REPUBLIC OF TURKEY
YILDIZ TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

WCDMA RADIO NETWORK PLANNING AND OPTIMIZATION INCLUDING PICOCELL AND FEMTOCELL TECHNOLOGIES

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A thesis submitted by Diby Jeo Raoul AMARA in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** is approved by the committee on 18.09.2013 in Department of Electronics and Communications Engineering,Telecommunications Engineering Program.

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Yıldız Technical University is one of the seven government universities situated in İstanbul besides being the 3rd oldest university of Turkey with its history dating back to 1911.It is regarded as one of the best universities in the country as well. Our university has 10 Faculties, 2 Institutes, the Vocational School of Higher Education, the Vocational School for National Palaces and Historical Buildings, the Vocational School for Foreign Languages and more than 25,000 students.

The Istanbul State Engineering and Architectural Academy and affiliated schools of engineering and the related faculties and departments of the Kocaeli State Engineering and Architecture Academy and the Kocaeli Vocational School were merged to form Yıldız University with decree law no.41 dated 20 June 1982 and Law no. 2809 dated 30 March 1982 which accepted the decree law with changes.

The new university incorporated the departments of Science-Literature and Engineering, the Vocational School in Kocaeli, a Science Institute, a Social Sciences Institute and the Foreign Languages, Atatürk Principles and the History of Revolution, Turkish Language, Physical Education and Fine Arts departments affiliated with the Rectorate.

Yıldız Technical University is one of the seven government universities situated in İstanbul besides being the 3rd oldest university of Turkey with its history dating back to 1911. It is regarded as one of the best universities in the country as well.

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Diby Jeo Raoul AMARA

TABLE OF CONTENTS

Page

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

CHAPTER 7

CHAPTER 8

CHAPTER 9

CHAPTER 10

APPENDIX-A

LIST OF SYMBOLS

$\frac{E_b}{N_0}$	Energy per bit to noise power ratio.
$\frac{1}{g} = L$	The attenuation for UE.
$f_{DL,n}$	The other-over-own cell received power ratio.
g_n	The link gain for UE.
P_{CCH}	Common Channel Power.
P_n	The allocated power to UE number "n"
P_N	The AWGN power.
P_{total}	The total power from the E-Node.
R_n	The user rate.
$\frac{W}{R}$	The UE processing gain.
η_{DL}	The downlink load.
η_{UL}	The uplink load.
1/N	The reuse factor.
d	The distance between transmitter and receiver.
D	The reuse distance.
f	The frequency.
G_R	The receiver antenna gain.
G_T	The transmitter antenna gain.
$H_{CLUTTER}$	The clutter loss.
H_{eff}	The efficient height of the Node B antenna.
H_{mef}	The height of the UE antenna.
K	Amount of duplex channels in a frequency.
K	In-building penetration.
K_1	The constant offset in dB.
K_2	The factor for log (d).
K_3	The multiplying factor for log(d), compensating for gain due to antenna height.
K_4	The multiplying factor for diffraction calculation.
K_5	The Okumura-Hata type of multiplying factor for $\log(H_{eff})\log(d)$.
K_6	The correction factor for the mobile effective antenna height gain.
L	The system loss factor.
Lf	The floor penetration loss factor.
L_n	The path loss, we will consider an average value, L.
M	The number of times the cluster will be replicated to cover a network.
N	The distance power loss coefficient according to the indoor environement.

N	Amount of cluster in a cell.
n	The number of floors between base station and portable terminal.
N	The total amount of UE served by the Node B.
N_{hop}	The hopping slots.
N_{sec}	The amount of sectors.
PG_{dB}	The processing gain in dB scale.
$P_{intercell}$	The intercell noise power level in the uplink or downlink.
$P_{intracell}$	The intracell noise power level in the uplink or downlink.
P_N	The noise power level (AWGN) in the uplink or downlink.
P_n	The power from/to user “n” in considered cell.
P_R	The received power.
P_T	The transmitted power.
R	The cell radius.
R_{max}	The radius of the biggest cell.
R_{min}	The radius of the smallest cell.
S	The total amount of duplex channels in the network.
T	The period of the transmission .
W	The chips rate.
α	The orthogonality factor.
α	The path loss exponent.
λ	The wavelength in meters.
ν	The activity factor for user.

LIST OF ABBREVIATIONS

3GPP	The 3rd Generation Partnership Project
AAS	Active Antenna System
ACS	Adjacent Channel Selectivity
ACS	Auto-Configuration Server
ADSL	Asymmetric Digital Subscriber Line
AICH	Acquisition Indication CHannel
AMC	Adaptive Modulation Coding
AMPS	Advanced Mobile Phone System
APL	Allowable Path Loss
ARQ	Automatic Repeat Request
ATM	Asynchronous Transfer Mode
AUC	Authentication Centre
AWGN	Additive white Gaussian Noise
BCCH	Broadcast Control CHannel
BCH	Broadcast CHannel
BDA	Bi-Directional Amplifiers
BHCA	Busy Hour Call Attempts
BS	Base Station
BSS	Base Station Subsystem
CBS	Cell Broadcast Service
CC	Channelization Code
CCCH	Common Control CHannel
CD/CA-ICH	Collision Detection / Channel Assignment Indicator Channel
CDMA 2000	Code Division Multiple Access 2000
CDMA	Code Division Multiple Access
CI	Cell Identity
CN	Core Network
CPCH	Common Packet CHannel
CPE	Customer Premises Equipment
CPICH	Common PIlot CHannel
CPICH-RSCP	Common PIlot CHannel Received Signal Code Power
CS	Circuit Switched
CSCF	Call Session Control Function
CSG	Closed Subscriber Group
CSICH	CPCH Status Indication Channel

CTCH	Common Traffic CHannel
D-AMPS	Digital Advanced Mobile Phone Service
DAS	Distributed Antenna Systems
DCCH	Dedicated Control CHannel
DCH	Dedicated CHannel
DCS 1800	Digital Cellular System 1800
DECT	Digital Enhanced Cordless Telecommunications
DPCCH	Dedicated Physical Control CHannel
DPCH	Dedicated Physical CHannels
DPDCH	Dedicated Physical Data CHannel
DSCH	Downlink Shared CHannel
DSL	Digital Subscriber Line
DTCH	Dedicated Traffic CHannel
DVB-H	Digital Video Broadcast - Handheld
DVB-H	Digital Video Broadcasting - Handheld
E-CSCF	Emergency - Call Session Control Function
E-DCH	Enhanced Dedicated CHannel
EDGE	Enhanced Data rates for GSM Evolution
EIRP	Equivalent Isotropic Radiated Power
E-UTRA	Evolved Universal Terrestrial Radio Access
EVDO HRPD	EVolution-Data Optimized High Rate Packet Data
EVDO	EVolution-Data Optimized
FACH	Forward Access Channel
FAP	Femto Access Point
FDD	Frequency Division Duplex
FDD	Frequency Division Duplexing
FDMA	Frequency Division Multiple Access
FDMA	Frequency Divison Multiple Access
FEC	Forward Error Correction
FUE	Femtocell User Equipment
GERAN	GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GIS	Geographic Information Systems
GMSC	Gateway Mobile-services Switching Centre
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
GSM850	Global System for Mobile Communication 850
GSM900	Global System for Mobile Communication 850
GWCN	GateWay Core Network
HARQ	Hybrid Automatic Repeat Request
HLR	Home Location Register
HMS	Home Node B Management System
HNB	Home Node B
HNBAP	Home Node B Application Protocol
HNB-GW	Home Node B Gateway
HPSK	Hybrid Phase Shift Keying
HSDPA	High Speed Downlink Packet Access
HS-DPCCH	Uplink High-Speed Dedicated Physical Control Channel
HS-DSCH	High Speed Downlink Shared Channel
HSPA	High Speed Packet Access

HSPA+	Evolved High Speed Packet Access
HSS	Home Subscriber Server
HS-SCCH	High-Speed Shared Control CHannel
HSUPA	High Speed Uplink Packet Access
HT	Hilly Terrain
HUE	Home Node B User Equipment
I-CSCF	Interrogating CSCF
IFU	Interface Unit
IMS	IM Subsystem
IMS	Internet Protocol Multimedia Subsystem
IMT 2000	International Mobile Telecommunications 2000
IP	Internet Protocol
ITU	International Telecommunication Union
KPI	Key Performance Indicators
LAC	Location Area Code
L-GW	Local Gateway
LIPA	Local IP Access
LTE	Long Term Evolution
MAC	Medium Access Control
MBMS	Multimedia Broadcast Multicast Service
MDT	Minimization of Drive-Tests
ME	Mobile Equipment
MGCF	Media Gateway Control Function
MGW	Media Gateway Function
MIMO	Multiple Input Multiple Output
MOCN	Multi Operator Core Network
MRB	Media Resource Broker
MRF	Multimedia Resource Function
MRFC	Multimedia Resource Function Controller
MRFP	Multimedia Resource Function Processor
MSC	Mobile-services Switching Centre
MT	Mobile Termination
MUE	Macrocell User Equipment
NAS	Non Access Stratum
NF	Noise Figure
NMT	Nordic Mobile Telephone
OFDMA	Orthogonal Frequency-Division Multiple Access
PCCH	Paging Control CHannel
PCCPCH	Primary Common Control Physical CHannel
P-CCPCH	Primary Common Physical CHannel
PCH	Paging CHannel
PCI	Physical Cell Identity
PCPCH	Physical Common Packet CHannel
P-CPICH	Primary Common Pilot CHannel
PCS	Personal Communications Service
PCS1900	Personal Communications Service 1900
P-CSCF	Proxy CSCF
PDH	Plesiochronous Digital Hierarchy
PDSCH	Physical Downlink Shared Channel
PIC	Parallel Interference Cancellation

PICH	Paging Indication Channel
PICH	Paging Indication Channel
PL	Path Loss
PLMN	Public land mobile network
PNB	Pico Node B
PRACH	Physical Random Access Channel
PS	Packet Switched
P-SCH	Primary Synchronisation Channel
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RA	Rural Area
RAC	Routing Area Code
RACH	Random Access CHannel
RAN	Radio Access Network
RF	Radio Frequency
RLC	Radio Link Controller
RNC ID	RNC Identity
RNC	Radio Network Controller
RNS	Radio Network Sub-System
RNS	Radio Network Subsystems
RRC	Radio Resource Control
RRM	Radio Resource Management
RSSI	Received Signal Strength Indicator
RTWP	Receive Total Wideband Power
SAS	Stand-Alone Serving Mobile Location Centre
SC	Scrambling code
SCCPCH	Secondary Common Control Physical CHannel
SCH	Synchronization Channel
S-CSCF	Serving CSCF
SCTP	Stream Control Transmission Protocol
SDH	Synchronous Digital Hierarchy
SF	Spreading Factor
SGSN	Serving GPRS Support Node
SGSN/SGW	Serving GPRS Support Node / Serving Gateway
SINR	Signal to Noise and Interference Ratio
SIPTO	Selected IP Traffic Offload
SIR	Signal to Interference Ratio
SMS	Short Message Service
SNR	Signal to Noise Ratio
SON	Self Organizing/Optimizing Network
SRNS	Serving Radio Network Subsystem
S-SCH	Secondary Synchronisation Channel
TACS	Total Access Communication System
TD – CDMA	Time Division Code Division Multiple Access.
TD – SCDMA	Time Division Synchronous Code Division Multiple Access
TDD	Time Division Duplexing
TDMA	Time Division Multiple Access
TD-SCDMA	Time Division Synchronous Code-Division Multiple-Access
TE	Terminal Equipment

TH-CDMA	Time-Hopping Code Division Multiple Access
TNL	Transport Network Layer
TU	Typical Urban
UE	User Equipment
UMB	Ultra Mobile Broadband
UMTS	Universal Mobile Telecommunication System
USB	Universal Serial Bus
USIM	User Services Identity Module
UTRA	Universal terrestrial radio Access
UTRAN	Universal Terrestrial Radio Access Network
UWC-136	Universal Wireless Communications-136
VLR	Visitor Location Register
WCDMA	Wideband Code Division Multiple Access
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide interoperability for Microwave Access
WMAN	Wireless Metropolitan Area Network

LIST OF FIGURES

Page

LIST OF TABLES

ABSTRACT

WCDMA RADIO NETWORK PLANNING AND OPTIMIZATION INCLUDING PICOCELL AND FEMTOCELL TECHNOLOGIES

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MSc. Thesis

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The advention of new smart mobile devices and the delivery of new high speed services for mobile devices bring about the need for more and more accurate coverage and capacity. For indoor systems, appropriate solutions will be picocell and femtocell that improve both indoor and outdoor capacity.

Picocells are adapted for huge buildings because the mobile operator's engineers install, manage and optimize them from the beginning to the end. On the other hand, femtocells use customer's internet connection as backhaul, are self-configuring, real-time optimizing and do not require a professional for installation.

In this thesis we study the consequence of introducing Pico Node Bs and Femto Access Points on the coverage and capacity of the whole mobile network. We start with an overview and the challenges of wireless cellular networks, in particular UMTS-WCDMA. We study the possible problems of the deployment of Pico Node Bs and Femto Access Points in UMTS-WCDMA network and evaluate the advantages and drawbacks of the particular case of Femto Access Points which are supposed to be randomly installed by the customers.

A simulation that copes with macrocell, picocell and femtocell in heterogeneous fashion is presented. The scenario of macrocell and picocell using same carrier and the scenario of macrocell and femtocell using same carrier are examined.

Keywords: WCDMA, Picocell, Femtocell, planning, optimization

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ÖZET

WCDMA RADYO AĞ PLANLAMA VE OPTİMİZASYONU, PİKOSEL VE FEMTOSEL TEKNOLOJİLERİ DAHİL

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Tez Danışmanı: Yrd. Dr Aktül KAVAS

Yeni akıllı mobil cihazların üretimi ve yeni yüksek hızlı mobil hizmetlerin daha hassas ağ kapsama alanı ve kapasite ihtiyacını getirmektedir. Bina içi sistemler için, pikosel ve femtosel uygun çözüm olacaktır. Bu teknolojiler hem bina içi ve bina dişi alanların kapasitesinin geliştirmek için uygun olacaktır.

Pikosel büyük binalar için uygun olacak çünkü mobil operatörün mühendisleri, başından sonuna kadar onların trafik yükünü yönetebilir. Femtoselin kurulumu için profesyonel mühendis gerektirmez. Femtosel kullanıcının internet bağlantısı kullanarak, kendini yapılandırebilir, gerçek zamanlı optimize edebilir.

Bu tezde piko hücre ve femto hücre acısından kapsama ve kapasite hesabi gerçekleştirilmiştir. Biz kablosuz hücresel ağların genel bir bakış ve zorlukları ile başliyoruz. Aynı anda UMTS-WCDMA'ya özel bir bakış atacağız. Biz Pico baz istasyonu ve femtosel baz istasyonu, UMTS-WCDMA ağına girerken, problemleri incelenip avantajlari ve dezavantajları çikacağız. Ayni anda Femtoselin zorluklarina, onlarin rastgele özelliği nedeniyle ozel bir bakis atacagiz.

Karişik hücreler kullanarak, makro hücre ve piko hücre aynı taşıyıcı kullanarak ve makro hücre ve femto hücre aynı taşıyıcı kullanarak bir simülasyon yapılacaktır.

Anahtar Kelimeler: WCDMA, Pikosel, Femtosel, planlama, optimizasyon

CHAPTER 1

INTRODUCTION

1.1 Literature Review

With the arrival of new smart mobile devices around year 2000, capacity demands of mobile radio networks in telecommunication are increasing year by year. All over the world people are using their phone not only for voice activities but also for high speed services that require a large amount of data with accurate delivery [14]. Expectations are rising and soon the mobile devices will be needed to achieve the same throughput as the computers in fixed networks and internet connections. Many solutions have been proposed, including Picocells and Femtocells which are the main interest of our study topic. However it is a constant remark to see that the numerous previous studies mainly concentrated on Picocells and Femtocell financial-business aspects. The few technical studies were very theoretical presenting mostly the standardization done by 3GPP or proposing their own guidelines [16]. Thus a pratical aproch of a real radio network scenario is necessary to allow the reader to understand the effects of Picocells and Femtocells in a WCDMA network.

1.2 Objective of this Thesis

Coverage and capacity are the most important factor in the radio network. Mobile operators' engineers constantly bring solutions for the best use of the limited wave resources. Distributed Antennas Systems (DAS), repeaters, leaky cables have been used to split big cells into small cells, more close to the end users. These solutions are effective but also expensive, time consuming for installation and reduce the outdoor cell capacity by sharing its base station resources. Very small base stations, Pico Node Bs and Femto Access Points offer a different approach to these problems.

Pico Node Bs and Femto Access Points are cheap, very small complete base stations and their maximum allowed transmit power level is low (around 0,1 Watts). For indoor system, when Pico Node Bs can be managed and optimized from the beginning to the end by radio network engineers, the real challenge for Femto Access Points will be a real-time optimization of the area it covers through Self Organizing Network technology (SON). Due to the specific environement where is deployed each radio network, it should be noted that self-optimization at Femto Access Points' level does not fully optimize the intracell's problems to enhance end user-perceived qualities. Indeed the optimization should take many geographically and end user-specific constraints into account, such as coverage in the public space, transportation network in the area, and the type of subscribers. The assessment depends on the mobile operator's experience, his arbitrary decisions and cannot be precisely formulated; hence the optimization is hard to automate completely.

A key question remain: "*What will be the effect on the total radio network performance by including Pico Node Bs and/or Femto Access Points in the current UMTS-WCDMA network elements*?"

1.3 Hypothesis

Picocells and Femtocells are attractive solutions to preserve both outdoor and indoor radio network capacity and coverage. Their deployment in WCDMA network can be done in dedicated channel or co-channel fashion with the outdoor sub-network. Dedicated channel is the safest way to deploy these very small cells regarding to interference management but remain costly in term of available frequencies. The co-channel fashion could be the most adopted by radio operators but could also bring new interference management challenges.

This thesis work is organized as following:

- **Chapter 1: Introduction**
- **Chapter 2: Overview of Cellular Systems.**

  We first give an overview of wireless cellular networks' principles; explain their main challenges. Secondly we make an introduction to the main air interface's standards used in Europeans countries and present the ITU IMT – 2000 technologies family.

- **Chapter 3: Universal Mobile Telecommunication System (UMTS-WCDMA).**
  We present the UMTS-WCDMA cellular network standard, member of ITU IMT - 2000 technologies family. We explain its basic architectural elements, their functioning and the interfaces between them. We also make an overview to its evolution to HSPA technology and explain the principles of their cohabitation in the same frequency.

- **Chapter 4: Pico Node B and Femto Access Point technologies.**
  We present the Pico Node B and Femto Access Point, explain their implementation and functioning inside UMTS-WCDMA network. We discuss about some available solutions for very small cells implementation, focusing on the special case of indoor coverage. We present the main differences between these solutions and explain the choice of Pico node B and Femto Access Point.

- **Chapter 5: Pico Node B and Femto Access Point technologies in radio network planning and optimization.**
  We present the main steps when designing a UMTS-WCDMA radio network using Pico Node B and Femto Access Point technologies. We explain the need of Pico Node B and Femto Access Point technologies planning process and then derive the optimization concept from it.

- **Chapter 6: Interference management in the presence of Pico Node B and Femto Access Points.**
  We explore the causes of possible interferences between indoor and outdoor layer. We introduce the management of interference in presence of picocells/femtocell and discuss the basic method of isolation between indoor and outdoor layers. A regard is done by presenting different interference scenarios in the presence of random Femto Access Points.

- **Chapter 7: Radio network performance in the presence of picocell and femtocell.**
  We, through a theoretical analysis study the benefit (in term of capacity) of including picocells and femtocells to the UMTS-WCDMA radio network.

We evaluate the whole system performance when the indoor users are served by outdoor Node B, precise its disadvantage to understand the importance of Pico Node Bs or Femto Access Points deployment.

- **Chapter 8: Picocells and Femtocells planning and optimization tool: Mentum Planet.**

  We will present Mentum Planet, a wireless network planning and optimization software developed by Mentum S.A. We explain its main features and its particularity in planning and optimizing UMTS-WCDMA picocells and femtocells radio network.

- **Chapter 9: Simulation.**

  We, through a simulation done with Mentum Planet 5.5 analyse the benefit (in term of capacity) of including picocells and femtocells to the UMTS-WCDMA's radio network.

- **Chapter 10: Results and Discutions.**

  We make a conclusion with the main result of our work.

CHAPTER 2

OVERVIEW OF CELLULAR SYSTEMS

The first modern transmissions through radio waves were accomplished with high masts that covered large areas with limited capacity. These systems were designed for cars with roof-top antennas and did not present the need of handover ability between the mats. The lack of the first systems permitted the concept of cellular system which was first developed by AT&T/Bell Laboratories. Indeed a huge popularity of "using mobile devices" started to enter into people daily life and the idea was born that the network coverage area needed to be divided into smaller cells.

In this chapter we present the concept of cellular system and briefly describe ITU IMT - 2000 technologies family (**I**nternational **T**elecommunication **U**nion - **I**nternational **M**obile **T**elecommunications - 2000).

2.1 Cellular systems

2.1.1 Cellular systems principles

A cellular network is a radio network shared over land areas called cells. Each cell is served by at least one fixed-location transceiver known as a cell site or base station. A cellular system depicts an area totally covered by radio, without any gaps. Any geographic shape will have gaps in coverage, but the hexagonal shape lets us visualize more neatly, how the system is laid out, allowing many possibilities like frequency re-use plan. The terms "cell" depict a covered area when the base station is said "cell site". In cellular system the base station are in the middle of the cell in order to cover the different sectors. A sector is the result of a cell splitting. In general, a cell is split into 3 or 6 sectors [1].

In the following figure, a cell is depicted by the hexagone form. The cell in the middle is divided into 3 sectors. The base sation is situated in the center of the cell and its antenas are directed to the 3 sectors. For a purpose of good frequencies management, adjacent cells are grouped in cluster. The cluster is replicated over the whole coverage area. A typical example of cluster can be formed with 4, 7 or 12 cells.

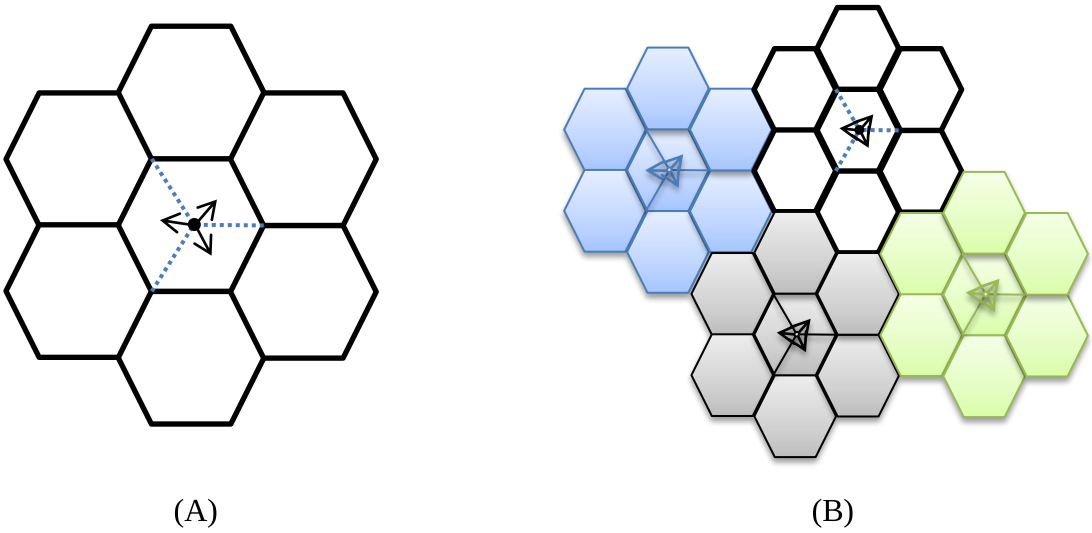


Figure 2.1 (A) The cell concept in cellular network.
(B) A cellular network with a cluster size, N equal to7.

Since the geographical area is divided into several cells, it appears a necessity of interference management between cells and mobile equipments. To allow good mobility and less interferences between cells and mobile equipments, each cell is allocated a number of (***k***) duplex channels to create an independant service area. The total amout of duplex channels, (***S***), available in the autorised frequency band is divided among the (***N***) cells of the cluster. Thus the total number of duplex channels used to covert the whole network can be considered as a measure of capacity and is claculated as following [1]:

$$Total\ number\ of\ duplex\ channels = M \times k \times N = M \times S \qquad (2.1)$$

(***M***) is the number of times the cluster will be replicated.

From this equation, the capacity of a cellular system is proportional to the factor (***N***).

By asuming that the cell size remain constant, a big value for (***N***) will mean a small value for (***M***) and (***k***) duplex channels in each cell. That will imply a small capacity of the whole cellular network. A small value for (***N ***) mean a big value for (***M***) and (***k***) duplex channels in each cell. That will imply more capacity in the whole cellular network. The value for (***N***) is a function of how much interference a mobile equipment or cell's base station can tolerate while maintainning a sufficient quality of communication. Indeed a large cluster size (large value for ***N***) indicates that the ratio between cell radius and the distance between co-channel cells is large, when a small cluster size (small value for ***N***) indicates that the co-channels cells are located much closer to each other.

In the following figure is depicted channels reuse principle in FDMA (Frequency Divison Multiple Access) and WCDMA (Wideband Code Division Multiple Access).

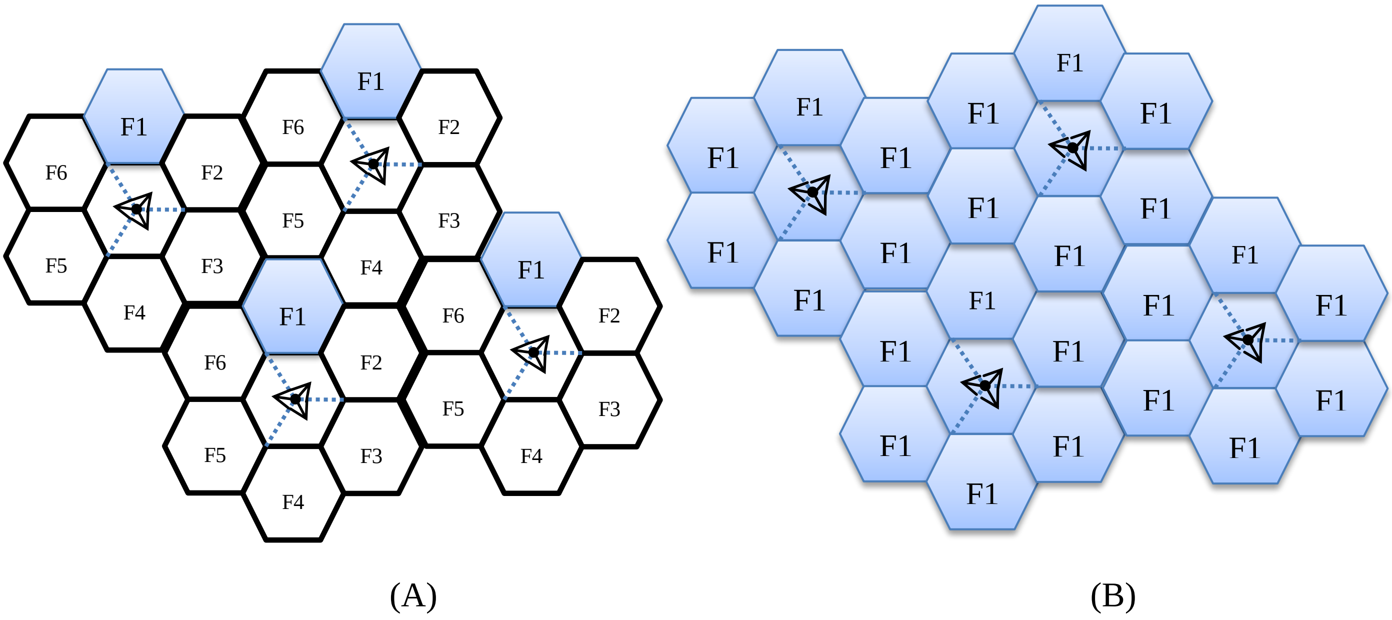


Figure 2.2 (A) Frequency reuse in FDMA (Frequency Division Multiple Access).
(B) Frequency reuse in WCDMA (Wideband Code Division Multiple Access), the same frequency is used for whole cells.

The notation (***1/N***) is said frequency reuse factor and is one of the two main elements that determine the frequency reuse. The second main element determining the frequency reuse is the reuse distance (***D***). The reuse distance, (***D***) is calculated as [1]:

$$D = R \times \sqrt{3 \times N}\text{ , (R) is the cell radius.} \qquad (2.2)$$

The co-channel reuse ratio (***Q***), directly related to the cluster size (***N***) is calculated from the reuse distance (***D***) and cell radius (***R***).

$$Q = \frac{D}{R} = \sqrt{3 \times N} \qquad (2.3)$$

The value of (***Q***) is important to be calculated because it is used to estimate the signal to interference ratio in the cellular system. The clutter size can so be decided by respect to the signal to interference ratio in order to reduce interferences between co-channel cells. When the interfering base stations are equidistant from the considered base station equal to the distance (***D***), the signal to interference ration can be estimated as following [1]:

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{Q^n}{i_0} = \frac{(\sqrt{3 \times N})^n}{i_0} \qquad (2.4)$$

(***n***) is the path loss exponent and ($\boldsymbol{i_o}$) is the number of co-channel interfering cells.

For the mobile equipment, the interference management is done by power controlling. The power levels transmitted by every mobile equipment are under constant control by the serving base station. This control is done to ensure that each mobile equipment transmits the smallest power necessary to maintain a good quality of communication with the base station.

The base station power is also set considering the possible overlap between adjacent cells or possible hole in the network. Cell overlap produce situation where the mobile equipment could be served by two or more base stations. Coverage holes produces the situation where the mobile equipment could not receive signal from the base station. To ensure roaming within the cellular network, handovers between cells are required. Handover is a feature of cellular system that allows a mobile equipment to move its radio connection from one channel to a new one. The new channel could belong to the same base station or to a new base station. Handover function involves the identification of the new channel and the transfer of control signals, voice and/or data signal to this new one. Handover functions required sophisticated measuring tasks and algorithms, increasing the complexity of the network.

2.1.2 Categories of cells

The 3GPP (The 3rd Generation Partnership Project) defined a number of different channel models based on the environment and speed of the UE (User Equipment) [2]. The environments can be:

- Typical Urban (TU),
- Rural Area (RA),
- Hilly Terrain (HT).

Table 2.1 Default mobile speeds for the channel models [2]

Channel model	**Mobile speed**
Typical Urban (TU)	3 Km / h
	50 Km / h
	120 Km / h
Rural Area (RA)	120 Km / h
	250 Km / h
Hilly Terrain (HT)	120 Km / h

Table 2.2 Preliminary environments identified by COST 259 [2]

	Macrocell	**Microcell**	**Picocell**
Channel Model	Typical Urban	Street, canyons	Tunnel / Corridor
	Bad Urban	Open places	Factory
	Rural Area	Tunnels	Office / Residencial Home
	Hilly Terrain	Street crossings	Open Lounge

Table 2.3 An example for WCDMA cell coverage [3]

	Antenna height	**Cell radius**
Rural cells	30 meters from the earth	8 Km
Macrocells	3 meters above the roof	2 Km
Microcells	5 meters from the earth	50 m to 1Km
Dense urban microcell	3 meters (below average roof-top level)	50 m to 500 m
Picocells	Inside buildings	Up to 50 m

*Because of the high frequencies and the importance of the traffic, the coverage for a typical WCDMA cell will be smal and therefore the number of Node B will be higher.

2.1.3 Influence of environment

Human made environment affect any transmitted wireless signal by creating many reflected signals. Propagation models are needed to predict and estimate the behavior of radio waves. Those models are divided into empirical, semi-empirical and deterministic models. Empirical models are developed based on large collections of data collected for a specific scenario. Semi-empirical models are developed with the same way like empirical model but taking strongly into account physical phenomena like reflection, diffraction and scattering. Deterministic model is based in site-specific geographical information. It requires ray tracing, ray launching methods and very important computational effort.

2.1.3.1 Free space loss environment

When there are no obstacles between the transmitter and the receiver, the propagation environment is known as free space loss environment and the power at the reception ($\boldsymbol{P_R}$) can be calculated from Friis formula [1].

$$P_R = P_T G_T G_R \times \frac{\lambda^2}{(4\pi)^2 d^2 L} \tag{2.5}$$

- ($\boldsymbol{P_T}$) is the transmitted power,
- ($\boldsymbol{G_T}$) is the transmitter antenna gain,
- ($\boldsymbol{G_R}$) is the receiver antenna gain,

- (***d***) is the distance between transmitter and receiver,
- ($\boldsymbol{\lambda}$) is the wavelength in meters,
- (***L***) is the system loss factor (not related to propagation, $L \geq 1$)

2.1.3.2 Physical effect on radio waves

For any device's antenna which is not in line of sight transmission, the total received signal is equal to the sum of the reflected, diffracted and scattered wave.

Reflection: When a radio wave propagating in one medium arrives at an obstacle, one part (the refracted part) will pass through this obstacle depending on the physical coefficients of the material. The second part will be reflected from the material to its initial medium.

Diffraction: When a radio wave propagating in one medium encounters an obstacle, many secondary waves in various directions depending of the shape of this obstacle could be produce and send to the initial medium.

Scattering: Scattering happen when a radio wave, by meeting an obstacle will produce many smaller rays corresponding to numerous reflections, diffused in all directions in its initial medium. This phenomena is due to the irregularities of the obstacle's surface and its roughness.

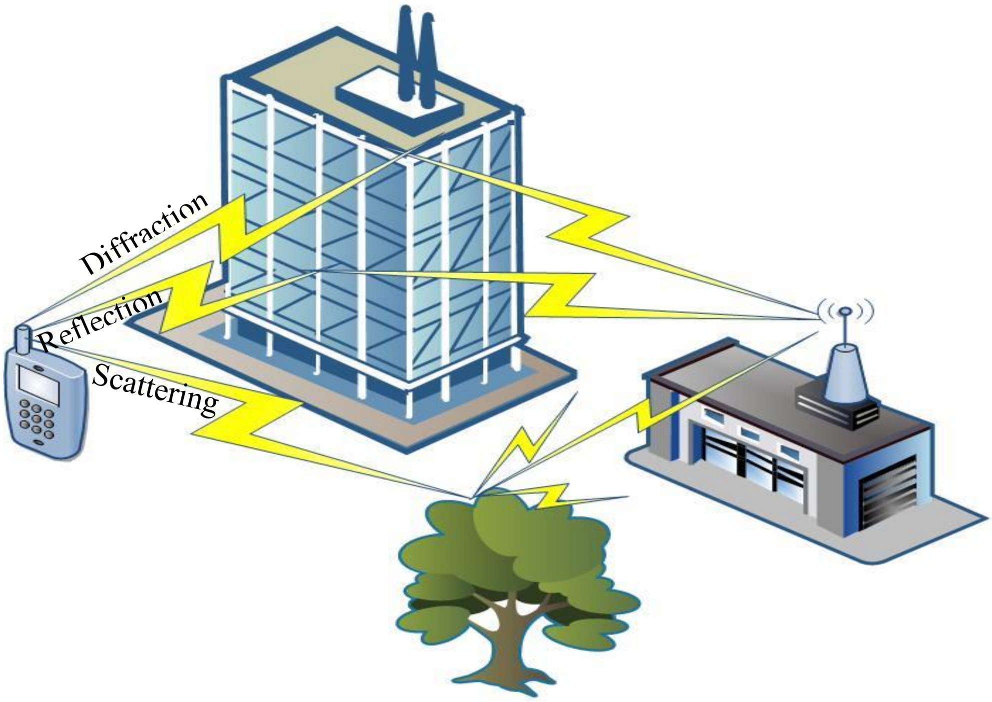


Figure 2.3 Multipath propagation environment.

2.1.3.3 Fading

Fading is used to describe the rapid change of the amplitude of a radio signal over a short period of time or travel distance.

It is caused by the reception of two or many versions of the transmitted signal at the receiver's antenna. These versions of the transmitted signal can be different in amplitude, phase and arrival time according to the distribution, the intensity, the bandwidth and the propagation time of the original signal. There are four different types of fading, flat fading, frequency selective fading, fast fading and slow fading [1].

Flat fading: flat fading happen when the coherence bandwidth of the radio channel is greater than the bandwidth of the transmitted signal. All frequency components of the transmitted signal will experience the same magnitude of fading.

Frequency selective fading: frequency selective fading happen when the coherence bandwidth of the radio channel is smaller than the bandwidth of the transmitted signal. Therefore, the radio channel operates a "frequency selection" on the transmitted signal.

Fast fading: fast fading happen when the coherence time of the radio channel is smaller than the symbol period of the transmitted signal. It results to a fast change of the signal amplitude over a short interval of time. It is based on the motion between the transmitter and the receiver.

Slow fading: Slow fading happen when the radio channel impulses response change at a rate much slower than the transmitted baseband signal. It results to a slowly change of the transmitted signal amplitude in the time. It is mainly caused by the obstacles like elevation, buildings and trees in the signal propagation path.

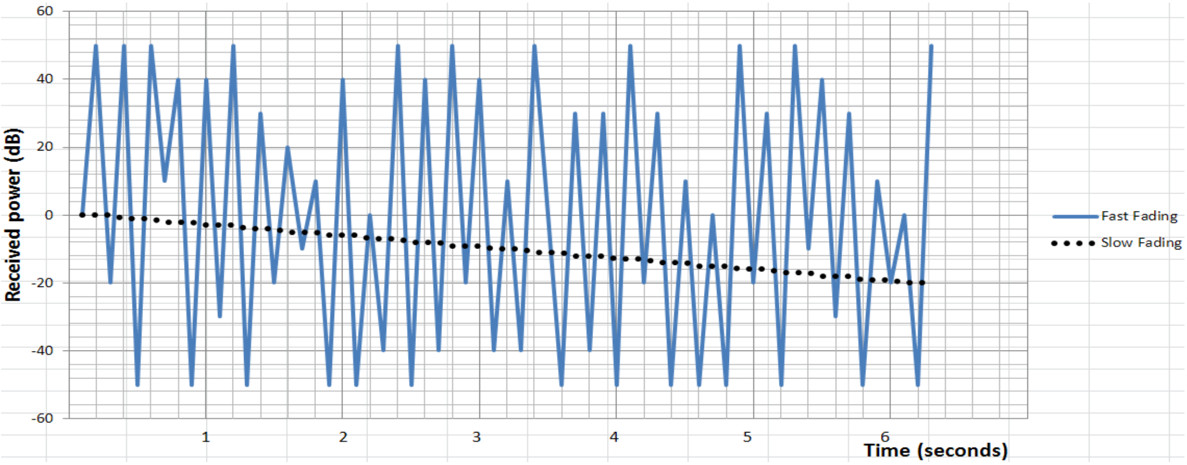


Figure 2.4 Multipath signal having fading.

(This figure is just an illustration to show the concept, it is not based on real data)

1.1.4 Air interface standards

The most used standards for a cellular network were/are [4]:

- For the first generation: NMT, AMPS, TACS;
- For the second generation: D-AMPS, PCS, GSM;
- For the third generation: CDMA 2000, and UMTS (WCDMA).

The first generation, usually called analog network were only able to support one user in one radio channel. This one user keeps the radio channel busy preventing other users to get it till he/she finish and release the channel.

The main similarity between those systems was the use of FDMA (Frequency Division Multiple Access) which divide the available spectrum into physical channels of equal bandwidth.

The second generation or the digital systems came with the possibility to carry many users in the same radio channel by altering the transmission of their information using time slots: TDMA (Time Division Multiple Access).

For the third systems the method was to use “codes” to separate the users in the same channel, CDMA (Code Division Multiple Access). Second and third generation systems perform a good mobility of users in the network, allowing the rise of more and more data exchange in the mobile network.

Table 2.4 Air interface standards mostly used in Europeens countries [4]

Features	**NMT** (first generation)	**GSM** (second generation)	**UMTS** (third generation)
Year of first use	1981	1991	2001
Technology	FDMA	TDMA and FDMA	WCDMA
Encoding	Analog	Digital	Digital
Frequency band	450 MHz for NMT-450 900 MHz for NMT-900	900 MHz for GSM 900 1.8 GHz for GSM 1800	2 GHz
Carrier	30 kHz	200 kHz	5 MHz
Data rate	600 to 1200 bit/s	Up to 9.6 Kbps	Up to 3,6 Mbps
Simultaneous voice & data services	No	Yes, with GPRS class A	Yes

1.2 ITU IMT 2000 technologies family

IMT-2000 (**I**nternational **M**obile **T**elecommunications-2000) is a set of recommendations set up by ITU (**I**nternational **T**elecommunication **U**nion) in years 2000 for third generation mobile system. A mobile telecommunication technology requires to meet IMT - 2000 technical specifications to belong to its family.

The selected spectrum to reach the goals of IMT-2000 is between 400 MHz and 3 GHz. IMT-2000, with a single standard envisages a platform for distributing converged fixed, mobile, satellite, voice, data, Internet and multimedia services. Any technology under IMT-2000 is expected to provide a minimum speed of 2 Mbps for stationary or walking users, and 348 kbps in a moving vehicle [5].

In addition, IMT-2000 has the following key characteristics:

- **Flexibility**: It consists to allow mobile operators to adapt to any national or foreign market and avoiding them to manage a wide range of different interfaces and technologies. IMT-2000 standard accommodates five possible radio interfaces based on three different access technologies (FDMA, TDMA and CDMA).
- **Affordability**: It consists to make the mobile system affordable, in order to encourage their adoption by consumers and operators.
- **Compatibility**: It consists to make IMT-2000 services compatible with existing systems, 2G systems, such as the GSM standard (prevalent in Europe and parts of Asia and Africa).
- **Modular design**: It consists for any IMT-2000 based system to be easily expandable in order to allow for growth in users, coverage areas, and new services, with minimum initial investment.

The following table lists the different technologies approved by ITU as complying with IMT-2000 specifications.

Table 2.5 IMT-2000 terrestrial radio interfaces [6]

Full name	**Common names**	**Duplex mode**
IMT-2000 CDMA Direct Spread (interface No. 1)	UTRA FDD **WCDMA** UMTS **HSPA, HSPA+** E-UTRA FDD (LTE FDD)	**FDD**
IMT-2000 CDMA Multi-Carrier (interface No. 2)	CDMA2000 CDMA2000 1X and 3X CDMA2000 HRPD CDMA2000 1xEV-DV CDMA2000 1xEV-DO EVDOHRPD UMB	FDD and TDD
IMT-2000 CDMA TDD (time-code) (interface No. 3)	UTRA TDD 7.68 Mchip/s UTRA TDD 3.84 Mchip/s UTRA TDD 1.28 Mchip/s (TD-SCDMA) UMTS HSPA, HSPA+ E-UTRA TDD (LTE TDD)	TDD
IMT-2000 TDMA Single-Carrier (interface No. 4)	UWC-136 EDGE	FDD
IMT-2000 FDMA/TDMA (frequency-time) (interface No. 5)	DECT	TDD
IMT-2000 OFDMA TDD WMAN (interface No. 6)	Mobile WiMAX	FDD and TDD

CHAPTER 3

UNIVERSAL MOBILE TELECOMMUNICATION SYSTEM-WIDEBAND CODE DIVISION MULTIPLE ACCESS

(UMTS-WCDMA)

The deployment of mobile network started with the first generation that was refering as analog systems. These system were not supporting a lot of connected users and the main challenges were communication over voice services. Later came the digital systems such as GSM opening the possibilities for data exchanges such as messages, images and many other multimedia services. The high demands of internet applications such as video call, E-mailing and internet via mobile phone brought the International Telecommunication Union (ITU) to define a common name for 3G systems where UMTS-WCDMA came from.

In this chapter we explain the principles of UMTS-WCDMA and present its basic architectural elements and the interfaces between them. We present the evolution of UMTS-WCDMA to HSPA and make an overview of the cohabitation between UMTS-WCDMA and HSDPA.

3.1 UMTS-WCDMA

UMTS is a third generation (3G) standart for cellular network which can use one of the following radio access technologies in its deployement [7]:

- W - CDMA, Wideband Code Division Multiple Acces.
- TD - CDMA, Time Division Code Division Multiple Acces.
- TD - SCDMA, Time Division Synchronous Code Division Multiple Access.

TD-CDMA and TD-SCDMA are not covered by our thesis thesis topic. We will only focus on the deployement with first option, i.e. UMTS - WCDMA.

There are two ways to implement UMTS - WCDMA.

- WCDMA - FDD, Frequency Division Duplexing,
- WCDMA - TDD, Time Division Duplexing.

WCDMA - FDD uses a frequency bands for the uplink and another one for the downlink. Such deployment allows the equipments in the system to transmits and receives in full duplex. WCDMA - TDD uses the same frequency band for the uplink and the downlink. This is possible because the system uses a time slot fashion for alternate the direction of the transmission over time in order to avoid interference. By respect to WCDMA frequencies allocation standards in Turkey where our work is doing, the rest of the thesis work will be done considering WCDMA-FDD.

WCDMA-FDD allows a maximum flow of 3,6Mbps and can be upgrade to HSPA technology (High Speed Packet Access), allowing peak rate of 14,4Mbps. It opens new sophisticated services like video telephony, video conferencing, multiple simultaneous connections and all kind of internet applications.

