 5040 kbps bearer is achievable right to the cell edge.

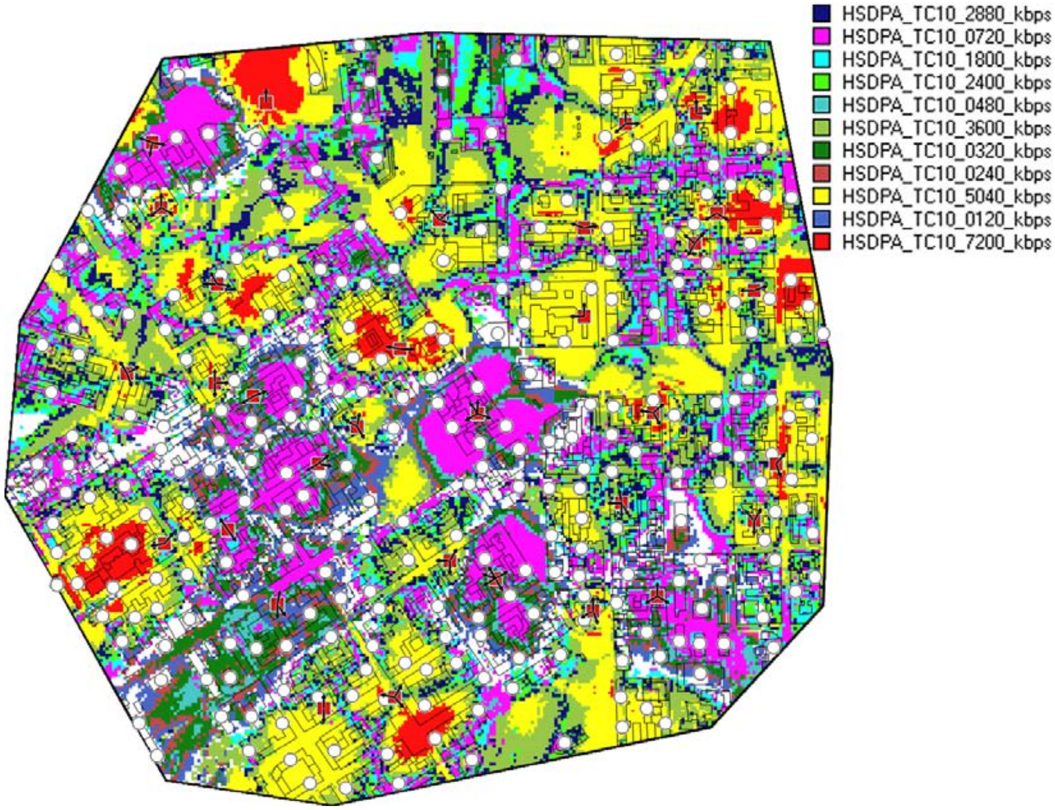


Figure 20. Achievable HSDPA bearer, Scenario 1

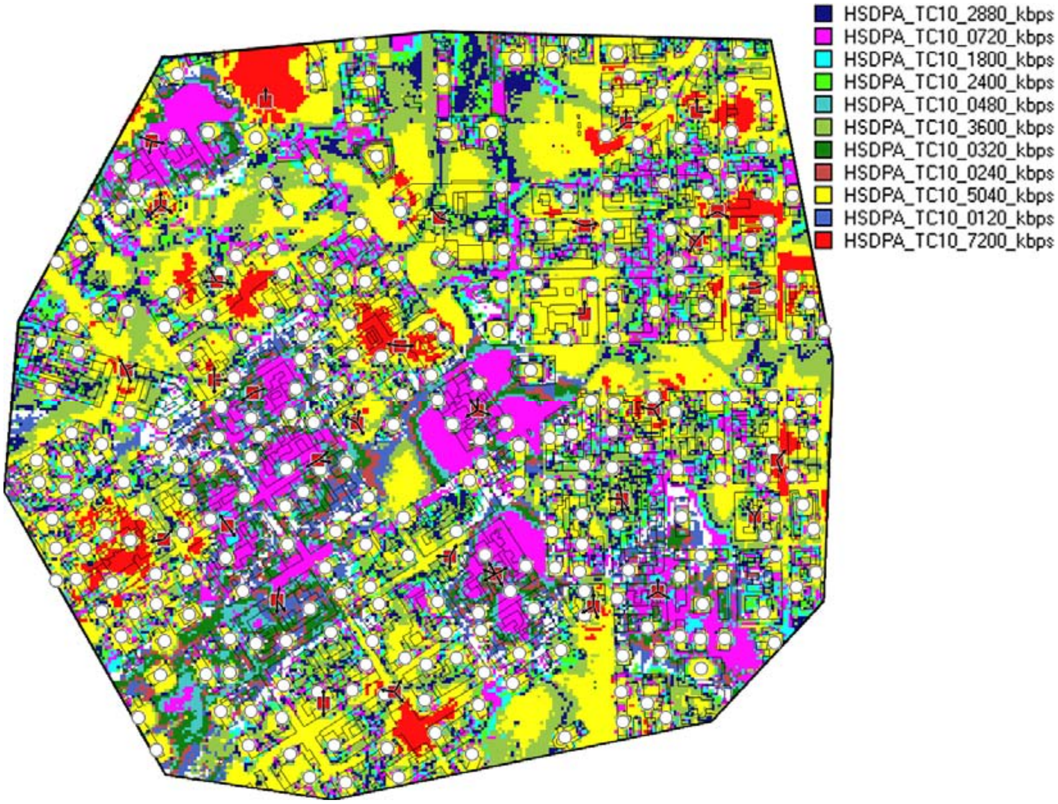


Figure 21. Achievable HSDPA bearer, Scenario 2

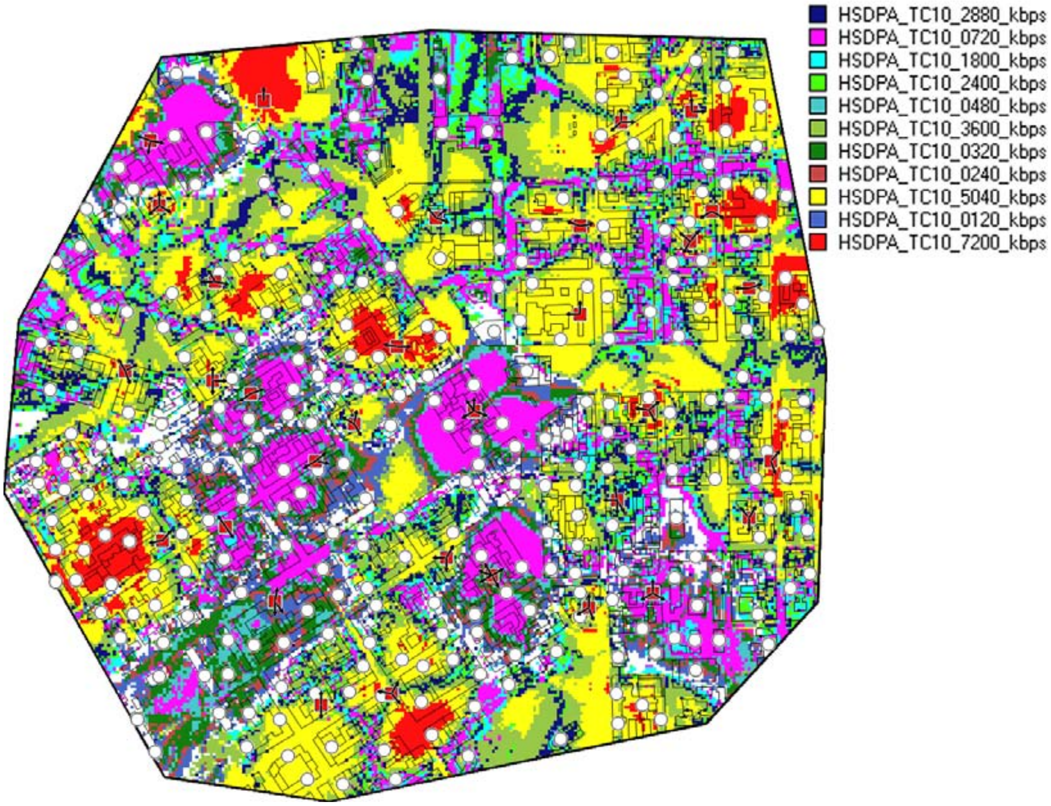


Figure 22. Achievable HSDPA bearer, Scenario 3, Macrocarrier

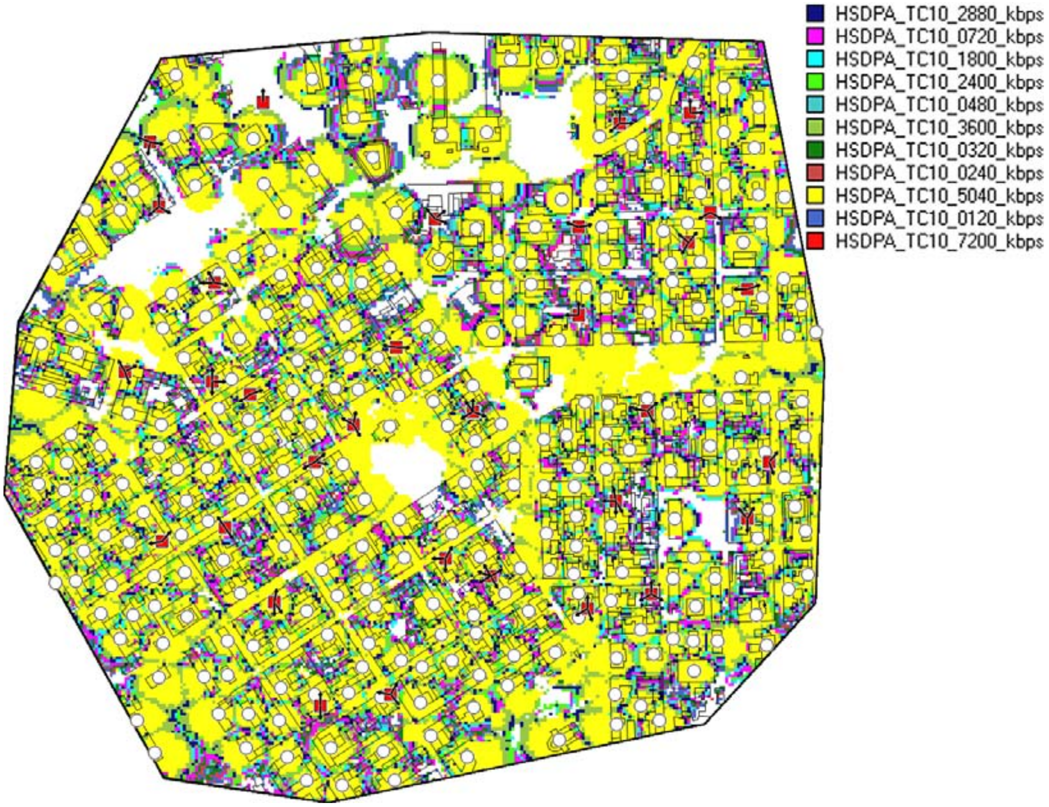


Figure 23. Achievable HSDPA bearer, Scenario 3, Femtocarrier

7.4 HSDPA Cell service rate

In ASSET the unloaded HSDPA effective cell service rate is defined as the total amount of data in a service session divided by the mean service time per terminal

$$\mu_{kM}^{unloaded} = \overline{X_M} / \overline{T_J} \tag{14}$$

Where $\overline{X_M}$ is the total data in bits for service *M* and $\overline{T_J}$ is the mean service time for a user in cell *J*. When calculated as *loaded,* queuing delay is taken into account [16].

Figure 24 shows the cumulative distribution function of the HSDPA cell service rates at 500 total terminals in scenarios 1, 2 and 3. The results were exported from ASSET per carrier and to get comparable results for scenario 3 the separate macrocarrier and femtocarrier results, also shown in the plot, were weighted with the amount of terminals served by macrocells and femtocells, respectively.

When interpreting a throughput CDF plot, the throughput levels of around 10% are usually considered to be available for almost all users while 90% level can be considered as the practical maximum data rates [27].