3.2 UMTS-WCDMA architecture

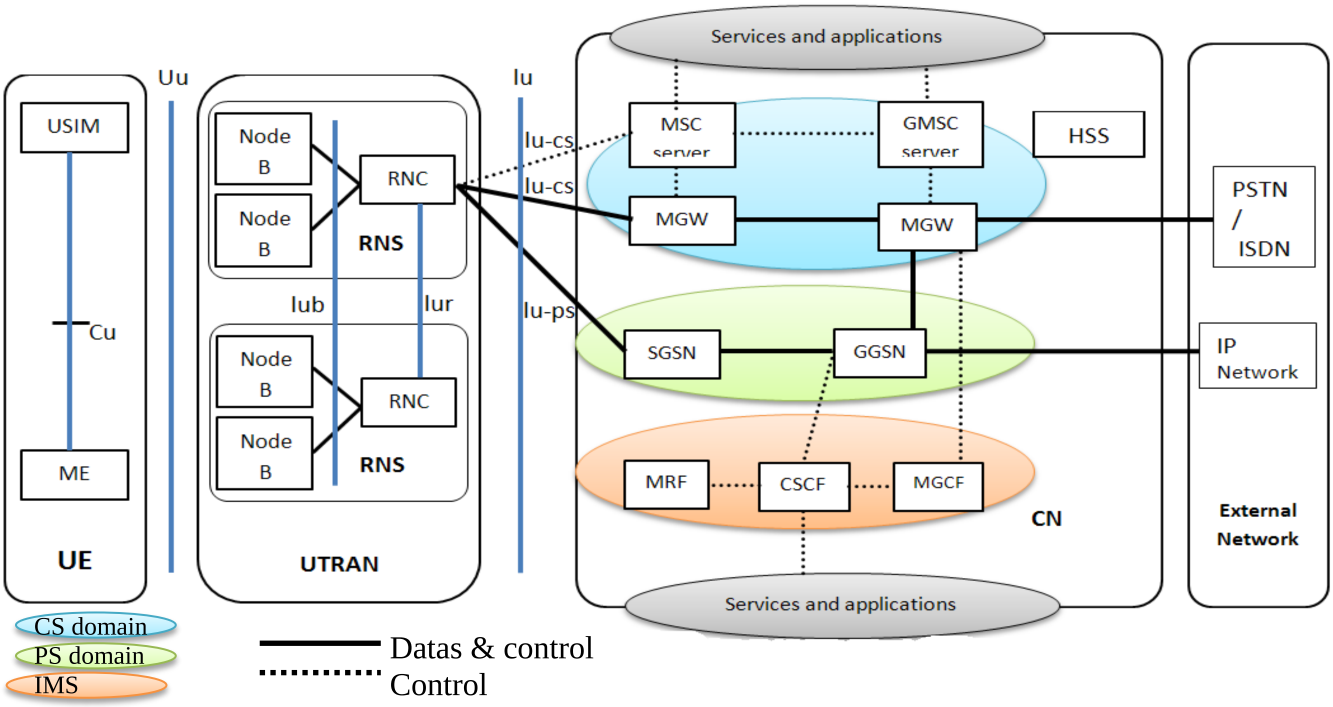


Figure 3.1 High level architecture of UMTS-WCDMA.

UMTS-WCDMA architecture contains three main elements which are: the User Equipment (UE), UMTS Terrestrial RAN (UTRAN) and the Core Network (CN). The figure2.1 depicts in details the three main elements [7].

3.2.1 User Equipment (UE)

The User equipment is the equipment used by the end user to access UMTS-WCDMA services. User equipment has a radio interface to the Node B (interface U_u) and is sub-divided into the Mobile Equipment Domain (ME) and the User Services Identity Module Domain (USIM) [8]. USIM and ME has an eletrical interface C_u.

The UE is mainly responsible of:

- Air interface transmission / reception;
- Modulation / demodulation;
- Identification, authentication, encryption of the exchanged datas;

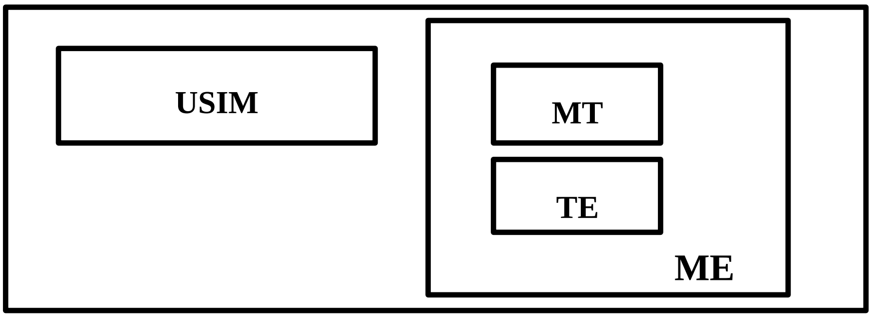


Figure 3.2 Simplified block diagram of user equipment (UE)

The Mobile Equipment (ME) is the radio terminal that performs radio transmission and contains applications. It is sub-divided into two entities:

- Mobile Termination (MT) that performs the radio transmission and related functions
- Terminal Equipment (TE) that contains the end-to-end application. Example of TE, a laptop connected to a mobile phone or to a USB HSPA modem.

USIM is a set of informations required for the identification, authentication, encryption keys and some subscription information of the end user owning and/or using the Mobile Equipment (ME). USIM functions are typically embedded in a stand alone smart card.

3.2.2 UMTS Terrestrial RAN (UTRAN)

The UTRAN consists of a set of Radio Network Subsystems (RNS) connected to the Core Network through the I_u. A Radio Network Subsystems consists of a Radio Network Controller (RNC), one or more Node Bs and optionally one SAS (Stand-Alone Serving Mobile Location Centre). The SAS is optional in UTRAN deployment. It is implemented for particular treatment of UE position [9].

3.2.2.1 Node B

The base station in UMTS, called Node B, is the termination point for UE towards RNC, handling the transmission of one or more cells. It is a physical nodes which perform various functions required to terminate the radio interface and to support the telecommunication services requirements of the User Equipments. A Node B is connected to the RNC through the I_{ub} interface and operate the following main functions [9 , 10]:

- FEC (Forward Error Correction) encoding / decoding of transport channels;
- Measurements and indication to higher layers (e.g. FER, SIR, interference power, transmission power, etc…);
- Macrodiversity distribution/combining and soft handover execution;
- Error detection on transport channels;
- Multiplexing of transport channels and demultiplexing of coded composite transport channels;
- Rate matching;
- Mapping of coded composite transport channels on physical channels;
- Modulation and spreading/demodulation and despreading of physical channels;
- Frequency and time (chip, bit, slot, frame) synchronisation;
- Inner-loop (Close-loop) power control ;
- Power weighting and combining of physical channels;
- Radio Frequency (RF) processing;

The Node B physical components depend on thechnologies used by the different manufacturers and cannot fully be standarized. In the following figure is proposed a block diagram based upon Node B’s main functions.

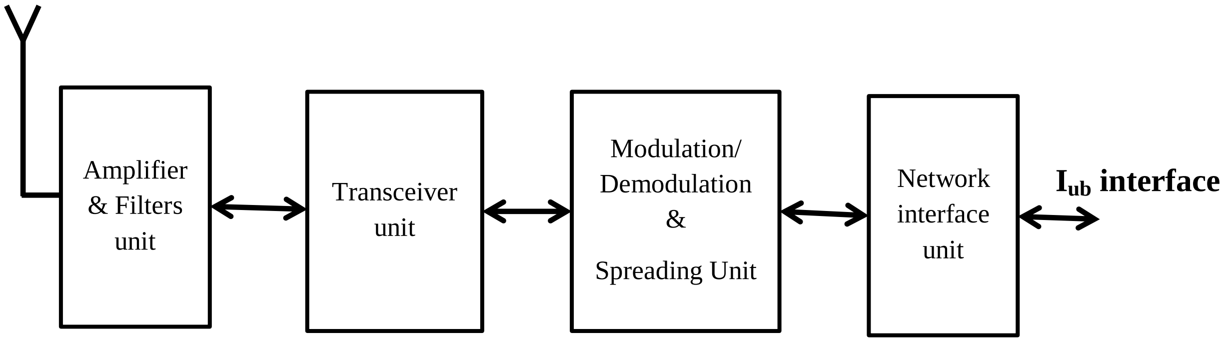


Figure 3.3 Simplified block diagram of WCDMA Node B

Amplifiers and Filters unit: This unit consists of signal amplifiers and antenna filters. The signal is amplified before to be release in the downlink (towards the UE). In the uplink, the filters select the required frequencies from the UE; amplify it before to send it to the transceiver for further processing.

Transceiver unit: The transceiver unit is capable of transmitting and receiving signals, by handling uplink and downlink traffic. It consists of one transmitter and one or more receiver.

Modulation / Demodulation and Spreading unit: This unit is responsible for modulating the signal in the downlink direction and demodulating in the uplink direction. It sum, multiplex the signal, and contains the digital signal processors, responsible for signals coding and decoding.

Network Interface unit: This unit acts as an interface between the Node B and the transmission network or any other network element.

3.2.2.2 Radio Network Controler (RNC)

The RNC is the control point between Node B and the core network. It mainly handles packet switch, circuit switch connections and code allocation. The main functions of RNC are [9]:

- Transfer of end user data.
- Functions related to overall system access control: (Admission Control, Congestion Control)
- System information broadcasting.
- Radio channel ciphering and deciphering.

- Integrity protection.
- Functions related to mobility: (Handover, SRNS (Serving Radio Network Subsystem) relocation, paging support, positioning, GERAN (GSM EDGE Radio Access Network) system information retrieval)
- Enhanced SRNS (Serving Radio Network Subsystem) relocation.
- Functions related to radio resource management and control: (radio resource configuration and operation, Radio environment survey, Combining / splitting control, connection set-up and release, allocation and deallocation of radio bearers, radio protocols function, RF (Radio Frequency) power control, radio channel coding, radio channel decoding, channel coding control, initial (random) access detection and handling, Core Network distribution function for non access stratum messages)
- Synchronisation.
- Functions related to broadcast and multicast services.
- Broadcast / multicast information distribution.
- Broadcast / multicast flow control.
- CBS (Cell Broadcast Service) status reporting.
- Tracing.
- MDT (Minimization of Drive-Tests).
- Volume reporting.
- NAS (Non Access Stratum) node selection.
- RAN (Radio Access Network) information management.
- MBMS (Multimedia Broadcast Multicast Service) provision.
- MBMS Notification.
- MOCN (Multi Operator Core Network) and GWCN (GateWay Core Network) configuration support.
- SIPTO (Selected IP Traffic Offload) at Iu-PS (optional).
- Explicit Congestion Notification

A simplified block diagram of the RNC based on its mains functionalities is given in the following figure [18].

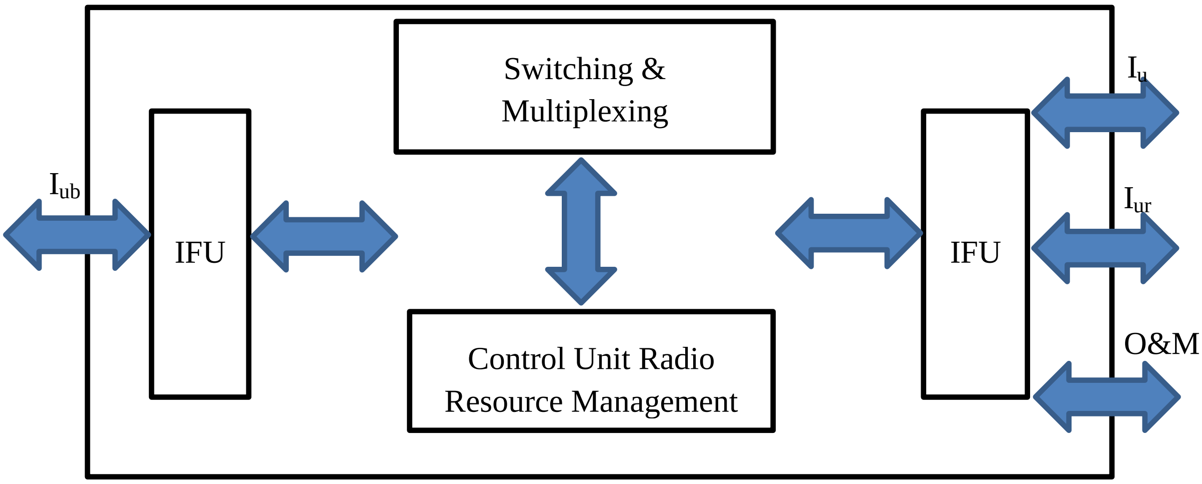


Figure 3.4 Simplified block diagram of Radio Network Controller (RNC).

Interface Unit (IFU): There are mainly two kinds of interface unit, PDH (Plesiochronous Digital Hierarchy) and SDH (Synchronous Digital Hierarchy) that could be configured for I_{ub}, I_{ur} or I_u.

Switching and Multiplexing Unit: The backbone of WCDMA network is formed by Asynchronous Transfer Mode (ATM). The functionalities of the switching unit include providing the required support for the ATM traffic.

Control Unit, Radio Resource Management: The control unit is responsible for radio resource management functions such as handovers, admission control, power control and load control. It is also responsible for the control mechanisms for packet scheduling and location-based services.

3.2.2.3 Core Network (CN)

The Core Network is logically divided into a Circuit Switched (CS) domain, Packet Switched domain (PS) and an Internet Protocol Multimedia Subsystem (IMS) [11].

The CS domain refers to all the components of the Core Network that offer "Circuit Switched type of connection" and all the related signaling to the end User Equipment. A "Circuit Switched type of connection" is a connection to which dedicated network resources are allocated at its establishment and released when it finish [11].

The PS domain refers to all the components of the Core Network that offer "Packet Switched type of connection" and all the related signaling to the end User Equipment.

A “Packet Switched type of connection” transports the user information using autonomous concatenation of bits called packets: each packet can be routed independently from the previous one [11].

The IM Subsystem (IMS) refers to all the components of the Core Network for provision of IP multimedia services comprising audio, video, text, chat, etc., over the PS domain.

In addition to these three main parts, the core network has commons registers which are the Visitor Location Register (VLR) and the Home Location Register (HLR). The VLR is a base of information related to the end user’s past and current location in the UTRAN and his/her subscription profile in the network system. The HLR is the end user’s home system database where is stored the master copy of his/her service profile.

- **Circuit Switched (CS) domain**, [11]

This domain is formed by the Mobile-services Switching Centre (MSC) server, the Gateway Mobile-services Switching Centre (GMSC) and the Media Gateway Function (MGW).

The MSC server containing the VLR is responsible of the management of the call control originated and terminated by an end user. It translates the signaling related to end user into network signaling.

The GMSC server mainly comprises the call control and mobility control parts of a GMSC. The GMSC is the MSC chosen by the mobile operator to route all the call from external network which cannot access directly to the HLR.

The MSC and GMSC servers take care of the control functionalities when the Media Gateway Function (MGW) is the one responsible of the data transportation and network interworking processing like echo cancellation or speech decoding/encoding. One MSC/GMSC server can control multiple MGWs, allowing better scalability of the network when, for example, the data rates increase with new data services.

- **Packet Switched domain (PS)** [11]

This domain is formed by the Serving General Packet Radio Service (GPRS) Support Node (SGSN) and the Gateway GPRS Support Node (GGSN).

The SGSN working with the VLR and HLR store two type of user information needed to originate and terminate packet data transfer: subscription and location information.

The SGSN functionality is similar to that of MSC/VLR but is typically used for Packet-Switched (PS) services.

The GGSN using the same set of information like SGSN connects the Packet-Switched (PS) domain to other external network like internet.

- **IM subsystem (IMS)** [11]

This domain is formed by the Call Session Control Function (CSCF), the Media Gateway Control Function (MGCF) and the Multimedia Resource Function (MRF).

The CSCF has multifunction in the IMS and can act acts as:

- Proxy CSCF (P-CSCF), the first contact point for the end user within the IMS.
- Serving CSCF (S-CSCF), handling the session states in the network.
- Emergency CSCF (E-CSCF), handling certain aspects of emergency sessions such as routing an emergency request to the correct emergency center.
- Interrogating CSCF (I-CSCF); the contact point within an operator's network for all IMS connections coming from external IP network.

The MGCF Handle protocols conversion. It works with the CSCF and circuit switched network entities to manage the routing of connections coming from previous generation of cellular network.

The MRF controls media stream resources or can mix different media streams. It has multifunction and can be split into:

- Multimedia Resource Function Processor (MRFP)
- Multimedia Resource Function Controller (MRFC)
- Media Resource Broker (MRB)

- **The Home Subscriber Server (HSS)** [11]

The HSS is user’s home system master database. A home system may contain one or several HSSs depending on the number of mobile subscribers, on the capacity of the equipment and on the organization of the network. It includes the HLR and the Authentication Centre (AUC). It consists of the following functionalities:

- IP multimedia functionality to provide support to control functions of the IMS.
- The subset of the HLR/AUC functionality required by the PS domain.
- The subset of the HLR/AUC functionality required by the CS domain.

3.2.3 UMTS-WCDMA frequency band

All the cells in UMTS-WCDMA system are operating on the same frequency. They are only separated by the use of different primary scrambling codes.

<table>
<tr><td colspan="4">From 2110 MHz</td><td colspan="5"><i>UMTS-WCDMA, FDD Download Band</i></td><td colspan="3">To 2170 MHz</td></tr>
<tr><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td></tr>
<tr><td colspan="12">↕ <i>There is 190 MHz Duplex distance between download band and upload band</i></td></tr>
<tr><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td><td>5 MHz</td></tr>
<tr><td colspan="4">From 1920 MHz</td><td colspan="5"><i>UMTS-WCDMA, FDD Upload Band</i></td><td colspan="3">To 1980 MHz</td></tr>
</table>

∗ *UMTS-WCDMA uplink and downlink frequency bands for the 12 FDD channels* [7].

3.2.4 UMTS-WCDMA radio technical specifications

The radio network for UMTS-WCDMA is tuned with respect to the environment, the network evolution and the defined strategy of the mobile operator. The following are ITU's recommendation for UMTS-WCDMA in a frequency sharing deployment [6].

Table 3.1 UMTS - WCDMA radio parameters

Parameter	**Value**
Frequency band	WCDMA FDD Uplink: 1920-1980 MHz Downlink: 2010-2170 MHz
Bandwidth	5MHz
Signal bandwidth	3.84 MHz
Chip rate	3,84 Mcps
Power control frequency	Up to 1500 Hz
Access technology	Direct Spread - CDMA (DS-CDMA)
Spreading factor	Uplink: 4 to 256 Downlink: 4 to 512
Data transfert peak	Up to 3.6Mbps

Table 3.2 Macrocell and UE thechnical specifiation for UMTS-WCDMA. Recommendations of ITU [6].

Parameter	**User Equipment**	**Parameter**	**Macrocell**
Transmitter power, dBm (typical)	20	**Transmitter power dBm**	43
Transmitter power, dBm (maximum)	24 or 21	**Antenna gain (dBi/120° sector)**	17
Antenna gain (dBi)	0	**Antenna height (m)**	30
Antenna height (m)	1,5	**Tilt of antenna (degrees down)**	2.5
Data rates Supported	Pedestrian: 384 kbps, Vehicular: 144 kbps, Indoors: 2 Mbps, Up to 42Mbps in downlink and 11,5 Mbps in uplink supported by evolution to HSDPA, HSUPA	**Data rates Supported**	Pedestrian: 384 kbps, Vehicular: 144 kbps, Indoors: 2 Mbps, Up to 42Mbps in downlink and 11,5 Mbps in uplink supported by evolution to HSDPA, HSUPA
Modulation parameters	QPSK, 16QAM	**Modulation parameter**	QPSK, 16QAM, 64QAM
Receiver noise figure, (worst case)	9 dB	**Receiver noise figure (worst case)**	5 dB for macro Node B
Thermal noise in Specified bandwidth	-108 dBm in 3.84 MHz	**Receiver thermal noise level**	-103 dBm in 3.84 MHz for macro Node B
Receiver thermal noise	- 99 dBm in 3.84 MHz	**Receiver bandwidth**	< 5 MHz
Receiver reference sensitivity	-117 dBm in 3.84 MHz	**Receiver reference sensitivity**	–121 dBm for macro Node B –111 dBm for micro Node B
Interference threshold	-105 dBm in 3.84 MHz	**Interference threshold (Node B)**	–109 dBm in 3.84 MHz

3.2.5 UMTS-WCDMA spreading and despreading principle

Every user in dedicated mode get his/her radio signal spreaded by the system before to be transmited. Spreading is applied to the physical channels and consists of two operations, channelisation operation and scrambling operation.

The channelisation operation transforms every data symbol of the end user into a number of chips. This number of chips used to represent every data symbol of the end user is called the Spreading Factor (SF) and is the ratio between the chip rate (constantly 3,84 Mchip/s) and the end user bit rate. It means that more the SF value will be small, more the related user bit rate will be big and vice versa.

The scrambling operation apply a scrambling code to the spread signal. The use of scrambling code make a difference between close Node Bs in the downlink and close User Equipments (UE) in the uplink, thus it limit intracell interference [7].

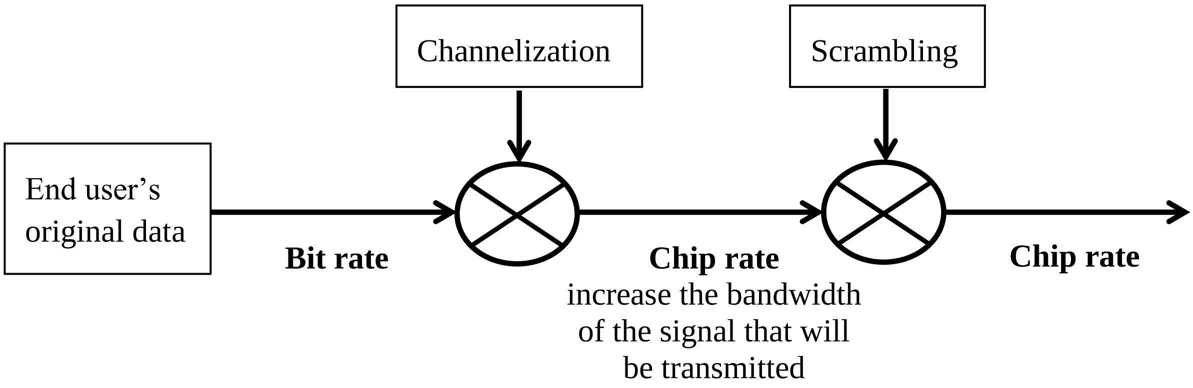


Figure 3.5 Spreading process in UMTS-WCDMA

The spreading code, a sequence of code bits called chips are multiplied by any transmitted bit. The principle is that the end user's information is multiplied by a code which have the higher frequency in UMTS-WCDMA, 3.84Mcps. By doing that, the end user's signal spectrum is spread over the 3.84Mcps carrier and becomes a spread spectrum signal. Finaly it will be the 3.84Mcps that takes up the 5Mhz UMTS-WCDMA radio. By applying the same spreading code like its transmitter, a receiver is able to decode (despread) its usefull signal when the rest are considered like a noise. Any coded signal become orthogonal to the coded signal from other users in the cell.

3.2.6 UMTS-WCDMA radio interfaces challenges

The greatest challenge of UMTS - WCDMA system management is based on its main feature, all the cells in the network are using the same 5Mhz frequency. At any time one end user is separeted from other end users by codes and can receive all communications which are happening in the network. It means that only one coded signal will be usefull for the considered end user when the rest of received signal will become noise.

3.2.6.1 Power control

UMTS-WCDMA radio management is all about noise and power control. Very strict power control is necessary to make sure that all transmitted signals are kept to a target level. There are two main power control operations, the closed loop power control or inner-loop power control and the outer loop power control.

The closed loop power control happen in the uplink and consist of the Node B commanding the User Equipment to readjust its transmitted power by respect to the target SIR. This "***measure–command–react***" cycle is executed at a rate of 1500 times per second (1.5 kHz) [7] for each User Equipment to prevent any power imbalance among all the uplink signals received at the Node B. The same closed loop power control technique is also used in the downlink to provide a marginal amount of additional power to User Equipment at the cell edge.

Outer loop control is typically implemented between the RNC and the Node B to readjust the target SIR. The Node B will tag each uplink data frame from the end user with a frame reliability indicator. This tag will be used by the RNC to evaluate the quality level of the transmission and will command an adjustment of the target SIR value.

3.2.6.2 Softer and soft handover

A Softer handover happen when a User Equipment is moving from ***frequency1*** to ***frequency2*** respectivelly belonging to ***sector1*** and ***sector2*** under the same Node B. In such situation the UE will be served, during its move by two adjacent sectors of the same Node B. The connection between the UE and its served Node B will take place through two air interface channel and will requires the use of two separate codes in the downlink direction.

A soft handover happen when the User Equipment is moving from ***frequency1*** to ***frequency2*** respectivelly belonging to ***sector1*** and ***sector2*** which are also respectivelly belonging to ***Node B1*** and ***Node B2***. In such situation the UE is in a position where it is served by two sectors of two different adjacent Node Bs. Like softer handover, the connection between the UE and the two adjacent Node B take place through two air interface channels belonging to each base Node B separately. In soft handover operation any UE will communicate with two or more cells operating on the same frequency.

That will allows the same user to take up core network and radio resources of all the cells he/she is in soft handover with. Therefore it become important to try to minimize the handover zones otherwise the soft handovers can paralyse the capacity in the whole network.

3.2.7 UMTS-WCDMA channels structure

In UMTS-WCDMA many channels are required to establish and maintain the connection between the UE and the network system. These channels carry a lot of information between the two entities and can be grouped into three type: logical channels, transport channels and physical channels.

These channels exis in both uplink and downlink directions and are depicted in the following figure.

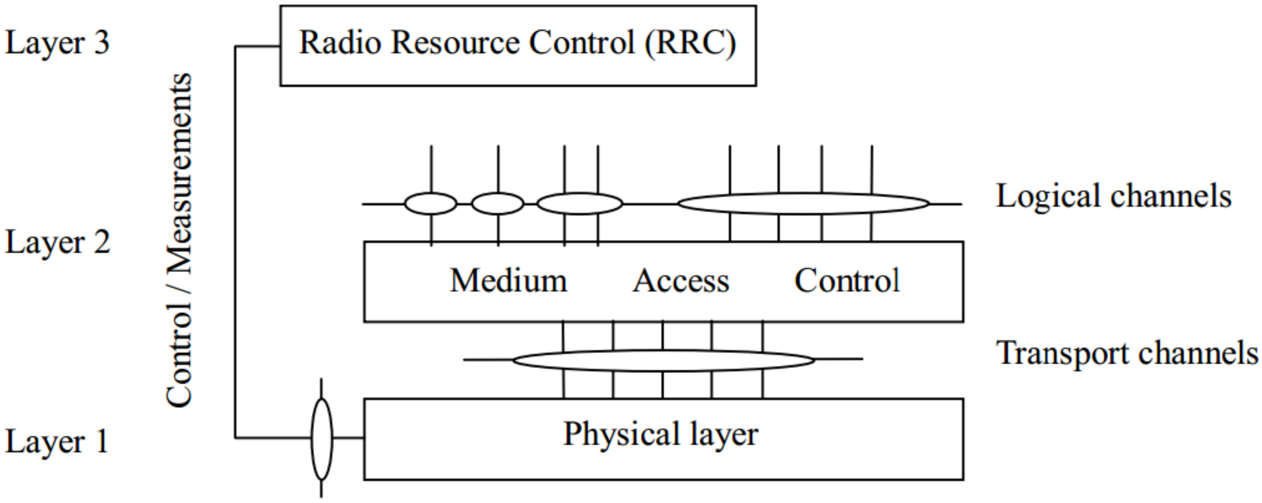


Figure 3.6 Radio interface protocol architecture around the physical layer [10]

3.2.7.1 Logical channels

The data transfer services of the Medium Access Control (MAC) layer are provided on logical channels. A set of logical channel types is defined for different kinds of data transfer services offered by the MAC. Each logical channel type is defined by what type of information is transferred.

The logical control channels are used to transfer control-plane information and the logical traffic channels are used for user-plane information [7].

The logical control channels are:

- **Broadcast Control CHannel (BCCH)**: provide system control information for User Equipment in a cell in the downlink.
- **Paging Control CHannel (PCCH)**: transfers the paging information in the downlink.
- **Dedicated Control CHannel (DCCH)**: a point-to-point bidirectional channel that transmits dedicated control information between a User Equipment and the RNC.
- **Common Control CHannel (CCCH)**: a bidirectional channel for transmitting control information between the network and User Equipments.

The logical traffic channels are:

- **Dedicated Traffic CHannel (DTCH)**: provides the end user's data in uplink and downlink direction.
- **Common Traffic CHannel (CTCH)**: provides data of one end user form one point-to-multipoint for all or a group of specified User Equipments.

3.2.7.2 Transport channels

Transport channels are services offered between layer 1 and layer 2 as depicted in the figure 2.6. Transport channels are defined by how and with what characteristics the end user data is transferred over the air interface. Transport channels are classified into two groups, dedicated transport channels and common transport channels[7, 12].

Dedicated transport channels:

- **Dedicated Channel (DCH)**: it is a downlink or uplink transport channel. The DCH is transmitted over the entire cell or over only a part of the cell using for example beam-forming antennas.
- **Enhanced Dedicated Channel (E-DCH)**: it is an uplink transport channel carrying the end user data with HSUPA.

Common transport channels:

- **Broadcast Channel (BCH)**: it is used in the downlink to broadcast system- and cell-specific information into the cell.

- **Forward Access Channel (FACH)**: it is used in the downlink to carry control information to terminals known to be located in the given cell. It can be also used to transmit packet data.
- **Paging Channel (PCH)**: it is continuously transmitted over the entire cell in the downlink, carrying data relevant to the paging procedure, for example when the network wants to initiate communication with an User Equipment.
- **Random Access Channel (RACH)**: it is continuously transmitted from the entire cell in the uplink, carrying control information from the User Equipment terminal, such as requests to set up a connection. It can also be used to send small amounts of packet data from the User Equipment to the network.
- **Uplink Common Packet CHannel (CPCH) or Enhanced Dedicated Channel (E-DCH)**: it is an extension to the RACH channel that is intended to carry packet-based end user data in the uplink direction.
- **High Speed Downlink Shared Channel (HS-DSCH) or Downlink Shared Channel (DSCH)** : it is a transport channel intended to carry dedicated user data and/or control information. It can be shared by several users.

3.2.7.3 Physical channels

In UTRA, the data generated at higher layers is carried over the air through physical channels. Firstly the information or data related to the system or to an end user is carried by logical channels which are mapped to different transport channels which are also mapped to different physical channels. The physical layer is required to support variable bit-rate transport channels, to offer enough bandwidth tothe demanded services and to be able to multiplex several services to one connection.

UMTS-WCDMA physical channels are [7]:

- **Primary Common Control Physical Channel (PCCPCH)**
- **Secondary Common Control Physical Channel (SCCPCH)**
- **Physical Random Access Channel (PRACH)**
- **Dedicated Physical Data Channel (DPDCH)**
- **Dedicated Physical Control Channel (DPCCH)**
- **Physical Downlink Shared Channel (PDSCH)**
- **Physical Common Packet Channel (PCPCH)**
- **Synchronization Channel (SCH)**

- **Common Pilot Channel (CPICH)**
- **Acquisition Indication Channel (AICH)**
- **Paging Indication Channel (PICH)**
- **CPCH Status Indication Channel (CSICH)**
- **Collision Detection/Channel Assignment Indicator Channel (CD/CA-ICH)**

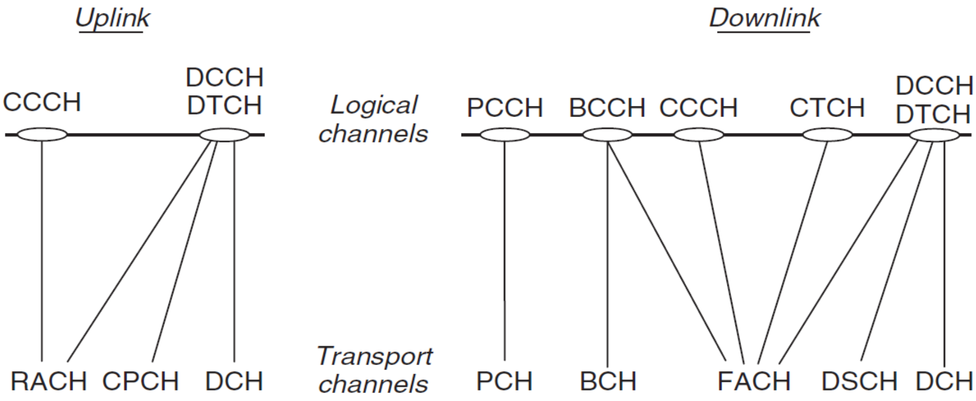


Figure 3.7 Mapping between logical channels and transport channels, uplink and downlink directions [7]

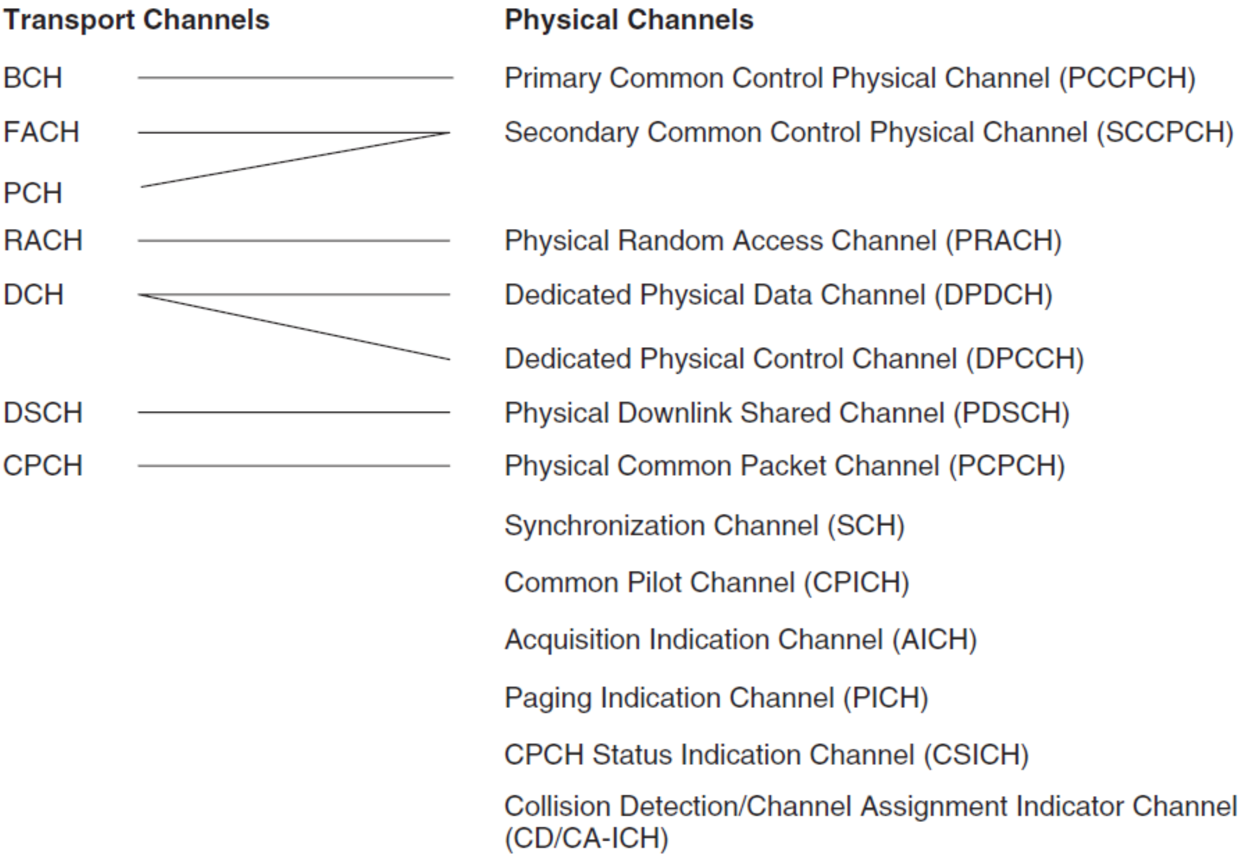


Figure 3.8 Transport-channel to physical-channel mapping [7]

3.2.8 UMTS-WCDMA evolution to HSPA (High Speed Packet Access)

HSPA is an evolution of the first version of UMTS-WCDMA, also know under the name of UMTS-R99. HSPA is a fusion of two mobile telephony protocols, High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA), that extends and improves the performance of existing UMTS-WCDMA protocols. HSPA is a Packet-Switched (PS) service which uses the same UMTS-WCDMA 5Mhz carrier with 3.84 Mcps assuring peak rate of 7,2 Mbps in the uplink and 14,4 Mbps in the downlink [7]. However HSPA introduces new logical channels that behave differently than standard UMTS-WCDMA connections. The capacity and user bits' speed of HSPA is directly related to UMTS-WCDMA traffic, which handles voice and other Circuit-Switched (CS) traffic that has higher priority.

If some HSPA traffic needs to be gauranteed, one can fix a certain amount of power in the base station only for HSPA connections. This can be done by lowering the maximum amount of CS traffic or alternatively assign to HSPA its own 5Mhz carrier (if the frequency is available). The coexistence between UMTS-WCDMA and HSPA brings out the sharing of radio resources between the two technologies: power resources and channelization codes. We note that the sharing of power and channelization codes will not exist if each technology is deployed on different frequencies. That is easy to implement. The difficult scenario is when they coexist. In this fashion coexistence rules wants UMTS-WCDMA to have priority on HSPA. That is well explained by the sensitivity of voice service and video call.

In the following of this thesis work, we will only consider the downlink side of HSPA, HSDPA. This choice is done with respect with our main topic which focuses on the planning and optimization of the network from the Node B side.

3.2.8.1 HSDPA new channels

The news channels of HSDPA are [7]:

- **The High-Speed Downlink-Shared Channel (HS-DSCH)**: it is the new HSDPA transport channel which carries the end user data with a spreading factor of 16. It has a peak rate reaching up to the 10 Mbps region with 16 quadrature amplitude modulation (QAM).

- **The High-Speed Shared Control Channel (HS-SCCH)**: it carries control information from the physical layer allowing to decode the data on HS-DSCH and to perform possible combining of the data sent on HS-DSCH in case of retransmission or an erroneous packet.
- **The Uplink High-Speed Dedicated Physical Control Channel (HS-DPCCH)**: it carries the necessary control information in the uplink, namely ARQ acknowledgements (both positive and negative ones) and downlink quality feedback information.

3.2.8.2 Hybrid Automatic Repeat Request (HARQ) and Scheduling in HSDPA

HARQ and Scheduling have a new implementation in HSDPA. HARQ basic operation consists to request for retransmission of corrupted or discarded received packets. This function, fully performed by the Radio Network Controler (RNC) in UMTS-WCDMA, rely on Error Detection to find uncorrectable errors and uses Forward Error Correction codes to correct a subset of errors. In HSDPA, the key idea is to increase packet data throughput by bringing the control for link adaptation closer to the air interface. The existing HARQ in UMTS-WCDMA will be readapting to allow the Node B to perform retransmission when necessary.

However the RNC remain the base of this function and take care of the retransmission in case the HS-DSCH transmission from the Node B would fail after, for instance, exceeding the maximum number of physical layer retransmissions [7].

Scheduling is a function to control the allocation of shared resources among users in different short interval of time. This function, in HSDPA, has been moving to the Node B allowing faster adaptation to radio channel variation and fast scheduling such that, if desired, most of the cell capacity may be allocated to one user for a very short time.

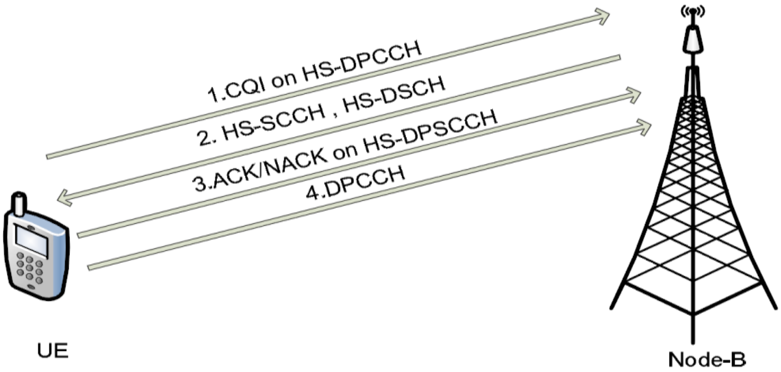


Figure 3.9 Transmission method in HSDPA

3.2.8.3 Resources sharing between WCDMA and HSDPA

The resources shared in the downlink between WCDMA's transport channels and HSDPA's transport channels are power and channelization codes [13].

WCDMA's transport channels have the priority when coexisting with HSDPA's transport channels in the power allocation. The Node B first provides power for WCDMA traffic and the rest will be used for HSDPA. This sharing is dynamically done and avoids the waste of power resource. If there is not traffic for WCDMA, all the available power of the Node B is use for HSDPA.

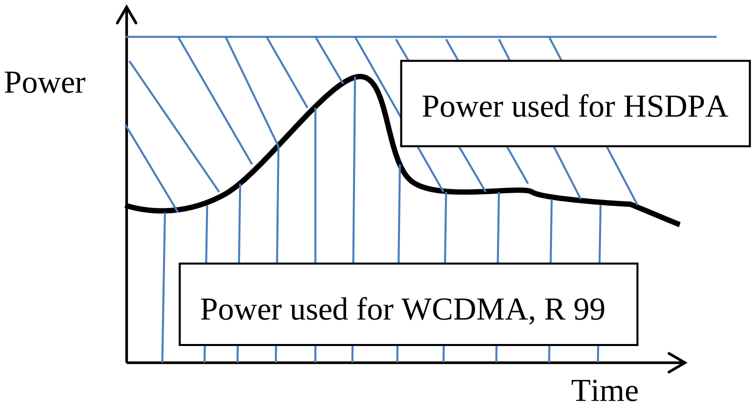


Figure 3.10 Power sharing between WCDMA and HSDPA

UMTS-WCDMA and HSDPA use the same channelization code tree when they coexist on the same frequency. The channelization codes for HSDPA have a fixed spreading factor, SF = 16 when UMTS-WCDMA use channelization code that varies between SF = 4 and SF = 512. It is important to manage the implementation of both technologies well; otherwise a sufficient power could be available while a lack of code can occur. That is explained in the following example, where UMTS-WCDMA's DCH (Dedicated Channel) is implemented with HSDPA 15 codes in the same frequency.

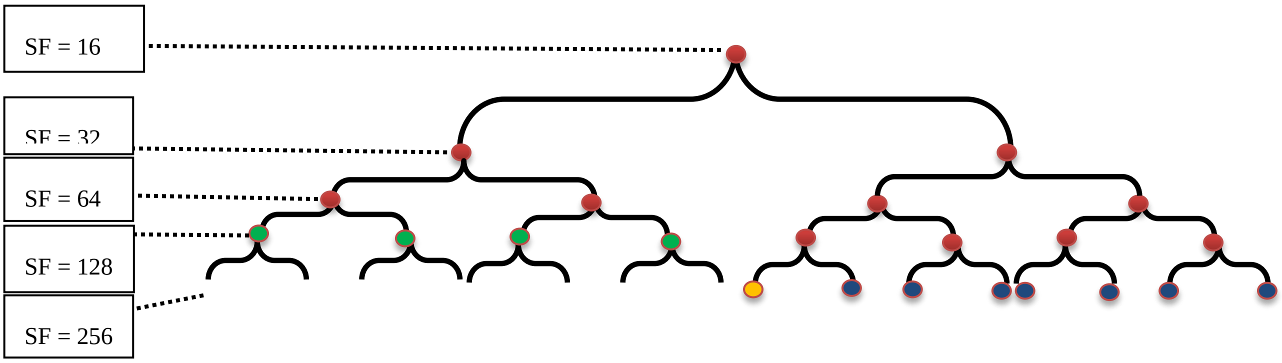


Figure 3.11 Remained code SF=16 after 15 codes SF=16 allocated for HSDPA

The following Spreading factor are used for the different channels [7,12]

- HS-SCCH (High Speed Shared Control Channel**)** is a fixed rate (60 kbps, SF=128)

- CPICH (Common Pilot Channel)*:* SF=256

- P-CCPCH (Primary Common Physical Channel): SF=256

- S-CCPCH (Secondary Common Physical Channel): SF=256

- P-SCH (Primary Synchronisation Channel): SF=256

- S-SCH (Secondary Synchronisation Channel): SF=256

- AICH (Acquisition Indication Channel): SF=256

- PICH (Paging Indication Channel): SF=256

In the previous figure we have 15 code SF = 16 used for the data of HSDPA's users. Only one code SF = 16 that correspond to 8 codes SF = 128 will remain.

4 codes SF=128 will be used for the four HS-SCCH channels. It will remains 4 codes SF=128 that correspond to 8 codes SF=256.

7 codes SF = 256 will be used from the remaining 8 codes SF = 256 for the commons channels.

Only one code SF = 256 will remain for R99' DCH. The rate for SF = 256 is calculated as follow: Data's rate = Chip / SF = 3.84Mbs / 256 **= 15 kbps**

15 kbps is not enough to establish UMTS - R99's DCH connection (minimum 30 Kbps channel bit rate for 12,2Kbps voice service [7]). Thus we see that it is important to define a good cohabitation when the two technologies have to coexist. Generally HSDPA 5 codes mode is used to coexist with UMTS - R99 for good data rate.

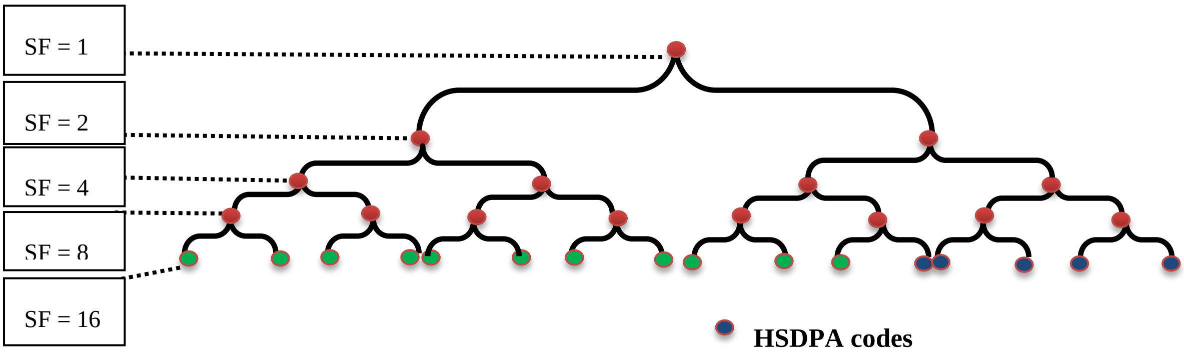


Figure 3.12 Code sharing between UMTS - R99 and HSDPA – 5codes

3.2.8.4 Main differences between WCDMA and HSDPA

Adaptive Modulation Coding (AMC) come in HSDPA to replace two important features in UMTS-WCDMA which are variable spreading factor and fast power control. When implementing HSDPA, resources such as codes and transmission power are shared between all the users in the time domain. All the data transmission is done by one shared HS-DSCH so soft handover is not possible. A user may simultaneously utilize up to 15 multi-codes in parallel. The use of more robust coding, fast HARQ and multi-code operation removes the need for variable SF [7]

Table 3.3 Comparison of different channel types [7]

Channel	**HS-DSCH**	**Downlink DCH**	**FACH**
SF	Fixed, 16	Fixed, (512-4)	Fixed (256-4)
Modulation	QPSK/16QAM	QPSK	QPSK
Power control	Fixed/slow power setting	Fast with 1500 kHz	Fixed/slow power setting
HARQ	Packet combining at L1	RLC level	RLC level
Interleaving	2 ms	10–80 ms	10–80 ms
Channel coding Schemes	Turbo coding	Turbo and convolutional Coding	Turbo and convolutional Coding
Transport channel multiplexing	No	Yes	Yes
Soft handover	For associated DCH	Yes	No
Inclusion in Specification	Release 5	Release 99	Release 99

CHAPTER 4

PICO NODE B AND FEMTO ACCESS POINT TECHNOLOGIES

For any mobile operator, producing a quality network means separating the outdoor area from the indoor area where are present the most important traffic requests, 2/3 of calls and over 90% of data services [14]. A simple way to fill the indoor radio need will be the re-use of outdoor macro's antennas for indoor coverage. This approach which is efficient in some cases presents a lot of drawbacks and permitted the development of small wireless access points for mobile network.

In this chapter, we present two technologies for indoor coverage, Pico Node B (PNB) and Femto Access Point (FAP). We also present some available solutions for very small cell. We present the main difference between them and discuss their impact on the outside cells.

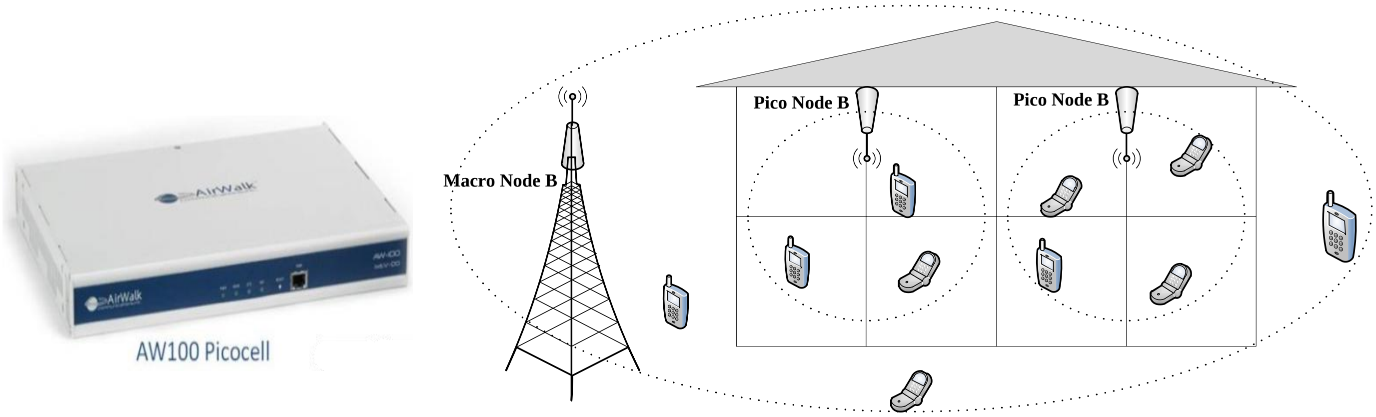
4.1 Pico Node B technology

4.1.1 Picocell and Pico Node B (PNB)

The Internationnal Telecommunication Union (ITU)'s recommendation ITU-R M.1035 defines a Picocell like a very small cell with a typical cell radius of less than 50 m, situated indoors, giving a very high traffic capacity for users moving at a speed less than 10 km/h. Thus a picocell is an autonomous very small cell for indoor coverage formed by the deployement of a small Node B, a Pico Node B (PNB).

A Pico Node B has an antenna which emits at low power than traditional macro Node B or micro Node B and are mainly designed to cover closed areas such as offices of big companies, shopping malls, ... , where the traditional macrocell's coverage is poor due to the wall and other building materials loss.

Another purpose could be the division of wide geographical area in order to provide good coverage and capacity for hot spots like train stations.



(A) (B)

Figure 4.1 (A) Example of Pico Node B (AW100 Picocell) made by UbeeAirWalk
(B) Example of Picocell in presence of outside Macrocell

4.1.2 Pico Node B deployment

A Pico Node B utilizes the architecture and protocols of UMTS-WCDMA network like a normal macro Node B as depicted and explained in the chapter 2, section 2. Its installation requires good planning and optimization to allow maximum end users to be served. For its implementation in UMTS-WCDMA, the Pico node B is directly linked to the closest Radio Network Controller (RNC) of the mobile operator.

As it happens for any Node B, the RNC linked to the Pico Node B will administrate all exchanges from the Pico Node B to the rest of the network and from the network to the Pico Node B. The RNC will perform the Pico Node B's radio resource allocation to end users, handover functions, and other decisions as precised in Chapter 2, section 2. The connection between Pico Node B and RNC is done through optical fiber, ethernet connection cabling for land buildings or satellite for aircraft or cruising ships.

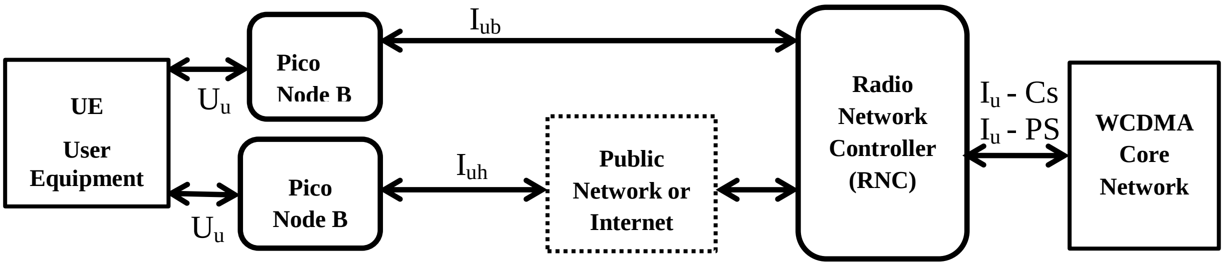


Figure 4.2 Picocell architecture in UMTS – WCDMA networks

When deploying Pico Node B, the mobile operators can choose between their own cabling network, a public network or internet to establish the interface between the Pico Node B and the RNC. The interface I_{ub} is choosen when implementing with the mobile operator own cabling network and the interface I_{uh} is choosen when implementing with a public network or internet.

The I_{ub} interface is the traditional interface between any Node B and the RNC in UMTS-WCDMA network and does not require special features. The I_{uh} interface is an interface based on I_{ub}, developped to transport mobile network transmissions through non secured network like public network or internet [14]. To meet its goal the I_{uh} interface should:

- be transported over IPv4 and optionally IPv6;
- enable transport of all kind of information necessary for data exchanges between the Node B and the RNC;
- provide specific encryption protection (e.g. IP Security);
- support integrity checking between the Node B and the RNC.

Pico Node B are available for GSM, CDMA 2000, W-CDMA, TD-SCDMA, WiMAX and LTE standards and can cover around 50 meters with many simultaneous users.

4.1.3 Pico Node B technical specifications

Table 4.1 Pico Node B main features

Aspect	**Pico Node B**
Type of cell provided	Fully autonomous very small cell with full services
Installation	Operator
Information transmission to operator's network	Operator, coaxial, optical fiber, satellite, …
Frequency/radio parameters	Centrally planned
Site rental and electrical bills	Operator
Price	Cheap
Coverage mode	Open
Average cell radius	1 - 50 meters
Average simultaneous users	1 - 50 users

Table 4.2 Pico Node B and UE technical specifiations for UMTS-WCDMA. Recommendations of ITU [6]

Parameter	**User Equipment**	**Parameter**	**Pico Node B**
Transmitter power, dBm (typical)	20	**Transmitter power dBm**	24
Transmitter power, dBm (maximum)	24 or 21	**Antenna gain (dBi/120° sector)**	0
Antenna gain (dBi)	0	**Antenna height (m)**	2
Antenna height (m)	1,5	**Tilt of antenna (degrees down)**	0
Data rates Supported	Pedestrian: 384 kbps, Vehicular: 144 kbps, Indoors: 2 Mbps, Up to 42Mbps in downlink and 11,5 Mbps in uplink supported by evolution to HSDPA, HSUPA	**Data rates Supported**	Pedestrian: 384 kbps, Vehicular: 144 kbps, Indoors: 2 Mbps, Up to 42Mbps in downlink and 11,5 Mbps in uplink supported by evolution to HSDPA, HSUPA
Modulation type	HPSK / 16QAM	**Modulation type**	QPSK / 16QAM
Receiver noise figure, (worst case)	9 dB	**Receiver noise figure (worst case)**	5 dB for macro Node B (Unspecified for pico Node B)
Thermal noise in Specified bandwidth	-108 dBm in 3.84 MHz	**Receiver thermal noise level**	-103 dBm in 3.84 MHz for macro Node B (Unspecified for pico Node B)
Receiver thermal noise	- 99 dBm in 3.84 MHz	**Receiver bandwidth**	< 5 MHz
Receiver reference sensitivity	-117 dBm in 3.84 MHz	**Receiver reference sensitivity**	–107 dBm for pico Node B
Interference threshold	-105 dBm in 3.84 MHz	**Interference threshold**	–109 dBm in 3.84 MHz for macro Node B (Unspecified for pico Node B)

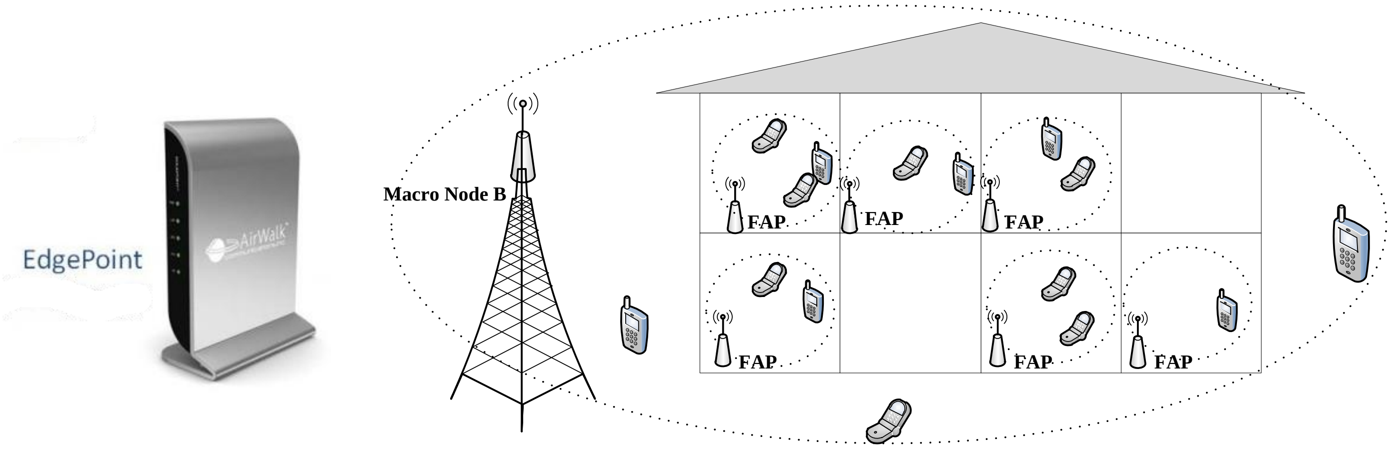
4.2 Femto Access Point technology

4.2.1 Femtocell and Femto Access Point (FAP)

Born from the success of Pico Node B, the Femto Access Points are the result of a project started in 2002 by a group of Motorola engineers. Since it is imposible for any mobile operator to fully cover all the buildings and houses in its autorised area, the idea to develope the smallest Node B came. This idea aimed to produce an easy plug and play Node B which could be well set by any user at home or at office.

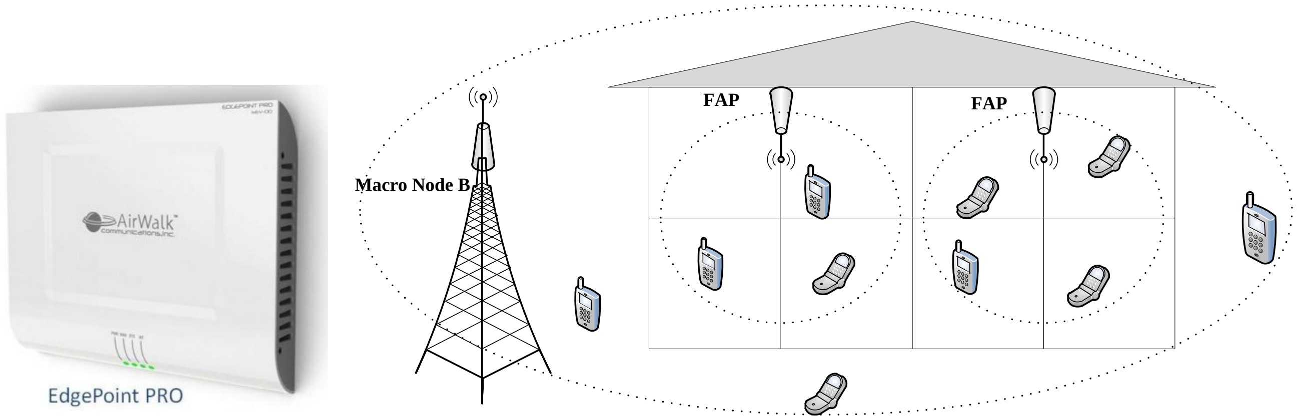
A femtocell is a small cell, smaller than picocell, formed by the deployment of a Home Node B (HNB), a femto unit or a Femto Access Point (FAP). The term HNB is from the 3GPP specification [15], and will be understand as Femto Access Point in the rest of our thesis work.

A Femto Access Point is a customer owned equipment that allows him/her to connect over UTRAN wireless air interface to a mobile operator's network using a broadband IP backhaul. Thus the FAP is a low-power radio access point, looking like a WiFi access point implementing cellular network technologies. It has an output power less than 0.1Watts with around 10 simultaneous calls and data sessions [16].



(A) (B)

Figure 4.3 (A) Example of residential FAP (EdgePoint) made by UbeeAirWalk
(B) Example of residential Femtocells in presence of outside Macrocell



(A) (B)

Figure 4.4 (A) Example of enterprise FAP (EdgePoint PRO) made by UbeeAirWalk
(B) Example of enterprise Femtocells in presence of outside Macrocell

4.2.2 Femto Access Point deployment

A FAP already includes all the components present in the UMTS-WCDMA's Universal Terrestrial Radio Access Network (UTRAN) and does not need the management of a Radio Network Controller (RNC) but only an internet connection to the core network. For this purpose, new elements are introduced in the traditional UMTS-WCDMA architecture: The Femto Access Point (FAP) or Home Node B (HNB), The Home Node B Gateway (HNB-GW), the Home Node B Management System (HMS), the Security Gateway, the Local Gateway (L-GW) [15].

4.2.2.1 FAP new elements in UMTS-WCDMA architecture

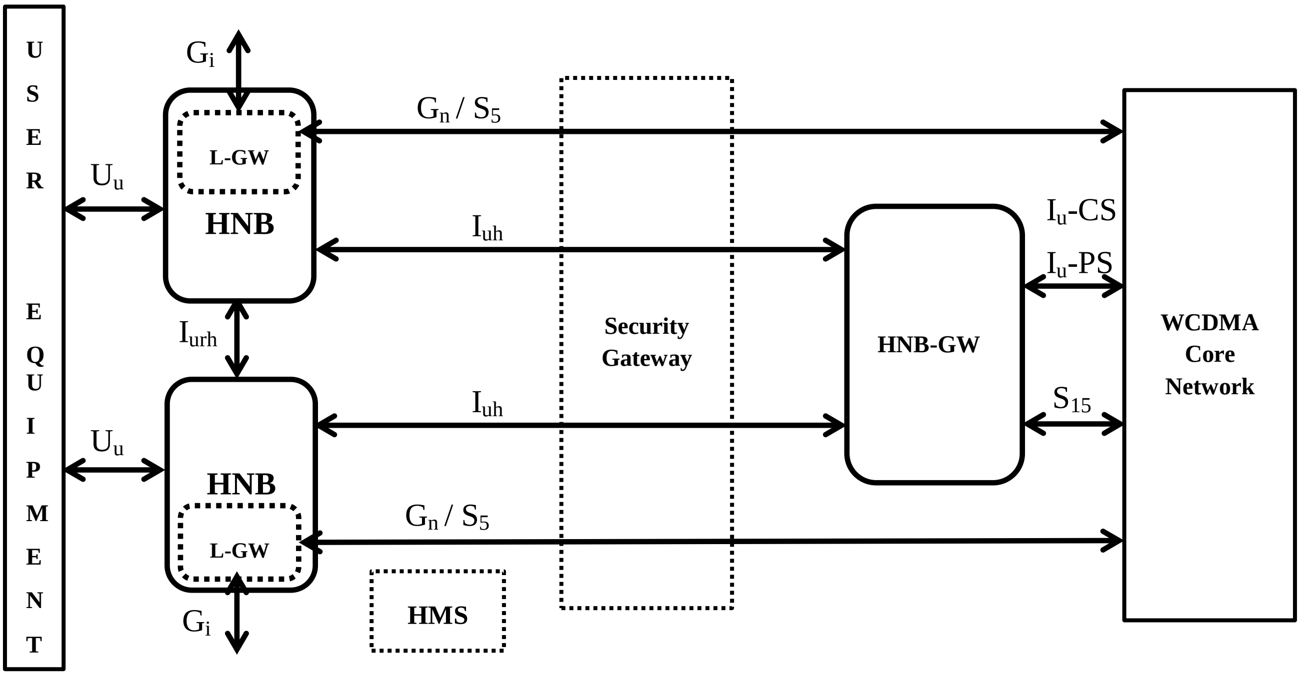


Figure 4.5 Femto Acces Point's architecture in UMTS -WCDMA networks [15]

- **Femto Access Point (FAP) or Home Node B (HNB)**

The Femto Access Point have the following functions [15]:

- offers the exchanges provides by U_u interface to the User Equipment;
- provides Radio Access Network (RAN) connectivity using the I_{uh} and I_{urh} interfaces;
- acts as Radio Network Sub-System (RNS) to the User Equipment;

- supports its own registration and the User Equipment's registration over I_{uh} interface;
- supports additional autonomous functions in case of Local IP Access mode.

The Local IP Access (LIPA) is the ability for any IP-enabled device (printer, scanner, computer, ...) to access the Customer's local area IP based network as well as his/her Internet connection directly using the air interface provided by the FAP.

- **The Home Node B Gateway (HNB-GW)**

The Home Node B Gateway (HNB-GW) is a concentrator for FAP and is designed to manage a huge amount of FAPs.

It is connected to the FAPs through the interface I_{uh} that has also be adapted to support a big amount of connections from many FAP. HNB-GW appears in the Core Network as an RNC and is uniquely identified amoung the RNCs by the RNC Identity (RNC ID) on a the interface I_{urh}.

The functions of the HNB-GW are [15]:

- terminates transmissions from FAP through I_{uh} interface;
- avoid FAP's request congestion at the CN and appears as an RNC;
- supports FAP registration and FAP's UE registration over the interface I_{uh};
- may terminate Transport Network Layer (TNL) connection for the I_{urh} interface between different FAP. TNL operation consist of monitoring of Physical Cell Identity (PCI) values between neighboring cells' nodes for resources sharing/allocation.
- may support Fixed Broadband Access network interworking via S_{15} interface for CS sessions.

- **The Home Node B Management System (HMS)**

The Home Node B Management System uses an interface based on the TR-069 standard widely used in Digital Subscriber Line (DSL) modem [15].

TR-069 standard is a set of management protocols for communication between a Customer Premises Equipment (CPE) and Auto-Configuration Server (ACS), developed by Broadband Forum. These protocols include secure auto-configuration as well as other CPE management functions within a common framework.

The HMS, using TR-069 protocols, assists the FAP in the HNB-GW discovery procedure. It performs location verification for FAP and provides information about the serving elements (HMS, Security Gateway and HNB-GW), if these are different from the initial ones used by the FAP. It sends configuration data to the FAP and can also initiate its software updates.

- **The Security Gateway**

The Security Gateway provides a secure connection between the FAP and the HNB-GW. It is situated on the border between the trusted operator's network and the unsecured public network or internet. The Security Gateway's main functions are [15]:

- provides an encrypted communication channel to assure the integrity of the data exchanged between the FAP's end user and the network.
- participates in the authentication of the FAPs.
- terminates secure tunnelling for I_{urh} and G_n/S_5 exchanges for certain deployment options.
- provides access to the HMS and HNB-GW for the FAP.

- **The Local Gateway (L-GW)**

The Local Gateway may be present only when the FAP is operating in Local IP Access (LIPA) mode. When LIPA is activate the FAP through the L-GW communicates directly to the SGSN/SGW using the interface G_n/S_5 and does not use the HNB-GW. It also communicates with residential local IP based network through the G_i interface.

The L-GW function within the FAP provides [15]:

- in idle mode, support for sending the first packet to the SGSN/SGW
- support for direct fowarding the end user's data to the corresponding FAP's module.
- deactivation of the G_n/S_5 interface connection.

4.2.2.2 FAP news protocols in UMTS-WCDMA's UTRAN

FAP deployment has inherited many protocols from traditional UMTS-WCDMA. However new protocols are introduced for the auto-management. The main steps required to be validate for any FAP before to provide radio coverage are [7, 15]:

1) Once powered up or reset to factory defaults, the FAP should performs an autonomous test to confirm that it has not be altered or modified for other purpose than UTRAN services. This confirmation test is done with TR-069 based protocols by uploading the FAP configuration from the HSM using a secure tunnel created by the Security Gateway.
2) The FAP boot and perform discovery operation to obtain the initial serving HNB-GW information through the Security Gateway secure tunnel. The secure tunnel is an obligation for FAP and HNB-GW's communication. It has to be created through the Security Gateway in case it is ommited during the first step.
3) Once the previous steps are completed, the FAP start the registration operation to notify the HNB-GW that it is available at a particular IP address through the Home Node B Application Protocol (HNBAP). For that the FAP sets up a Stream Control Transmission Protocol (SCTP) transport session to the registered port of the serving HNB-Gw for I_{uh} exchanges. The FAP send to the serving HNB-GW, an HNB REGISTER REQUEST message containing its location information, its identity, its operating parameters, its operation mode and its own IP address.
4) The HNB-GW use the information containing in the HNB REGISTER REQUEST message to verify the FAP identity, to validate if it is allowed to work with the transmission mode that it has indicated and to check if it is allowed to emit in the geographical area where it is located. After those verification the HNB-GW could accept or refuse the registration of the FAP. When its is accepted, the HNB-GW respond the FAP with a HNB REGISTER ACCEPT message. The HNB-GW may provide its IP address to the FAP in order to allow it to either establish I_{urh} exchanges via the HNB-GW or to establish connectivity to an RNC via the HNB-GW.

The FAP start to broadcast only after successful registration with the HNB-GW. It could so perform the registration of the User Equipments under its coverage according to its operating mode or deployment configurations that is explained in the following section.

4.2.3 Femto Access Points deployment configurations

The 3GPP organisation has defined a number of different deployment configurations for Femto Access Points. These are: Open access or Closed Subscriber Group (CSG), dedicated channel or co-channel, Fixed or adaptive downlink maximum transmit power [17].

4.2.3.1 Open access or Closed Subscriber Group (CSG)

Femto Access Point technology allows two access methods, the public (open) and the private access (CSG).

Public access allows any home resident or passing end user to connect the closest FAP which give the strongest signal. In this mode an handover can be done between many FAP. An exemple could be a multi-floored building where a very good coverage for the whole building will be possible.

In private access, only a Closed Subscribers Group (CSG), a list of registered users can access the FAP. In this mode many interferences could happen in the whole network. For example an unauthorized User Equipment close to the FAP will be oblige to increase its power in order to reach the closest micro or macro Node B.

The private access is one of the key problem of FAP deployement. To fix this issue a hibrid mode is proposed where the FAP’s owner and his CSG’s users will get full priority in the radio resources allocation. The non registered users in the CSG could so connect to the FAP but with low priority level. However the main problem remain as the femtocell’s owners pay for FAP device and for the internet connection used to reach the core network. The public access could be a full reality in FAP deployement if mobile operator in exchange provide some services like:

- low cost for call emmited by a registered user from his/her FAP;
- financial compensation or bonus for any call emitted by non registered user under a FAP coverage;
- low cost for data packets tranfer generated by a registered user from his/her FAP;
- financial compensation or bonus for any data packets transfer generated by non registered user under a FAP coverage,

- Free SMS from the operator to notify when someone enters or leaves the home, whre is deployed a FAP,
- ...

Another important factor that could allow a mobile operator to bring the users under FAP open or hibrid access is the sensitization about interferance avoidance. Interference advoidance in open or hibrid access will allow them to fully beneficiate the deployment of their Femto Access Point.

4.2.3.2 Configuration A: CSG, Dedicated Channel, Fixed Power

The FAP is configured as a Closed Subscriber Group and is deployed on a dedicated channel. The FAP's channel is not used within the macro layer. In such scenario the interference remain between the FAPs. Worst case of interference will only happen if a different mobile operator owns an adjacent channel close to the FAPs. When deployed in dedicated channel, the power transmited by any FAP could potentially be fixed to not surpass a maximum level that will decide the mobile operator. Such strategy will allow the dominance of the FAP in the femtocell with respect to the closest macrocell.

4.2.3.3 Configuration B: CSG, Dedicated Channel, Adaptive Power

The FAP is configured as a Closed Subscriber Group and is deployed on a dedicated channel. It should dynamically adapts its output power considering the possible other cells around it. In such configuraiton, maximum transmit power should only be used when it is appropriate for the deployed environment, and when the resulting interference is acceptable.

4.2.3.4 Configuration C: CSG, Co-channel, Adaptive Power

The FAP is configured as a Closed Subscriber Group and is deployed on the same channel as the macro network. The FAP and the macro Node B are using the same channels for transmission. This is considered the worst case interference scenario with highest risk of deployment. The FAP's location and dynamic output power adaptation is done under strong conditions [16]. It is not possible to fix a maximum level for the output transmited power for such configuration, it is not feasible and this option has been removed from further analysis [15].

4.2.3.5 Configuration D: Partial Co-Channel

Partial co-channel is proposed for FAP operating in CSG mode. The macro Node B and the FAP share the same frequencies, as shown in following figure. The macro Node B will be able to use the all available frequencies,when the FAP could only use a part of it. In such scenario, any macrocell's users experiencing interference in the shared part of the frequencies can move to the clear part. This configuration could also be applicable to open access in order to limit the influence of the FAP in the whole radio network and allow full mobility.

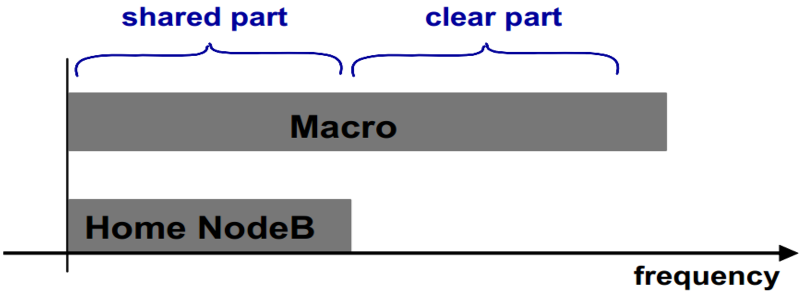


Figure 4.6 Spectrum sharing for Macrocell and Femtocell [15]

4.2.3.6 Configuration E: Open Access, dedicated or co-channel

Open access FAP serve all UEs, in the same way as other pico Node Bs and macro NodeBs do.

4.2.4 Femtocell Access Point technical specifications

Table 4.3 Femtocell main features

Aspect	**Femto Access Point**
Type of cell provided	Fully autonomous very small with full services
Installation	Customer
Information transmission to operator's network	Customer, ADSL or cable
Frequency/radio parameters	Locally determined
Site rental and electrical bills	Customer
Price	Very cheap
Coverage mode	Open, Closed or hybrid
Average cell radius	1 - 30 meters
Average simultaneous users	1 to 4 users for home &1 to16 users for office

The 3GPP has investigated the similatitudes between Femto Access Points and PicoNode B. The following summarises the investigation of whether the picocell class can be extended to cover scenarios for femtocell class or a if new class needs to be defined.

Table 4.4 FAP's transmitter characteristics. List of changes identified with respect to the current definition of a picocell class. Recommendations of ITU [17].

Specification	**Value proposed by 3GPP TR 25.820**	**Current value for Pico Node B (PNB)**
Maximum output power	20 dBm	24 dBm
Control of output power	From Maximum power to 0 dBm	Not applicable
Spurious emissions.Protection of the Node B receiver of own or different Node B	Same with PNB values	-82 dBm
Spurious emissions. Co-existence with colocated and co-sited Node B	Same with PNB values	-70 dBm (Picocell 900/850 Mhz) -82 dBm
Spurious emissions **Co-existence with UTRATDD**	Same with PNB values	- 55dBm

Table 4.5 FAP's receiver characteristics. List of changes identified with respect to the current definition of a picocell class. Recommendation of ITU [17].

Specification	**Value proposed by 3GPP TR 25.820**	**Current value for Pico Node B (PNB)**
Reference sensitivity level	Same with PNB values	-107 dBm
Dynamic range	[Potential impacts]	-59dBm (wanted -77dBm)
Adjacent channel selectivity (ACS)	Same with PNB values	-38dBm (wanted -101dBm)
Blocking characteristics. Minimum requirement	Same with PNB values	-101 dBm (interferer various)
Blocking characteristics. Minimum Requirement. Co-location with GSM900, DCS 1800, PCS1900, GSM850 and/or UTRA FDD	Same with PNB values	- 115 dBm (interferer various)
Blocking characteristics. Minimum Requirement. Co-location with UTRATDD	Same with PNB values	- 101 dBm (-4dBm)
Intermodulation	Same with PNB values	- 38dBm (wideband) - 37dBm (narrowband)

4.2.5 Required conditions for a FAP deployment inside a Macrocell covered area.

The main targets of femto Access Point technology are homes and small business office areas where the FAPs are self-deployed by the users. This aspect of FAP solution should oblige any mobile operator to simulate the behavior of the radio network with a huge deployement of those home Nodes. Indeed to avoid interference with the surrounding Node Bs, the FAP must be able to sense its environment and configure itself automatically. This auto-configuration will define important parameters like transmission power, channel allocation and handover management. Thus it is important to define a Femtocell Access Point framework deployement which will match with the whole network.

The auto-configuration, respecting the radio network situation in the geographical area where they are deployed is done, meeting the following conditions [17].

- FAP should not degrade significantly the performance of networks deployed in other channels.
- The configurations of a FAP in the same channel with an existing UTRAN should be done in a maner that their combined performance (FAP & UTRAN) is not significantly worse than that of the original UTRAN network.
- FAP should provide reasonable performance whether deployed in isolation or whether multiple FAP are deployed in the same area.
- Since the FAP may be privately owned and portable, it should only radiate and offer voice and data services while it is confirmed that such an emission complies with regulatory requirements in force where it is operating.
- FAP must support UE speeds up to 30 km/h.
- FAP must support existing UTRAN User Equipments.

4.3 Other very small cell technologies

4.3.1 Repeater

Repeaters are devices which receive the signal from the macrocell, amplifies it and send it inside the building in order to avoid the walls attenuation.

Three main elements compose a repeater: an external antenna to the building to receive the macrocell signal, an amplifier and an intern antenna which retransmit the amplified signal inside the building.

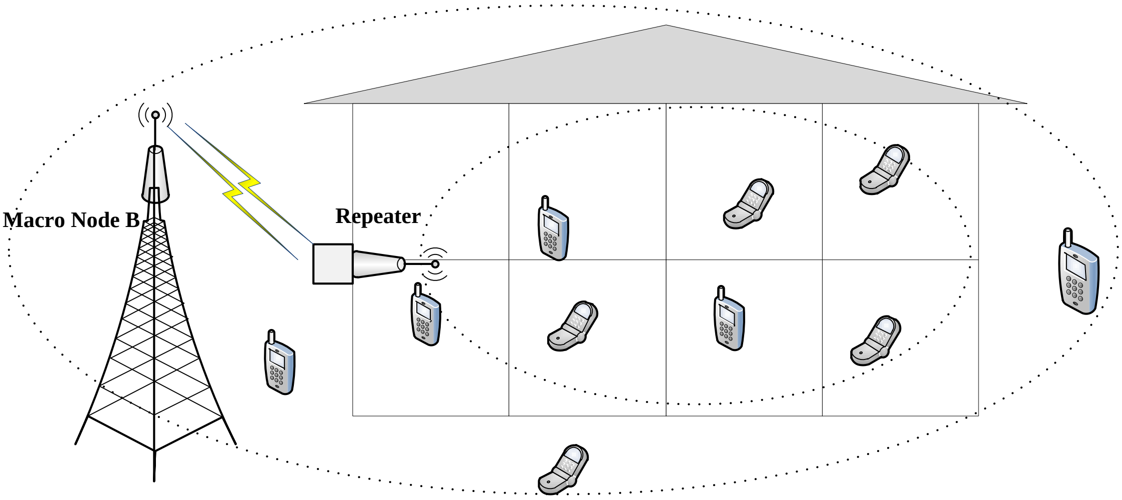


Figure 4.7 Example of repeater in a building in presence of outside Macrocell

The power gain generated by a repeater in decibel is [14] :

$$G = 10 \times log\left(\frac{P}{P_0}\right) \tag{4.1}$$

Where P_0 is the power of the signal received at the external antenna, and P the power of the amplified signal broadcast indoor.

There are two kind of repeaters, the active and the passives. An active repeater is able to process its received signal before to amplifie it. It thus improves the performance of the radio network when a passive repeaters, cheaper than active repeaters, just amplifie its received signal including possible noise.

4.3.2 Distributed Antenna Systems (DAS)

The idea of distributed antennas is the use of 2 or many antennas instead of one for buildings indoor coverage. The transmitted high power which suppose to be broadcast by one antenna is divided into low power between separated antennas with the goal to get an homogeneous coverage.

Rather than a single antenna if a given area is covered by N antennas, the total radiated power is reduced by approximately a factor $N^{(1-\frac{\alpha}{2})}$ for a total coverage area improved $N^{(1-\frac{2}{\alpha})}$ times [14]. α is the path loss exponent.

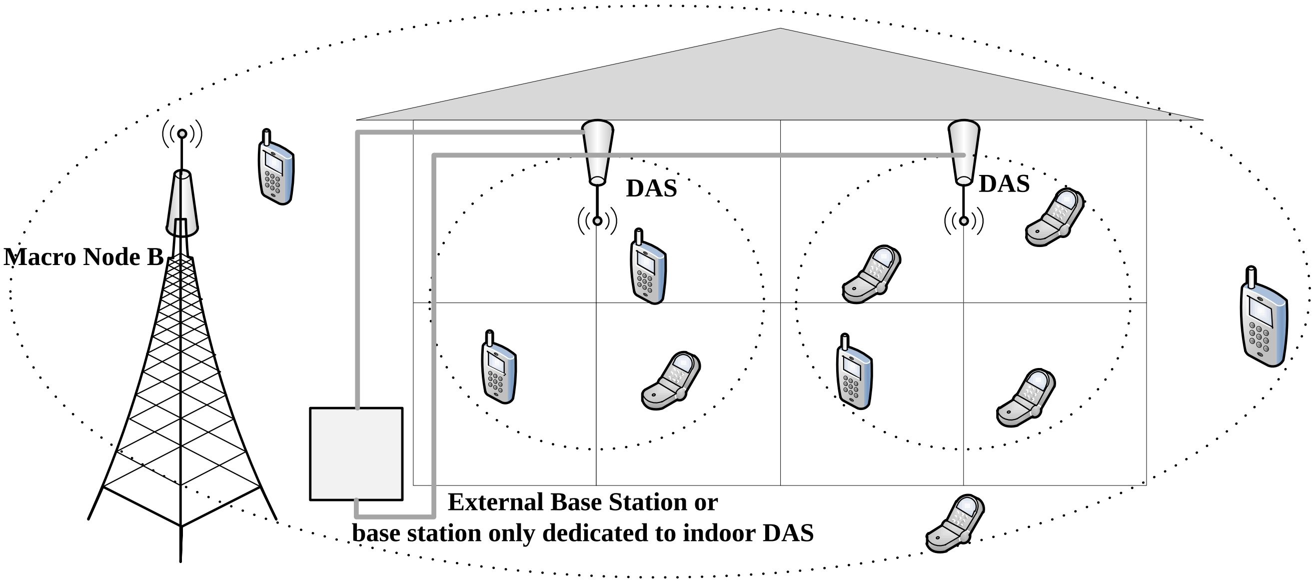


Figure 4.8 Example of DAS in a building in presence of outside Macrocell

For a path loss equal to 5 and for an area covered by 4 antennas instead of one.

$$\frac{Power\ radiated\ by\ N\ antennas}{Power\ radiated\ by\ single\ antenna} = N^{(1-\frac{\alpha}{2})} = 4^{(1-\frac{5}{2})} = 0.125 = \ -9\ dB, \tag{4.2}$$

the total power emited in the covered area is reduice by 9dB

$$\frac{Area\ covered\ by\ N\ antennas}{Area\ covered\ by\ single\ antenna} = N^{(1-\frac{2}{\alpha})} = 4^{(1-\frac{2}{5})} = 2.29, \tag{4.3}$$

the total covered area is improved by 2.29

DAS existed in two forms: active DAS and passive DAS. Active DAS more expensive than passive DAS are easy to install in building like big office where they are almost invisible to the user. It allows good performance and good management since automatic controls and alarms are integrated into the remote unit. Passive DAS are cheap but the operator have to operate a high charge for the coaxial cabling which sometime surcharge the building design. The engineers in this case also have to take into account the length of the cables in order to manage the global loss which is not alway a simple task.

A mix of passive and active DAS solutions is sometimes a good compromise to reduice the coverage cost and resolve covered area specifications which change according to the considered building.

4.3.3 Radiating or Leaky cable

The radiating cable, similar to coaxial cable is a metallic wire which acts like an antenna by receiving and transmitting electromagnetic energy all along. It includes some tuned slots on its surface to set the radio network bandwidth. It is an optimised solution than distributed antennas for covert long narrow areas like corridors, elevators or tunnels where it provides homogeneous coverage all along the cable with competitive cost.

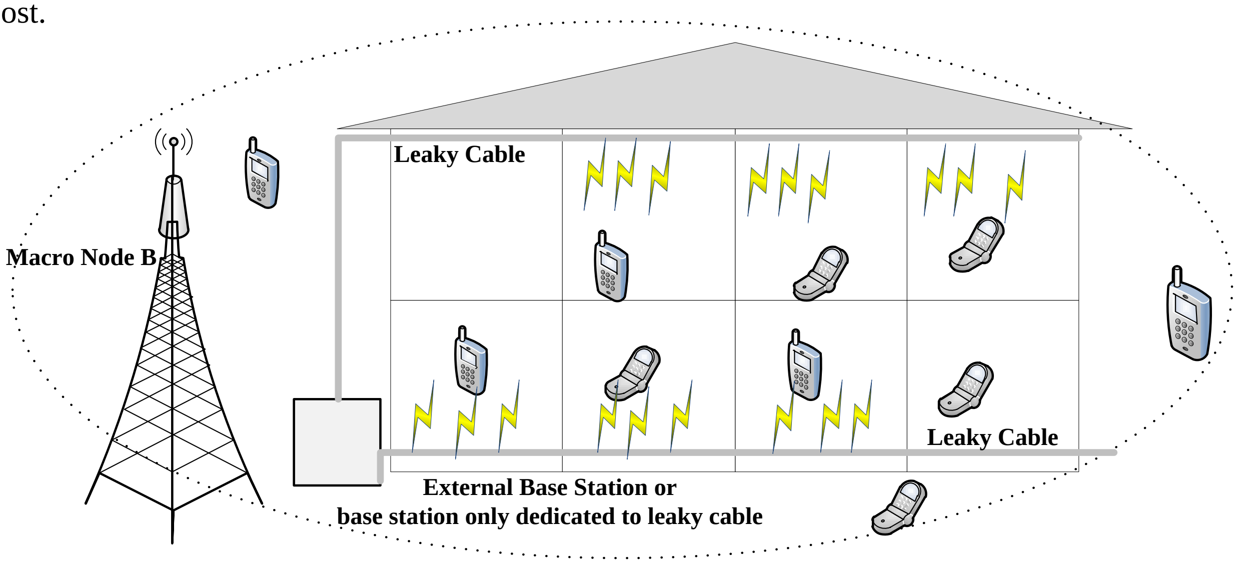


Figure 4.9 Example of leaky cable in a building in presence of outside Macrocell

Radiating cable implementation in a radio network is done by connecting the cable directly to the Node B, using Bi-Directional Amplifiers (BDA) to maintain the signal at a certain level. Another way is to include some T-Feed option into the “sub-network” design which will allow the BDA to be a “router” between the radiating cable and the Node B through optical fiber.

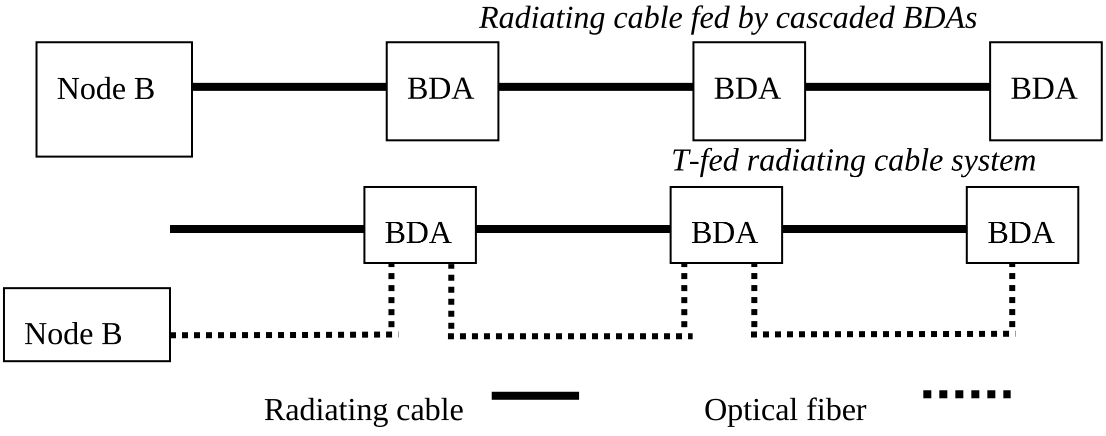


Figure 4.10 Implementation of radiating cable in a radio network

In T-Feed system each BDA with its optical interface converts the optical signal into electromagnetic signal and the electromagnetic signal into optical signal before to send it via cable in both directions. In this configuration the radiating cable can cover over long distances with a good noise control since the different BDAs just relay the information from each other.

4.4 Comparison of Pico Node B, Femto Access Point and other very small cell techologies.

4.4.1 Pico Node B and Femto Access Point versus other small cell technologies

We described in the above sections some technologies used for indoor coverage. Since the main goal for any mobile operator is to improve cost and quality factor, every environment and situation will be adapted to a specific technology with its advantages and side effects. Repeater, DAS and leaky cable are technologies aimed to forward the signal from a close macro Node B. They increase the indoor signal and get a homogenous indoor coverage through the signal emitted by outdoor Node B. Such technologies, by presenting a lack of autonomy could be a burden for the outdoor layer since they share the same power and radio resources of outside Node B.

A new proposal is to get homogenous coverage by directly deploying small Node B inside the buildings, the Pico Node Bs and Femto Access Points. The following table explains the main differences between the two groups of very small Node B.

Table 4.6 Main differences between autonomous very small Node B and non-autonomous very small Node B

Autonomous very small Node B (PNB and FAP)	**Non-autonomous very small Node B (Repeaters, DAS, Leaky cable)**
Autonomous performances that can be optimize.	Performance directly related to outside Node B situation.
Adds both coverage and capacity to indoor and outdoor area. Ability to improve data rates.	Only extends outside macrocell Node B coverage and power, no additional capacity.
Generates its own signal that can be well planned and managed to avoid intercells interference.	Requires outside donor antenna which can sometimes produce intercells interference.
Create a new cell so provides full control of handover	Cannot create a new cell so the cell neighbors will be the same as the macrocell. Possibility of handover overload.
Easy connection with the core network (broadband IP connection, satellites, …)	Works in isolation, but needs nearby macrocell Nobe B.

4.4.2 Pico Node B versus Femto Access Point

Both Pico Node B and Femto Access Points are low power emitting, cheap, more adapted for indoor coverage and easy to deploy. They both increase indoor and outdoor capacity since they don’t share the outdoor base station resources and give strong radio signal to indoor users.

A Pico Node B could only be installed and maintained by the mobile operator, who pay for site rent, electrical power and set the necessary connections to his closest RNC. This deployment, for Pico Node B allows strict planning and organized deployment according to the mobile operator coverage strategies. A Pico Node B is deployed in open mode and allows any users to get the network connection that it provides.

Femto Access Points derives from the success of Pico Node B and share some features with it. The main differences are the presence of big autonomy in the deployment by the customer, the transmitting mode configuration and the automatic sensing of the surrounding environment for frequency use and signal power adjustement. Self-installed by the end user, the FAP could be set in closed group mode where only a list of registered users can access the mobile network through it. It could also be set in open mode like the Pico Node B and give coverage to passing users but the decision remains its owner’s. FAP are randomly deployed so the inteference in the whole radio network cannot be strongly assess like it is done for Pico Node B deployment.

CHAPTER 5

PICO NODE B AND FEMTO ACCESS POINT'S RADIO NETWORK DEPLOYMENT SCENARIO

The radio network is the part of the mobile network that is directly connected to the mobile user. It is part of the UTRAN and includes the Node B, the User Equipment (UE) and the air interface between them. The Node B has a certain coverage area and should be able to communicate with the UE within this area, maintaining call quality standards with a sufficient capacity.