The plots show that whether femtocell service is implemented on co-channel or on a dedicated carrier the service rates are higher for both the cell edge terminals and the terminals receiving at high data rates. For the practical maximum rates there is a difference of 1 megabytes per second between the pure macrocell scenario 1 and femtocells on dedicated carrier scenario 3. When the femtocells are on co-channel in scenario 2 the achieved gain compared to scenario 1 is approximately 900kbps.

The scenario 3 macrocarrier and scenario 3 total results are similar in the limits of the plot precision. This is due to the very low total amount of terminals served by femtocells with 500 total terminals. When looking at the plot of the femtocarrier in scenario 3, it can be seen that the femtocells on dedicated carrier offer excellent service for almost all the users they serve. The total results would be noticeably higher, if the traffic distribution would be different so that there would be much more terminals very near the femtocells using femtocell service.

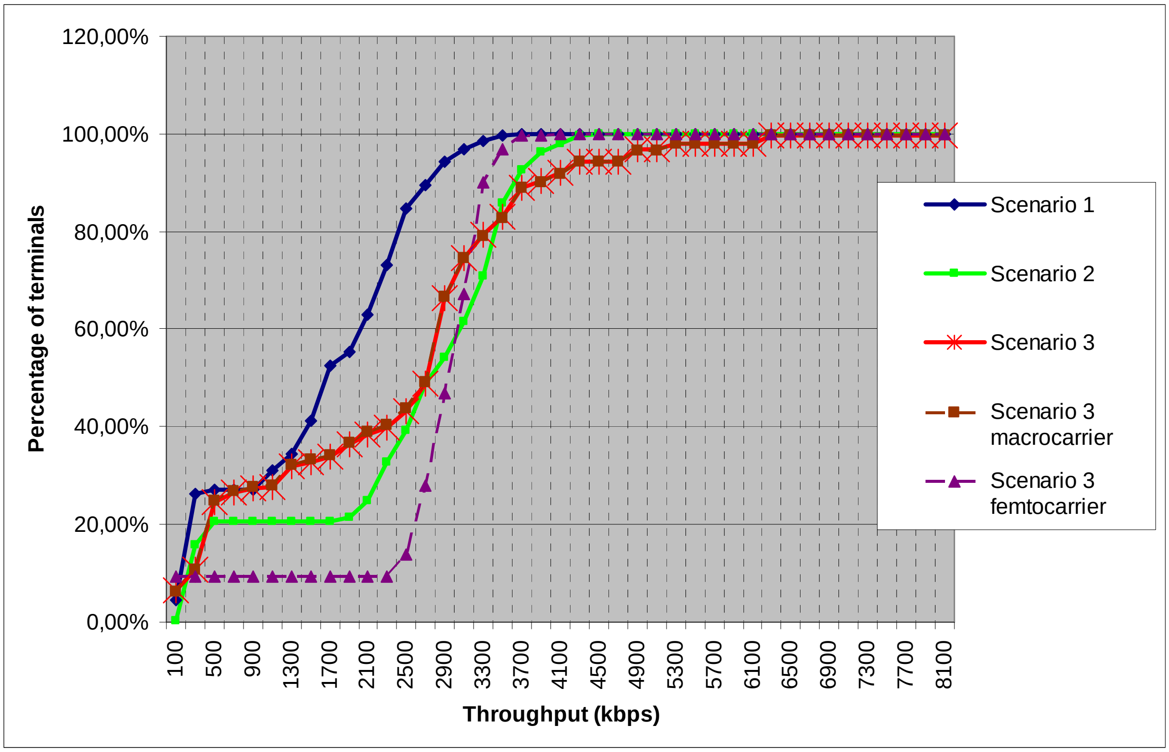


Figure 24. HSDPA cell service rate (loaded) CDF

7.5 Total network throughput

To examine the additional capacity offered by femtocells on the operator's point of view, the total throughputs in the network were examined. Reports containing cell and service specific throughput information were exported from ASSET, and from those reports total amounts for all macrocells and femtocells were summed.

A decision was made to substantially increase the amount of traffic in the network to see how much more throughput can be achieved and also to add users near the femtocells without altering the traffic distribution. Total throughputs in all three scenarios at different terminal amounts are shown in Figure 25.