The aim of this chapter is to understand the different steps when designing a UMTS-WCDMA radio network using Pico Node B and Femto Access Point technologies. First we explain the need of Pico Node B and Femto Access Point technologies in the whole mobile network planning. From this explanation we present the basic steps of radio network planning and then derive the optimisation concept from it.

5.1 Necessity of including Pico Node B and Femto Access Point in radio network.

Pico Node B and Femto Access Points are devices used to establish or improve indoor radio coverage. A simple way to fill the indoor radio need will be the re-use of outdoor macro Node B for indoor coverage. This approach which is efficient in some cases presents a lot of drawbacks:

- **No improved use of radio resources**: indoor users will need high power from the outdoor Node B to overcome wall penetration loss. Thus every 'Kbit' used by indoor users will be more expensive (in term of radio resource). In such situation the remaining less power will be shared by outside users who may experiment many dropped call.

- **No possibilities to achieve high traffic or sometimes coverage**: indoor users who are in a building that is not facing the macro Node B may suffer high traffic and coverage problem because of antenna pattern.
- **Not enough radio range in the building, possibility of dead zone**: a building which is located close to 2 or many macro Node Bs may suffer dead zone problem because of conflicting signals from multiple macrocells.
- **No adequate frequency range**: the high frequencies (from 2 GHz and above) that are specially used by 3G network are more easily attenuated by building materials.
- **No accurate coverage and capacity in the building**: it is not possible to determine exactly the indoor area where the coverage is weak with the macro Node B, especially for high-rise buildings. Hence the mobile operator cannot maximize it revenue and lose his credulity in front of indoor users.

To solve the indoor coverage and capacity problems, mobile operator choose to separate their total covered area into two layers, the outdoor layer and the indoor layer. Each layer is planned and optimize taking into account the situation of the other one.

For indoor layer, the mobile operator when planning hotspots such as large office centers, shopping malls, airports, ..., will choose a technology implementing Pico Node B. A deployment of Femto Access Points (FAP) or macro Node B approach will be preferred for small office and home cases. Indeed FAP, by nature are plug and play devices that are directly installed by the customers. FAPs deployment does not need planning from the mobile operator. They are full autonomous devices that can adapt themselves to the environment through their SON feature (Self Organizing/Optimizing Network) as explained in the chapter 3, section 2. The mobile operator can find the details of the signal transmission related to a FAP that start to emit but cannot predict its installation and other inputs needed to plan its deployment.

Therefore planning will happen when deploying Pico Node B or FAPs in a big office scenario. The following sections of this chapter will treat the planning of Pico Node B that will be the same when deploying FAPs in big office scenario.

5.2 Planning paradigm of Pico Node B and Femto Access Points.

The principal goal of radio network planning for Pico Node B is to find a cost-effective solution for the indoor radio network in terms of coverage, capacity and quality.

In other words it consist to obtain the maximum indoor coverage and quality at minimum cost. Radio network planning process for Pico Node B depend upon the building indoor area's and some criterias formulated by the mobile operator.

5.2.1 Picocell and Femtocell planning process

Taking into account the conditions such as the expected area to be covered, the type of area, the propagation conditions and the future indoor system capabilities, the radio planning process can be summarize in the following figure [18].

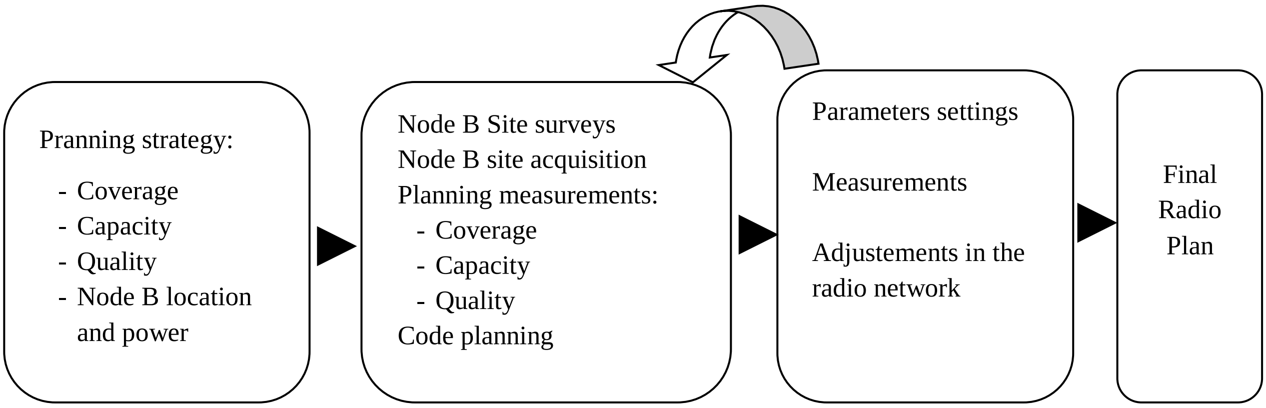


Figure 5.1 Picocell radio planning process

The theoretical workflow for an effective radio network planning strategy can be divided into three sub-plans [18]:

- Network dimensioning and capacity estimation,
- Link budget calculation and coverage estimation,
- Hardware parameter planning and first tuning test.

In UMTS-WCDMA network, coverage, capacity and quality go hand-in-hand. Considering these aspects when planning a UMTS-WCDMA radio network means to take into account the area expected to be covered, the physical forms presents on this area, the propagation conditions and the network tuning. Defining the amount and the location of Pico Node B is an important part of this process. A link budget calculation, propagation models and capacity estimation are the keys to find this amount of Pico Node B. The main results of such calculations will be the required number of cells and transceivers for the indoor system deployment. These steps are summurized in the following figure.

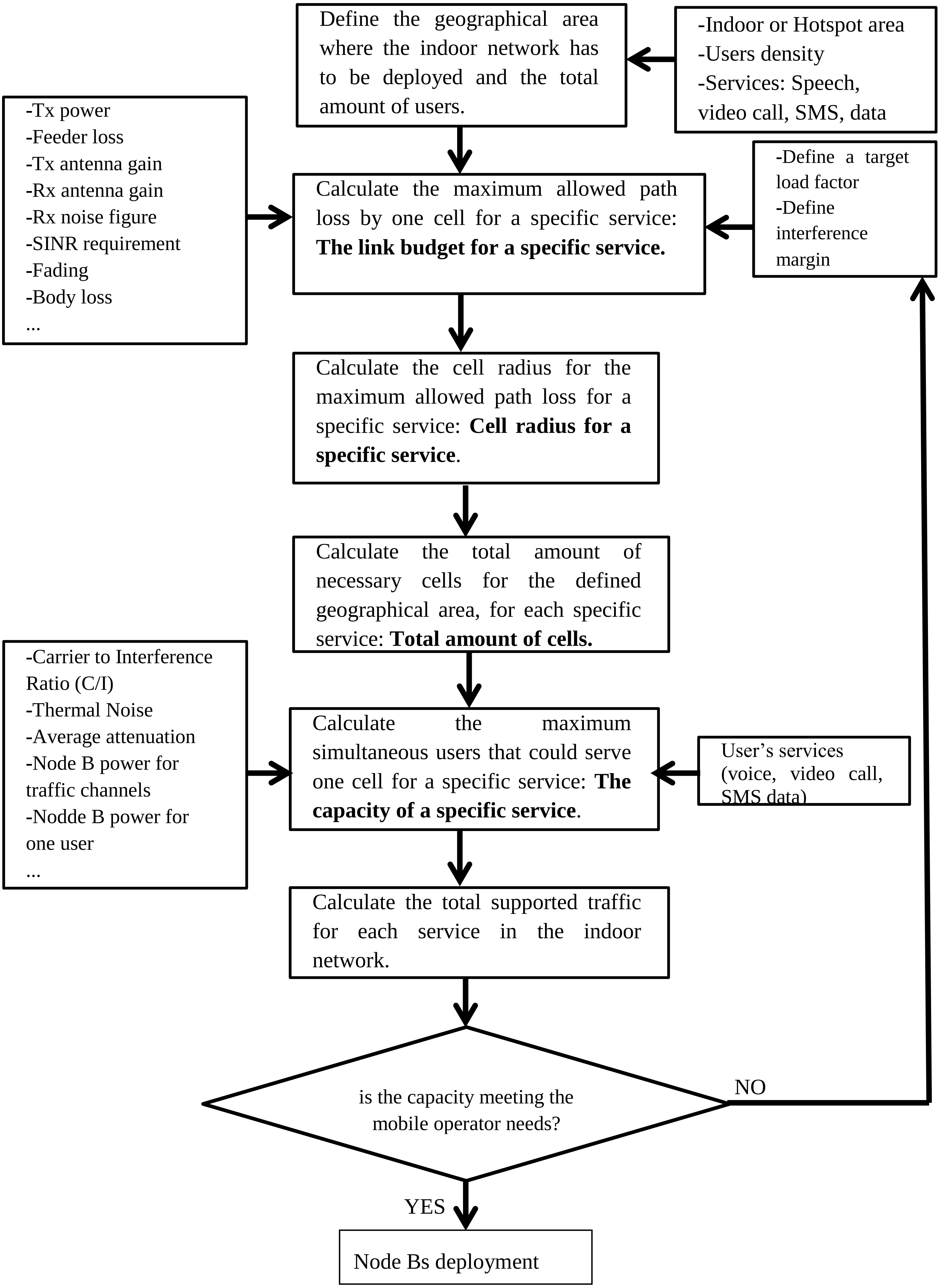


Figure 5.2 Workflow for picocell or femtocell radio network planning strategy

5.3 Deployment scenario for picocell & femtcocell

The considered area for the scenario case for picocell deployment is a building build upon 78 300 m^2 area (length: 435 m, width: 180 m). The building is a convention center with 4 floors, 3 floors are inside the building and has a total of 10 meters height. The 4th floor is outside and is the terrace. The Pico Node Bs are deployed inside the 3rd floor at the toop level and covert indoor area of the the whole building. The 4th floor is covered by the macro Node B. The average amount of mobile users in the building is assumed to be 1000.

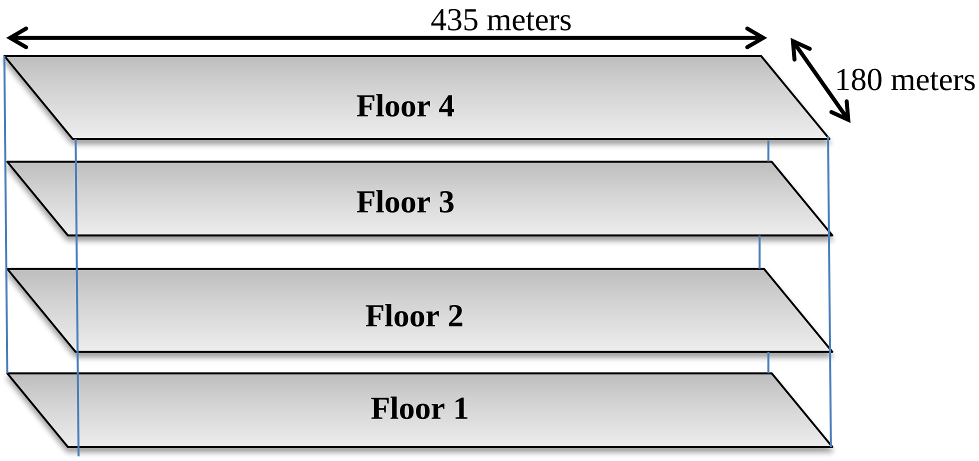


Figure 5.3 Example of building for picocell and femtocell deployment

5.3.1 Link Budget calculation and coverage estimation

The link budget calculations allows to find the maximum allowable path loss (APL) in the emitted signal strength from the Pico Node B to the User Equipment in the downlink and from the User Equipment to the Pico Node B in the uplink. For this, we need to take into account the different attenuations during the signal trip which can be produced by the distance, the environment, the cables and the antenna gains. Adding a safety margin to these calculations, a good cell ranges and coverage thresholds can be found. Coverage threshold is a downlink power budget that gives the signal strength at the cell's edge for a given location probability.

5.3.1.1 Link budget calculation for specific WCDMA services

The link budget for Pico Node B and Femto Access Point deployment are respectively detailed in Table 4.1 and Table 4.2.

Table 5.1 Link budget for Pico Node B dimensioning inside the example building.

		12,2Kbps voice, Downlink	**12,2Kbps voice, Uplink**
Target Load		**0,75**	**0,5**
Simultaneous User		**35**	
Transmitter Characteristics	Transmitter Power (mWATT)	**251,1886432**	**125**
	Transmitter Power in Traffic Channel (mWATT)	**8,133727493**	
	A: Transmitter power in Traffic Channel (dBm)	9,10289618	20,96910013
	B: Transmitter antenna gain (dBi)	8	0
	C: Transmitter cable loss (dB)	3	0
	D: Transmitter Body loss (dB)	0	3
	E: Transmitter EIRP (dBm)	**14,10289618**	**17,96910013**
Receiver Characteristics and margins	**F**: Receiver antenna gain (dBi)	0	8
	G: Thermal noise density (dBm/Hz)	-174	-174
	H: Receiver noise figure (dB)	8	5
	I: Receiver noise density (dB)	-166	-169
	J: Receiver noise power (dBm)	-100,1566878	-103,1566878
	K: Processing gain (dBm)	24,97971394	24,97971394
	L: Requiered Eb/No (dB)	7,3	4,4
	M: Interference margin (dB)	6,020599913	3,010299957
	N: Receiver requiered signal power (dBm)	**-111,8158018**	**-120,7261017**
	O: Receiver cable loss (dB)	0	3
	P: Receiver body loss (dB)	3	0
	Q: Diversity gain (dB)	0	3
	R: Fast fading margin (dB)	0	3
	S: Maximum path loss (dB)	**122,918698**	**143,6952019**
	T: Soft handover gain (dB)	1,2	1,2
	U: Shadow fading standard deviation (dB)	6	6
	V: Shadow Fading Margin(dB)	7,5	7,5
	W: Indoor penetration loss (dB)	0	0
	Allowed propagation loss (dB)	**110,618698**	**131,3952019**
	Cell radius using ITU-R P. 1238 (meter)	**59,22118167**	**291,7609733**
	Cell covered area (m^2)	**9118,585732**	**221323,6104**
	Pico Node Bs for 78 300m^2	8,586857908	0,353780601

Table 5.2 Link budget for FAP dimensioning inside the example building.

		12,2Kbps voice, Downlink	12,2Kbps voice, Uplink
Target Load		**0,75**	**0,5**
Simultaneous User		**16**	
Transmitter Characteristics	Transmitter Power (mWATT)	**100**	**125**
	Transmitter Power in Traffic Channel (mWATT)	**7,083333333**	
	A: Transmitter power in Traffic Channel (dBm)	8,502376797	20,96910013
	B: Transmitter antenna gain (dBi)	8	0
	C: Transmitter cable loss (dB)	3	0
	D: Transmitter Body loss (dB)	0	3
	E: Transmitter EIRP (dBm)	**13,5023768**	**17,96910013**
Receiver Characteristics and margins	**F**: Receiver antenna gain (dBi)	0	8
	G: Thermal noise density (dBm/Hz)	-174	-174
	H: Receiver noise figure (dB)	8	5
	I: Receiver noise density (dB)	-166	-169
	J: Receiver noise power (dBm)	-100,1566878	-103,1566878
	K: Processing gain (dBm)	24,97971394	24,97971394
	L: Requiered Eb/No (dB)	7,3	4,4
	M: Interference margin (dB)	6,020599913	3,010299957
	N: Receiver requiered signal power (dBm)	**-111,8158018**	**-120,7261017**
	O: Receiver cable loss (dB)	0	3
	P: Receiver body loss (dB)	3	0
	Q: Diversity gain (dB)	0	3
	R: Fast fading margin (dB)	0	3
	S: Maximum path loss (dB)	**122,3181786**	**143,6952019**
	T: Soft handover gain (dB)	1,2	1,2
	U: Shadow fading standard deviation (dB)	6	6
	V: Shadow Fading Margin (dB)	7,5	7,5
	W: Indoor penetration loss (dB)	0	0
	Allowed propagation loss (dB)	**110,0181786**	**131,3952019**
	Cell radius using ITU-R P. 1238 (meter)	**56,55353493**	**291,7609733**
	Cell covered area (m^2)	**8315,586013**	**221323,6104**
	FAP amount for 78 300m^2	9,416053165	0,353780601

Target Load and Simultaneous Users: These are the assuptions done for the indoor network dimensioning. Target load and simultaneous users are based on accurate prediction of service and traffic for the present and future demand. For Speech service, 12,2 Kbps, downlink target load is assumed to 0,75 and uplink target load is assume to 0,5. The maximum simultaneous users of speech service are assumed to 35.

Transmitter Power: It is the total tramsmitted power from the transmitter. The Pico node B total transmitted power is assumed to 251,1886432mWATT (24dBm). The UE total transmitted power is assumed to 125mWATT (20,969dBm) [6].

Transmitter Power in Traffic Channel: In the downlink the total transmitted power from the Node B has to be shared between many UEs. The total transmitted power for traffic channel is calculated as following [25].

$$Tx\ Power\ Traffic\ Channel = \frac{(1-Control\ Overhead) \times TransmitterPower}{Load\ target \times simultaneous\ user} \qquad (5.1)$$

The control overhead is assumed to 15% and is the power allocated for control channels management.

Transmitter antenna gain, Transmitter cable loss, Transmitter Body loss: There are respectively the gain generated by the transmitter antenna, the loss due to the cable from the Node B site to the antenna and the loss produce by the humain body as an obstacle between the UE and the Node B.

Transmitter (Equivalent Isotropic Radiated Power) EIRP: It is the absolute power radiated by the antenna and it is equal to $A + B - C - D$ (refer to Table 4.1 and 4.2).

Thermal noise density, Receiver noise figure: There are respectively the noise relatead to the used bandwidth, the temperature and the noise related to the amplifiers and electronics inside the receiver.

Receiver noise density: Sum of thermal noise density and receiver noise figure.

Receiver noise power: Equal to receiver noise density x chip rate. In dBm values it is receiver noise density + 10 log (3 840 000).

Processing gain: Chip rate divided by the user bit rate.

Interference margin: Related to the target load and is equal to -10log (1-Target load).

Receiver requiered signal power: Represents the weakest signal that can be received by the receiving antenna. It is equal to $J - K + F + L + M$ (refer to Table 4.1 and 4.2).

Maximum path loss: Maximum path loss that could support a communication between the UE and the Node B under the study's assumptions, equal to *E– N+Q+H– O – P– R* (refer to the Table 4.1 and 4.2).

Allowed propagation loss: Pathloss that fulfill the network design criteria. It is equal to: *S + T – V – W – X* (refer to the Table 4.1 and 4.2).

The allowed propagation loss for different WCDMA services using Pico Node B and Femto Access Point in the example building are respectively summurazed in Table 5.3 and Table 5.4.

Table 5.3 Allowed propagation loss between the Pico Node B and the UE

Services	Simultaneous users	Target loads	Pico Node B Tx power	UE Tx power	Allowed propagation loss (dB)
Voice 12,2 Kbps	35	Downlink 75% Uplink 50%	24dBm	20,969 dBm	Downlink: **110,618** Uplink: **131,395**
CS 64 Kbps	15	Downlink 75% Uplink 50%	24dBm	24dBm	Downlink: **112,50** Uplink:**128,40**
PS 64 Kbps	15	Downlink 75% Uplink 50%	24dBm	24dBm	Downlink: **113,6** Uplink:**131,607**
PS 128 Kbps	8	Downlink 75% Uplink 50%	24dBm	24dBm	Downlink: **114,119** Uplink:**129,197**
PS 384 Kbps	4	Downlink 75% Uplink 50%	24dBm	24dBm	Downlink: **111,759** Uplink:**124,125**

*See appendix-A for calculations details

Table 5.4 Allowed propagation loss between the FAP and the UE

Services	Simultaneous users	Target loads	FAP Tx power	UE Tx power	Allowed propagation loss (dB)
Voice 12,2 Kbps	16	Downlink 75% Uplink 50%	20dBm	20,969 dBm	Downlink: **110,018** Uplink: **131,395**
CS 64 Kbps	8	Downlink 75% Uplink 50%	20dBm	24dBm	Downlink: **111,23** Uplink:**128,407**
PS 64 Kbps	8	Downlink 75% Uplink 50%	20dBm	24dBm	Downlink: **112,33** Uplink:**131,607**
PS 128 Kbps	4	Downlink 75% Uplink 50%	20dBm	24dBm	Downlink: **113,13** Uplink:**129,197**
PS 384 Kbps	2	Downlink 75% Uplink 50%	20dBm	24dBm	Downlink: **110,769** Uplink:**124,125**

*See appendix-A for calculations details

5.3.1.2 Coverage estimation for specific WCDMA services

The link budget goal was to provide the necessary inputs for the estimation of the amout of Pico Node B or FAP to cover the whole building. For this purpose we will use the indoor propagation model ITU-R P.1238 poposed in [23] for our calculations.

The path loss for ITU-R P.1238 is:

$$L_{total} = 20 \log10 f + N \log_{10} (d) + L_f (n) - 28 \text{ dB} \qquad (4.2)$$

where:

(***N***) : the distance power loss coefficient according to the indoor environement; for our study the value of (***N***) is 30.

(***f***) : the frequency (MHz); for our study the value of (***f*** *)* is 2100.

(***d***) : separation distance in metter between the base station and UE, $d > 1$.

(***n***) : number of floors between base station and portable terminal, $n \geq 1$; for our study the value for (***n***) is 2.

(***Lf***) : floor penetration loss factor (dB); For our study $L_f(n)=15+4(n-1)=15+4(2-1)= 19$

Thus the cell radius is calculated as following:

$$d = 10^{\left(\frac{L_{total} - 20\log(2100) - 19 + 28}{30}\right)} \qquad (4.3)$$

For a cell of hexagonal shape covered by an antenna, the coverage area can be approximated as $2{,}6 \times d^2$ [7]. Thus the total amont of required Pico Node B to covert the area of 78 300 m^2 for the building is equal to $78\,300 / 2{,}6{\times}d^2$ (4.4)

The cell radius and the amount of Pico Node B and Femto Access Point needed to cover the building for differents services in the example building are respectively summarized in Table 4.5 and Table 4.6.

Table 5.5 Picocell radius and covered area. Amount of PNB to cover the building.

Services	**Cell radius (m)**	**Cell covered area (m^2)**	**Amount of Pico Node B to cover 78300m^2** (435 m×180 m)
Voice 12,2 Kbps	Downlink:**59,221** Uplink:**291,760**	Estimation in the downlink: **9 118,585**	Estimation in the downlink:**8,58** Approximately **9 Pico Node Bs**
CS 64 Kbps	Downlink:**68,422** Uplink:**231,969**	Estimation in the downlink: **12 172,092**	Estimation in the downlink:**6,43** Approximately **7Pico Node Bs**
PS 64 Kbps	Downlink:**74,449** Uplink:**296,549**	Estimation in the downlink: **14 411,148**	Estimation in the downlink:**5,43** Approximately **6 Pico NodeBs**
PS 128 Kbps	Downlink:**77,479** Uplink:**246,464**	Estimation in the downlink: **15 607,958**	Estimation in the downlink:**5,01** Approximately **6 Pico Node Bs**
PS 384 Kbps	Downlink:**64,638** Uplink:**166,998**	Estimation in the downlink: **10 863,053**	Estimation in the downlink:**7,20** Approximately **8 Pico Node Bs**

*See appendix-A for calculations details

Table 5.6 Femtocell radius and covered area. Amount of FAP to cover the building.

Services	**Cell radius (m)**	**Cell covered area (m^2)**	**Amount of FAP to cover 78300m^2** (435 m×180 m)
Voice 12,2 Kbps	Downlink:**56,553** Uplink:**291,760**	Estimation in the downlink: **8 315,586**	Estimation in the downlink:**9,41** Approximately **10 FAP.**
CS 64 Kbps	Downlink:**62,067** Uplink:**231,969**	Estimation in the downlink: **10 016,117**	Estimation in the downlink:**7,81** Approximately **8 FAP.**
PS 64 Kbps	Downlink:**67,535** Uplink:**296,549**	Estimation in the downlink: **11 858,582**	Estimation in the downlink:**6,6** Approximately **7 FAP.**
PS 128 Kbps	Downlink:**71,811** Uplink:**246,464**	Estimation in the downlink: **13 408,064**	Estimation in the downlink:**5,83** Approximately **6 FAP.**
PS 384 Kbps	Downlink:**59,909** Uplink:**166,998**	Estimation in the downlink: **9 331,939**	Estimation in the downlink: **8,39** Approximately **9 FAP.**

*See appendix-A for calculations details

As we can see, the cell radius is limited for downlink estimations. Uplink estimation gave bigger cell radius because the main input that is the UE power does not change for all kind of cells (macrocell, picocell or femtocell). Also the other inputs involved in uplink link budget do not produce great changes because the UE is assumed being indoor without many interferences and loss. Thus the uplink estimation can be used in the case of macrocell dimensioning where it could allow a good comparison with the downlink estimation.

For our study we will estimate the cell radius from the downlink link budget where the Node B transmitter power will be related to the typical cases of picocell and femtocell.

5.3.2 Traffic and capacity estimation

The capacity of each Node B that will be deployed inside the building is predicted through estimations based on the actual traffic and possible futur traffic. The capacity estimation allows the mobile operator to define a objective strategy about the possible sectorisation of each cell with respect to the traffic demand in its covered area. Capacity estimation include:

- downlink scrambling code planning,
- antenna height estimation,
- traffic estimation.

5.3.2.1 Downlink scrambling code

UMTS-WCDMA network does not use the frequency re-use plan like GSM since all the cell are emitting at the same frequency. The only way to separate the different transmitters, receivers and their data is the use of channelization and scrambling codes. In the downlink, orthogonal channelization codes are used to distinguish between data and control channels from the same Pico Node B or FAP. In the uplink they are used to distinguish between data channels from the same User Equipment. It could happen that adjacent Pico Node Bs, FAP or User Equipments use the same orthogonal channelization codes. In such scenario the difference between them is assured by the use of scrambling codes.

There is no need for plan channelization and uplink scrambling code because they are managed by the Radio Network Controler (RNC). The allocation of those codes is a simple task since every RNC has a big set of codes that are unique to it. However it is important to plan the downlink scrambling codes because it is limited and only possible to allocate 512 downlink scrambling codes [19].

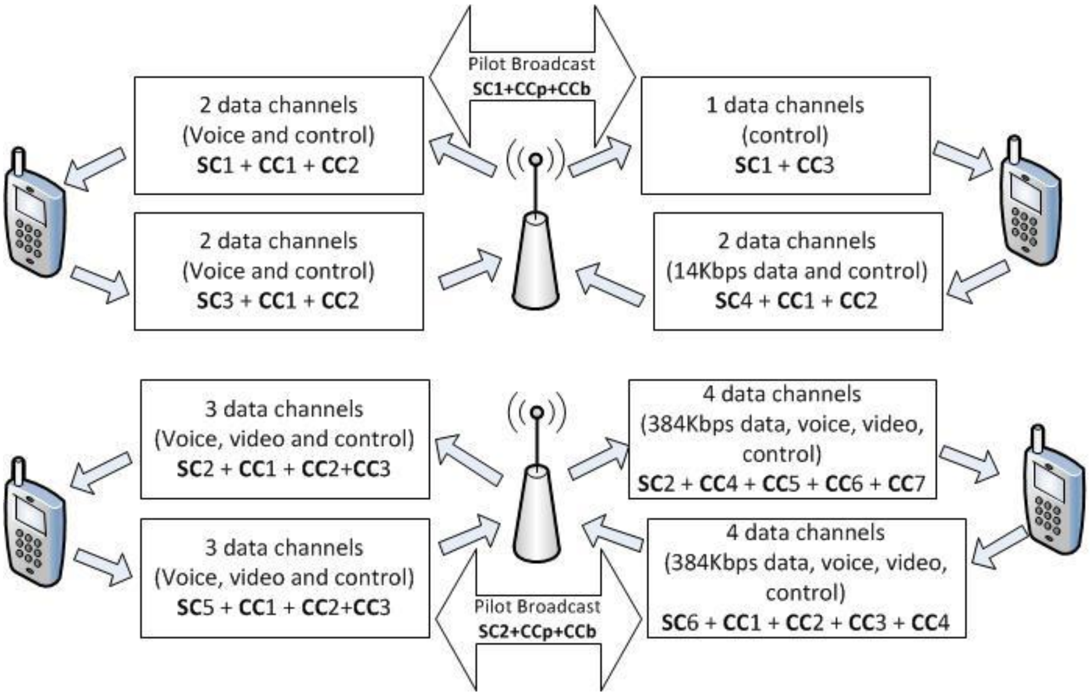


Figure 5.4 Scrambling and Channelization code use in WCDMA radio network
SC = Scrambling code, CC=Channelization code

Each cell within the radio network must be assigned one primary scrambling code. The fundamental requirement for scrambling code planning is isolation between cells which are assigned the same scrambling code. This isolation should be enough great to ensure that a UE never simultaneously receives the same scrambling code from more than a single cell. That means that scrambling code planning should be done according to the cell's neighbor list planning to ensure that neighboring cells will never implement duplicate scrambling codes.

There are two methods to implement downlink scrambling code [20]:

- Cluster reuse-based method
- Graph coloring-based method

5.3.2.1.1 Cluster reuse-based method

Cluster reuse-based planning assigns scrambling code sets according to a pre-determined code set reuse pattern. The total cells in the network are divided into clusters and every cluster will contain a fix amount of cells. The amount of cell in a cluster is recommended to be 8 in order to define 64 possible different clusters that could be repeated to cover the whole network [19]. However the amount of cell in a cluster could change with respect to the following formulas [20].

$$Number\ of\ cell\ in\ a\ cluster\ > \frac{R_{max}^2}{3R_{min}^2} \times \left(1 + 10^{\frac{PG_{dB}}{10\alpha}}\right)^2 \tag{4.5}$$

(R_{max}) is the radius of the biggest cell. (R_{min}) is the radius of the smallest cell.

(PG_{dB}) is the processing gain in dB scale and (α) is the path loss exponent.

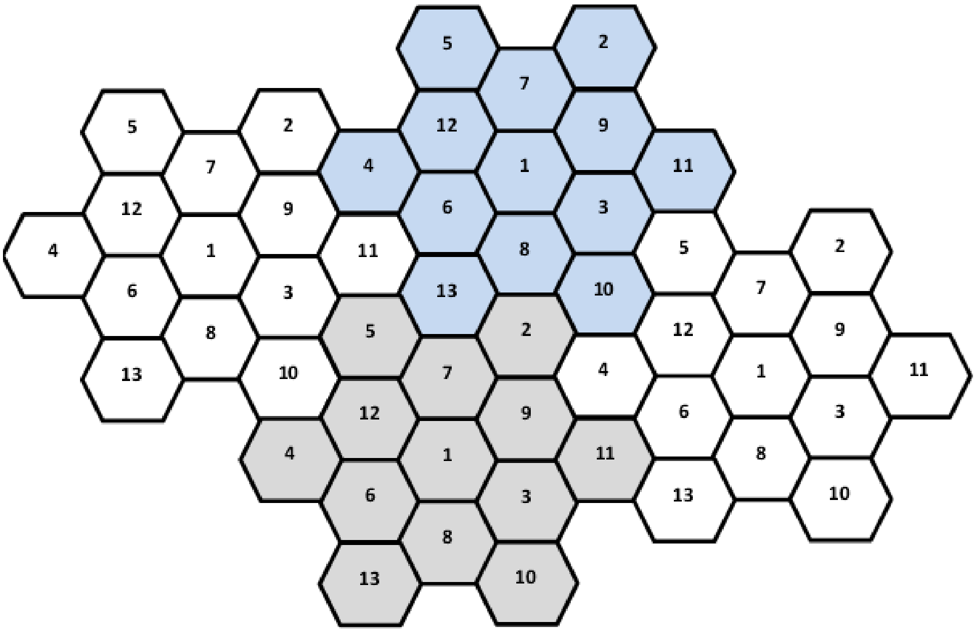


Figure 5.5 Cluster reuse-based scrambling code planning. The number assigned to each cell is the scrambling code index.

5.3.2.1.2 Graph coloring-based method

Graph coloring considers a problem of assigning a color to each Node B in a graph [20].

It is a random allocation of scrambling code from any code set separately to each cell in order to cover the whole network. This method takes into account the precise geographical position of any Node B and the distance between this one and its neighbors. It requires exhaustive information and computation through heuristic algorithms to find the optimal solution when allocating scrambling codes.

5.3.2.2 Average antenna height

Considered from transmitters and receivers, the average antenna height is the base of a cellular network. If the average height of antennas in an area is high, it will lead signals travelling a long distance with a great probability of interference.

However a low average antenna height will reduce the probability of interference and will lead to the creation of more cells. A compromise average height, based on the interference analysis, topography and propagation conditions will alway be necessary for a good coverage and capacity planning.

5.3.2.3 Traffic estimation

The traffic in the network is related to the user dedicated mode rate and movements in the covered area. The traffic is estimated from a model based on statistical datas of existing networks (the traffic experience of many previous network). Traffic estimation in the network is given in terms of ‘erlangs’ and allows to know how much one user in dedicated mode occupies the radio resource in term of amount of traffic during one hour, when the request of the radio resource is at maximum: one Erlang (1 Erl).

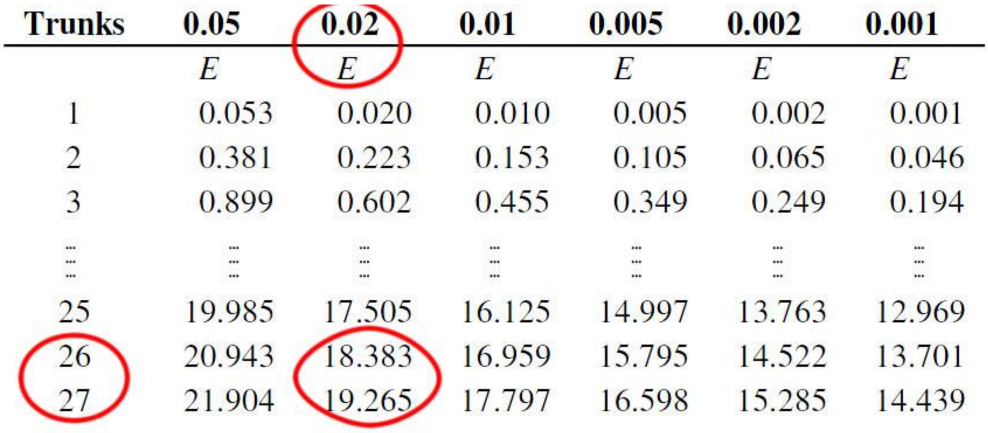
The second term frequently used for traffic estimation process is ‘blocking’. Blocking describes the situation when because of lack of radio resources, the network system blocks a user who is trying to get the dedicated mode. The traffic flowing in the network can be predicted by the commonly used Erlang B or Erlang C tables.

Erlang B assumes that a call is rejected when there is lack of radio resources when Erlang C considers that this call will not be rejected but will wait in a queue till the resource became available [18]. In our thesis work we will consider Erlang B for the traffic prediction because it fit with the blocking reality of the mobile network available in Turkey where our study is done. Let us estimate the amount of required channels to support 1000 users in the building for average call duration of 2,8 minutes. We assume Busy Hour Call Attempts (BHCA) for speech service is 0,42 and call blocking is 0,2.

$$Speech\ traffic\ for\ one\ user = 0{,}42\ \times \left(\frac{2{,}8\ minutes}{60\ minutes}\right) = 0{,}019\ Erlangs \tag{4.6}$$

$$Speech\ traffic\ for\ the\ indoor\ system = 1000\ \times 0{,}019 = 19\ Erlangs \tag{4.7}$$

Using Erlang B table, 19 Erlang for 2% GOS requiered minimum 27 duplex channels.



Trunks	0.05	0.02	0.01	0.005	0.002	0.001
	E	*E*	*E*	*E*	*E*	*E*
1	0.053	0.020	0.010	0.005	0.002	0.001
2	0.381	0.223	0.153	0.105	0.065	0.046
3	0.899	0.602	0.455	0.349	0.249	0.194
⋮	⋮	⋮	⋮	⋮	⋮	⋮
25	19.985	17.505	16.125	14.997	13.763	12.969
26	20.943	18.383	16.959	15.795	14.522	13.701
27	21.904	19.265	17.797	16.598	15.285	14.439

Figure 5.6 An example of using Erlang B table. *(The full table is available in Appendix-A)*

5.3.2.4 Capacity calculation for Pico Node B

In the previous example of section 3.1.3 we presented the method to find the necessary amount of duplex channels needed for 1000 users in the convention center's building with respect to their traffic demand. The output of this example gave us the information that the indoor Pico Node B should at least provide 27 duplex channels. In reality a Pico Node B can provide more than 27 duplex channels. The next question that could give us more precisions in the capacity of this Pico Node B from our previous example is: how much, maximum simultaneous duplex channels could the Pico Node B provide to its covered area when the demand become huge? In another words, how much maximum simultaneous users can carry the Pico Node B in case of very huge demand? In the following example of this section we will estimate the maximum simultaneous users according to available channelization code and according to the power from the Pico Node B.

5.3.2.4.1 Capacity calculation in the downlink, according to available channelization code.

The flow rate experimented by one user depends on the spreading factor corresponding to the channelization code allowed to him/her.

Table 5.7 Downlink user data rate and spreading factor [7]

Spreading Factor	**Channel symbol rate**	**Channel bit rate**	**Maximum User data rate**
512	7,5 Kbps	15 Kbps	**1-3 Kbps**
256	15 Kbps	30 Kbps	**6-12 Kbps**
128	30 Kbps	60 Kbps	**20-24 Kbps**
64	60 Kbps	120 Kbps	**45 Kbps**
32	120 Kbps	240 Kbps	**105 Kbps**
16	240 Kbps	480 Kbps	**215 Kbps**
8	480 Kbps	960 Kbps	**456 Kbps**
4	960 Kbps	1920 Kbps	**936 Kbps**
4, with 3 parallel codes	2880 Kbps	5760 Kbps	**2,8 Mbps**

From the previous table, ***Table 3.7***, we assume a spreading factor (SF=128) for speech services (minimum 12,2Kbps for user bit rate). It means that for only speech service the possible simultaneous channelization code amount is 128.

From this value we will take 4 codes (SF=128), i.e. 8 codes (SF=256). These 8 codes (SF=256) are used to fulfill the exchanges over the seven common channels with spreading factor (SF=256) as explained in chapter 3 section, 2. Thus the total amount of possible simultaneous channelization code is 124, only for speech service. By applying a blocking of 2% with Erlang B table we finally have 111,324 possible simultaneous connections. We do the same with other services and the have the results in the following table.

Table 5.8 Maximum simultaneous connections according to available channelization code, only UMTS-WCDMA (R99) on the frequency.

Services	**Spreading factor (SF)**	**Number of simultaneous connections**	**Traffic for 2% blocking (Erlang B)**
Voice 12.2 kbps	128	(128 - 4) = 124 *	**111.324**
PS 16 kbps	128	(128 - 4) = 124 *	**111.324**
CS 64 kbps	32	(32 - 1) = 31 **	**22.827**
PS 64 kbps	32	(32 - 1) = 31 **	**22.827**
PS 128 kbps	16	(16 - 1) = 15 ***	**9.010**
PS 384 kbps	8	(8 - 1) = 7 ****	**2.935**

**** 7 codes (SF = 256) will be used for common channels. That correspond to 4 codes (SF = 128).***

***** One code (SF = 32) that correspond to 8 codes (SF = 256) will be used for the common channels.***

****** One code (SF = 16) that correspond to 16 codes (SF = 256) will be used for common channels.***

******* One code (SF = 8) that correspond to 32 codes (SF = 256) will be used for common channels.***

We now assume that both UMTS-WCDMA (R99) and HSDPA 5 codes are deployed in the network. Five codes (SF=16) will be used for HDSPA, it will remain eleven codes (SF=16) for UMTS-WCDMA (R99), for the common channels and for signaling.

11 codes (SF = 16) ⬄ 11 x 2 codes (SF = 32), **so a total of 22 codes (SF=32)**

⬄ 11 x 2 x 2 codes (SF = 64), **so a total of 44 codes (SF=64)**

⬄ 11 x 2 x 2 x 2 codes (SF = 128), **a total of 88 codes (SF=128)**

As it is detailed in the chapter 3 section2, let now estimate the codes used for the common channels and signaling.

$$\begin{cases} \mathbf{4}\ \boldsymbol{codes}\ (\boldsymbol{SF} = \mathbf{128}) for\ the\ 4\ \ HS - SCCH\ channels \\ \mathbf{4}\ \boldsymbol{codes}\ (\boldsymbol{SF} = \mathbf{128})\ that\ correspond\ to\ 8\ codes\ (SF = 256)\ for\ commons\ channels \\ \mathbf{2}\ \boldsymbol{code}\ (\boldsymbol{SF} = \mathbf{128})\ that\ correspond\ to\ 4\ codes\ (SF = 512)\ for\ the\ \ signalisation\ channels\ related\ to\ each\ UE \end{cases}$$

It will be a total of **4 + 4 + 2 = 10 codes (SF = 128)** that correspond to **2.5 code (SF = 32)** so **2 codes (SF = 16) for the common channels and signaling**. The calculations results are summarize in the following table.

Table 5.9 Maximum simultaneous connections according to available channelization code, both UMTS-WCDMA (R99) and HSDPA on the frequency.

Services	Spreading factor (SF)	Number of simultaneous connections	Traffic for 2% blocking (Erlang)	Maximum Throughput for 5 codes HSDPA
Voice 12.2 kbps	128	(88 - 10) = 78 *	**66.771**	**QPSK:** 1.8 Mbit/s peak data rates **16 QAM:** 3.6 Mbit/s peak data rates.
PS 16 kbps	128	(88 - 10) = 78 *	**66.771**	
CS 64 kbps	32	18**	**11.491**	
PS 64 kbps	32	18**	**11.491**	
PS 128 kbps	16	9***	**4.345**	
PS 384 kbps	8	4 ****	**1.092**	

*** 10 codes (SF = 128) for commons channels and signaling***

**** 2 code (SF = 16) out of 11 codes (SF = 16) give 9 codes (SF = 16) that correspond to 18 codes (SF =32).***

***** 2 code (SF = 16) out of 11 codes (SF = 16) give 9 codes (SF = 16).***

****** 11code (SF =16) correspond to 5 codes (SF = 8). One code (SF = 8) will be used for HS-SCCH and common channels. It will remain 4 codes (SF = 8).***

5.3.2.4.2 Capacity calculation in the downlink, according to available power from Pico Node B.

In UMTS-WCDMA, the Node B's total power in the downlink is divided into two parts, one part (P_{CCH}) is the power used for signaling and common control channels. The second part is for the Dedicated Physical Channels (DPCH).

P_{CCH} power is generally around 15% of the total Node B's power budget and can be modeled as a constant. Thus for a total of "*n*" users, we have the following equation, expressing the total transmit power from the Node B [21, 22].

$$P_{total} = \sum_{n=1}^{N} \nu \times P_n + P_{CCH} \tag{4.8}$$

(P_n) is the allocated power to UE number "*n*" and "*N* " is the total amount of UE served by the Node B of the considered cell. We assume a perfect power control and that all the UE can reach the target $\frac{E_b}{N_0}$ value, so $\left(\frac{E_b}{N_0}\right)_n \approx \left(\frac{E_b}{N_0}\right)_{target}$. The SINR will give [21]:

$$\left[\frac{E_b}{N_0}\right] \times \frac{R_n}{W} = SINR = \frac{P_n \times g_n}{(1-\alpha)(P_{intracell} - (P_n \times g_n)) + P_{intercell} + P_N} \tag{4.9}$$

The required transmit power (P_n) for UE "*n*" can then be expressed like [21]:

$$P_n = \frac{SINR}{1+(1-\alpha)SINR}\left[\left(1-\alpha+f_{DL,n}\right)P_{total} + \frac{P_N}{g_n}\right] \tag{4.10}$$

$$Average\ SINR = \frac{SINR}{1+(1-\alpha)SINR} \approx SINR \tag{4.11}$$

$$P_n = SINR \times \left[\left(1-\alpha+f_{DL,n}\right)P_{total} + \frac{P_N}{g_n}\right] \tag{4.12}$$

Where

- $\boldsymbol{\nu}$ is the activity factor for user "*n*" . We will consider an average value for all the users for equation simplification.
- $\boldsymbol{\alpha}$ is the orthogonality factor.
- $\boldsymbol{f_{DL,n}}$ is the other-over-own cell received power ratio. We will consider an average value for all the users and we will note it $\boldsymbol{f} = \frac{Interference\ from\ other\ cells}{Interference\ from\ own\ cell}$

- $\boldsymbol{P_{total}}$ is the total power from the E-Node.
- $\boldsymbol{P_N}$ is the AWGN power
- $\boldsymbol{g_n}$ is the link gain for UE "n". It is related on the distance separating the UE "n" to the considered E-Node. We will consider an average value for all the users and we will note it $\boldsymbol{g}$. We remark that the inverse of g, noted $\left(\boldsymbol{\frac{1}{g} = L}\right)$ is an attenuation.
- $\boldsymbol{R_n}$ is the user rate and **W** is the chips rate.

Let now give the expression of (P_{total}) in equation (4.8), considering handover effect, no intracell interference, no intercell interference and replacing (P_n) by its expression in equation (4.12).

- ➢ We consider handover effect.

For users in soft hand-over, the $\text{SINR}_{\text{target}}$ value will be decreased to allow them to get a continuous good connection with the Node B, otherwise they could be dropped by this one. We denote by "p" the percentage to which the $\text{SINR}_{\text{target}}$ is decreased, the soft handover gain.

$\text{SINR}_{\text{target}}$ (for UE non in soft handover) = $\text{SINR}_{\text{target}}$ (for a UE in soft handover) + Soft handover gain. ***(These values are in dB)*** (4.13)

In percentage we will have:

$\text{SINR}_{\text{target}}$ = 100% so 1

$\text{SINR}_{\text{target}}$ (for user non in soft hand over) = 1 + p (4.14)

A typical value for "p" can be 30%

To manage the important increase of signaling due to the presence of soft handover, a supplementary power from the Node B will be dedicate to common control channel with the percentage "β".

So $P_{CCH} = \beta \times P_{max}$ (4.15)

P_{max} is the maximum power from the Node B. When the Node B reach its maximum power, $P_{total} = P_{max}$

- We consider no intracell interference: $\alpha = 0$
- We consider no intercell interference, interference from other cells = 0, so $f = 0$

The expression of (P_n) in equation (4.12) becomes:

$$P_n = SINR \times \left[P_{total} + \frac{P_N}{g}\right] \tag{4.16}$$

The effect of soft handover is taken into account and we replace (P_{CCH}) by its expression in equation (4.8):

$$P_{total} = P_{max} = \sum_{n=1}^{N}(1+p) \times \nu \times P_n + (\beta \times P_{max}) \tag{4.17}$$

$(1+p) \times \nu \times P_n$ is the power dedicated to user "*n*" when considering the handover.

$(\beta \times P_{max})$ is the power dedicated to common channels and signaling when considering the handover.

$$(1-\beta)P_{max} = \sum_{n=1}^{N}(1+p) \times \nu \times P_n = \sum_{n=1}^{N}(1+p) \times \nu \times SINR \times \left[P_{max} + \frac{P_N}{g}\right] \tag{4.18}$$

$$(1-\beta)P_{max} = N \times \nu \times (1+p) \times SINR \times \left[P_{max} + \frac{P_N}{g}\right] \tag{4.19}$$

We solve for P_{max}

$$P_{max} = \frac{N \times \nu \times (1+p) \times SINR \times P_N}{g \times (1-\beta)} \tag{4.20}$$

The expression of (P_{max}) in equation (4.20) is the necessary maximum power from Node B in the presence of ANWG noise only. By comparing equation (4.20) with the expression of (P_{max}) when considering the intracell and intercell interferences, we will be able to find the expression of interference margin. From the interference margin we can so deduce the downlink load expression that will allow us to find the maximum simultaneous connections.The equation considering interferences from other cells gives:

$$(1-\beta)P_{max} = \sum_{n=1}^{N}(1+p) \times \nu \times SINR \times \left[(1-\alpha+f)P_{max} + \frac{P_N}{g}\right] \tag{4.21}$$

$$(1-\beta)P_{max} = (1+p) \times N \times \nu \times SINR \left[\times (1-\alpha+f)P_{max} + \frac{P_N}{g}\right] \tag{4.22}$$

We solve for P_{max}

$$P_{max} = \frac{\frac{(1+p)\times N\times v\times SINR \times \frac{P_N}{g}}{(1-\beta)}}{1-\frac{(1+p)\times N\times v\times SINR \times(1-\alpha+f)}{(1-\beta)}} \tag{4.23}$$

The numerator of this equation represents the necessary maximum power from the Node B in the presence of ANWG noise only. See equation (4.20).

The denominator of this equation is the necessary maximum power increase cause by the presence of interferences from surrounding cells. It represents the interference margin. From the interference margin we can also deduce the downlink load expression [7, 22].

$$P_{max} = \frac{\frac{(1+p)\times N\times v\times SINR \times \frac{P_N}{g}}{(1-\beta)}}{1-Downlink\ load} \tag{4.24}$$

$$\text{Downlink load} = \frac{(1+p)\times N\times v\times SINR \times(1-\alpha+f)}{(1-\beta)} \tag{4.25}$$

We also deduce 2 possible equations for simultaneous users' number taking into account soft handover effect as follow (See equation 4.10 and 4.18):

$$N = \frac{(1-\beta)P_{max}}{(1+p)\times v\times P_n} \tag{4.27}$$

$$P_n = \frac{SINR}{1+(1-\alpha)SINR}\left[(1-\alpha+f)P_{max} + \frac{P_N}{g}\right]$$

$$= \frac{SINR}{1+(1-\alpha)SINR}\left[(1-\alpha+f)P_{max} + P_N \times L\right] \tag{4.28}$$

$$N = \frac{\text{Downlink load}\times(1-\beta)}{(1+p)\times v\times SINR \times(1-\alpha+f)} = \frac{\text{Downlink load}\times(1-\beta)}{(1+p)\times v \times SINR_{linear}\times(1-\alpha+f)} \tag{4.29}$$

SINR value in equation (4.29) should be linear. It is calculated taking into account the soft handover gain (G_{sh}) as explained above.

$$SINR_{linear} = 10^{\frac{(SINR-Gsh)}{10}} \tag{4.30}$$

We will refer in the rest of this example equation (4.27) as Formula 1 and equation (4.29) as formula 2 when making the calculation for "*N*".

Table 5.10 Assumptions for the Pico Node B deployed in the building

UE distribution	100% indoor in office area (convention center)
Picocell's size and environment	70 m radius. UE in dense building moving at 3km/h The building has 4 floors and the Pico Node B is located at the top of the 3rd floor, serving the 1rst, the 2nd and the 3rd floor's users.
Propagation model [23]	ITU-R P.1238
Path Loss	Loss = $20 \log_{10}(f) + N \log_{10}(d) + L_f(n) - 28$
Path loss parameters [23]	f, (frequency in MHz) = 2100 N, distance power loss coefficient (value for a big oficce area) = 30 d, (distance separation between Node B and UE in meters) = average value of 70 m n, (number of floors between Node B and UE) =2 So $L_f(n) = 15+4(n-1) = 19$
Pico Node B maximum power in one frequency	P_{max} = 24dBm = -6 dB =250 mW =0,25W
% of Node B maximum power for common channels	β = 20% = 0,2
% of Node B maximum power for dedicated channels	Downlink load = 80% = 0,8
Mean Other Cell Interference Factor	f = 0,65
Orthogonality factor	α = 90% = 0,9
Percentage of EU in soft handover	P = 30% = 0,3
Percentage of UE using 3G+ services in the network	75% = 0,75
Percentage of UE using 3G services in the network	25% = 0,25
Activity factor for voice and videophone services	ν = 0,67
Activity factor for data services	ν = 0,2
Antenna gain	8 dBi
Average gain on DL Eb/No due to Soft Handover	1,2dB
Feeder loss	3 dB
Average attenuation for the indoor UE*	$20\log_{10}(2100) + 30\log_{10}(70)+19-28+3$ =**115,79 dB**
Average attenuation without antenna gain	115,79 – 8 = **107,79 dB**

**Average attenuation for indoor UE = PL (cell diameter / 2) + feeder loss*

** We subtract the antenna gain from attenuation to deduce the required power from the Node B to achieve the target SINR*

- **Example of calculation with Speech service (12,2 Kbps).**

<u>Imputs</u>: Eb/No for speech (3Km/h) = 7,3 dB

Thermal Noise Density = -174 dBm/Hz

Mobile Noise Figure = 5 dB

Body loss = 3dB

1- **Carrier to interference ratio before despreading in dB (C/I)**

$$\frac{C}{I} = 7{,}3 - \left(10\log\left(\frac{3840}{12{,}2}\right)\right) = -17{,}68\ dB$$

2- **Thermal Noise (Receiver noise power) in dBm**

$$Thermal\ Noise = -174 + 10\log(3840000) + 5 = -103{,}16\ dBm$$

3- **Total average attenuation within the cell for one UE in dB**

$$Average\ attenuation\ for\ one\ UE = 3 + 107{,}79 = 110{,}79\ dB$$

4- **Node B power for traffic channels in watts**

$$Node\ B\ power\ for\ traffic\ channels = (1 - 0{,}2) \times 0{,}25 = 0{,}2\ Watts$$

5- **Node B power for one channel, transmit power per link, for one user**

$$SINR_{linear}\ (taking\ the\ handover\ into\ account) = 10^{((-17{,}68-1{,}2)/10)}$$

$$1 + (1-\alpha)SINR_{linear} = 1 + (1 - 0{,}9) \times 10^{((-17{,}68-1{,}2)/10)}$$

$$\left(1-\alpha+f_{DL,n}\right)P_{max} + P_N \times Attenuation = (1 - 0{,}9 + 0{,}65) \times 0{,}25 + 10^{((-103{,}16+110{,}79)/10)\times 10^{-3}}$$

PS: $P_N \times Attenuation = 10^{((-103{,}16+110{,}79)/10)\times 10^{-3}}$. We have a sum here because the values are in dB. We sum (P_N) and attenuation in dB value; we take the linear value of the result and convert it into Watts. So the power from the Node B for one UE is:

$$\frac{10^{((-17{,}68-1{,}2)/10)}}{1 + (1-0{,}9) \times 10^{((-17{,}68-1{,}2)/10)}} \times \left[(1 - 0{,}9 + 0{,}65) \times 0{,}25 + 10^{((-103{,}16+110{,}79)/10)\times 10^{-3}}\right]$$
$$= 0{,}00249\ Watts$$

6- **Maximum simultaneous transmission with formula 1, activity factor = 0,67:**

$$N = \frac{0{,}2}{0{,}00249 \times (1+0{,}3) \times 0{,}67} = 92{,}21$$

7- **Maximum simultaneous transmission with formula 2, activity factor = 0,67:**

$$N = \frac{0{,}8 \times (1-0{,}2)}{(1+0{,}3) \times 0{,}67 \times (1 - 0{,}9 + 0{,}65) \times 10^{((-17{,}68-1{,}2)/10)}} = 75{,}17$$

We take the minimum of the two results from the two formulas to find the real user number served by the Pico Node B. Thus the Maximum simultaneous transmission that can carry the Pico Node B is 75. We do the same calculation with the other services and we have the results of the following tables. ***See appendix-A for calculations details***.

Table 5.11 Maximum simultaneous connections according to Pico Node B maximum power. Only UMTS-WCDMA (R99) on the frequency (Activity factor = 1)

Services	**Number of simultaneous connections**	**Traffic for 2% blocking (Erlang)**
Voice 12.2 kbps	61	**50.589**
CS 64 kbps	20	**13.182**
PS 64 kbps	26	**18.383**
PS 128 kbps	15	**9.010**
PS 384 kbps	4	**1.092**

See appendix-A for calculation's details

Table 5.12 Maximum simultaneous connections according to Pico Node B maximum power. Both UMTS-WCDMA (R99) (25% of Node B power) and HSDPA (75% of node B power) on the frequency (Activity factor = 1)

Services	**Number of simultaneous connections**	**Traffic for 2% blocking (Erlang)**
Voice 12.2 kbps	15	**9,010**
CS 64 kbps	5	**1,657**
PS 64 kbps	6	**2,276**
PS 128 kbps	4	**1,092**
PS 384 kbps	1	**0,020**
PS 512 Kbps (HDPA only)	3	
PS 1024 Kbps (HSDPA only)	1	

See appendix-A for calculation's details

Table 5.13 Comparison between capacity according to code and according to the Pico Node B transmittted power. Only UMTS-WCDMA (R99) is deployed in the frequency.

Services	CODE Simultaneous connections, only R99	POWER Simultaneous connections, only R99		CODE Traffic for 2% blocking (Erlang), only R99	POWER Traffic for 2% blocking (Erlang), only R99
Voice 12.2 kbps	124	61		**111.324**	**50.589**
CS 64 kbps	31	20		**22.827**	**13.182**
PS 64 kbps	31	26		**22.827**	**18.383**
PS 128 kbps	15	15		**9.010**	**9.010**
PS 384 kbps	7	4		**2.935**	**1.092**

Table 5.14 Comparison between capacity according to code and according to Pico Node B transmitted power. Both UMTS-WCDMA (R99) and HSDPA are deployed in the frequency.

Services	CODE Simultaneous connections, both R99 and HSDPA	POWER Simultaneous connections, both R99 and HSDPA		CODE Traffic for 2% blocking (Erlang), both R99 and HSDPA	POWER Traffic for 2% blocking (Erlang), both R99 and HSDPA
Voice 12.2 kbps	78	15		**66.771**	**9,010**
CS 64 kbps	18	5		**11.491**	**1,657**
PS 64 kbps	18	6		**11.491**	**2,276**
PS 128 kbps	9	4		**4.345**	**1,092**
PS 384 kbps	4	1		**1.092**	**0,020**
PS 512 Kbps (HDPA only)	3	3			
PS 512 Kbps (HDPA only)	1	1			

We remark that the simultaneous users number is limited in the estimation based on the Node B power than the estimation based on the available channelization codes.

5.3.3 The parameter planning and first tuning test

In UMTS - WCDMA, the flow of original datas from the end user in the network requires some additional information which allow a good delivery. Those additional information are known as signallings and contain some reports such as handover or power control measurement datas.

The network system, using some algorithms, compare the signallings to the radio parameter to order the User Equipment or execute requests from it. Some specific parameters such as Cell Identity (CI), Location Area Code (LAC) and list of neighbouring cells must be provided specifically for each cell during the network planning. The radio parameters can be divided into three groups [18] :

- Fixed parameters preloaded in the Base station subsystem (BSS) by its manufacturer. These parameters cannot be changed by mobile operator.
- Customer dependent parameters; related to the network topology and defined by the mobile operator. Example, Node B name, Cell ID, ...
- Adjustable parameters, that are set to a default value but could be modified according to Quality-of-Service and Traffic observations. Example, Radio

Resource Management (RRM), mobility management, signalling, handover, and power control parameters.

5.4 Picocell and Femtocell radio network optimization

This level of the network life starts with the network opening to users.

The first steps explained above manage the coverage, capacity and quality questions from theoretical and experimental studies, not based on people real-life use. In the real life, the network is always growing with increasing subscriber numbers and traffic demand. The radio network optimization process addresses the same issues like network dimensioning and planning, with the difference that the Pico Node B sites are fixed. It involves monitoring, verifying and update tuning to improve the radio network. For that the most important measurement results are defined as Key Performance Indicators (KPI) and are closely compared to the network daily situation.

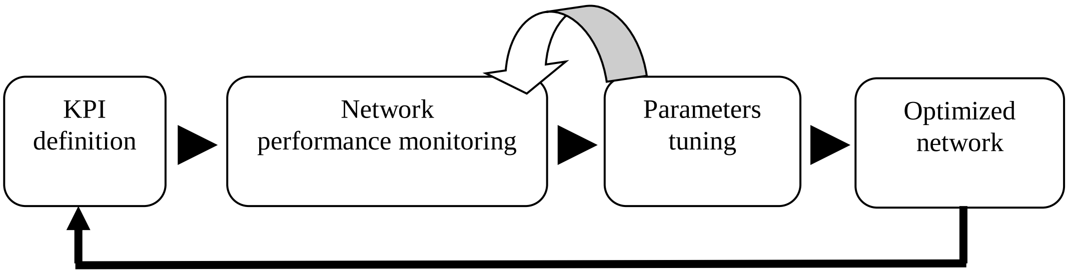


Figure 5.7 Picocell radio optimization process

The KPI generally relate:

- The radio network resource availability and accessibility.
- The UE reception level and quality.
- The Node B transmission power and power control.
- The amount of dedicated mode request, successful voice and data traffic, blocking rate.
- The success and failure of different handovers type.

Those measurements will be assessed, simulated in a cellular network optimization tool before to be implemented in the real network. The changes can be the updates of BSS parameters but can also include changes of antenna directions. For that, one can choose between antenna mechanical and electrical tilting.

5.4.1 Planning and optimization tool, Mentum Plannet

In this thesis we will use the tool Mentum Planet to implement planning and optimization process. We are choosing this tool for its availability of several accurate propagation models and extremely detailed modeling of the air interface for all radio standards.

Mentum Planet allows possibilities like:

- Accurate urban propagation (indoor & outdoor)
- 3D traffic maps, coverage and performance modeling
- Advanced simulation solutions
- Ability to import drive tests
- Powerful statistical analyses

CHAPTER 6

INTERFERENCE MANAGEMENT IN THE PRESENCE OF PICO NODE B AND FEMTO ACCESS POINTS

The deployment of Pico Node B and Femto Access Points shares any mobile network into two clearly separated layers, the outdoor layer (macrocells) and the indoor layer (picocells and/or femtocells). The outdoor layer is totally under the mobile operator control since it is the planned traditional cellular network. In the other side, the indoor layer which is a set of several very short range cells can be planned (picocells) or randomly distributed by the customer (femtocells). Because the two layers are located inside the same geographic area or are very close to each other, they will bring new design challenges, especially in the case of UMTS-WCDMA where all the cells exploit the same frequency.

In this chapter we will explore the causes of possible interferences between indoor and outdoor layer. We will introduce the management of interference in presence of picocells/femtocell and discuss the basic method of isolation between indoor and outdoor layers. Some special scenarios of interference in presence of femtocells in co-channel deployment with the outside layer will be presented and evaluated.

6.1 Interferences causes between indoor layer (picocells and/or femtocells) and outdoor layer (macrocell)

UMTS-WCDMA uses the same frequency channel, known as a carrier to carry the communication of a large amount of users. The transmission of different information on the single carrier are separated by using orthogonal scrambling and spreading codes as explained in chapter 3 and 5.

When the scrambling and spreading codes are known in the receiving end, the wanted channel can be separated from all other channels. The information sent with other scrambling codes than the code of the channel expected by the receiver appears as noise or interferences. It happen interferences because of non-perfect orthogonally between the spreading codes and because of the presence of environment's effect like reflection, diffraction and scattering as explained in chapter 2. Thus it appears the problem of interference where the receivers by sensing the frequency band cannot be able to distinguish which transmitter it is listening to. Interference in a cellular network could come from:

- Another operating receiver and/or transmitter inside the same cell (intracell interference),
- Another operating receiver and/or transmitter close to the considered cell (intercell interference),
- Any non-cellular system which leaks energy into the cellular system.

Interference on voice channels causes crosstalk when it will cause blocked and dropped calls on control channels. The main types of interferences in cellular system are co-channel interference and adjacent channel interference [1]. Interference resulting from signals which have adjacent carrier to the carrier of the desired signal is called adjacent channel interference. Interference resulting from signals coming from two cells (close or not), using the same carrier or set of carriers is called co-channel interference. Co-channel interference is not a real problem for UMTS-WCDMA cellular network since all the cells are using the same carrier.

When the cellular network has two layers, the interference challenges mainly became the cohabitation of the two layers in the same space. Let us consider the case where Pico Node B or Femto Access Points are deployed inside or close to a macrocell covered area. The radiated signal related to the Pico Node B or Femto Access Points will produce radio waves in all the directions according to their antennas’ pattern. A part of the emitted radio wave will remain indoors when another part will go outside and affect the outdoor signal quality. In the same way, the radio waves from an outside macro Node B’s antenna will not only cover the exterior area. A part of it will enter the buildings and interfere with the picocell or femtocell indoor system. Moreover dead zone can appear within the considered area if interference managements are not done.

6.2 Interferences management

In indoor areas, environment’s effects like reflection, diffraction and scattering will typically occur from the walls, the furnitures and any other physical forms. For outdoor areas these phenomena will mainly occur from the buildings, the trees, the electrical mats and cars. The goal of interference management is to achieve a desired quality of the signal in the radio network. Indeed the performance in the radio network will not be appreciated by the level of absolute received signal but to its quality. The quality is described as Signal to Noise Ratio (SNR), when we only focus on the signal and the noise present in the system. It will be described as Signal to Noise and Interference Ratio (SINR), when we take into account the interferences. Thus interference management became an important factor to take into account when planning the indoor layer (picocell and/or femtocell sub-system). In fact, the bigger the SNR or SINR will be the better performance the radio link will have.

Interference management can be divided into two mains techniques [14]: interference cancellation and interference avoidance.

6.2.1 Interfence cancellation

Interference cancellation techniques refer to any methods used to cancel or minimize the effects of interference at the receiver side. The principal methods of interference cancellation that could be used in the case of two layers in the cellular network are [14]:

- **Parallel Interference Cancellation (PIC)**: allow the Pico Node B or the FAP to be aware of the codes used at the macro Node B in order to cancel the possible interference between the two layers.
- **Filtering**: provide a filter to the receiver that attenuates the parts of the spectrum of the original signal which are highly affected by interference. The parts of the spectrum of the original signal which are not highly affected by interference will be amplified. In other words, the parts of the original signal spectrum with a very low SINR will be attenuated and the parts of the spectrum of the original signal with high SINR will be amplified.
- **Multiuser detection**: mostly used in the uplink this method allows every user to have a certain signature waveform different from others.

- **Cyclostationary**: use the radio waves features in the frequency domain to extract interferences. The cyclic frequencies of the useful signal correspond to the carrier and the data rate. The cyclic frequencies of a useless signal, caused by co-channel interference, cannot match with the useful signal one. Thus it can then be detected by exclusion.
- **Higher Order Statistics**: mostly used in the uplink, this method is based on the use of signal statistics. The objective is to separate independent signals from others many signals which came to add themselves to the original waves. This could be done by using spatial diversity with array antennas. Array antennas are a group of antenna elements operating at different amplitudes and phases.

6.2.2 Interference avoidance

Interference avoidance techniques refer to any methods used to avoid interferences at the receiver side. The principal methods of interference avoidance that could be used in the case of two layers in the cellular network are [14]:

- **Adaptive Control of FAP Transmit Powers**: only used in the case of FAP deployment, this method is to adjust the maximum allowed FAP transmit power based on information exchange with the nearest macro Node B.
- **Time-hopping**: only implemented using TH-CDMA technology, this method is to not transmit over the whole spectrum all the time but only during short periods. It assumes that there are not information exchanges between the FAP and the macro Node B. If the period of the transmission is (T) divided into (N_{hop}) hopping slots, each femtocell UE, for transmission can randomly choose one of the hopping slots of length (T/N_{hop}). This approach reduces the interference between different femtocells and between femtocells and macrocells by a factor of (N_{hop}) [14].
- **Femtocell exclusion region**: consists of silencing FAP that are too close to a macrocell according to a minimum distance required to guaranty negligible interferences between the two layers.

  The exclusion region can be implemented with a layer selection handover policy that could turn the FAP in open access mode in case this one is too much close to the macrocell.

- **Use of sectorial antennas in FAP**: This method is for possible future FAP that should be manufactured with antennas with (N_{sec}) sectors. Such a configuration of the FAP could reduce interference between the two layers by a factor of (N_{sec})[14].

6.3 Interference management in the presence of Pico Node B

The first challenge for an optimal picocell solution would be the amount of Pico Node B present inside big building like shopping mall or big office. The number has to be sufficient to ensure the coverage and capacity requirements, but also not too high in order to avoid inter-picocell interference. The Pico Node B's deployment should be done with the goal of maximum isolation from the outside umbrella macrocell. As already explained, all the cells in UMTS-WCDMA are using the same radio bandwidth, macrocell or picocell. Thus isolation becomes the key success for picocells sub-network in order to:

- Avoid the macrocell high signal to come into the indoor area.
- Avoid the indoor users to camp on macro Node B' antennas instead of the Pico Node B.
- Avoid the indoor users to emit with high power when they are in the indoor area. Indeed if a user increases his/her emission power, when being inside the building, he/she may reach the macrocell's antenna and camp on it.
- Avoid the indoor or outdoor users to be constantly in picocell-macrocell soft handover.
- Allow the macrocell's Node B to have enough resources left to maintain service to outside users

The Pico Node B's location in the building will be a determinant factor in interference management. In [4, 14], is explained some simulations for overlapping picocells. It shown that to improve the performance a good solution is to take into account the Pico Node Bs' positions accurately. These positions of the Pico Node B should meet a compromise that fit closely with the building structure. It will give in the practice a result where indoor radio signal will be more powerful inside the building than any outside radio signal, because of isolation. In the same perspective, the indoor system will not leak too much radio signal outside the building, so the soft handover zone will not be pushed outside, around the building.

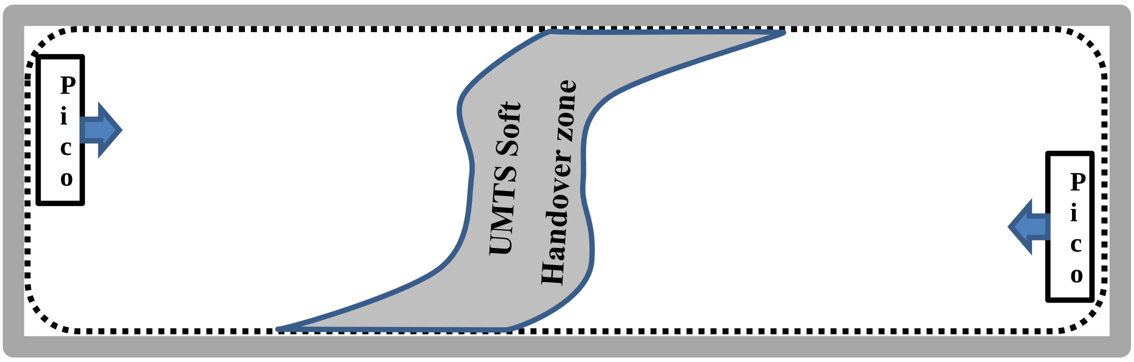


Figure 6.1 Example of 2 Pico Node B deployments in one building floor

Thanks to modern building structure, isolation goal could be reach with an acceptable level. In fact energy-efficient windows and the special wall materials of modern buildings will attenuate the signal from both side and become the limit between the two layers. The design of picocell sub-system has to cope with the building's map and features in order to use it to fulfill the radio network deployment needs. An example could be the use of directional antennas along the border of the building that are directed to its center. The use of corridors and firewalls locations inside the building could help to attenuate the indoor cells radio signal for efficient management of soft handover area.

This kind of indoor design that takes into account the features of the building construction will insure a strong indoor radio signal than the outdoor signal even with very high signals from the nearby macro Node B. It will be possible because of the users' proximity that will allow line-of-sight propagation.

6.4 Interferences management in the presence of femtocells

In UMTS-WCDMA system, sharing the same radio bandwidth without any planning for the location of Node B could create important interference problems. Femto Access Points' deployment by their randomness feature will increase interference, especially when the indoor and outdoor layers are in co-channel fashion. The isolation methode cannot be used for FAP to avoid interference since the end user installing it will not necessary be a mobile network engineer. The radio network will recquire news interference avoidance techniques such as time-hopping, power control or exclusion region [14].

However the biggest part of interference management in presence of femtocells is done through the FAP's Self Organizing Networks (SON) module. This module will collect information around the FAP and will automatically decide the strategy to adopt, allowing less interferences. These informations are colected from: surrounding cells' radio environment, surrounding macro Node B and surrounding FAPs [17].

6.4.1 Measurements done by the FAP for interferances management

- Home Node B (HNB) is understood as Femto Access Point (FAP)
- Home Node B User Equipment (HUE) is understood as the User Equipment served by a FAP

Table 6.1 FAP measurements from surrounding cells [17]

Measurement Type	**Purpose**	**Measurement Source(s)**
Co-channel carrier Received Signal Strength Indicator (RSSI)	Calculation of co-channel downlink interference towards HUEs from neighboring cells	HNB downlink receiver HUE
Adjacent channel carrier Received Signal Strength Indicator (RSSI)	Calculation of adjacent channel downlink interference towards HUEs from neighboring cells	HNB downlink receiver HUE
Common Pilot Channel (CPICH) Ec/No	Calculation of downlink interference towards HNB	HNB downlink receiver HUE
Receive Total Wideband Power (RTWP)	Calculation of uplink interference towards HNB	HNB Physical Layer

Table 6.2 FAP measurements to identify macrocells [17]

Measurement Type	**Purpose**	**Measurement Source(s)**
Public land mobile network (PLMN) ID	Identification of operator Distinction between macrocell and HNB	HNB downlink receiver
Cell ID	Identification of surrounding macrocells	HNB downlink receiver
Location Area Code (LAC)	Distinction between macrocell and HNB	HNB downlink receiver
Routing Area Code (RAC)	Distinction between macrocell and HNB	HNB downlink receiver

Table 6.3 FAP measurements from surrounding macrocells [17]

Measurement Type	**Purpose**	**Measurement Source(s)**
Co-channel Common Pilot Channel Received Signal Code Power (CPICH-RSCP)	Calculation of co-channel downlink interference towards macro UEs (from HNB) Calculation of co-channel uplink interference towards macro layer (from HUEs)	HNB downlink receiver HUE
Adjacent channel Common Pilot Channel Received Signal Code Power (CPICH-RSCP)	Calculation of adjacent channel downlink interference towards macro UEs (from HNB) Calculation of adjacent channel uplink interference towards macro layer (from HUEs)	HNB downlink receiver HUE
P-CPICH Transmission power	Calculation of pathloss to macro Node B	HNB downlink receiver

Table 6.4 FAP measurements from adjacent FAPs [17]

Measurement Type	**Purpose**	**Measurement Source(s)**
Co-channel Common Pilot Channel Received Signal Code Power (CPICH-RSCP)	Calculation of co-channel downlink interference towards neighbor HUEs (from HNB) Calculation of co-channel uplink interference towards neighbor HNBs (from HUEs)	HNB downlink receiver HUE
Adjacent channel Common Pilot Channel Received Signal Code Power (CPICH-RSCP)	Calculation of adjacent channel downlink interference towards neighbor HUEs (from HNB) Calculation of adjacent channel uplink interference towards neighbor HNBs (from HUEs)	HNB downlink receiver HUE

The FemtoForum [16] and 3GPP [17] have studied many scenarios in which the impact of FAP on UMTS -WCDMA system is evaluated in order to propose some interferences management in the presence of femtocells. These studies have been done using extreme case scenarios, considering the co-channel deployment because of its importance and the possibility that the FAP could be turned into Close Subscriber Group (CSG) mode. Here we will list the scenarios according to the order in [16].

6.4.2 Scenario A: macrocell downlink interference with the femtocell user

In this scenario the Femto Access Point (FAP) is close to a window that is in direct sight with the closest macrocell’s antenna (approximately 30m). The considered user is connected to the FAP and is located at the edge of its range.

- **The victim link**: the downlink from the FAP to the femtocell's user (FUE),
- **The aggressor transmitter**: the downlink from the macrocell,
- **Objective of this scenario**: determine at the edge of the FAP range, the services that can be delivered to the FUE when the macrocell is fully loaded.

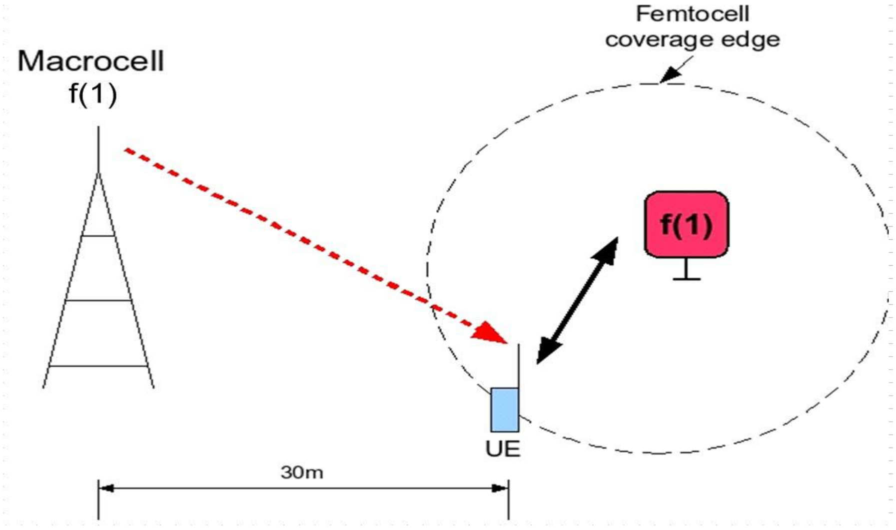


Figure 6.2 Macrocell downlink interference with the downlink from FAP to FUE [16]

The situation depicted in this scenario could show the useless of a FAP even if the likelihood to see it in real life is small (below 0.01%). It means that the number of FUE who will be affected in this kind of scenario are very small and the FAP can still keep its users under its coverage. The best estimation was realized for 250m between the FUE and a close microcell with 14.4Mbps High Speed Downlink Packet Access (HSDPA) [16]. To get full coverage from the FAP, the FUE is required to be close to the FAP otherwise he/she could handover to the macrocell.

6.4.3 Scenario B: macrocell uplink interference with the femtocell user

In this scenario the Femto Access Point (FAP) is somewhere inside the apartment where is available a week coverage from the closest macrocell. The FAP is in Close Subscriber Group (CSG) mode serving one Femtocell User (FUE) in dedicated mode located to its coverage edge. A user who is not in the CSG and does not have access to the femtocell, a macrocell's user (MUE) is located close to the FAP.

- **The victim link**: the uplink from the FUE to the FAP,
- **The aggressor transmitter**: the uplink from the macrocell's user,
- **Objective of this scenario**: determine the requisite to maintain the uplink connection between the FUE and the FAP. Determine the impact that the macrocell's user has on the radio service requested by the FUE.

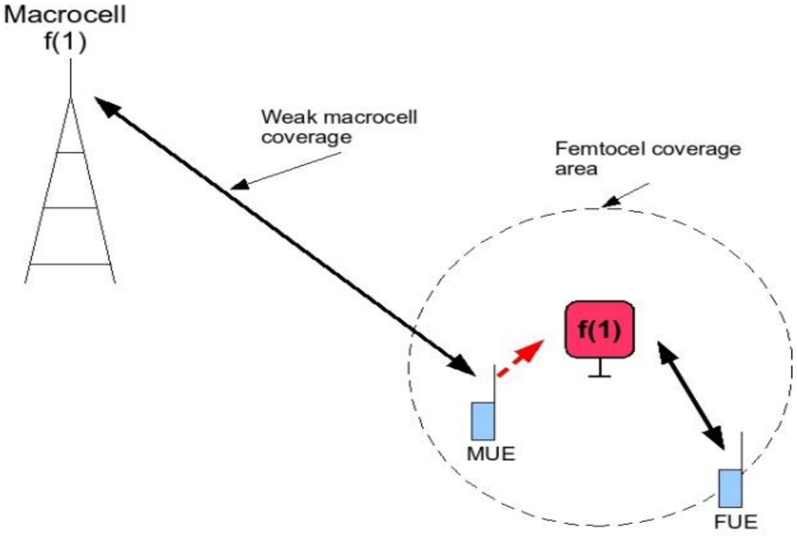


Figure 6.3 Macrocell's user uplink Interference with the uplink from FUE to FAP [16]

Because of the weak macrocell coverage the MUE will suffer near-far effect and will increase its transmit power in order to reach a desired Quality of Service (QoS). This situation could create a big interference in the FAP coverage. However it has been tested that the FUE has enough power to maintain a voice call. For High Speed Uplink Packet Access (HSUPA) the FUE is required to move closer to the FAP in order to achieve a good throughput. At least 2.8Mbps can be achieved, when the FUE is 5m close to the FAP and the MUE located at 15m around the FAP. In that case the FUE should transmit at a power level greater than 15dBm. In the other hand the MUE could suffer great coverage difficulties due to the death zone created by the FAP. Thus it is recommended for the MUE to reserve alternative resources like second carrier for handing off otherwise the MUE could be dropped.

6.4.4 Scenario C: femtocell downlink interference with the macrocell user

In this scenario the Femto Access Point (FAP) is somewhere inside the apartment where a macrocell's user is located. The FAP, fully loaded in the downlink is in Close Subscriber Group (CSG) mode and does not serve the MUE who is in dedicated mode.

- **The victim link**: the downlink from the macrocell to the macrocell's user,
- **The aggressor transmitter**: the downlink from the FAP,
- **Objective of this scenario**: determine the capacity impact of a densely deployed FAP on the macrocell's user link when both femtocell and macrocell are in co-channel deployment.

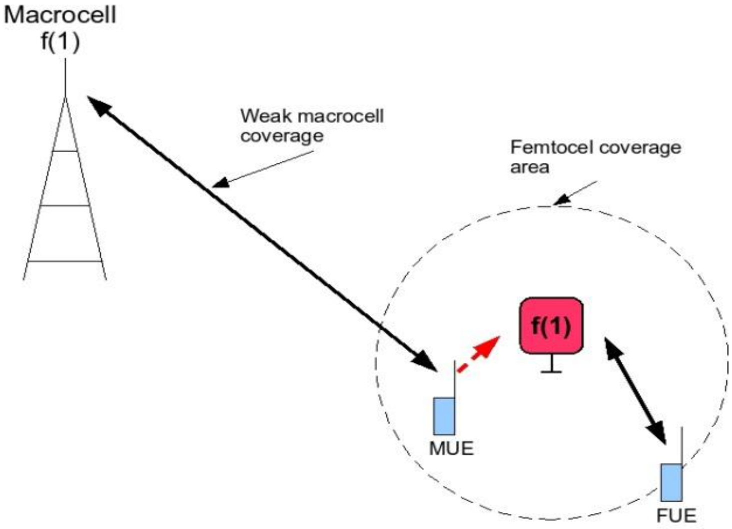


Figure 6.4 Femtocell downlink interference with downlink from the macrocell to MUE [16]

A huge hole in the macrocell coverage could be created around the FAP that is transmitting at full power. This situation will only be a serious problem for the MUE when the FAP is in Closed Subscribers Group. The proposed way to mitigate this problem is the use of adaptive power control on the FAP to maintain the macrocell capacity even for a MUE inside FAP coverage. Here also the use of alternative resources like second carrier could be the best solution.

6.4.5 Scenario D: femtocell uplink interference with the macrocell Node B

In this scenario the Femto Access Point (FAP) is somewhere inside the apartment serving a femtocell's user located close to the apartment's window that is in direct sight with the macrocell's antenna (approximately 30m). The femtocell's user at the FAP coverage edge and is transmitting at full power.

- **The victim link**: the uplink from the macrocell's user (MUE) to the macrocell,
- **The aggressor transmitter**: the uplink from the femtocell's user (FUE),
- **Objective of this scenario**: determine the noise rise experimented by the macrocell node B receiver due to the femtocell's user.

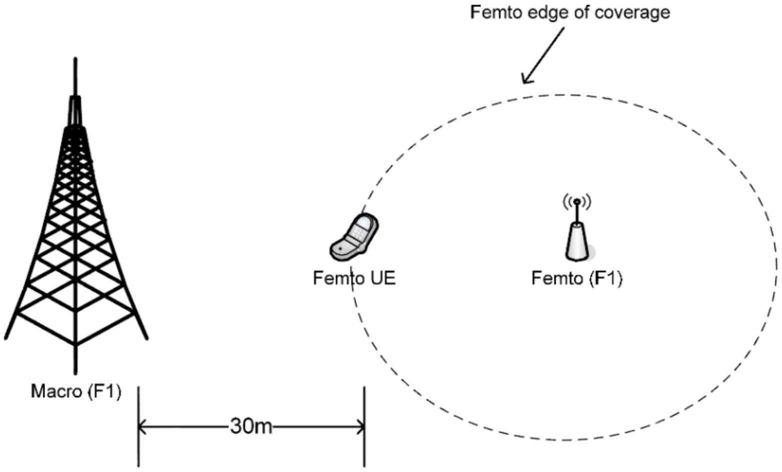


Figure 6.5 Femtocell uplink Interference with MUE uplink to the macrocell [16]

This scenario is not relevant because of a possible handover to the macocell layer by the femtocell's user. However it is showed that a femtocell's user will produce less noise than a macrocell's user at the same position. The noise rise produce by a femtocell'user will be around 0.03dB for voice activities and around 1.3dB for 1.5Mbps HSUPA data service, when a macrocell's user at the same position will produce double [16].

6.4.6 Scenario E: femtocell downlink interference with nearby femtocell users

In this scenario two apartment (AP1 and AP2) with Femto Access Point are adjacent to each other, separated at least by one wall. One AP2's user visits his/her neighbor and is on the edge of his/her own FAP coverage, but very close to AP1.

One AP1's user enters in dedicated mode that requires full power from his/her FAP. A macrocell is also within range.

- **The victim link**: AP1's user (home user) transmitting link,
- **The aggressor transmitter**: AP2 downlink and macrocell downlink,
- **Objective of this scenario**: determine the impact of a neighboring femtocell access points and macrocell on a femtocell link.

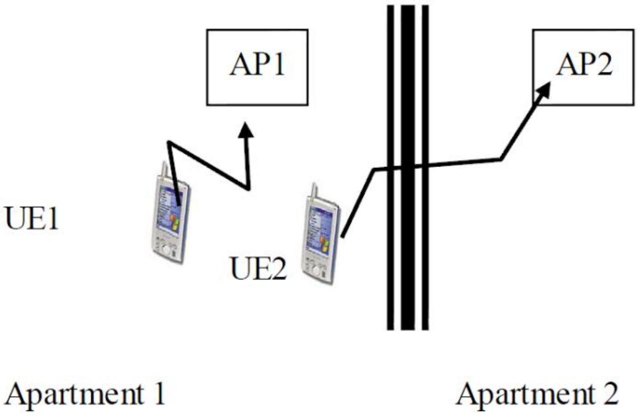


Figure 6.6 Femtocell downlink interference with nearby femtocell users [16]

A FAP aim is the accurate coverage for only one house or apartment. In the situation depicted in this scenario a key solution will be accurate adaptive power control at FAP level. That will allow any “visiting” femtocell’s user to only see the closest macrocell as the strongest cell in order to handover to it, and the interference scenario will be identical to Scenario A. However, it could always remain situation where a neighboring FAP will cause dead zones to other FAP. In such situation, alternative resources like second carrier could be the best solution.

6.4.7 Scenario F: femtocell uplink interference with nearby femtocell users

In this scenario we consider the same disposition like scenario E, but this time the user of AP2 enters in dedicated mode that requires full power from his/her FAP. A macrocell is also within range.

- **The victim**: AP1 coverage and capacity,
- **The aggressor transmitter**: AP2’ user uplink,
- **Objective of this scenario**: determine the impact of a neighboring femtocell user to the coverage and the capacity of a FAP.

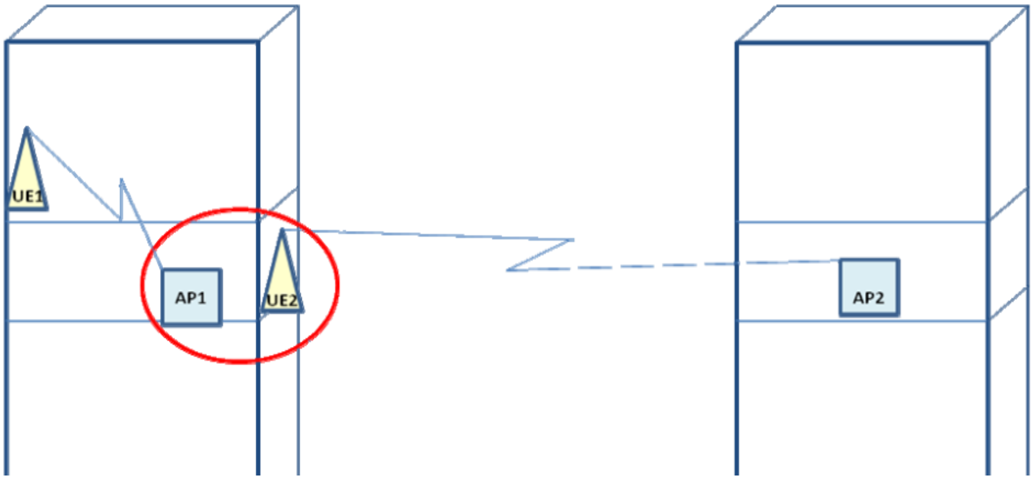


Figure 6.7 Femtocell uplink interference with nearby femtocell Users

This scenario shown that co-channel interference created by uplink from a neighboring femtocell’s user located close to the considered FAP could reduce its maximum range if power management is not employed. The closer the aggressor user is to the considered FAP (the victim), the greater its range reduction is.

CHAPTER 7

RADIO NETWORK PERFORMANCE IN THE PRESENCE OF PICOCELL AND FEMTOCELL

Capacity for WCDMA radio is defined like the possible total traffic load, the maximum number of simultaneous users for all services which satisfy the expected quality and coverage respecting the allowed frequency band. Coverage and capacity have always to compromise each other to keep the quality to a certain constant. Indeed cell breathing mechanism and other Node B's algorithms could reduce the coverage proportionally to the capacity increment, vice versa, when keeping a certain quality constant. Difficult situation happen when the cell needs to keep its coverage, capacity and quality constant. In such scenarios new strategies or compromises have to be found to solve the problem.

In this chapter we will, through a theoretical analysis study the benefit (in term of capacity) of including picocells and femtocells to the radio network. We will evaluate the whole system performance when the indoor users are served by outdoor Node B, precise its disadvantage to understand the importance of Pico Node Bs or Femto Access Points deployment.

7.1 Cell breathing and soft capacity

In UMTS-WCDMA system the capacity limit is soft. The cell capacity can be trade off against its coverage using the cell breathing function. Cell breathing is a function at the Node B that allows this one to shrink its coverage when the loading increases. In the uplink, when more and more UE are served by the Node B, it appears a competition between them because they will need to transmit higher power to compensate for the uplink noise rise.

As a consequence, the UE with weaker link (UE at greater distance or UE deeply in indoor position) may not have enough power to reach the NodeB. Therefore a coverage shrinkage. In the downlink, the Node B also needs to transmit higher power when more UE are being served. As a consequence UE with weaker link (UE at greater distance or UE deeply in indoor position) may not be reachable by the NodeB. Here also there will be a coverage shrinkage .

By managing the increase of the maximum permitted noise rise in the cell, the cell breathing function allows increase of the capacity that also means decrease of the coverage. Soft capacity in UMTS-WCDMA is by definition the maximum capacity of the network limited by the amount of interference in the air interface. In chapter 5 section 2, we had learned how to calculate the maximum available capacity limited by the hardware and the estimation through Erlang B table. For a soft capacity limited system, the Erlang B capacity cannot be estimated [7]. For soft capacity, the less the interference in the air interface will be the more the capacity will increases. In the other hand, the more the interference in the air interface will be the less the capacity will be.

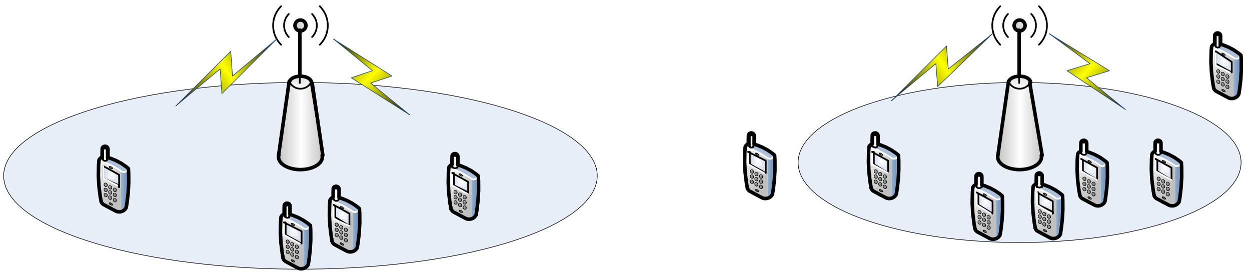


Figure 7.1 Cell breathing function, coverage decrease when UE number increase.