The scenarios 2 and 3, with femtocell service, reach their maximum total throughputs at around 12000 total terminals. While the increased terminal amounts are raising the total throughputs and we can see the total available capacity offered by the femtocells, the terminals connected to macrocells are experiencing high failure rates in all scenarios. The fact that the femtocells do not offer service everywhere and that the traffic distribution stays unaltered, creates a situation, where we need to adjust the simulation parameters so that failure rates become high, to see the total capacity available.

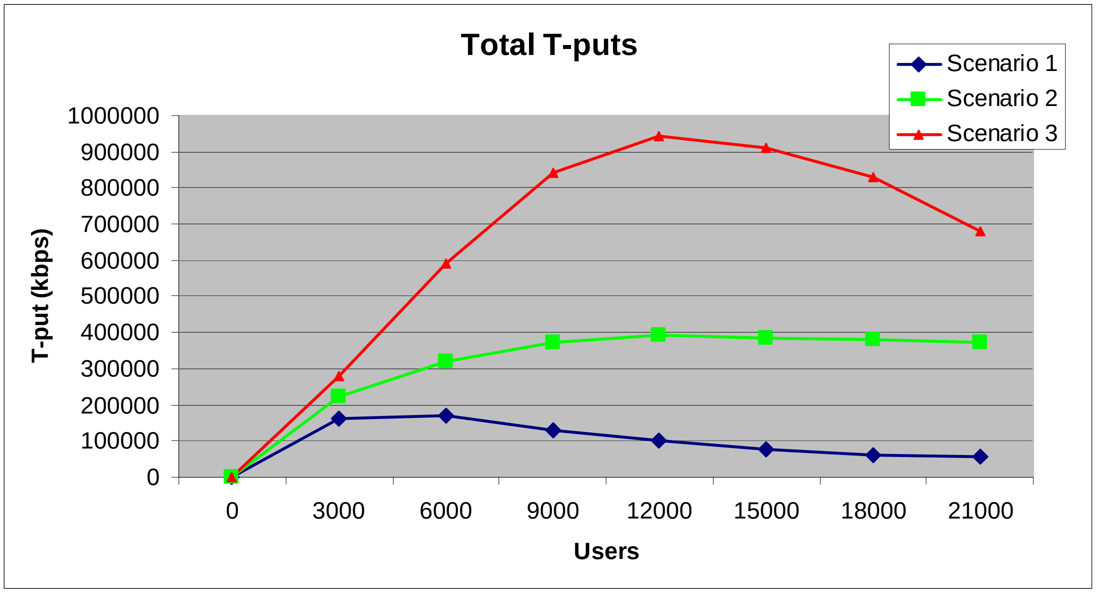


Figure 25. Total network throughputs over traffic

To examine the different scenarios more closely, total throughputs are plotted by service. The results are presented in Figure 26, Figure 27 and Figure 28. To clarify the plots, the services have been grouped to two groups, Data and Voice. Actual services belonging to data services are the two HSDPA services and the two PS Release 99 UMTS services. The only voice service CS 12,2kbps Voice Outdoor.

In scenario 1, the total throughput peaks at around 6000 users when more terminals are added to the simulation voice services are starting to gradually dominate. This can be seen in Figure 26.

Figure 27 and Figure 28 show how the macrocell service behaves roughly the same way in spite of the femtocells. Closer look at the numeric data reveals that while the macrocell service peaks at around 158 Mbps at 6000 total terminals in scenarios 1 and 2, the peak is at 174 Mbps at 9000 total terminals in scenario 3. Thus, the femtocells on dedicated carrier improve also the macrolayer capacity.

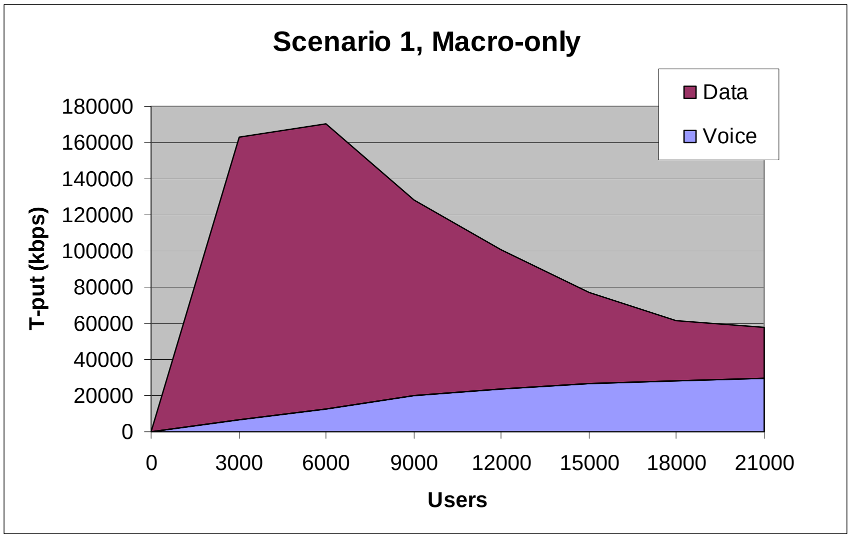


Figure 26. Scenario 1, throughput by service

The femtolayer total throughputs reach their peaks at around 12000 total terminals the dedicated carrier approach seems to be twice as efficient as the co-channel. Peak throughputs are 207 Mbps and 846 Mbps for the femtocells only for co-channel and dedicated carrier scenarios, respectively. Total rates, with macrolayer included, being 342 Mbps and 943 Mbps.