7.2 Macrocell's capacity enhancement with Pico Node B or Femto Access Point deployment.

As explained in the chapter 6 section 2, the system performance is not appreciated by the level of absolute received signal but to its quality which is related to the signal-to-noise and interference ratio (SINR) and the processing gain. A quality UMTS-WCDMA network mainly means less noise in order to keep the capacity and the coverage constant as expected by the end user.

The uplink and downlink capacities in UMTS-WCDMA cannot be study and discussed in the same way. The uplink capacity is mostly related to the number of users in a cell or in the whole network, and to noise rise generated by them in the uplink. In the downlink, the capacity is related to the Node B transmitted power shared among each user. The more hidden each individual user will be (because of environment's forms or indoor position), the stronger the power required for him/her will be.

The processing gain which is the ratio between the constant WCDMA chip rate and the user bit rate $\left(\frac{W}{R}\right)$ does not have any impact on the quality. It is a constant value according to the service that the end user is using in the network. Thus the quality is fully related to the SINR value. The SINR in the uplink is [7, 21]:

$$SINR_{user\ "n"} = \frac{P_n \times g_n}{(P_{intracell} - (P_n \times g_n)) + P_{intercell} + P_N} \tag{7.1}$$

$$SINR_{user\ "n"} = \frac{\frac{P_n}{L_n}}{P_{intracell} - \frac{P_n}{L_n} + P_{intercell} + P_N} \tag{7.2}$$

The SINR in the downlink is [7, 21]:

$$SINR_{user\ "n"} = \frac{P_n \times g_n}{(1-\alpha)(P_{intracell} - (P_n \times g_n)) + P_{intercell} + P_N} \tag{7.3}$$

$$SINR_{user\ "n"} = \frac{\frac{P_n}{L_n}}{(1-\alpha)(P_{intracell} - \frac{P_n}{L_n}) + P_{intercell} + P_N} \tag{7.4}$$

L_n = is the path loss, we will consider an average value, **L**

P_n = is the power from/to user "*n*" in considered cell,

α = is the orthogonality factor,

P_N = is the noise power level (AWGN) in the uplink or downlink,

$P_{intracell}$ = the intracell noise power level in the uplink or downlink from considered cell,

$P_{intercell}$ = the intercell noise power level in the uplink or downlink from surrounding cells,

$P_{intracell} - (P_n \times g_n)$ = the total intracell noise power level in the uplink or downlink without taking into account the user "*n*" transmitted or received power.

7.2.1 Analysis in the uplink

Let's consider two different User Equipments (UE), which are transmitting from the same distance to the closest node B. One UE is inside a building when the second is outside. We take $P_{indoor,UL}$ the indoor UE transmitting power and $P_{outdoor,UL}$ the outdoor UE transmitting power in the uplink. For equations' simplification, the path loss applied to indoor and the outdoor user is assumed such a way that:

- the total intracell noise power level in the uplink will be the same for all the indoor and all the outdoor users, whatever their exact geographical position, ($P_{intracell,\ UL}$);
- The total intercell noise power level in the uplink will be the same for all the indoor and all the outdoor users, whatever their exact geographical position, ($P_{intercell,\ UL}$);
- The noise power level (AWGN) will be the same for all the indoor and all the outdoor users whatever their exact geographical position (P_N).

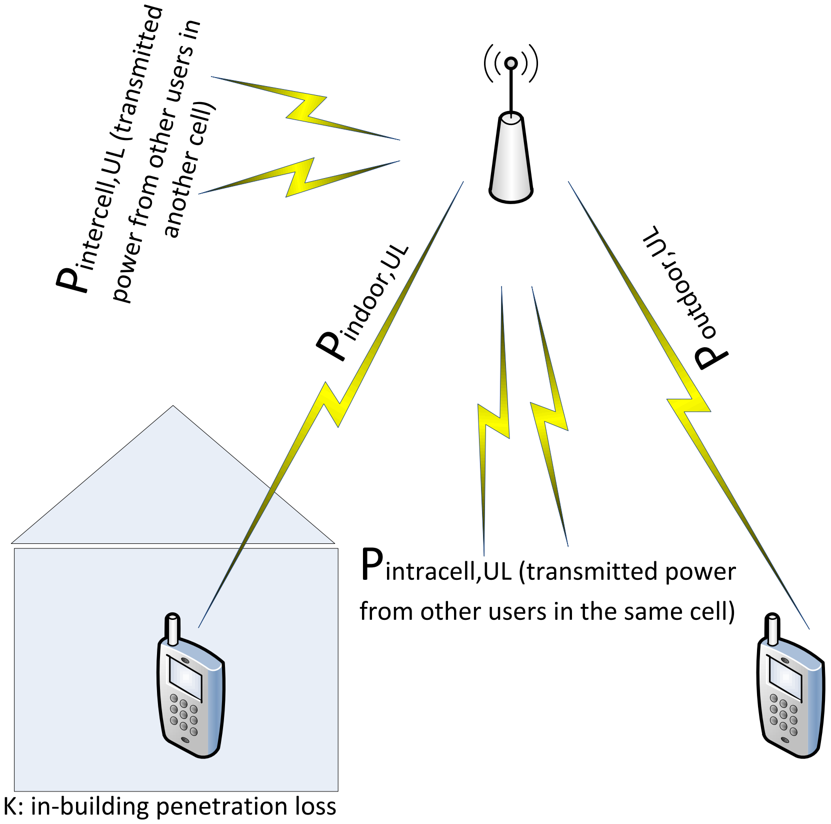


Figure 7.2 Uplink scenario for two different UE, first indoor and the 2nd outdoor

$$SINR_{target} = \frac{\frac{P_{indoor,UL}}{L \times K}}{P_{intracell,UL} + P_{intercell,UL} + P_N} \quad (7.5)$$

$$SINR_{target} = \frac{\frac{P_{outdoor,UL}}{L}}{P_{intracell,UL} + P_{intercell,UL} + P_N} \quad (7.6)$$

(7.5) is the SINR’s equation for the indoor UE and **(7.6)** is the SINR’s equation for the outdoor UE. We combine equation (7.5) and (7.6) by assuming that both indoor and outdoor users are under the same propagation and quality conditions;

$$\frac{\frac{P_{indoor,UL}}{L \times K}}{P_{intracell,UL} + P_{intercell,UL} + P_N} = \frac{\frac{P_{outdoor,UL}}{L}}{P_{intracell,UL} + P_{intercell,UL} + P_N} \quad (7.7)$$

$$\frac{P_{indoor,UL}}{L \times K} = \frac{P_{outdoor,UL}}{L} \quad (7.8)$$

$$P_{indoor,UL} = K\, P_{outdoor,UL} \quad (7.9)$$

Without the deployment of Pico Node Bs or Femto Access Points inside the UMTS-WCDMA network, all the users will be served by the macro Node B. In such situation the transmitted power from an indoor UE should be “*K*” times more than the transmitted power from an outdoor UE in order to keep the same quality of service for both users.

The deployment of Pico Node Bs or Femto Acces Points will avoid the indoor users to be served by the macro Node B. Useless transmission power increment will be avoid for these indoor users in the macrocell and so decrease the total noise value in the uplink for the WCDMA network. In another words the presence of picocells or femtocells inside or close to the macrocell increase the value of the SNIR and will improve or keep constant the coverage, the capacity and the quality of the whole WCDMA network.

In practice “*K*” could vary between 15 to 50 dB and depend on the wall type, used materials and thickness [23].

7.2.2 Analysis in the downlink

We consider the same scenario. We denote by $P_{indoor,DL}$ the node B transmitting power to the indoor UE and $P_{outdoor,DL}$ the node B transmitting power to the outdoor UE. For equations' simplification, the path loss applied to indoor and the outdoor user is assumed such a way that:

- the total intracell noise power level in the downlink will be the same for all the indoor and all the outdoor users, whatever their exact geographical position, ($P_{intracell,\ DL}$);
- The total intercell noise power level in the downlink will be the same for all the indoor and all the outdoor users, whatever their exact geographical position, ($P_{intercell,\ DL}$);
- The noise power level (AWGN) will be the same for all the indoor and all the outdoor users, whatever their exact geographical position, (P_N).

In the downlink the Node B send its transmitted power over the air "to" all the users that will take a part of it as useful signal and consider the rest as noise. When expressing the SINR for a user "*n*" in the downlink, it is important to apply the path loss to the rest of the Node B transmitted power devoted to other users and commons channels. This precision is done in the downlink because the receiver at the UE expects one useful signal. It is not the same case in the uplink where the receiver at the Node B expects many useful signals.

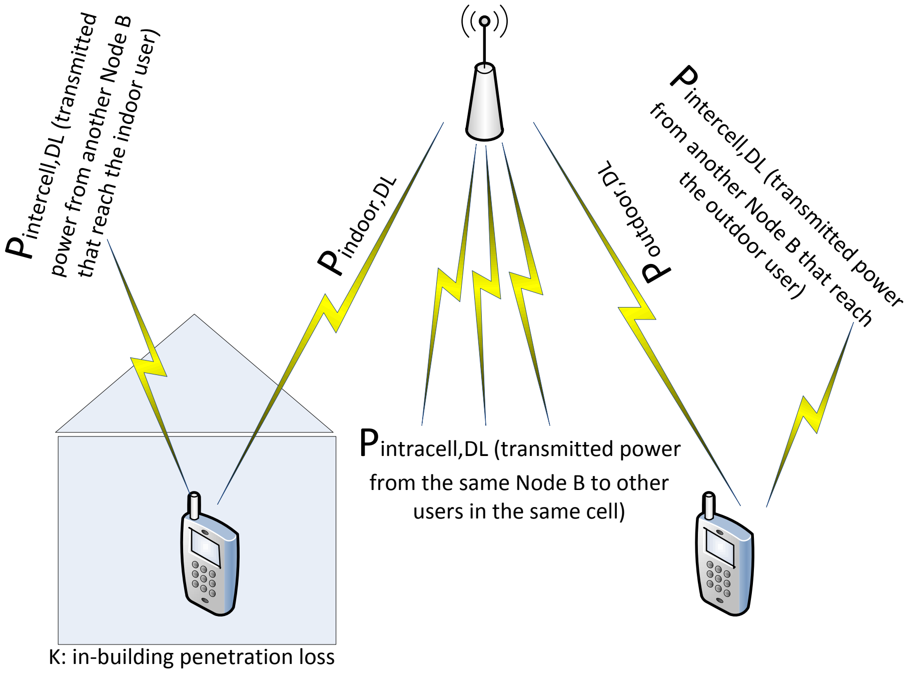


Figure 7.3 Downlink scenario for two different UE, first indoor and the 2nd outdoor

$$SINR_{target} = \frac{\frac{P_{indoor,DL}}{L\times K}}{(1-\alpha)\left(\frac{P_{intracell,DL}}{L\times K}\right) + \frac{P_{intercell,DL}}{K} + P_N} \tag{7.10}$$

$$SINR_{target} = \frac{\frac{P_{oudoor,DL}}{L}}{(1-\alpha)\left(\frac{P_{intracell,DL}}{L}\right) + P_{intercell,DL} + P_N} \tag{7.11}$$

(7.10) is the SINR's equation for the indoor UE and **(7.11)** is the SINR's equation for the outdoor UE. We combine equation (7.10) and (7.11) by assuming that both indoor and outdoor users are under the same propagation and quality conditions,

$$\frac{\frac{P_{indoor,DL}}{L\times K}}{(1-\alpha)\left(\frac{P_{intracell,DL}}{L\times K}\right) + \frac{P_{intercell,DL}}{K} + P_N} = \frac{\frac{P_{oudoor,DL}}{L}}{(1-\alpha)\left(\frac{P_{intracell,DL}}{L}\right) + P_{intercell,DL} + P_N} \tag{7.12}$$

$$P_{indoor,DL} = K \times P_{outdoor,DL} \times \frac{(1-\alpha)\left(\frac{P_{intracell,DL}}{L\times K}\right) + \frac{P_{intercell,DL}}{K} + P_N}{(1-\alpha)\left(\frac{P_{intracell,DL}}{L}\right) + P_{intercell,DL} + P_N} \tag{7.13}$$

$$P_{indoor,DL} = P_{outdoor,DL} \times \frac{(1-\alpha)\left(\frac{P_{intracell,DL}}{L}\right) + P_{intercell,DL} + (K \times P_N)}{(1-\alpha)\left(\frac{P_{intracell,DL}}{L}\right) + P_{intercell,DL} + P_N} \tag{7.14}$$

As said above (K) varies between 15 and 50 dB, thus:

$$(1-\alpha)\left(\frac{P_{intracell,DL}}{L}\right) + P_{intercell,DL} + (K \times P_N) > (1-\alpha)\left(\frac{P_{intracell,DL}}{L}\right) + P_{intercell,DL} + P_N$$

$\frac{(1-\alpha)\left(\frac{P_{intracell,DL}}{L}\right) + P_{intercell,DL} + (K \times P_N)}{(1-\alpha)\left(\frac{P_{intracell,DL}}{L}\right) + P_{intercell,DL} + P_N}$ Will be a number bigger than 1.

In the downlink also, referring to equation (7.14), the transmitted power from the outside Node B to any indoor UE will be bigger than its transmitted power to any outside UE. The deployment of Pico Node Bs or Femto Access Points will avoid the indoor users to be served by the outside Node B and reduce the total noise in the network. Indeed, the more the users will be receiving in indoor position, the more the Node B will be obliged to transmit bigger power than the power it will transmit in the case of users located outside.

In such situation more useless power will be spread towards the users in the downlink and could activate the cell breading function to reduce the total coverage of the outside Node B. Therefore the presence of Pico Node Bs or Femto Access Points will assure the coverage, the capacity and the quality of the data exchanges in the downlink.

7.3 Noise rise consequence on the system load

When a new user get the dedicated mode in the UMTS-WCDMA network and is exchanging data, additional noise is added to the system. In another words, each new user causes a "noise rise". The noise rise is defined as the ratio of total received wideband power to the noise power. As already explained in the previous sections, more users in the network mean that each of them has to transmit higher power to overcome the noise level. According to [7], the uplink load, downlink load and the noise rise could be written as:

$$Uplink\ load = \eta_{UL} = \frac{\frac{E_b}{N_0}}{W/R} \times N \times \nu \times (1 + f) \tag{7.15}$$

$$Downlink\ load = \eta_{DL} = \sum_{j=1}^{N} \nu_j \times \frac{\left(\frac{E_b}{N_0}\right)_j}{W/R_j} \times \left[\left(1 - \alpha_j\right) + f_j\right] \tag{7.16}$$

$$Noise\ rise = \frac{1}{1-\eta} \tag{7.17}$$

$$Noise\ rise_{(dB)} = -10 \times \log(1 - \eta) \tag{7.18}$$

$\boldsymbol{N}$ = number of simultaneous users,

$\boldsymbol{W}$ = chips rate,

$\boldsymbol{\nu}$ = user's activity factor.

$\boldsymbol{\alpha_j}$ = channel orthogonality of user j

$\boldsymbol{f} = \frac{Other\ cell\ interference}{Own\ cell\ interference}$.

According to (7.17), when the load increases in the uplink and becomes close to 1, the corresponding noise rise approaches infinity and the system start to reach its pole capacity. We deduce that increase of load inevitably increase the noise in the system and vice versa.

In the previous section we have already presented how the noise increases in the network because of indoor users served by the outdoor Node B. It means that the system can be full loaded, not because of the arrival of many new connected users but because of many users in indoor position. We so understand that the presence of Pico Node B or Femto Access Points by serving indoor users will avoid useless load in the system.

The downlink load factor (see equation (7.16)) presents similar impacts like the uplink load factor in the sense that the noise rise goes to infinity when its value approaches 1. However an important factor in the Node B management is the estimation of the required transmission power. This is based on the average transmission power that fulfills all UEs reception need, not the transmission power required to reach the cell edge. Indeed, while some UE at the cell edge are requiring high power, other UE close to Node B need much less power at the same time. This feature at the Node B could help to reduce the noise rise in downlink, but it will not be enough to solve the indoor user's needs for its transmitting power level. Here again Pico Node B and Femto Access point will play a major role to avoid useless load in the downlink and improve the whole performance level of the WCDMA network.

CHAPTER 8

PICOCELLS AND FEMTOCELLS PLANNING AND OPTIMIZATION TOOL: MENTUM PLANET

Today mobile operator must quickly evolve and offer advanced and cost-effective data services when deploying a picocell and/or femtocell radio network. Picocell and femtocell technologies present new opportunities, but their advanced features and needs for strong interference management drive the requirement for innovative network planning and optimization software.

In this chapter we will present Mentum Planet, a wireless network planning and optimization software developed by Mentum S.A. We will present its main features and its particularity in planning and optimizing picocells and femtocells radio network.

8.1 Presentation of the company Mentum Planet S.A.

Mentum S.A. was formerly known as CTS International S.A. and changed its name to Mentum S.A. in 2007 after getting the license for exploitation of Planet EV, the wireless networks planning tool of Ericsson.

The company was founded in 2000 and is headquartered in Vélizy, France. The official website of Mentum S.A. for Mentum software solutions is http://www.mentum.com

From November 28, 2012, Mentum S.A. operates as a subsidiary of InfoVista S.A. Mentum S.A. provides wireless network planning and optimization software solutions for mobile operator and the whole wireless industry. Its products include:

- **Mentum Planet**, a Microsoft Windows-based software solution that helps wireless operators, integrators, and equipment vendors to assess, manage, and improve the performance of wireless network coverage and capacity;

- **Mentum Ellipse**, a simulation-based software solution for dimensioning and planning microwave links and transmission networks. It also supports the planning, operation, and optimization of wireless backhaul networks;
- **Cityscapes**, a solution that provides network design in urban areas;
- **Skylines**, which offers three dimensional building models for dense urban planning;
- **Mentum Fusion**, a server-based cloud or hosted computing platform that streamlines network planning, optimization, and management tasks.

After these solutions Mentum S.A. is also involved in:

- **Mentum CellPlanner**, formerly known as TEMS CellPlanner, an advanced radio network design solution, developed in close relationship with Ericsson.
- **Mentum LinkPlanner**, formerly known as TEMS LinkPlanner, is an advanced feature-rich software for microwave network planning.

8.2 Presentation of the software Mentum Planet

Mentum Planet is a wireless network planning and optimization software that is built to address the complex requirements of wireless broadband technologies for mobile operators, equipment vendors, and consulting firms involved in the planning, operation, and optimization of wireless networks.

The most evolved version of Mentum Planet in May 2013 is Mentum Planet 5.6 and supports wireless standards, including GSM, GPRS, EDGE, WCDMA, HSPA, HSPA+, LTE (TDD and FDD), Wi-Fi, WiMAX, cdma2000, EVDO, TDMA, FDMA, DVB-H and generic TDMA/FDMA systems using simulcast.

Mentum Planet offers accurate Geographic Information Systems (GIS) capabilities as it includes the MapInfo Professional GIS desktop system.

The tool can deal with the notion of scenarios by allowing the user to manage many planning and optimization scenario for the same project, compare them in order to select the best one. This ability allows the tool to manage advanced heterogenous network composed of differents radio acces technologies and/or small cells to offload traffic from the macrocellular network.

In this thesis we will use the version of Mentum 5.5, Education edition.

8.3 Architecture of Mentum Planet 5.5

Like other versions of Mentum Planet, Mentum Planet 5.5 has a modular architecture and is based on software-based licensing. Mentum Planet 5.5 can be customized to fit the mobile operator specifics requirements and can easily be expanded in the future with additional modules in order to support the new technology roadmap and network planning and optimization requirements.

The familly Mentum Planet 5.x supports extensions. Extensions “extend” the functionality of the core product and available modules. Currently, all extensions are developed for Mentum, but in the future there may be other third party developers.

8.3.1 Mentum Planet 5.5 core and modules

Mentum Planet 5.5 consists of a core platform (Planet Core), and a series of associated technology modules, enabling configurations that will meet the customer’s requirements. The customer can also purchase features and functions of optional modules, enabled by a license. A typical version of Mentum Planet 5.5 could be composed of :

- Technology modules that are designed to address the modeling of specific radio access network technologies,
- Optional modules that are non dependant of the network technology.

Any version of Mentum 5.5 must have at least one technology module. To this end, the TDMA/FDMA technology module is included as part of all Mentum Planet 5.5 software editions.

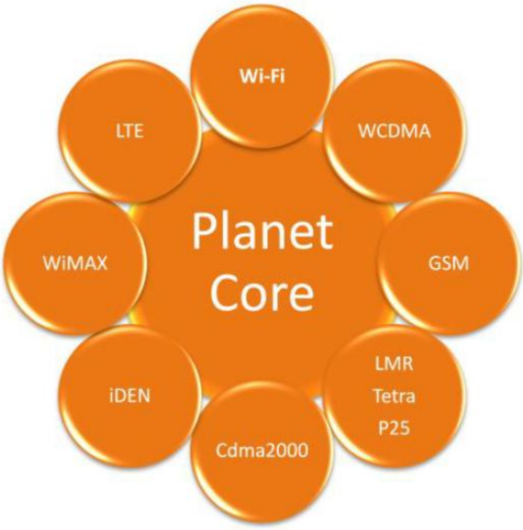


Figure 8.1 Possible technologies modules for Mentum Planet 5.5(depending on the edition) [24]

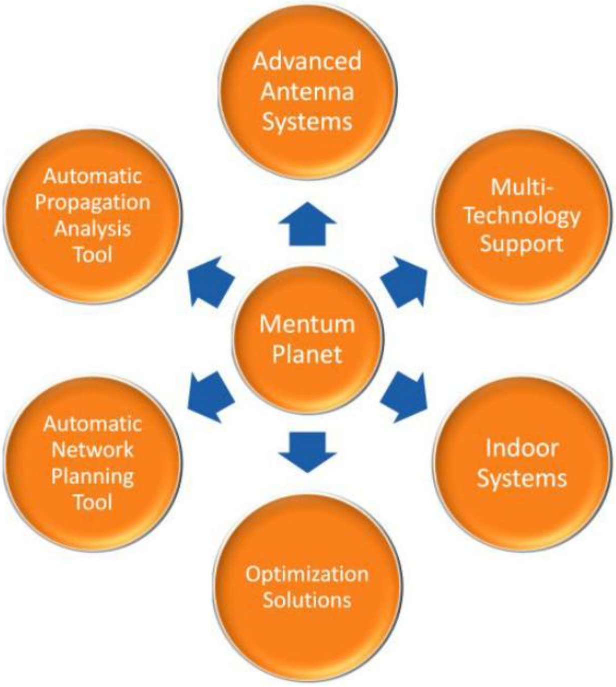


Figure 8.2 Possible optional modules for Mentum Planet 5.5(depending on the edition) [24]

Mentum Planet 5.5 has a number of editors according to the version and to the purchased license. The most importants editors are depicted in figure 7.3.

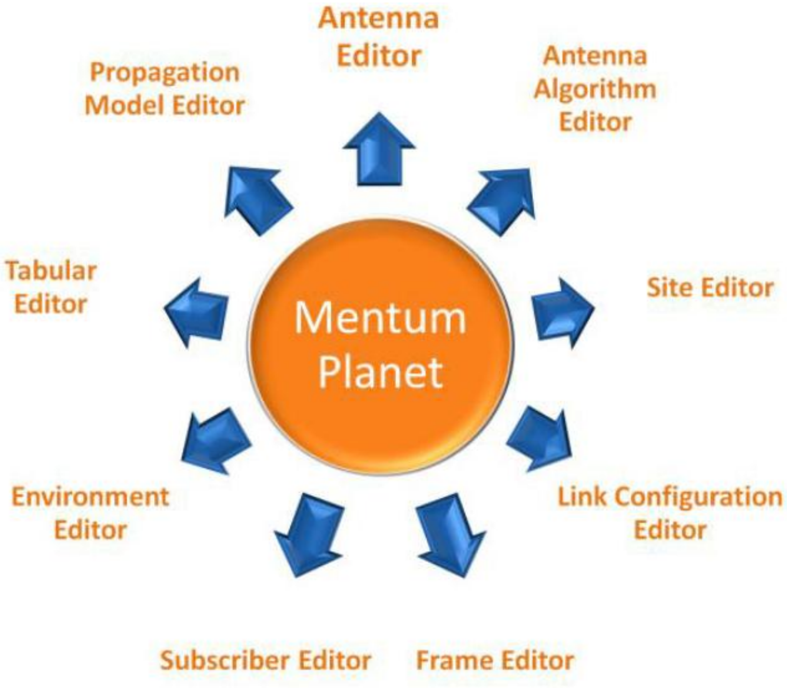


Figure 8.3 Possible editors available in Mentum Planet 5.5(depending on the edition) [24]

- **Antenna Editor**, contains all the elements necessary to model advanced antenna systems including smart antennas and MIMO;
- **Antenna Algorithm Editor**, contains the algorithms used to model complex antenna systems;
- **Site Editor**, contains all the parameters related to the site and sector;
- **Link Configuration Editor**, enables the user to define link configurations for specific environments;
- **Frame Editor**, enables the user to define frame configurations that meet his/her requirements;
- **Subscriber Editor**, enables the user to define the characteristics of network subscribers;
- **Environment Editor**, contains a list of clutter classes to which the user associates environment parameters;
- **Tabular Editor**, provides to the user, with the ability to visualize and globally edit project data in an easy-to-use tabular format;
- **Propagation Model Editor**, enables the user to refine any propagation model;
- **Fixed Subscriber Editor**, enable fixed subscribers' control for WiMAX, LTE.

8.3.2 Mentum Planet 5.5 extensions

Mentum Planet 5.5 through its modules is able to manage many scenarios according to the network situation. To implement a special scenario case is easily done thank to the flexibility of Mentum 5.5 editors but sometimes need a lot of time and efforts. To simplify the task, extentions are developed for most happening scenarios.

In May 2013 the available extentions for Mentum Planet family are:

- **Femtocell**

The Femtocell Extension will work for LTE, CDMA2000 and mobile WiMAX technologies using Mentum Planet 5.1

- **MediaFLO**

The MediaFLO Extension works with Mentum Planet 5.1.

- **DVB-H**

The DVB-H Extension works with Mentum Planet 5.1

8.4 Mentum Planet 5.5 for the deployement of picocell and femtocell.

Picocell and Femtocell technologies are supported by Mentum planet 5.5. Both technologies can be simulated using a special extension related to their requirements. In May 2013 the only developed extention that could match with small cells (expecialy picocells and femtocells) is the “Femtocell extention” that only work for LTE, CDMA2000 and mobile WiMAX technologies using Mentum Planet 5.1.

Another option to simulate picocell and femtocell access points with Mentum Planet 5.5 is to use its editors presented above, in section 6.3.1.

With Mentum Planet 5.5, any network including small base stations like picocell or femtocell access points are considered as Heterogeneous Networks because of the presence of two distinct layer, indoor layer and outdoor layer. Using Mentum Planet 5.5 one can define two differents Heterogeneous Network:

- Heterogeneous Network for a single radio access technology with different cellular layer (example: macrocell, microcell, picocell, femtocell)
- Heterogeneous Network for multiple radio access technologies (example:GSM and WCDMA or wifi and LTE)

In our thesis we are interested of the first type of Heterogeneous Network (single radio access technology with different cellular layer). To achive the simulatioon of such network in Mentum Planet 5.5 we will need to:

- Define a picocell and/or femtocell access point antenna using the Mentum 5.5’s Antenna Editor;
- Using Mentum 5.5’s Site Editor, define a ‘Group’ for picocell and femtocell access points. A group is a colection of sector sharing the same characteristics and conditions;
- Define a picocell and/or femtocell’s sector (picocell and/or femtocell access points) using Mentum 5.5’s Sector Editor. Specify “Picocell Group” to the picocell access points and “Femtocell Group” to the femtocell access points. Assign the defined picocell antenna to the picocell access points and assign the defined femtocell antenna to the femtocell access points.
- Using Mentum 5.5’s Network settings, in the Cellular Layer tab, define the different network layers.

For example, the macrocell, microcell, picocell and femtocell layers. In the Site Editor, assign the every sectors or access points to a specific cellular layer.

In Mentum Planet 5.5, each sector has to be assign to an antenna system. Antenna definition in Antenna Editor is one of the delicate task to manage when simulating Picocell and Femtocell technologies in Mentum Planet 5.5. Choosing and configuring the antennas correctly is essential in order to maximize the coverage and capacity of the network. Antenna definition can be done through Mentum Planet Online Antenna Server that allows Antenna Vendors to publish their antenna patterns and caracteristics for the use of Mentum Planet users. Another option is to do it step by step. Mentum Planet 5.5's Antenna Editor supports:

- Advanced antenna systems including electrical tilt antennas, MIMO, and AAS;
- Multi-band antennas;
- Multi-beam antennas, used in single sector or multi-sector configurations;
- Eectrical tilt, azimuth, beamwidth;
- Remote control units;
- Explicit definition of antenna ports;
- Polarizations, including cross-pole and quad-pole;
- 3D antenna viewer;
- Selection of Uplink and Downlink ports.

CHAPTER 9

SIMULATION

It’s extremely challenging to examine the gain of the performance bring by the indoor layer in the traditional outdoor layer (macrocell). The true indoor-outdoor interoperability can only been seen through piloting a real heterogeneous network. Since the actual network data and devices are not available for our thesis work, simulation based on very theoretical network data and radio propagation environments is the second best alternative.

A typical simulation scenario consists of a very small indoor cells deployed inside the umbrella macrocell [16]. For Pico Node Bs and enterprise FAP, the deployment is done with respect to the macro Node B position and coverage when it will be randomly positioned for home FAP. It is evident that only main consideration will be used for the simulation and that some features like backhaul connection with the core network cannot be taken into account. Therefore it’s impossible to reliably predict the operation of the 3GPP Iu-h interface in live action.

The radio network planning tool and simulator used in this thesis is Mentum Planet 5.5 Educational Edition by Mentum Planet S.A. The simulation case is performed inside the covered area of a macro Node B where many building, roads, open areas and vegetation are located. The simulation is divided into 2 parts with a total of 4 scenarios.

Scenario 1: Only 1 macrocell in use. The macrocell is simulated across the considered building;

Scenario 2: 1 macrocell and 8 Pico Node Bs or 8 enterprises FAP are added to the building in the same carrier with the macrocell;

Scenario 3: Only 1 macrocell in use. The macrocell is simulated across its covered area for reference;

Scenario 4: 50 home FAP are deployed in the macrocell covered area in the same carrier with the macrocell.

The throughput studies in these cases will be focused on the downlink using WCDMA Release 99 bearers in order to fit with our thesis goal.

9.1 Environemt and cells

9.1.1 Simulation area

The considered area for the simulation is a building build upon 78 300 m^2 (0,0783 Km^2) area (length: 435 m, width: 180 m). The building is a convention center with 4 floors. 3 floors are inside the building and has a total height of 10 meters. The 4th floor is outside and is the terrace. The Pico Node Bs are deployed inside the 3rd floor at the top level and cover indoor area of the whole building. The 4th floor is covered by the macro Node B assumed to be at an average distance of 350 m from the considered building. The average amount of mobile users in the building is assumed to be 1000. The availabe users profils are voice, video and data users. For voice and video call services, the average demand per subcriber is assumed to 0,05 Erlang and 0,1 for other data services.

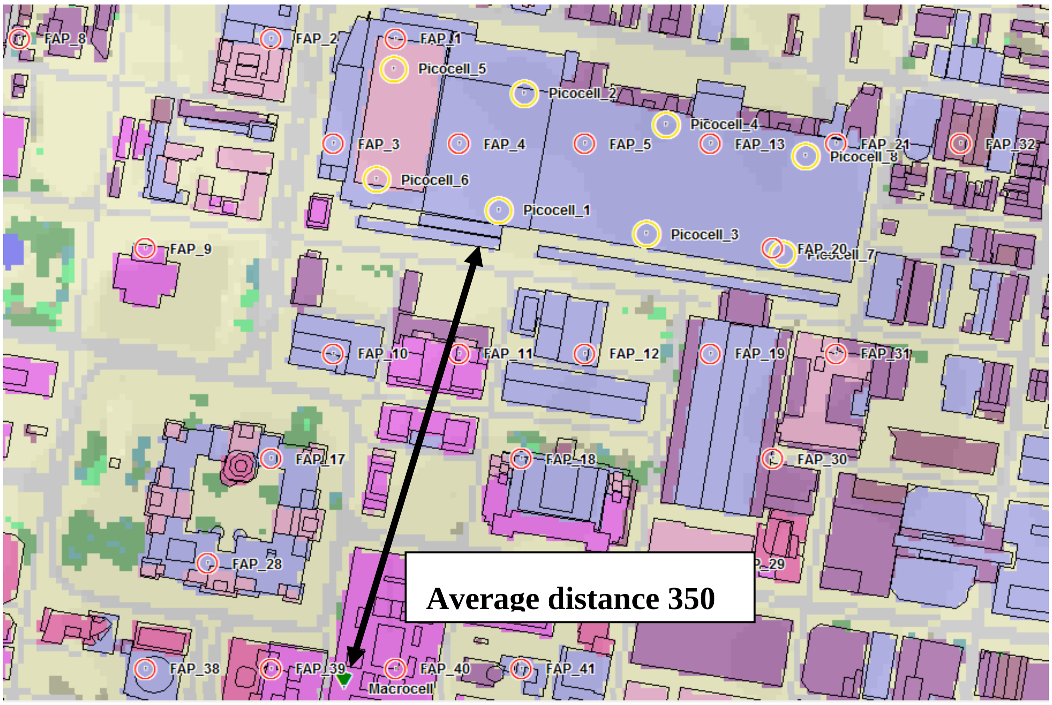


Figure 9.1 Main view of the simulation area.

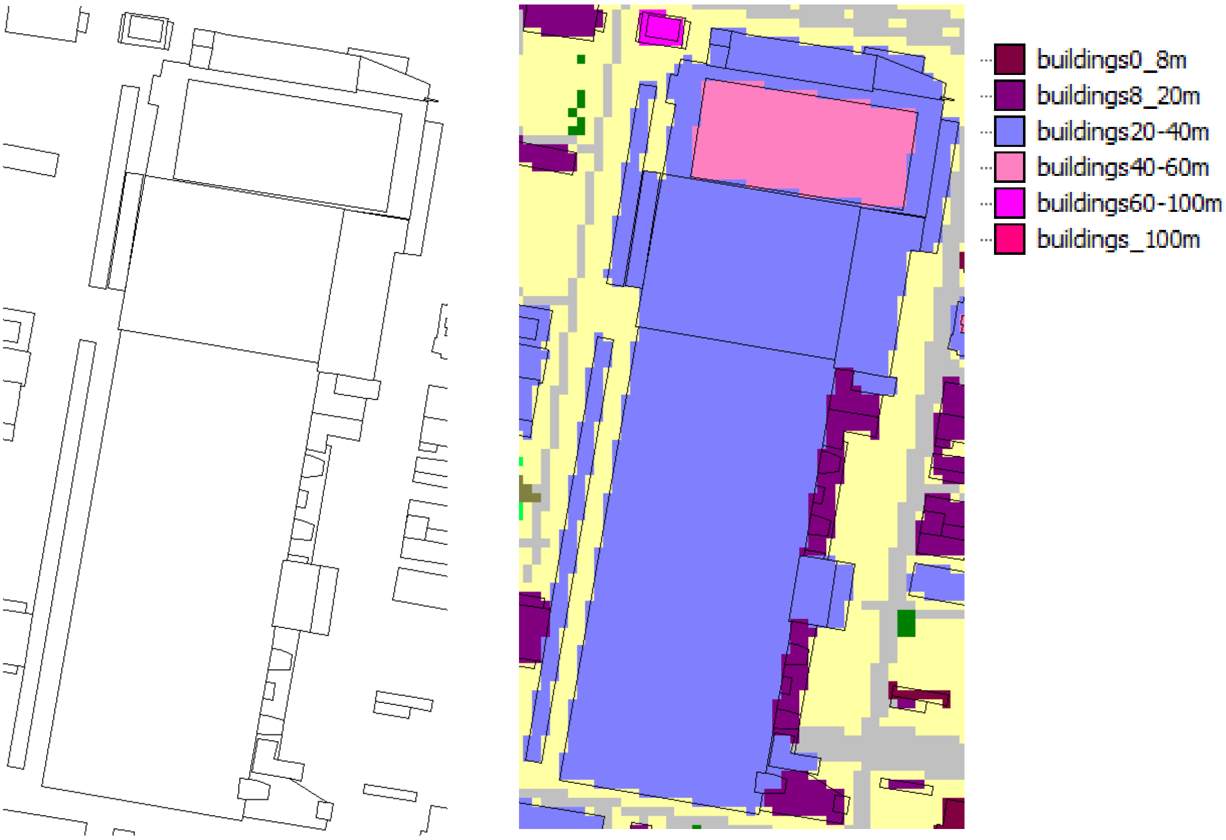


Figure 9.2 Main view of the considered building for scenario 2

The amount of picocells is assumed to be 8 according to the calculations done in the chapter 5 in dimensioning estimation. This amount is an average value and is relatively low because there are no floors or inside walls in the map data about the building using for the simulation. In a real world situation a considerably larger amount of picocells or femtocells could be placed in the same building and still maintain the same amount of attenuation between them. They could be for instance on top of each other in different floors separated by a concrete sheat.

In this simulation picocells or enterprises femtocells share the same challenge with the same cell radius. The only differences between them are the radiated power which is 24 dBm for the Pico Node B and 20 dBm for the enterprise FAP. For this reason we will consider residential FAP randomly deployed in the macrocell area to simulate the femtocell scenario.

The following figure gives the detailed workflow to simulate the different scenarios.

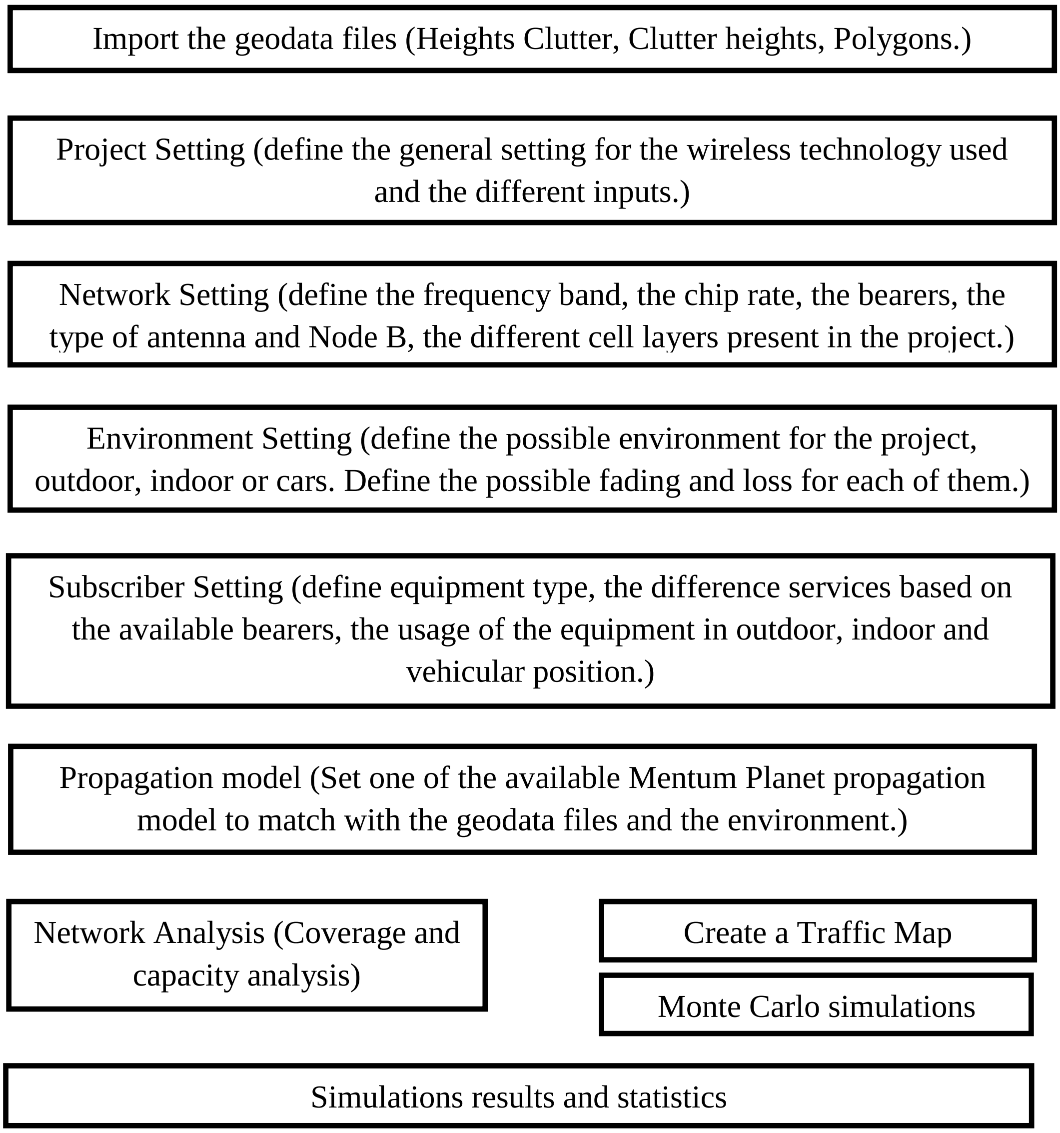


Figure 9.3 Workflow for radio network simulation in Mentum Planet 5.5

9.1.2 The environment

The simulation's environment is defined in Mentum planet via geodata files, including digital terrain models, clutter files, building outlines, region files along with other data required to accurately model a network.

The geodata files of the simulation area are organized into categories that as following:

Heights layer: a folder that contains Digital Elevation Model files used to define the height of the terrain above sea level.

Clutter layer: a folder that contains files used to describe land classification or land use.

Clutter Heights layer: a folder that contains files used to define the height of clutter Above Ground Level (AGL).

Polygons layer: a folder that contains files used to define buildings and other area geometric forms.

sea
inland water
wetland
barren
grass-agriculture
rangeland
woodland
forest
buildings0_8m
buildings8_20m
buildings20-40m
buildings40-60m
buildings60-100m
buildings_100m
roads
airport

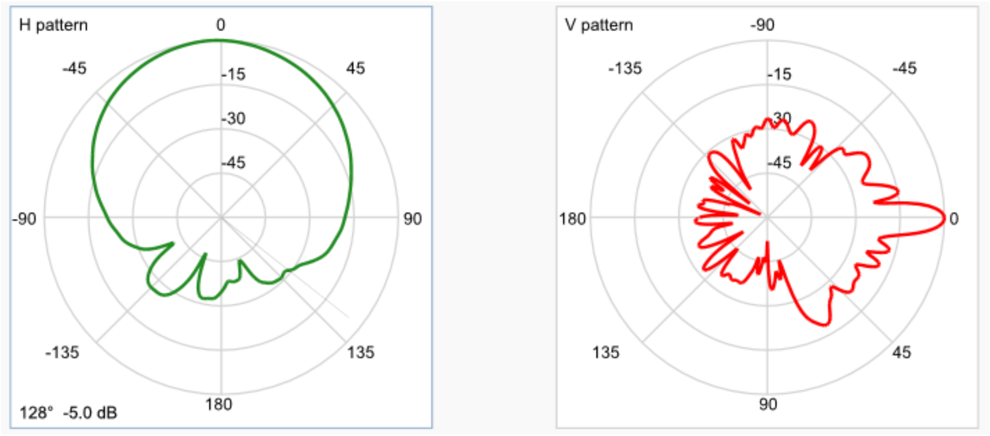
Figure 9.4 Legend of the clutter layer from the simulation digital map

The loss and other fading are assumed to:

- Slow fading standard deviation: 7 dB
- Outdoor, indoor and deep indoor fast fading margin: 0 dB
- Respective loss and speed of vehicles: 7 dB, 50 Km/h
- Indoor penetration loss: 10 dB
- Deep indoor penetration loss: 20 dB

9.1.3 Antennas and Node types

- **Node B antenna Pattern (directional antenna)**



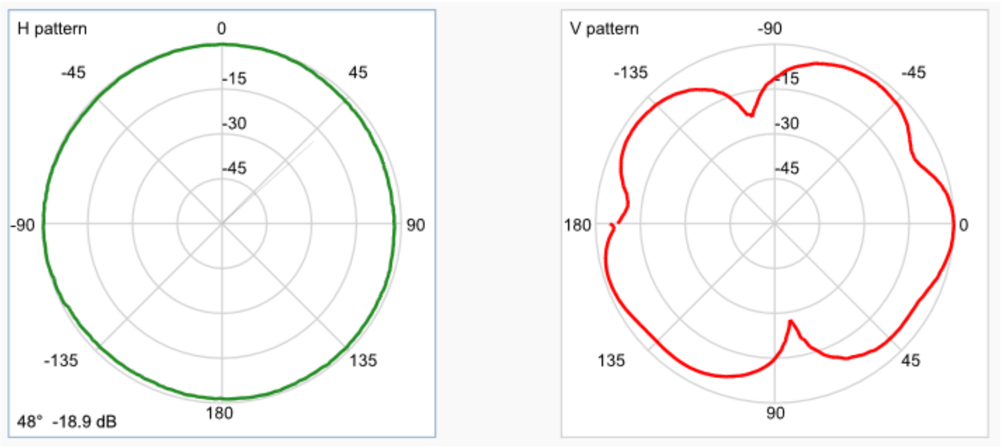
Minimum frequency: 1920 Mhz

Maximum frequency: 2200 MHz

Polarization: Vertical
Type: Co-polarization

Figure 9.5 Antenna pattern of the macro Node B used in the simulation

- **Pico Node B and Femto Access Point antenna Pattern (omni-directional antenna**



Minimum frequency: 1900 Mhz

Maximum frequency: 2000 MHz

Polarization: Vertical
Type: Co-polarization

Figure 9.6 Antenna pattern of the Pico Node B and the FAP used in the simulation

- **The settings of the Node B**

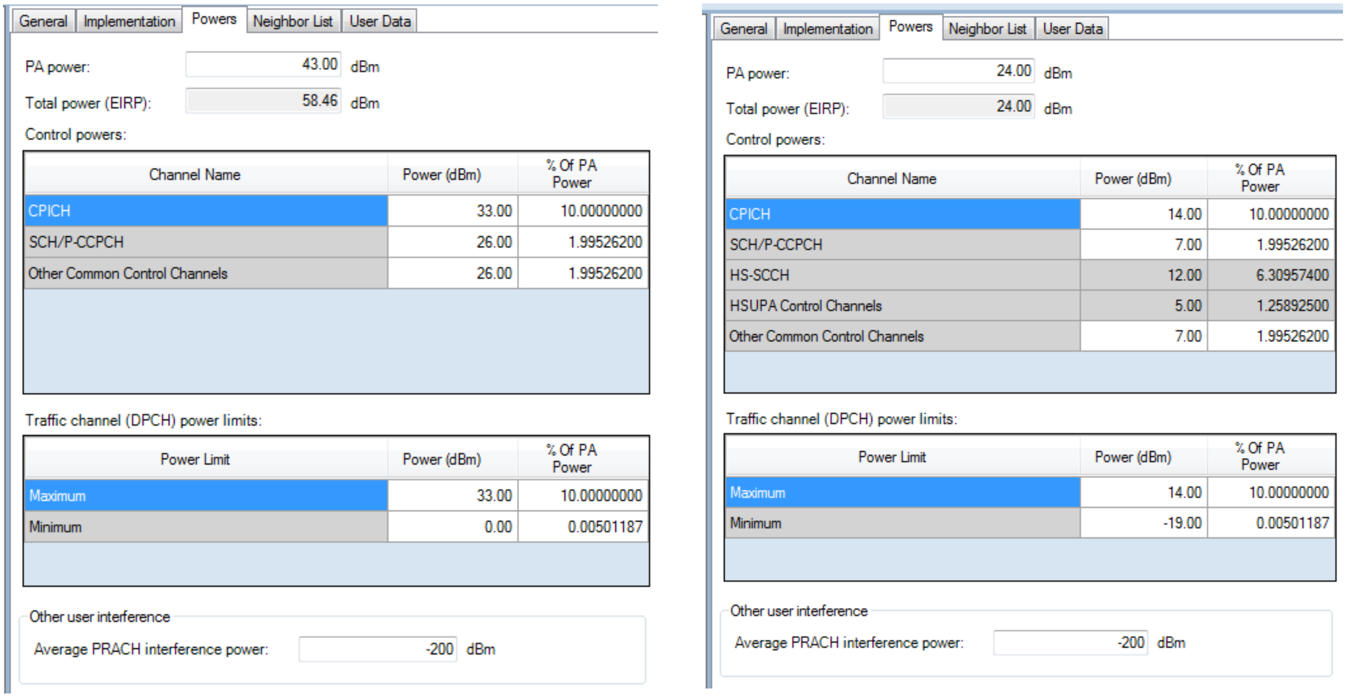
The main keys used to differentiate a traditional macro Node B from a Pico Node B or a Femto Access Point using the Site Editor of Mentum Planet are:

- The total power spread by the Node B antenna (PA power in Mentum Planet);
- The maximum cell radius;
- The maximum users per sector.