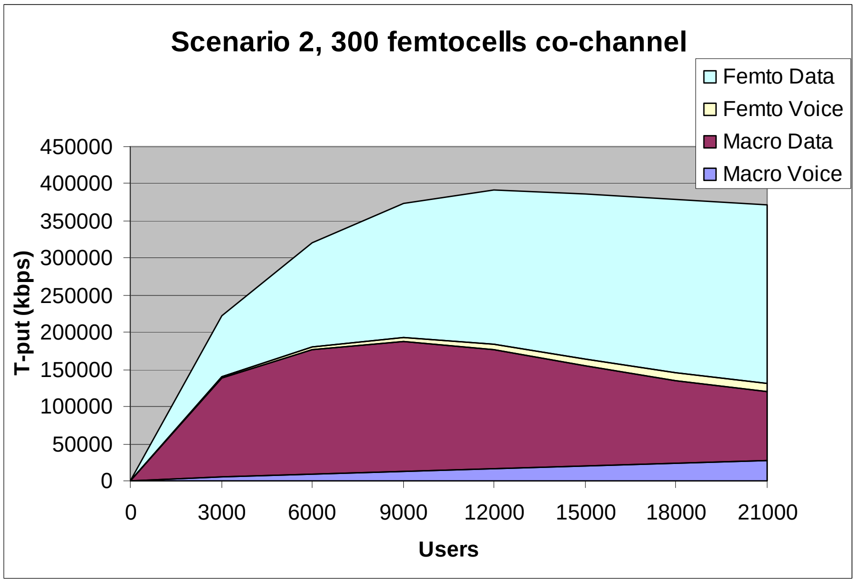


Figure 27. Scenario 2, throughput by service

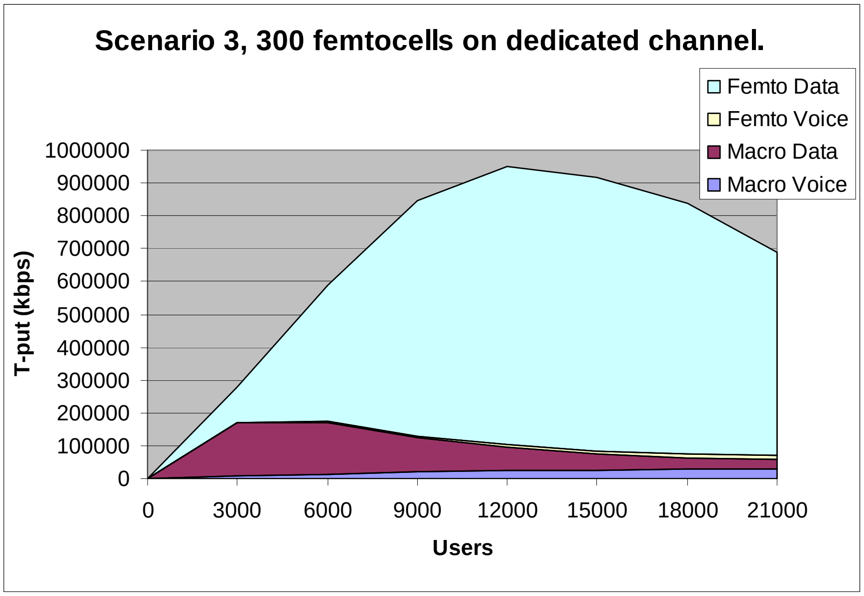


Figure 28. Scenario 3, throughput by service

7.6 Chapter summary

In Chapter 7, the simulation results from the three scenarios of the case were presented. In Section 7.1, we presented the network coverage with and without the femtocells. It was noted how implementing femtocell service will improve coverage. However, a single femtocell only increases the coverage in its close proximity, thus a large number of femtocells is needed to truly have an effect on the network coverage.

Next, in Section 7.2 the HSDPA SINR in all three scenarios was shown. The percentage of area with levels of high SINR is substantially increased when femtocells are deployed, especially on dedicated carrier. The HSDPA achievable bearer, related very closely to SINR values, was presented in Section 7.3. The achievable bearers were plotted by carrier. It was seen how the share of bearer with high throughputs were higher in the femtocell scenarios. The 5040 kbps bearer was achievable in the proximity of all femtocells.

Next we presented the cell service rates for individual users in Section 7.4. The practical maximum service rates were around 30% higher in the femtocell scenarios and the users with lower service rates were experiencing better rates too.

Finally, the total network throughput results were evaluated in Section 7.5. It was noted how the amount traffic had to be raised to a level of high failure rates, before the total capacity, the femtocells could offer, was possible to be seen. Total throughput of 5 times the macrocells-only-scenario was seen with the 300 femtocells on dedicated carrier. For co-channel scenario the throughput was doubled. This means that technically femtocells would be an excellent solution for current UMTS networks.

8 Conclusions

8.1 Progress of the thesis

The original scope of this thesis was to introduce the concept of femtocells and report the current status of the technology and standards, so that possible problems in femtocell deployment to 3G networks could be studied. It was also pointed out that the gained performance is an important issue when femtocell feasibility is evaluated. A key question: "*What will be the effect on the total network performance when using femtocells together with the current network elements*?", was set.

After the thesis subject had been decided, a wide literature study was performed to deeply understand the femtocell concept and to select the important issues that needed to be included in this thesis. It was seen early on, how the numerous previous studies, mostly whitepapers, mainly concentrated on the femtocell business aspects and the few more technical studies were very theoretical. There was a clear need for some simulations in an environment closer to live network planning.

After the literature study was done, the femtocells were implemented to the Aircom ASSET planning tool and simulator through a relatively long process of trial and error. One by one, the problems were solved and the final work flow for configuring the simulations, presented in this thesis, was set.

The study and research work done not only created this thesis paper to document the work done, but also a great amount of information and expertise on femtocells, and on mobile telecommunication networks in general, was gained during the process.

8.2 Key findings

In this thesis, the concept of femtocells was introduced. An overview of the main challenges was presented to the reader. The standards and architectural overview of 3rd Generation Partnership Project's (3GPP) femtocell solution Home NodeB (HNB) were presented. It was shown that the standard and the key technology elements are ready for vendors and operators to go forward with pilot projects and large scale UMTS femtocell rollouts, if so decided.

Studies by the 3GPP and the Femto Forum were evaluated to present the most important interference scenarios. The documents show that in certain situations femtocells operating on co-channel with the macro layer can create holes to the macro network coverage. However, there are mitigation techniques, such as using open access to all users of the operator in co-channel operation.

Mobility scenarios will as well need special attention. While everything needed for full implementation is specified it, is very hard to predict the possible problems in handovers and cell reselection without piloting. In addition, a lot depends on the delay and jitter on the backhaul connection. These things will need further study and careful planning.

The performance of the WCDMA air interface was examined in a theoretical study and it was shown how the smaller cell sizes and deployment of indoor basestations clearly increase the total network capacity. The increase of capacity was further analyzed by simulations.