The macro Node B is deployed with one sector (a directional antenna) which covers the building area. We set 43 dBm as total power from the macro Node B for 58,46 dBm as total EIRP. This is done to allow a medium coverage around the building area (average of -98 dBm total power from the macro node B in the building area). We also assume a maximum cell radius of 5 km and 100 maximum simultaneous users for WCDMA release 99 users.

Each Pico Node B and enterprise FAP is deployed with one Omni-directional antenna. The total power from the Pico Node B is assume to be 24dBm and 20 dBm for the Femto Access Point. The maximum cell radius is assumed to be 60 meters for both Pico Node B and enterprise FAP. The maximum users per sectors are assumed to be 35 for the Pico node B and 16 for the FAP.

The rest of the parameters, mainly, the uplink load and other quality and power parameter are summarized in the following figure.



PA power: 43.00 dBm

Total power (EIRP): 58.46 dBm

Control powers:

Channel Name	Power (dBm)	% Of PA Power
CPICH	33.00	10.00000000
SCH/P-CCPCH	26.00	1.99526200
Other Common Control Channels	26.00	1.99526200

Traffic channel (DPCH) power limits:

Power Limit	Power (dBm)	% Of PA Power
Maximum	33.00	10.00000000
Minimum	0.00	0.00501187

Other user interference

Average PRACH interference power: -200 dBm

PA power: 24.00 dBm

Total power (EIRP): 24.00 dBm

Control powers:

Channel Name	Power (dBm)	% Of PA Power
CPICH	14.00	10.00000000
SCH/P-CCPCH	7.00	1.99526200
HS-SCCH	12.00	6.30957400
HSUPA Control Channels	5.00	1.25892500
Other Common Control Channels	7.00	1.99526200

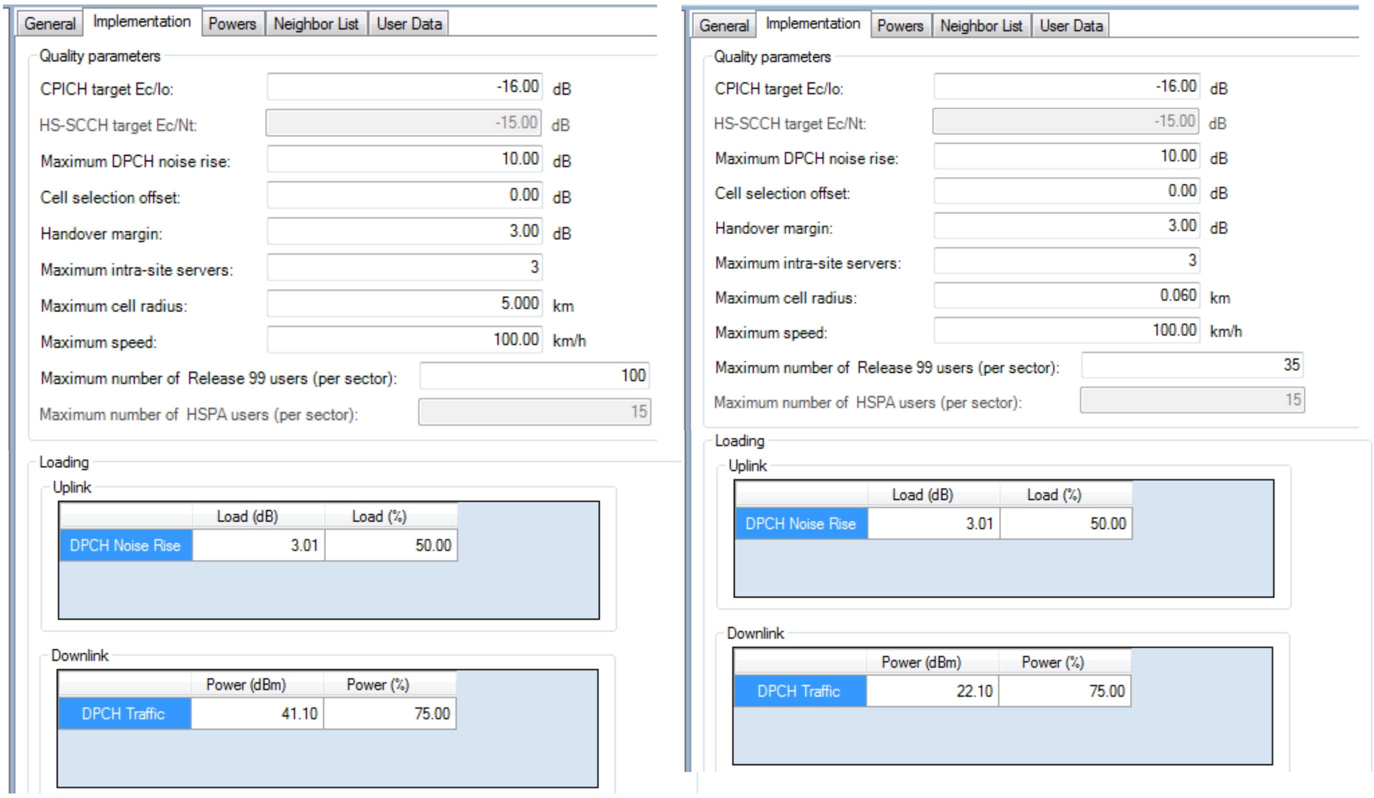
Traffic channel (DPCH) power limits:

Power Limit	Power (dBm)	% Of PA Power
Maximum	14.00	10.00000000
Minimum	-19.00	0.00501187

Other user interference

Average PRACH interference power: -200 dBm

Figure 9.7 Node Power setting in Mentum Planet 5.5



Quality parameters

CPICH target Ec/Io: -16.00 dB
HS-SCCH target Ec/Nt: -15.00 dB
Maximum DPCH noise rise: 10.00 dB
Cell selection offset: 0.00 dB
Handover margin: 3.00 dB
Maximum intra-site servers: 3
Maximum cell radius: 5.000 km
Maximum speed: 100.00 km/h
Maximum number of Release 99 users (per sector): 100
Maximum number of HSPA users (per sector): 15

Loading

Uplink

	Load (dB)	Load (%)
DPCH Noise Rise	3.01	50.00

Downlink

	Power (dBm)	Power (%)
DPCH Traffic	41.10	75.00

Quality parameters

CPICH target Ec/Io: -16.00 dB
HS-SCCH target Ec/Nt: -15.00 dB
Maximum DPCH noise rise: 10.00 dB
Cell selection offset: 0.00 dB
Handover margin: 3.00 dB
Maximum intra-site servers: 3
Maximum cell radius: 0.060 km
Maximum speed: 100.00 km/h
Maximum number of Release 99 users (per sector): 35
Maximum number of HSPA users (per sector): 15

Loading

Uplink

	Load (dB)	Load (%)
DPCH Noise Rise	3.01	50.00

Downlink

	Power (dBm)	Power (%)
DPCH Traffic	22.10	75.00

Figure 9.8 Quality parameters and loads setting in Mentum Planet 5.5

9.1.4 Propagation models

Mentum Planet propagation model editor does not allow programming of a full propagation model from beginning to end. Some basic types of propagation models are proposed. The propagation editor allows choosing a predefined model from a “type” list to describe the simulation’s propagation situation. Thus the parameters of the “type propagation model” are modified to correspond to the simulation network design. The propagation models available in the “type” list are: Predict 4, Planet General Model and Universal Model. We will base the simulation propagation model on the Planet General Model type because it allow us to match it better to an urban area. It is also the only activated propagation model for the Educational version of Mentum Planet 5.5 used for our thesis work. The following table presents the “type” of available propagation model in Mentum Planet and the case they are used for.

Table 9.1 List of “type” of propagation model available in Mentum Planet 5.5

Usages	Predict 4	Planet General Model	Universal Model
For macro-cell planning	Good	Good	Excellent
For mini-cell planning	Poor	Fair	Excellent
For micro-cell planning	Very poor	Fair	Excellent
Over large propagation distances	Excellent	Fair	Good
With no model tuning	Fair	Poor	Good
With cluster tuning	Fair	Poor	Good
On a per-sector basis	Fair	Fair	Excellent
With merged predictions	Good	Fair	Good

The Planet General Model is best used for frequencies between 150 and 2000 MHz where the distance between the transmitter and the receiver varies between 1 and 100 kilometers. Ideally, when using this model, the base station antenna heights should varies between 30 and 1000 meters and the mobile station antenna heights should be between 1 and 10 meters. The model calculates the path loss for each pixel or element within the prediction area and by interpolation generates predictions for each of them [26].

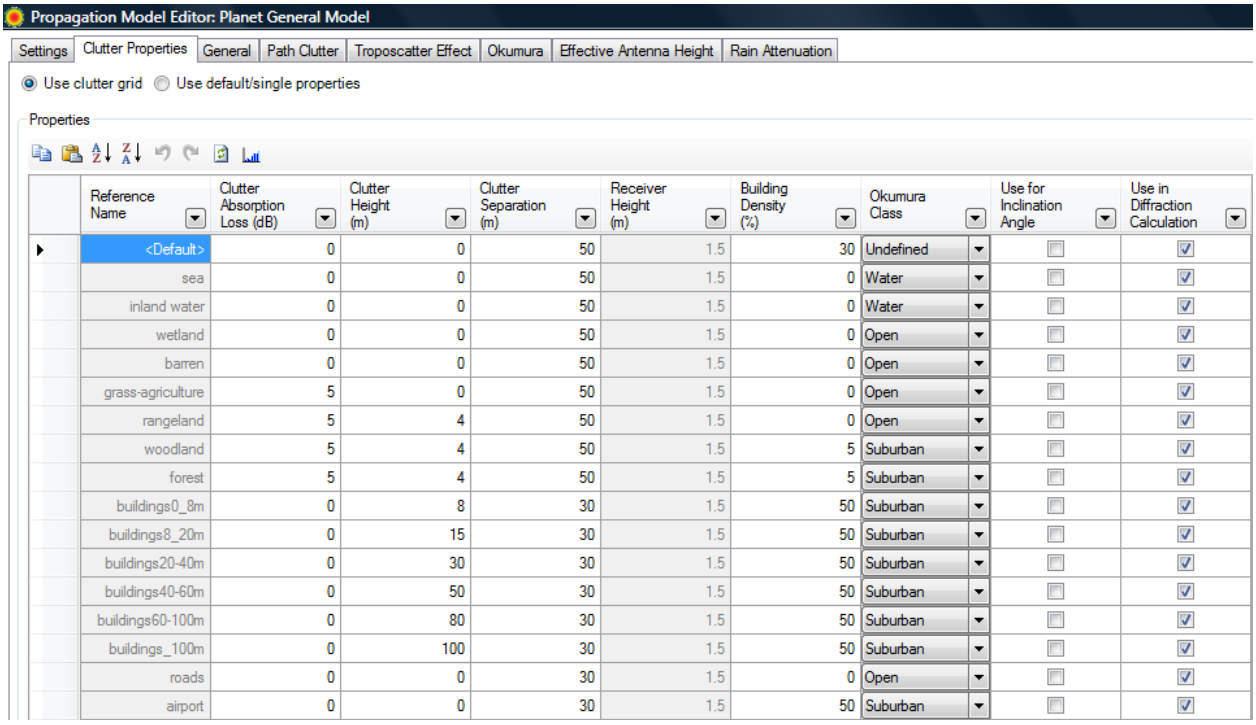
The Loss equation of Planet General Model is based on Epstein-Peterson Model and is defined as following [26].

$$Loss = + K_1 + K_2 \log(d) + K_3 \log\left(H_{eff}\right) + K_4 Diffraction + K_5 \log\left(H_{eff}\right) \log(d) + K_6\left(H_{meff}\right) + K_{CLUTTER}$$

Where:

(d) is the distance between the UE and the Node B in kilometers, (H_{mef}) is the height of the UE antenna, (H_{eff}) is the efficient height of the Node B antenna, (*Diffraction*) is the diffraction loss calculated by using the Epstein-Peterson model, and ($H_{CLUTTER}$) is the clutter loss. These parameters of the path loss are set in the propagation editor or automatically calculated by Mentum Planet using the digital map clutter layer’s information.

Parameters (K_1) and (K_2) are the constant offset in dB and the multiplying factor for log(*d*), respectively. (K_3) is the multiplying factor for log(*d*), it compensates for gain due to antenna height. (K_4) is the multiplying factor for diffraction calculation. (K_5) is the Okumura-Hata type of multiplying factor for log(H_{eff})log(*d*). (K_6) is correction factor for the mobile effective antenna height gain. These parameters are set in the propagation model editor using Hata urban environment propositions available in Mentum Planet 5.5.



● Use clutter grid ○ Use default/single properties

	Reference Name	Clutter Absorption Loss (dB)	Clutter Height (m)	Clutter Separation (m)	Receiver Height (m)	Building Density (%)	Okumura Class	Use for Inclination Angle	Use in Diffraction Calculation
▶	<Default>	0	0	50	1.5	30	Undefined	☐	☑
	sea	0	0	50	1.5	0	Water	☐	☑
	inland water	0	0	50	1.5	0	Water	☐	☑
	wetland	0	0	50	1.5	0	Open	☐	☑
	barren	0	0	50	1.5	0	Open	☐	☑
	grass-agriculture	5	0	50	1.5	0	Open	☐	☑
	rangeland	5	4	50	1.5	0	Open	☐	☑
	woodland	5	4	50	1.5	5	Suburban	☐	☑
	forest	5	4	50	1.5	5	Suburban	☐	☑
	buildings0_8m	0	8	30	1.5	50	Suburban	☐	☑
	buildings8_20m	0	15	30	1.5	50	Suburban	☐	☑
	buildings20-40m	0	30	30	1.5	50	Suburban	☐	☑
	buildings40-60m	0	50	30	1.5	50	Suburban	☐	☑
	buildings60-100m	0	80	30	1.5	50	Suburban	☐	☑
	buildings_100m	0	100	30	1.5	50	Suburban	☐	☑
	roads	0	0	30	1.5	0	Open	☐	☑
	airport	0	0	30	1.5	50	Suburban	☐	☑

Figure 9.9 Different steps to match the digital map to the Planet General Model

9.1.5 Terminal type, services and bearers

It is possible in UMTS-WCDMA to allocate different amount of capacity to each user according to their needs and the radio network’s conditions. This is done by dividing the different transport resources into Radio Access Bearers (RAB). A bearer is negotiated or renegotiated on the basis of the service speed and the signal to noise and interference ratio (SINR) in the radio network. Thus bearers represent the different services with their technical feature delivered in WCDMA system (voice and other data services). The bearers used in this simulation are related to Release 99 and are the following:

- 3Km/h voice 12,2Kbps downlink and uplink;
- 3Km/h video Call CS 64 Kbps downlink and uplink;
- 3Km/h data PS 64 Kbps, PS 128 Kbps, PS 256 Kbps, PS 384 Kbps downlink and uplink.

The activity factors are assumed to be 50% in the uplink and the downlink for voice and CS 64 services. It is assumed to be 100% in the downlink and 50 % in the uplink for other data services.

A terminal type in Mentum Planet is defined in the Subscriber editor according to the different bearer it use. Four different terminals are defined in our simulation for the following usages:

- **Usage1**- Voice: Only voice 12,2 Kbps;
- **Usage2**- Voice-Video&PS64: voice 12,2Kbps, CS 64 Kbps and PS 64Kbps;
- **Usage3**- Voice-Video&PS128: voice 12,2Kbps, CS 64 Kbps and PS 128Kbps;
- **Usage4**- Voice-Video&PS256: voice 12,2Kbps, CS 64 Kbps and PS 256Kbps;
- **Usage5**- Voice-Video&PS384: voice 12,2Kbps, CS 64 Kbps and PS 384Kbps.

The following table explains how these terminals are shared over the simulation area

Table 9.2 Weighing factor of different terminals according to the environment.

Usages	Total percentage of use	Percentage of use according to the environment
Usage1- Voice	100% voice 12,2 Kbps	50% indoor, 25% deep indoor 25% outdoor
Usage2- Voice-Video&PS64	50% voice 10% Video CS64 40% PS 64, 128, 512, 384	55% indoor 23% deep indoor 22% outdoor
Usage3- Voice-Video&PS128		
Usage4- Voice-Video&PS256		
Usage5- Voice-Video&PS384		

9.1.6 Traffic Map

Modeling traffic in Mentum Planet is to spatially represent the density of potential subscribers in a cell, that is said traffic map. For this purpose Mentum Planet allows the use of the different geodata layers which are:

Regions: a Mentum Planet-MapInfo (.tab) file containing a set of geographical regions with a total traffic count assigned to each region.

Vectors: a Mentum Planet-MapInfo (.tab) file containing geographical vector objects with a total traffic count assigned to each vector. Vector objects include streets, roads, and hot spots.

Classified Grid: a Mentum Planet-MapInfo classified grid (.grc) file containing a set of geographical regions. A text file that contains the total traffic counts for each region should be also added when this option is chosen.

Another option is to edit a Microsoft Excel (.xls) file containing the total amount of subscriber under each cell coverage. This last option will be used for the simulation because the geodata files used for our thesis work does not contain the necessary to implement other options. For the simulation we will set an average total amount of 5000 users constantly under the macrocell area and an average total amount of 150 users constantly under each picocell or enterprise femtocell.

The weighting factor for the distribution of these amount of subscribers over the clutter type of the digital map is detailed in the following table.

Table 9.3 Weigting factors for subscriber deployment over the simulation area.

Clutter type	Weight	Percentage (%)
Sea	1	0,2949
inland water	1	0,2949
Wetland	1	0,2949
Barren	5	1,4749
grass-agriculture	5	1,4749
Rangeland	5	1,4749
Woodland	5	1,4749
Forest	5	1,4749
buildings0-8m	30	8,8495
buildings8-20m	40	11,7994
buildings20-40m	50	14,7492
buildings40-60m	50	14,7492
buildings60-100m	50	14,7492
buildings-100m	60	17,6991
Roads	20	5,8997
Airport	10	2.9498
Default	1	0,2949
TOTAL	339	100%

9.1.7 Network Analysis

Mentum Planet provides the required information through Network Analyses to determine the coverage and capacity of the network. This Analysis is generated with the inputs like the equipment type and a service defined in the subscriber settings. This analysis requires less time to automatically generate predictions for the analysis layers. However, this type of analysis does not generate detailed subscriber information.

9.1.8 Monte Carlo simulations

In order to take into account the change of the amount of available users and their behaviors at any time a Monte Carlo simulation is done. A Monte Carlo simulation is a serial of runs where at each run, some users are randomly chosen and are given a fixed position and static behavior. A more reliable view of the real network is achieved when more than one of these static runs is simulated.

Thus a Monte Carlo simulation is a process of repeating a number of static simulations, with redistribution of the terminals between the steps. The distribution of the users over the considered area is done taking into account the service they are using and their traffic demand. That is summarized in the following equation:

Average number of subscribers spread Monte Carlo = Number of subscribers in Traffic Map (user density in the considered area) × Amount of Erlangs per subscriber (9.1)

Mentum Planet use a settings dialog box to define simulation settings for Monte Carlo Simulation. Unlike a network analysis, a Monte Carlo simulation takes all subscriber parameters into account when generating simulation layers. To do this, at each Monte Carlo run, Mentum Planet:

- Creates a random pattern of subscribers. The simulation places the subscribers at random locations using the traffic map densities, and determines the subscriber types from the definitions in the Subscriber Editor.
- Generates downlink and uplink analyses. This uses the random subscriber pattern to determine the number of subscribers that can be served, while taking into account the impact of each served subscriber on the network.

On the last run of the simulation, Mentum Planet generates “operating points” that are the results of the simulation divided by sector, carrier, and subscriber type. Mentum Planet averages these and uses them to create reports.

9.2 Simulation results

9.2.1 Traffic map, user density

A traffic map is generated to find the density of the user in the simulation area. Assuming a constant amount of 5000 users under the macrocell coverage and 125 constant users under the picocell, the traffic map generator of Mentum Planet give the traffic map depicted in the following figure.

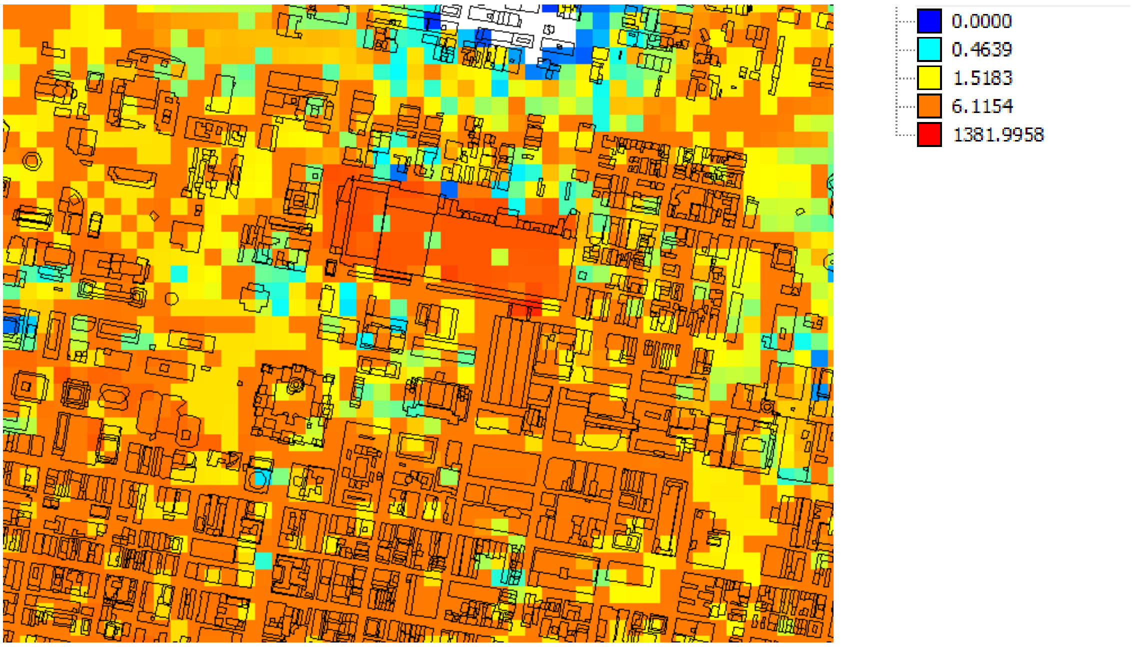


Figure 9.10 User density inside and around the considered building (Unit: subscriber /Km^2)

9.2.2 Coverage predictions

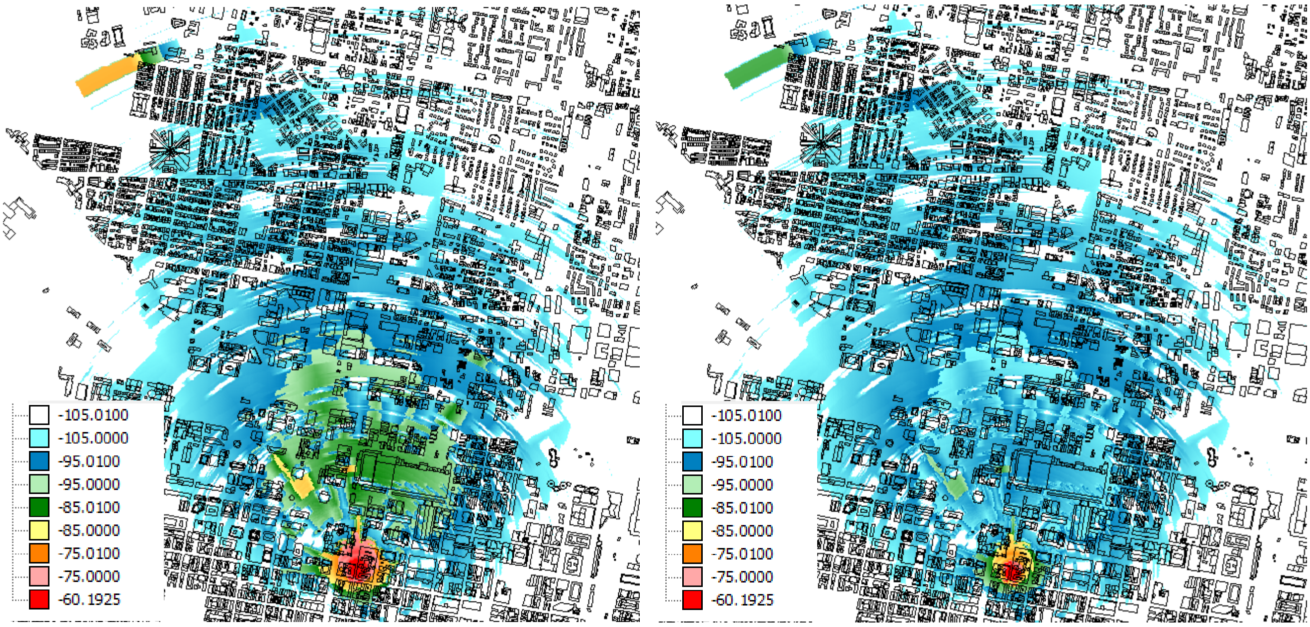
Coverage is presented by the best Total received signal power or by the best total received signal power for CPICH at the considered area.

In Figure 8.11 the best total received signal power for CPICH is shown for only macrocell deployment (scenario1). It can be clearly seen that while the coverage is mainly very good around the macro Node B, there are clear problems in indoor coverage for the considering building located at average 350 meters. The received best total signal power for CPICH is very low inside the building, between -95 and -105 dBm.

The picocells or enterprise femtocells will help in poor indoor coverage for the building as depicted in figure 8.12. It is shown that the deployment of indoor nodes will help to achieved between -75 and -60 dBm for the best total received signal power for CPICH.

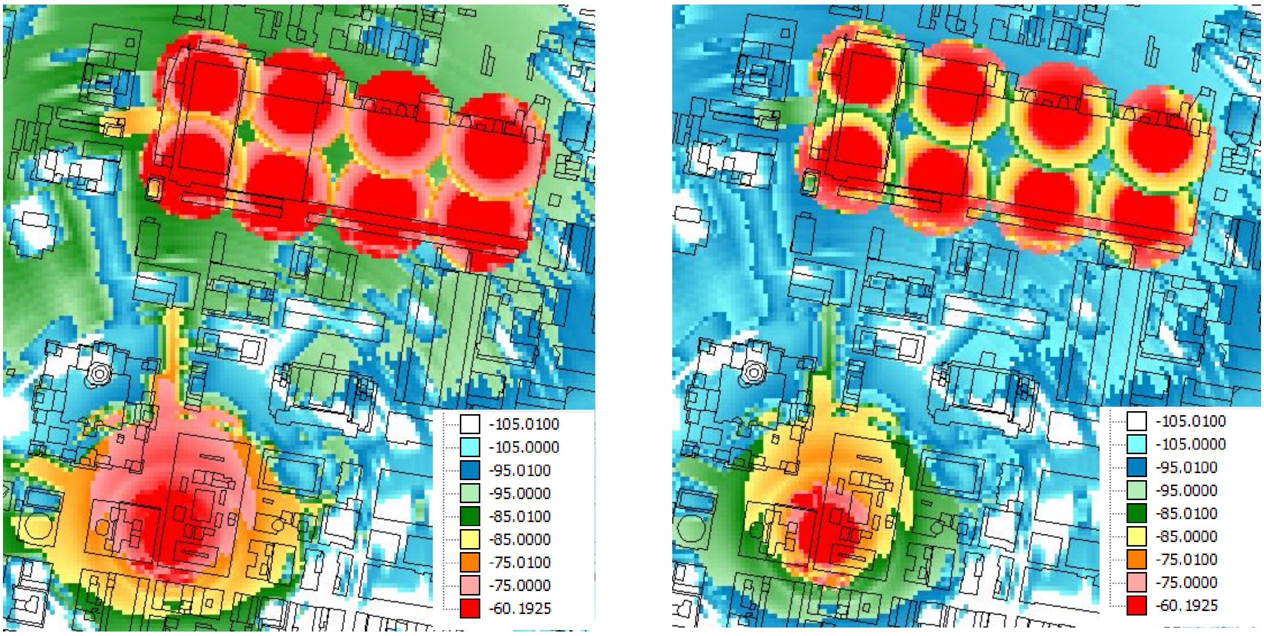
In figure 8.13, a plot depicting the best total received signal power for CPICH for both macrocell and home femtocell is presented. All the home femtocell coverage prediction has not being displayed for the figure clarity. The red circles in figure 8.12 represent Pico Node B or enterprise FAP. In the figure 8.13 the red circles represent home femtocells.

It is noticeable how a single picocell or femtocell enhances the coverage only in its relatively small area. Thus, a great number of femtocells will surelly affect the overall coverage area.



(A) (B)

Figure 9.11 (A) Macro Node B Total Power (Unit: dBm)
(B) Macro Node B CPICH Power (Unit: dBm)
(*The different Nodes have been removed for figure clarity.*)



(A) (B)

Figure 9.12 (A) Macro Node B and Pico Node B Total Power (Unit: dBm)
(B) Macro Node B and Pico Node B CPICH Power (Unit: dBm)
(*The different Nodes have been removed for figure clarity.*)

The deployment of the home femtocell is done randomly using the Automatic Site Placing tool of Mentum Planet 5.5. The deployment of 50 FAP is depicted in the following figures.

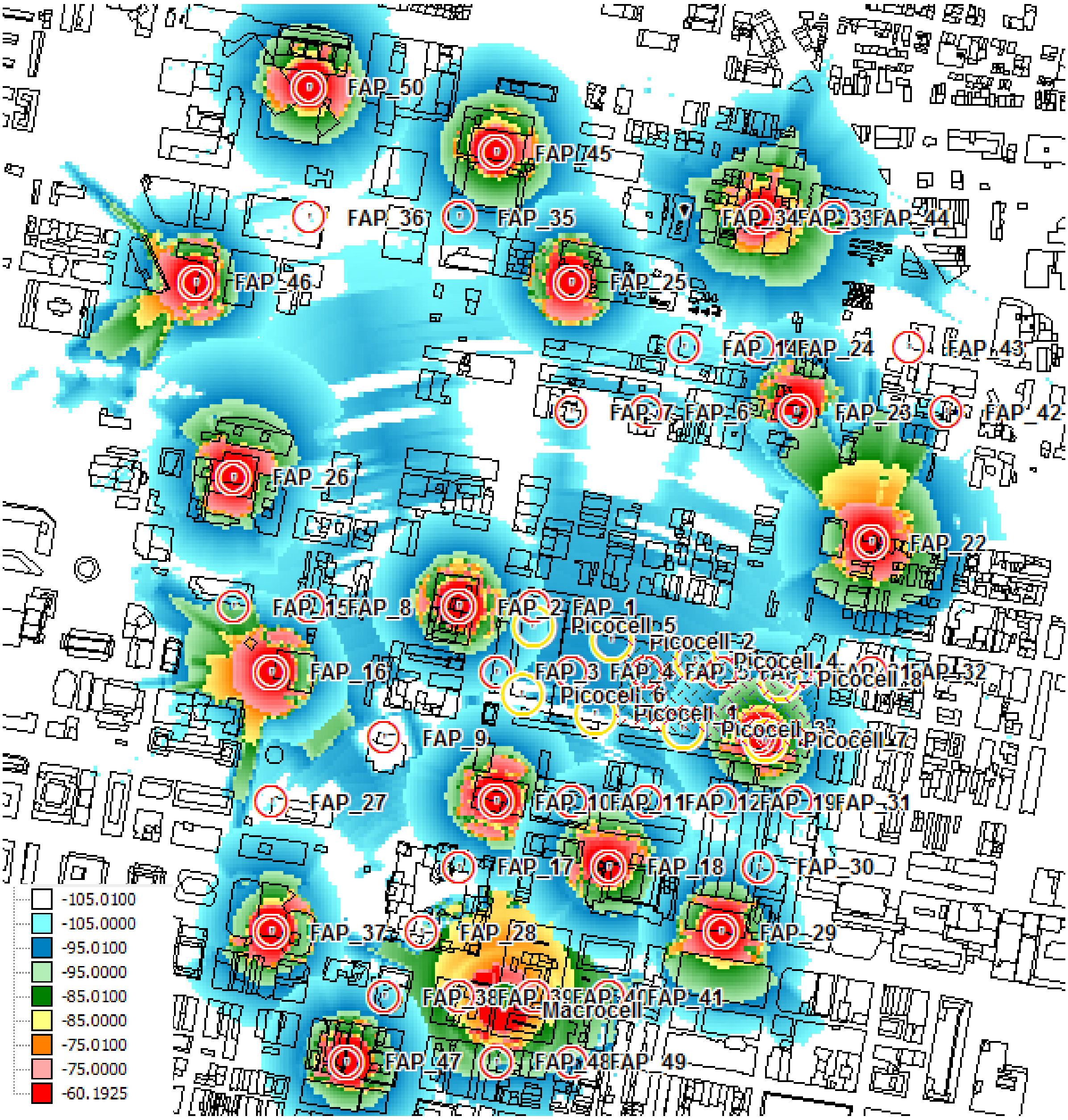


Figure 9.13 Macro Node B and Home Femto Access Points Total Power (Unit: dBm).

All the entire red circles represent a FAP. The total CPICH power of all FAP have not displayed for the figure clarity.

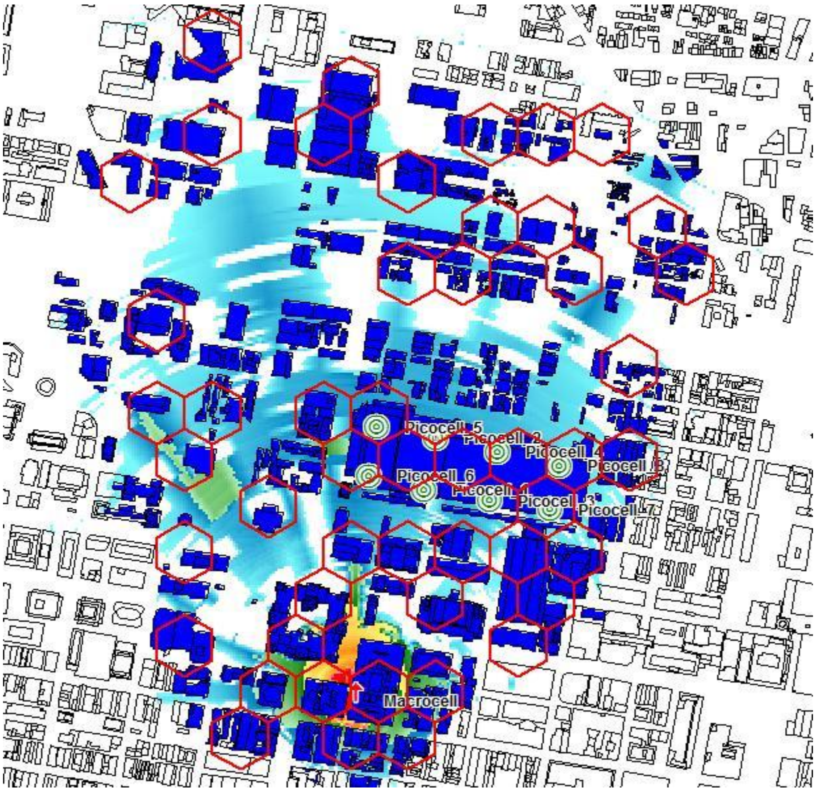


Figure 9.14 Random deployment of home FAP in the macro Node B covered area

9.2.3 Received power and noise rise

- **Scenario 1: Macro Node B over the building area for reference.**

For 25 Monte Carlo runs with 72 users spread over the building area, the average of total received power for indoor, deep indoor and outdoor is -112,33dBm. The load is 6,15% for the three environments with an average noise rise of 0,28dB.

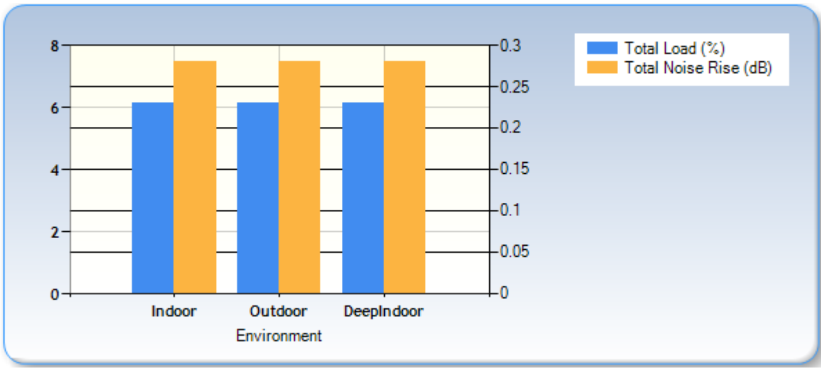


Figure 9.15 Load and Noise rise in the building when only the macrocell is deployed.

- **Scenario 2: Macro Node B and 8 Pico Node B or 8 enterprise FAP over the building area.**

For 95 Monte Carlo runs with 72 users spread over the building area, the average of total received power from the macrocell is -124,67 dBm and -107,02 from the picocells or enterprise femtocells. In this scenario we can see that the main traffic from the subscribers is moved from the macrocell to the picocells or enterprise femtocells where more load and noise rise is present.

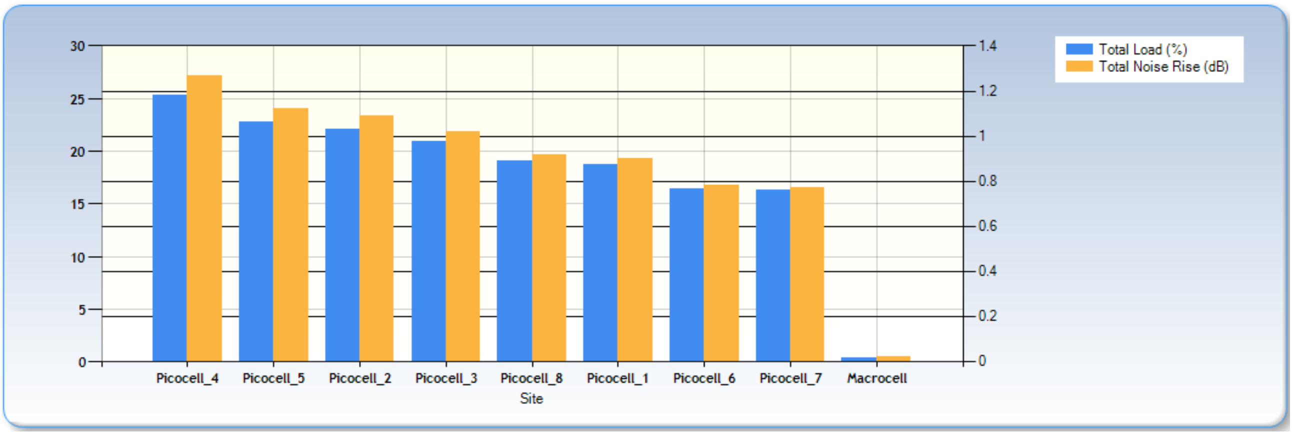


Figure 9.16 Load and Noise rise in the building when both macrocell and 8 picocells or 8 enterprise femtocells are deployed.

- **Scenario 3: Macro Node B over the macro area for reference.**

For 18 Monte Carlo runs with 92 users spread over the macrocell coverage, the average of total received power for indoor, deep indoor and outdoor is -110,42dBm. The load is 9,22% for the 3 environment with an average noise rise of 0,42dB.

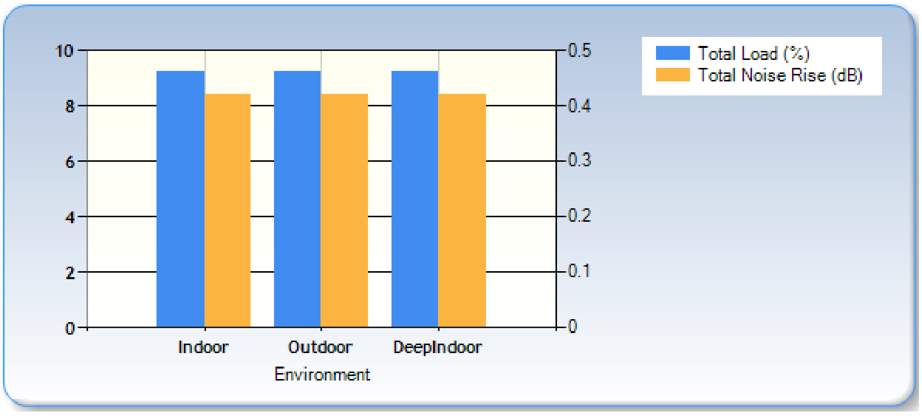


Figure 9.17 Load and Noise rise in the macro area when only the macrocell is deployed.

- **Scenario 4: Macro Node B and 50 home FAP over the macro area.**

For 17 Monte Carlo runs with 91 users spread over the macro area, the average of total received power from the macrocell is -121,34 dBm and -114,51 for the home femtocells. Here also we can see that the main traffic from the subscribers is moved from the macrocell to the home femtocells where more load and noise rise is present.

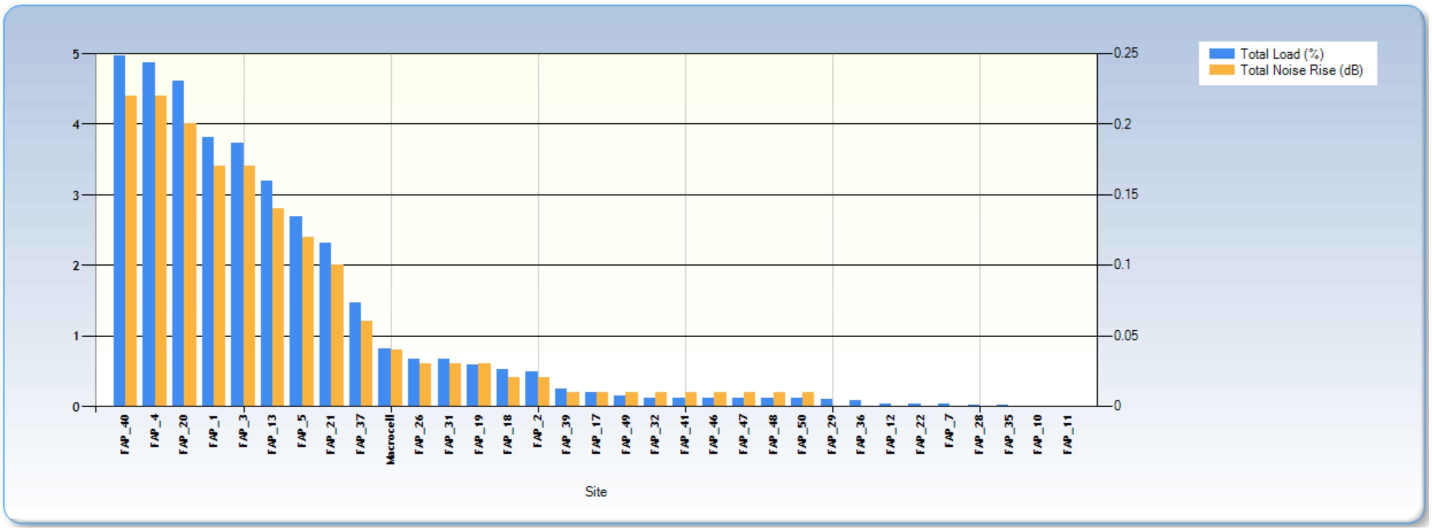


Figure 9.18 Load and Noise rise in the macro area when both macrocell and 50 home femtocells are deployed.