The simulations investigated the coverage and capacity comparing three different scenarios. A network with only the macro layer enabled and both macro and femtocells on co-channel and on dedicated carriers. The femtocells offered more coverage and capacity in all scenarios. The total network capacity was doubled in the co-channel scenario and increased up to 5 times the macro capacity when the a dedicated carrier was used.

The biggest problems in 3G femtocell deployment will most likely be in the co-operation between the mobile operator and fixed line internet service provider. Even through the technology is designed to operate over a Best-Effort-type backhaul connection, bad quality of service on the connection can seriously impact to the additional benefits experienced by the customers. The added air interface capacity is very promising and it is not likely to be a showstopper for rollouts.

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Appendix A – Services and bearers

HSDPA Cat10, 384UL	**Activity factor**	**UMTS Codes**	**HSDPA Codes**
Downlink			
HSDPA_TC10_0120_kbps	6,25 %	17	1
HSDPA_TC10_0240_kbps	6,25 %	17	1
HSDPA_TC10_0320_kbps	6,25 %	33	2
HSDPA_TC10_0480_kbps	6,25 %	33	2
HSDPA_TC10_0720_kbps	6,25 %	49	3
HSDPA_TC10_1200_kbps	6,25 %	65	4
HSDPA_TC10_1800_kbps	6,25 %	81	5
HSDPA_TC10_2400_kbps	6,25 %	81	5
HSDPA_TC10_2880_kbps	6,25 %	81	5
HSDPA_TC10_3600_kbps	6,25 %	81	5
HSDPA_TC10_5040_kbps	6,25 %	113	7
HSDPA_TC10_7200_kbps	6,25 %	161	10
HSDPA_TC10_10800_kbps	6,25 %	241	15
Uplink			
PS 384kbps UL	2,53 %	N/A	N/A

HSDPA Cat10, 64UL	**Activity factor**	**UMTS Codes**	**HSDPA Codes**
Downlink bearers			
HSDPA_TC10_0120_kbps	6,25 %	17	1
HSDPA_TC10_0240_kbps	6,25 %	17	1
HSDPA_TC10_0320_kbps	6,25 %	33	2
HSDPA_TC10_0480_kbps	6,25 %	33	2
HSDPA_TC10_0720_kbps	6,25 %	49	3
HSDPA_TC10_1200_kbps	6,25 %	65	4
HSDPA_TC10_1800_kbps	6,25 %	81	5
HSDPA_TC10_2400_kbps	6,25 %	81	5
HSDPA_TC10_2880_kbps	6,25 %	81	5
HSDPA_TC10_3600_kbps	6,25 %	81	5
HSDPA_TC10_5040_kbps	6,25 %	113	7
HSDPA_TC10_7200_kbps	6,25 %	161	10
HSDPA_TC10_10800_kbps	6,25 %	241	15
Uplink bearers			
PS 64kbps UL	13,50 %	N/A	N/A

PS 384kbps web browsing data	**Activity factor**	**UMTS Codes**	**HSDPA Codes**
Downlink			
DL PS data 384 kbps	4,57 %	32	N/A
DL PS data 128 kbps	12,37 %	16	N/A
DL PS data 64 kbps	21,59 %	8	N/A
Uplink			
UL PS data 64kbps	6,69 %	N/A	N/A

PS 64kbps	**Activity factor**	**UMTS Codes**	**HSDPA Codes**
Downlink			
DL PS data 64 kbps	13,51 %	8	N/A
Uplink			
UL PS data 64 kbps	13,51 %	N/A	N/A

CS 12.2 kbps Voice Outdoor	**Activity factor**	**UMTS Codes**	**HSDPA Codes**
Downlink			
DL speech 12,2 kbps	50,00 %	2	N/A
Uplink			
UL speech 12,2 kbps	50,00 %	N/A	N/A

Appendix B – Clutter weights and indoor losses

Clutter type	**Indoor loss (dB)**	**Traffic weigth**
water	0	1
forest	0	10
sparse forest	0	15
half open	0	20
apartment building area	10	20
open	0	20
family house area	8	10
commerce / office area	10	40
building < 8m	12	40
building > 8m	12	45
building > 15m	18	50
building > 23m	21	60