9.2.4 Achievable WCDMA Release 99 bearers

- **Scenario 2: Macro Node B and 8 Pico Node B or 8 enterprise FAP over the building area**

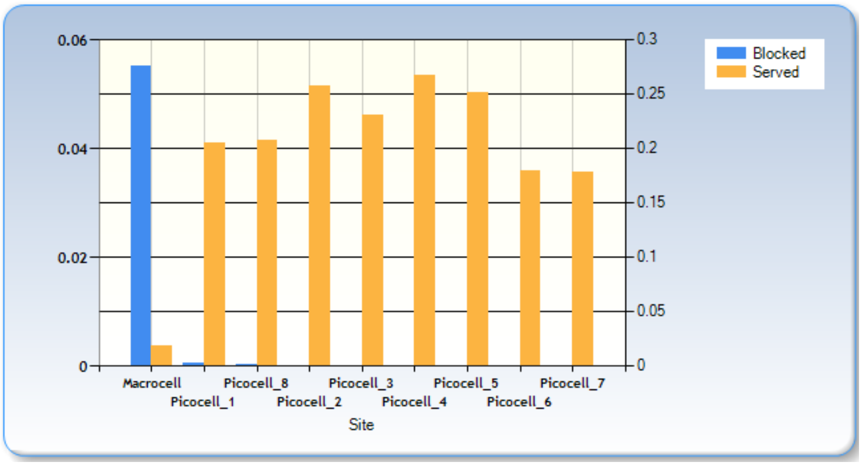


Figure 9.19 services acceptance and block for scenario 2.

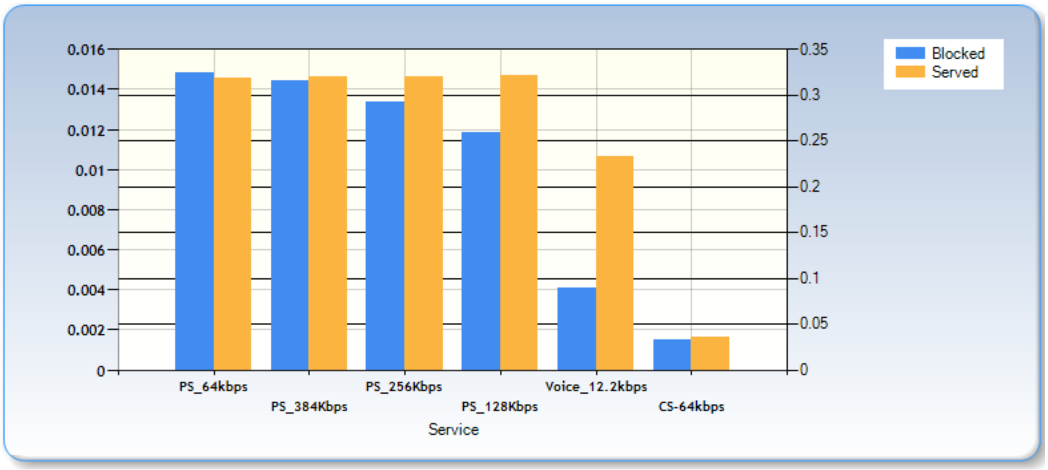


Figure 9.20 Achievable WCDMA Release 99 bearers for scenario 2.

The maximum blocks are observed for the macro Node B. The services most affected by the macro Node B blocks are the data services (PS 64Kbps, PS 128Kbps, PS 256Kbps and PS 256Kbps). These blocks are caused by the UE limited Transmission power that cannot overpass the in-building loss. That is possible only if the UE is not in line of sight with a close picocell of enterprise femtocell.

- **Scenario 4: Macro Node B and 50 home FAP over the macro area.**

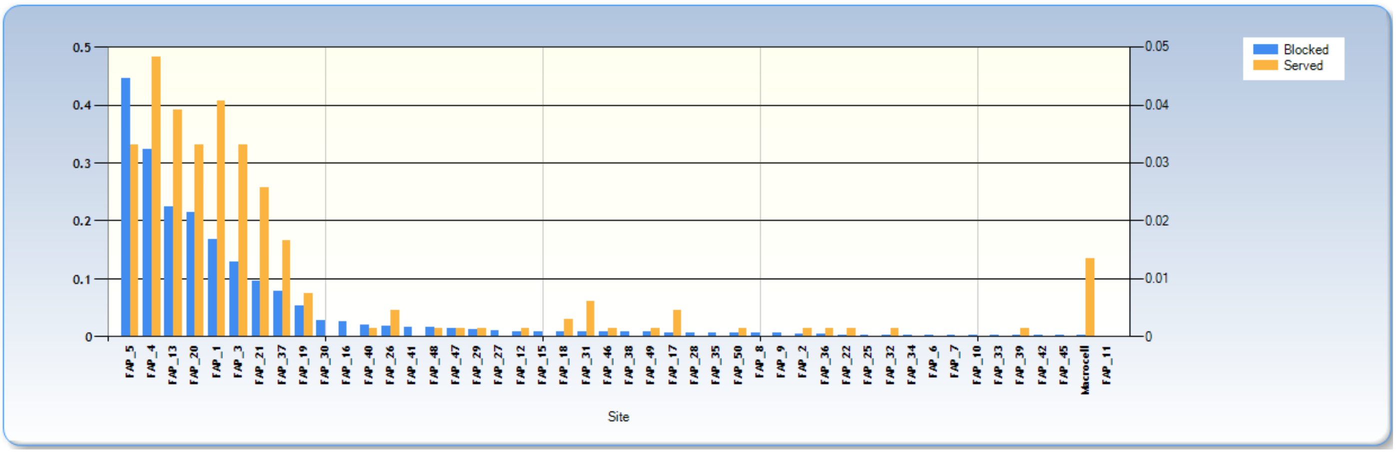


Figure 9.21 services acceptance and block for scenario 4.

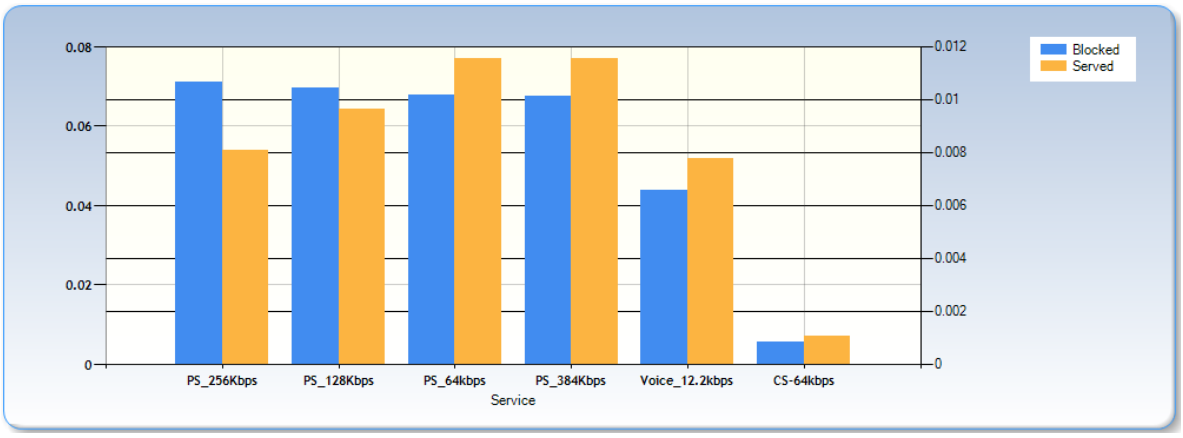


Figure 9.22 Achievable WCDMA Release 99 bearers inside macro area for both macrocell and 50 home femtocells.

The maximum blocks are observed for some FAP which are also the more serving node in this scenario's result. This is normal because the active traffic is moved from the macrocell to the FAP as explained in the previous sections. Also the version of Mentum Planet (Educational) does not allow us to specify the access mode of the FAP. Therefore all the FAP are considered deployed in open mode with a small capacity (maximum 8 users) when they have to face a macro Node B traffic demand. Here also the services most affected by blocks are the data services (PS 64Kbps, PS 128Kbps, PS 256Kbps and PS 256Kbps).

9.2.5 Achievable throughput

- **Scenario 1**

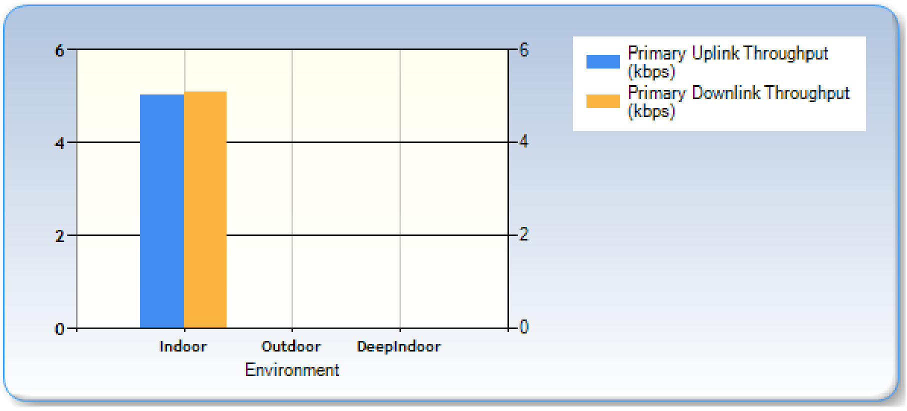
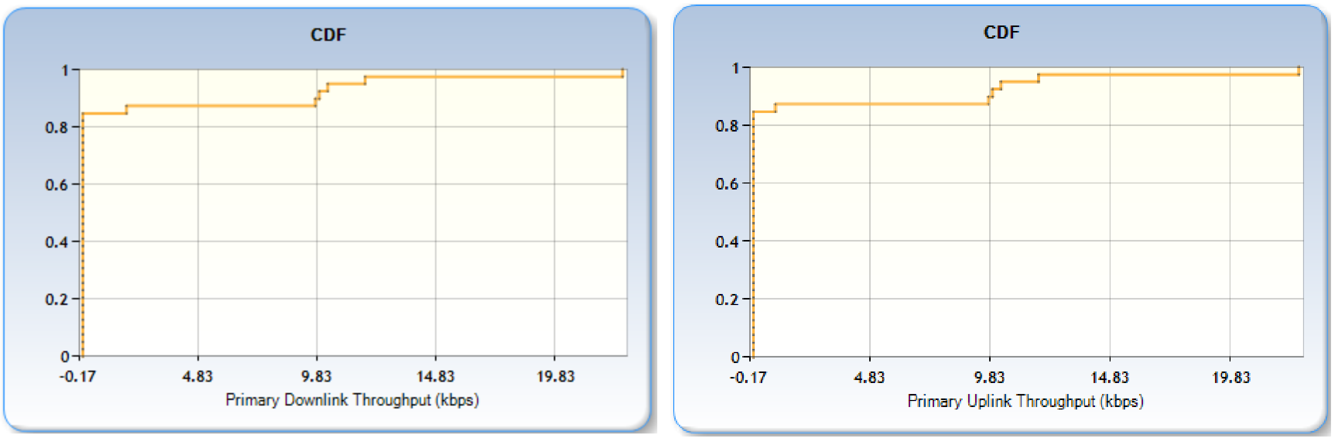


Figure 9.23 Achievable average throughput for scenario 1 according to environment



(A) (B)

Figure 9.24 (A) Downlink average throughput for scenario 1
(B) Uplink average throughput for scenario 1

- **Scenario 2**

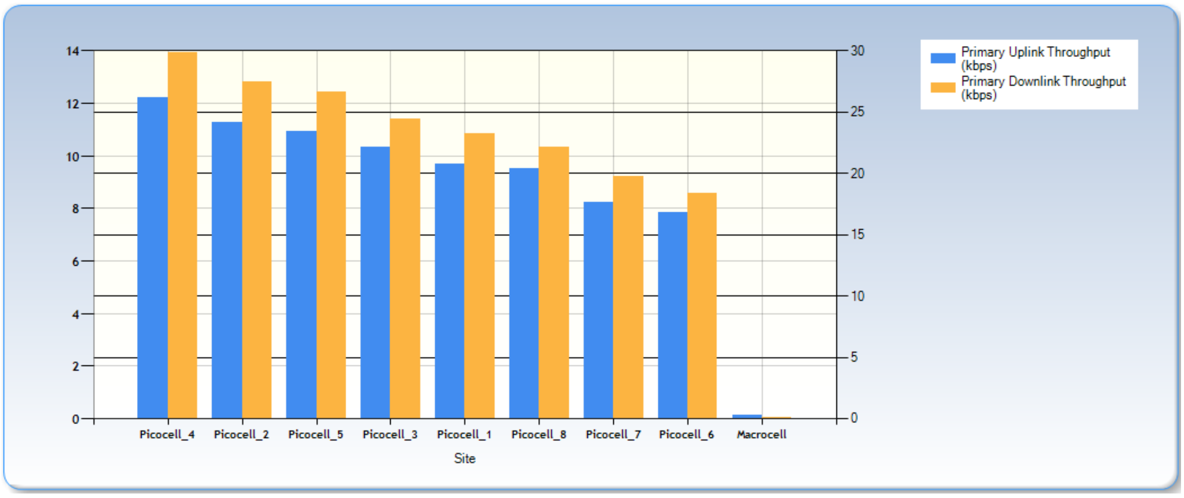
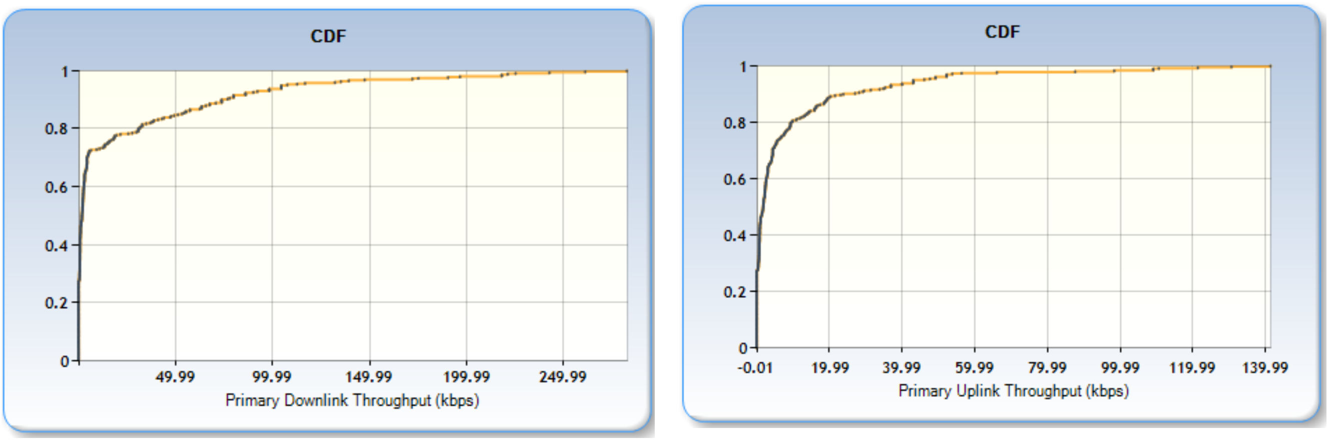


Figure 9.25 Achievable throughput for scenario 2 according to available nodes



(A) (B)

Figure 9.26 (A) Downlink average throughput for scenario 2
(B) Uplink average throughput for scenario 2

- **Scenario 3**

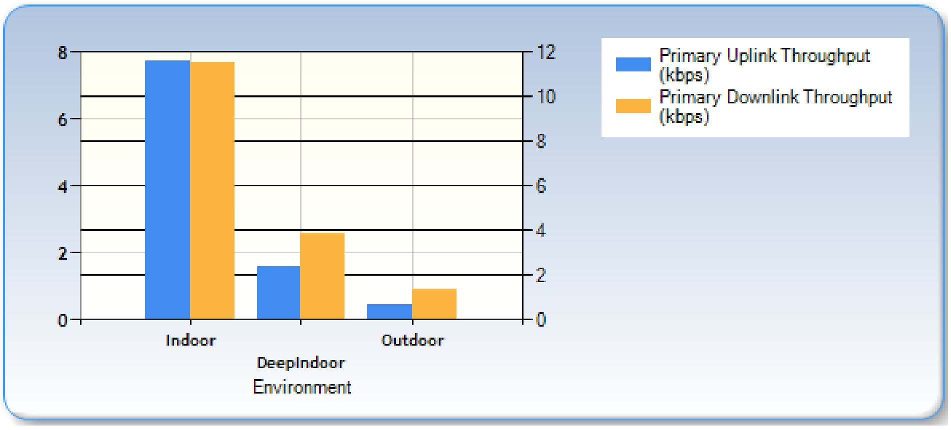
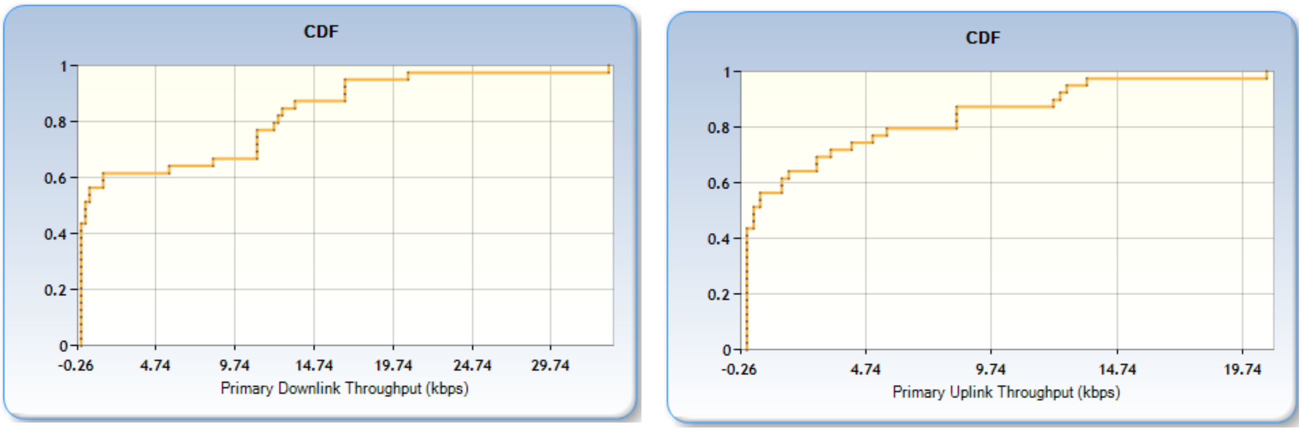


Figure 9.27 Achievable throughput for scenario 3 according to environment



(A) (B)

Figure 9.28 (A) Downlink average throughput for scenario 3
(B) Uplink average throughput for scenario 3

- **Scenario 4**

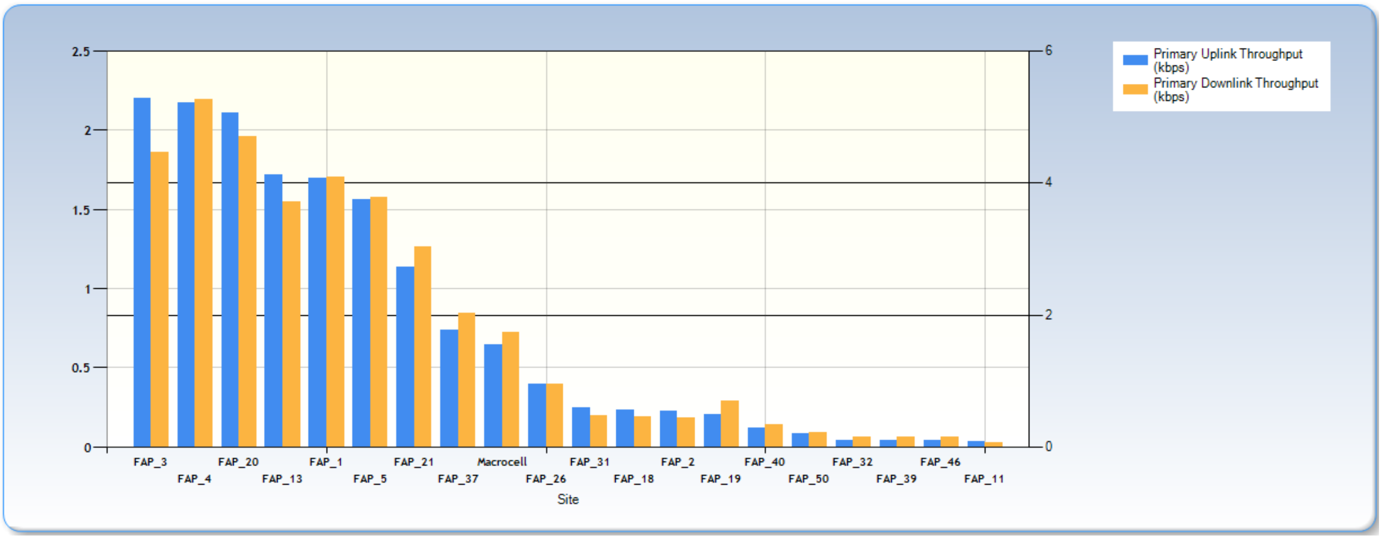


Figure 9.29 Achievable average throughput for scenario 4 according to available nodes

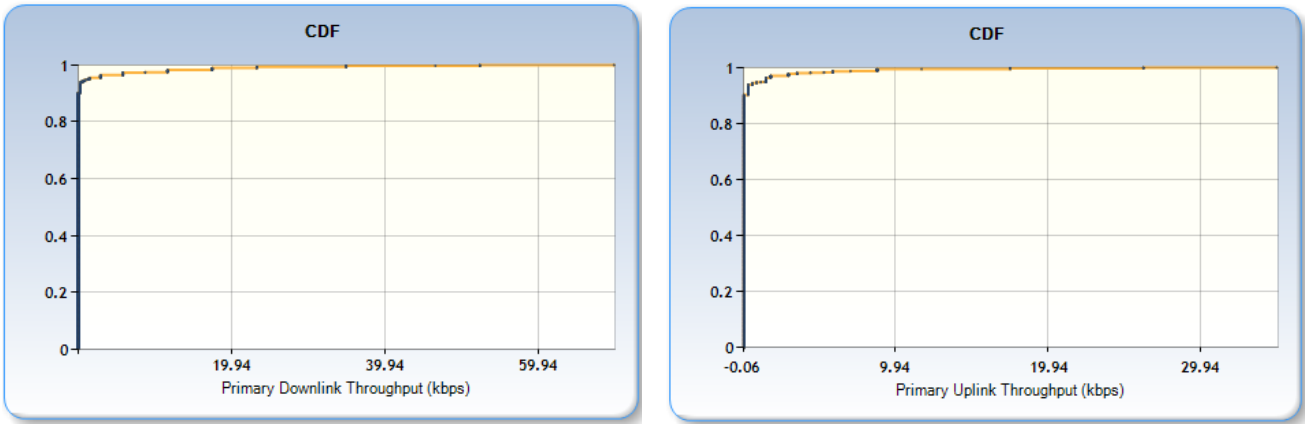


Figure 9.30 (A) Downlink average throughput for scenario 3
(B) Uplink average throughput for scenario 3

Table 9.4 Results summary for scenario 1 and 2

Scenario	**Average total in cell subscriber received power**	**Average total noise rise**	**Average total load**	**Average blocking rate**	**Average throughput**
Only the Macrocell for the building coverage	-122,18 dBm	0,28 dB	6,33%	1,56	Downlink: 11,43 Kbps Uplink: 11,26 Kbps
Both Macrocell and Picocells for the building coverage	-108,295 dBm	0,949	19,33%	0,055	Downlink: 30,00 Kbps Uplink: 13,38 Kbps

Table 9.5 Results summary for scenario 3 and 4

Scenario	**Average total in cell subscriber received power**	**Average total noise rise**	**Average total load**	**Average blocking rate**	**Average throughput**
Only the Macrocell for the Maco covered area	-109, 68 dBm	0,48 dB	10,35%	1,99	Downlink: 10,31 Kbps Uplink: 6,09 Kbps
Both Macrocell and Picocells for the Maco covered area	-128,78 dBm	0,026 dB	0,62%	2,096	Downlink: 3,60 Kbps Uplink: 1,66 Kbps

CHAPTER 10

RESULTS AND DISCUSSION

The first scope of this thesis work was to present and understand the principles of UMTS-WCDMA indoor very small cells deployed through Pico Node B and Femto Access Points. Following this goal we developed the current status of WCDMA’s standards and principles, so the possible problems related to the deployment of these very small cells (picocells and femtocells) could be studied. We also pointed out the important issue of performance gain when Pico Node B and Femto Access Points are used. The key question: “*“What will be the effect on the total radio network performance by including Pico Node Bs and/or Femto Access Points in the current UMTS-WCDMA network elements*?”, was set.

Following the key question a wide literature study was performed to deeply understand the behavior of the autonomous indoor small cells and to select the important issues that needed to be included in our thesis work. It was a constant remark to see that the numerous previous studies mainly concentrated on picocell and femtocell business aspects. The few technical studies were very theoretical, presenting mostly the standardization done by 3GPP about the Pico Node B and Femto Access Points. Therefore a pratical study of a scenario case and simulation in an environment closer to real life is needed.

After the theoretical study, the picocells and femtocells were implemented to the Mentum Planet 5.5 Educational edition planning tool. Through a relatively long process of trial and error we showed the main advantages of picocells and femtocells in the whole coverage and capacity. One of our real issue and that has been omitted in our work was to use the planning tool to simulate the special femtocells access modes.

Despite this omission that brought negative consequences on the simulations results, it has been shown how the Pico Node B and Femto Access Point improve the whole network coverage and capacity. This omission is not related to the hardness of femtocell to be simulated, but to the restrictions of the Educational version of the simulation tool. They could be access in the study of an experimental or real femtocell network deployment.

In the simulation chapter we mostly investigated the coverage and capacity comparing four different scenarios where the nodes where deployed in co-chanel fashion. The picocells and femtocells offered more coverage and capacity in all scenarios but also more load and noise are generated. These results make us understand more about the studies done by the 3GPP and the FemtoForum, where the most important interference scenarios were evaluated. These studies showed that in certain situations the random deployment of femtocells operating in co-channel fashion with the macrocell can create holes to the macro coverage. In the same time some mitigation techniques are proposed and must need attention according to the network real situation.

Other challenges like backhaul connection consequences and mobility scenarios should need special attention. In fact these situations need more details inputs for study and simulation and could be access in further study with careful planning in a real deployment case.

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APPENDIX-A

WCDMA SERVICES LINK BUDGET CALCULATIONS (PNB)

	VOICE 12,2 Kbps	12,2Kbps voice, Downlink	12,2Kbps voice, Uplink
Target Load		**0,75**	**0,5**
Simultaneous Users		**35**	
Transmitter Characteristics	Transmitter Power (mW)	**251,1886432**	**125**
	Transmitter Power in Traffic Channel (mW)	**8,133727493**	
	A: Transmitter power in Traffic Channel (dBm)	9,10289618	20,96910013
	B: Transmitter antenna gain (dBi)	8	0
	C: Transmitter cable loss (dB)	3	0
	D: Transmitter Body loss (dB)	0	3
	E: Transmitter EIRP (dBm)	**14,10289618**	**17,96910013**
Receiver Characteristics and margins	**F**: Receiver antenna gain (dBi)	0	8
	G: Thermal noise density (dBm/Hz)	-174	-174
	H: Receiver noise figure (dB)	8	5
	I: Receiver noise density (dB)	-166	-169
	J: Receiver noise power (dBm)	-100,1566878	-103,1566878
	K: Processing gain (dBm)	24,97971394	24,97971394
	L: Requiered Eb/No (dB)	7,3	4,4
	M: Interference margin (dB)	6,020599913	3,010299957
	N: Receiver requiered signal power (dBm)	**-111,8158018**	**-120,7261017**
	O: Receiver cable loss (dB)	0	3
	P: Receiver body loss (dB)	3	0
	Q: Diversity gain (dB)	0	3
	R: Fast fading margin (dB)	0	3
	S: Maximum path loss (dB)	**122,918698**	**143,6952019**
	T: Soft handover gain (dB)	1,2	1,2
	U: Shadow fading standard deviation (dB)	6	6
	V: Shadow Fading Margin (dB)	7,5	7,5
	W: Indoor penetration loss (dB)	0	0
	Allowed propagation loss (dB)	**110,618698**	**131,3952019**
	Cell radius using ITU-R P. 1238 (meter)	**59,22118167**	**291,7609733**
	Cell covered area (m^2)	**9118,585732**	**221323,6104**
	Pico Node B amount for 78 300m^2	8,586857908	0,353780601

	VIDEO CALL CS 64 Kbps	**CS 64Kbps video, Downlink**	**CS 64Kbps video, Uplink**
Target Load		**0,75**	**0,5**
Simultaneous Users		**15**	
Transmitter Characteristics	Transmitter Power (mW)	**251,1886432**	**250**
	Transmitter Power in Traffic Channel (mW)	**18,97869748**	
	A: Transmitter power in Traffic Channel (dBm)	12,78266403	23,97940009
	B: Transmitter antenna gain (dBi)	8	0
	C: Transmitter cable loss (dB)	3	0
	D: Transmitter Body loss (dB)	0	3
	E: Transmitter EIRP (dBm)	**17,78266403**	**20,97940009**
Receiver Characteristics and margins	**F**: Receiver antenna gain (dBi)	0	8
	G: Thermal noise density (dBm/Hz)	-174	-174
	H: Receiver noise figure (dB)	8	5
	I: Receiver noise density (dB)	-166	-169
	J: Receiver noise power (dBm)	-100,1566878	-103,1566878
	K: Processing gain (dBm)	17,7815125	17,7815125
	L: Requiered Eb/No (dB)	4,9	2,2
	M: Interference margin (dB)	6,020599913	3,010299957
	N: Receiver requiered signal power (dBm)	**-107,0176003**	**-115,7279003**
	O: Receiver cable loss (dB)	0	3
	P: Receiver body loss (dB)	0	0
	Q: Diversity gain (dB)	0	3
	R: Fast fading margin (dB)	0	4
	S: Maximum path loss (dB)	**124,8002644**	**140,7073004**
	T: Soft handover gain (dB)	1,2	1,2
	U: Shadow fading standard deviation (dB)	6	6
	V: Shadow Fading Margin (dB)	7,5	7,5
	W: Indoor penetration loss (dB)	0	0
	Allowed propagation loss (dB)	**112,5002644**	**128,4073004**
	Cell radius using ITU-R P. 1238 (meter)	**68,42202913**	**231,9692846**
	Cell covered area (m^2)	**12172,09258**	**139905,3474**
	Pico Node B amount for 78 300 m^2	6,432747654	0,559664097

	DATA SERVICE PS 64 Kbps	**PS 64Kbps data, Downlink**	**PS 64Kbps data, Uplink**
Target Load		**0,75**	**0,5**
Simultaneous Users		**15**	
Transmitter Characteristics	Transmitter Power (mW)	**251,1886432**	**250**
	Transmitter Power in Traffic Channel (mW)	**18,97869748**	
	A: Transmitter power in Traffic Channel (dBm)	12,78266403	23,97940009
	B: Transmitter antenna gain (dBi)	8	0
	C: Transmitter cable loss (dB)	3	0
	D: Transmitter Body loss (dB)	0	0
	E: Transmitter EIRP (dBm)	**17,78266403**	**23,97940009**
Receiver Characteristics and margins	**F**: Receiver antenna gain (dBi)	0	8
	G: Thermal noise density (dBm/Hz)	-174	-174
	H: Receiver noise figure (dB)	8	5
	I: Receiver noise density (dB)	-166	-169
	J: Receiver noise power (dBm)	-100,1566878	-103,1566878
	K: Processing gain (dBm)	17,7815125	17,7815125
	L: Requiered Eb/No (dB)	3,8	2
	M: Interference margin (dB)	6,020599913	3,010299957
	N: Receiver requiered signal power (dBm)	**-108,1176003**	**-115,9279003**
	O: Receiver cable loss (dB)	0	3
	P: Receiver body loss (dB)	0	0
	Q: Diversity gain (dB)	0	3
	R: Fast fading margin (dB)	0	4
	S: Maximum path loss (dB)	**125,9002644**	**143,9073004**
	T: Soft handover gain (dB)	1,2	1,2
	U: Shadow fading standard deviation (dB)	6	6
	V: Shadow Fading Margin (dB)	7,5	7,5
	W: Indoor penetration loss (dB)	0	0
	Allowed propagation loss (dB)	**113,6002644**	**131,6073004**
	Cell radius using ITU-R P. 1238 (meter)	**74,44964242**	**296,5494684**
	Cell covered area (m^2)	**14411,14807**	**14411,14807**
	Pico Node B amount for 78 300 m^2	5,433293701	0,34244759

	DATA SERVICE PS 128 Kbps	PS 128Kbps data, Downlink	PS 128Kbps data, Uplink
Target Load		**0,75**	**0,5**
Simultaneous Users		**8**	
Transmitter Characteristics	Transmitter Power (mW)	**251,1886432**	**250**
	Transmitter Power in Traffic Channel (mW)	**35,58505778**	
	A: Transmitter power in Traffic Channel (dBm)	15,51267675	23,97940009
	B: Transmitter antenna gain (dBi)	8	0
	C: Transmitter cable loss (dB)	3	0
	D: Transmitter Body loss (dB)	0	0
	E: Transmitter EIRP (dBm)	**20,51267675**	**23,97940009**
Receiver Characteristics and margins	**F**: Receiver antenna gain (dBi)	0	8
	G: Thermal noise density (dBm/Hz)	-174	-174
	H: Receiver noise figure (dB)	8	5
	I: Receiver noise density (dB)	-166	-169
	J: Receiver noise power (dBm)	-100,1566878	-103,1566878
	K: Processing gain (dBm)	14,77121255	14,77121255
	L: Requiered Eb/No (dB)	3	1,4
	M: Interference margin (dB)	6,020599913	3,010299957
	N: Receiver required signal power (dBm)	**-105,9073004**	**-113,5176003**
	O: Receiver cable loss (dB)	0	3
	P: Receiver body loss (dB)	0	0
	Q: Diversity gain (dB)	0	3
	R: Fast fading margin (dB)	0	4
	S: Maximum path loss (dB)	**126,4199771**	**141,4970004**
	T: Soft handover gain (dB)	1,2	1,2
	U: Shadow fading standard deviation (dB)	6	6
	V: Shadow Fading Margin (dB)	7,5	7,5
	W: Indoor penetration loss (dB)	0	0
	Allowed propagation loss (dB)	**114,1199771**	**129,1970004**
	Cell radius using ITU-R P. 1238 (meter)	**77,47942249**	**246,4641846**
	Cell covered area (m^2)	**15607,95837**	**157935,9452**
	Pico Node B amount for 78 300 m^2	5,016671506	0,495770611

	DATA SERVICE PS 384 Kbps	**PS 384Kbps data, Downlink**	**PS 384Kbps data, Uplink**
Target Load		**0,75**	**0,5**
Simultaneous Users		**4**	
Transmitter Characteristics	Transmitter Power (mW)	**251,1886432**	**250**
	Transmitter Power in Traffic Channel (mW)	**71,17011556**	
	A: Transmitter power in Traffic Channel (dBm)	18,52297671	23,97940009
	B: Transmitter antenna gain (dBi)	8	0
	C: Transmitter cable loss (dB)	3	0
	D: Transmitter Body loss (dB)	0	0
	E: Transmitter EIRP (dBm)	**23,52297671**	**23,97940009**
Receiver Characteristics and margins	**F**: Receiver antenna gain (dBi)	0	8
	G: Thermal noise density (dBm/Hz)	-174	-174
	H: Receiver noise figure (dB)	8	5
	I: Receiver noise density (dB)	-166	-169
	J: Receiver noise power (dBm)	-100,1566878	-103,1566878
	K: Processing gain (dBm)	10	10
	L: Requiered Eb/No (dB)	3,6	1,7
	M: Interference margin (dB)	6,020599913	3,010299957
	N: Receiver required signal power (dBm)	**-100,5360878**	**-108,4463878**
	O: Receiver cable loss (dB)	0	3
	P: Receiver body loss (dB)	0	0
	Q: Diversity gain (dB)	0	3
	R: Fast fading margin (dB)	0	4
	S: Maximum path loss (dB)	**124,0590646**	**136,4257879**
	T: Soft handover gain (dB)	1,2	1,2
	U: Shadow fading standard deviation (dB)	6	6
	V: Shadow Fading Margin (dB)	7,5	7,5
	W: Indoor penetration loss (dB)	0	0
	Allowed propagation loss (dB)	**111,7590646**	**124,1257879**
	Cell radius using ITU-R P. 1238 (meter)	**64,63820515**	**166,9988189**
	Cell covered area (m^2)	**10863,05367**	**72510,37438**
	Pico Node B amount for 78 300 m^2	7,207917993	1,07984548

WCDMA SERVICES LINK BUDGET CALCULATIONS (FAP)

	VOICE SERVICE 12,2 kbps	**12,2Kbps voice, Downlink**	**12,2Kbps voice, Uplink**
Target Load		**0,75**	**0,5**
Simultaneous Users		**16**	
Transmitter Characteristics	Transmitter Power (mW)	**100**	**125**
	Transmitter Power in Traffic Channel (mW)	**7,083333333**	
	A: Transmitter power in Traffic Channel (dBm)	8,502376797	20,96910013
	B: Transmitter antenna gain (dBi)	8	0
	C: Transmitter cable loss (dB)	3	0
	D: Transmitter Body loss (dB)	0	3
	E: Transmitter EIRP (dBm)	**13,5023768**	**17,96910013**
Receiver Characteristics and margins	**F**: Receiver antenna gain (dBi)	0	8
	G: Thermal noise density (dBm/Hz)	-174	-174
	H: Receiver noise figure (dB)	8	5
	I: Receiver noise density (dB)	-166	-169
	J: Receiver noise power (dBm)	-100,1566878	-103,1566878
	K: Processing gain (dBm)	24,97971394	24,97971394
	L: Requiered Eb/No (dB)	7,3	4,4
	M: Interference margin (dB)	6,020599913	3,010299957
	N: Receiver requiered signal power (dBm)	**-111,8158018**	**-120,7261017**
	O: Receiver cable loss (dB)	0	3
	P: Receiver body loss (dB)	3	0
	Q: Diversity gain (dB)	0	3
	R: Fast fading margin (dB)	0	3
	S: Maximum path loss (dB)	**122,3181786**	**143,6952019**
	T: Soft handover gain (dB)	1,2	1,2
	U: Shadow fading standard deviation (dB)	6	6
	V: Shadow Fading Margin (dB)	7,5	7,5
	W: Indoor penetration loss (dB)	0	0
	Allowed propagation loss (dB)	**110,0181786**	**131,3952019**
	Cell radius using ITU-R P. 1238 (meter)	**56,55353493**	**291,7609733**
	Cell covered area (m^2)	**8315,586013**	**221323,6104**
	Pico Node B amount for 78 300m^2	9,416053165	0,353780601

	VIDEO CALL CS 64Kbps	**CS 64Kbps video, Downlink**	**CS 64Kbps video, Uplink**
Target Load		**0,75**	**0,5**
Simultaneous Users		**8**	
Transmitter Characteristics	Transmitter Power (mW)	**100**	**250**
	Transmitter Power in Traffic Channel (mW)	**14,16666667**	
	A: Transmitter power in Traffic Channel (dBm)	11,51267675	23,97940009
	B: Transmitter antenna gain (dBi)	8	0
	C: Transmitter cable loss (dB)	3	0
	D: Transmitter Body loss (dB)	0	3
	E: Transmitter EIRP (dBm)	**16,51267675**	**20,97940009**
Receiver Characteristics and margins	**F**: Receiver antenna gain (dBi)	0	8
	G: Thermal noise density (dBm/Hz)	-174	-174
	H: Receiver noise figure (dB)	8	5
	I: Receiver noise density (dB)	-166	-169
	J: Receiver noise power (dBm)	-100,1566878	-103,1566878
	K: Processing gain (dBm)	17,7815125	17,7815125
	L: Requiered Eb/No (dB)	4,9	2,2
	M: Interference margin (dB)	6,020599913	3,010299957
	N: Receiver requiered signal power (dBm)	**-107,0176003**	**-115,7279003**
	O: Receiver cable loss (dB)	0	3
	P: Receiver body loss (dB)	0	0
	Q: Diversity gain (dB)	0	3
	R: Fast fading margin (dB)	0	4
	S: Maximum path loss (dB)	**123,5302771**	**140,7073004**
	T: Soft handover gain (dB)	1,2	1,2
	U: Shadow fading standard deviation (dB)	6	6
	V: Shadow Fading Margin (dB)	7,5	7,5
	W: Indoor penetration loss (dB)	0	0
	Allowed propagation loss (dB)	**111,2302771**	**128,4073004**
	Cell radius using ITU-R P. 1238 (meter)	**62,06732668**	**231,9692846**
	Cell Covered area (m^2)	**10016,11791**	**139905,3474**
	Pico Node B amount for 78 300 m^2	7,817399987	0,559664097

	DATA SERVICE PS 64 Kbps	**PS 64Kbps data, Downlink**	**PS 64Kbps data, Uplink**
Target Load		**0,75**	**0,5**
Simultaneous Users		**8**	
Transmitter Characteristics	Transmitter Power (mW)	**100**	**250**
	Transmitter Power in Traffic Channel (mW)	**14,16666667**	
	A: Transmitter power in Traffic Channel (dBm)	11,51267675	23,97940009
	B: Transmitter antenna gain (dBi)	8	0
	C: Transmitter cable loss (dB)	3	0
	D: Transmitter Body loss (dB)	0	0
	E: Transmitter EIRP (dBm)	**16,51267675**	**23,97940009**
Receiver Characteristics and margins	**F**: Receiver antenna gain (dBi)	0	8
	G: Thermal noise density (dBm/Hz)	-174	-174
	H: Receiver noise figure (dB)	8	5
	I: Receiver noise density (dB)	-166	-169
	J: Receiver noise power (dBm)	-100,1566878	-103,1566878
	K: Processing gain (dBm)	17,7815125	17,7815125
	L: Requiered Eb/No (dB)	3,8	2
	M: Interference margin (dB)	6,020599913	3,010299957
	N: Receiver requiered signal power (dBm)	**-108,1176003**	**-115,9279003**
	O: Receiver cable loss (dB)	0	3
	P: Receiver body loss (dB)	0	0
	Q: Diversity gain (dB)	0	3
	R: Fast fading margin (dB)	0	4
	S: Maximum path loss (dB)	**124,6302771**	**143,9073004**
	T: Soft handover gain (dB)	1,2	1,2
	U: Shadow fading standard deviation (dB)	6	6
	V: Shadow Fading Margin (dB)	7,5	7,5
	W: Indoor penetration loss (dB)	0	0
	Allowed propagation loss (dB)	**112,3302771**	**131,6073004**
	Cell radius using ITU-R P. 1238 (meter)	**67,53512482**	**296,5494684**
	Cell covered area (m^2)	**11858,58202**	**228648,1267**
	Pico Node B amount for 78 300 m^2	6,602813041	0,34244759

	DATA SERVICE 128 Kbps	PS 128Kbps data, Downlink	PS 128Kbps data, Uplink
Target Load		**0,75**	**0,5**
Simultaneous Users		**4**	
Transmitter Characteristics	Transmitter Power (mW)	**100**	**250**
	Transmitter Power in Traffic Channel (mW)	**28,33333333**	
	A: Transmitter power in Traffic Channel (dBm)	14,52297671	23,97940009
	B: Transmitter antenna gain (dBi)	8	0
	C: Transmitter cable loss (dB)	3	0
	D: Transmitter Body loss (dB)	0	0
	E: Transmitter EIRP (dBm)	**19,52297671**	**23,97940009**
Receiver Characteristics and margins	**F**: Receiver antenna gain (dBi)	0	8
	G: Thermal noise density (dBm/Hz)	-174	-174
	H: Receiver noise figure (dB)	8	5
	I: Receiver noise density (dB)	-166	-169
	J: Receiver noise power (dBm)	-100,1566878	-103,1566878
	K: Processing gain (dBm)	14,77121255	14,77121255
	L: Requiered Eb/No (dB)	3	1,4
	M: Interference margin (dB)	6,020599913	3,010299957
	N: Receiver requiered signal power (dBm)	**-105,9073004**	**-113,5176003**
	O: Receiver cable loss (dB)	0	3
	P: Receiver body loss (dB)	0	0
	Q: Diversity gain (dB)	0	3
	R: Fast fading margin (dB)	0	4
	S: Maximum path loss (dB)	**125,4302771**	**141,4970004**
	T: Soft handover gain (dB)	1,2	1,2
	U: Shadow fading standard deviation (dB)	6	6
	X: Shadow Fading Margin (dB)	7,5	7,5
	W: Indoor penetration loss (dB)	0	0
	Allowed propagation loss (dB)	**113,1302771**	**129,1970004**
	Cell radius using ITU-R P. 1238 (meter)	**71,81189274**	**246,4641846**
	Cell covered area (m^2)	**13408,06464**	**157935,9452**
	Pico Node B amount for 78 300 m^2	5,839768983	0,495770611

	DATA SERVICE PS 128 Kbps	**PS 384Kbps data, Downlink**	**PS 384Kbps data, Uplink**
Target Load		**0,75**	**0,5**
Simultaneous Users		**2**	
Transmitter Characteristics	Transmitter Power (mWATT)	**100**	**250**
	Transmitter Power in Traffic Channel (mWATT)	**56,66666667**	
	A: Transmitter power in Traffic Channel (dBm)	17,53327667	23,97940009
	B: Transmitter antenna gain (dBi)	8	0
	C: Transmitter cable loss (dB)	3	0
	D: Transmitter Body loss (dB)	0	0
	E: Transmitter EIRP (dBm)	**22,53327667**	**23,97940009**
Receiver Characteristics and margins	**F**: Receiver antenna gain (dBi)	0	8
	G: Thermal noise density (dBm/Hz)	-174	-174
	H: Receiver noise figure (dB)	8	5
	I: Receiver noise density (dB)	-166	-169
	J: Receiver noise power (dBm)	-100,1566878	-103,1566878
	K: Processing gain (dBm)	10	10
	L: Requiered Eb/No (dB)	3,6	1,7
	M: Interference margin (dB)	6,020599913	3,010299957
	N: Receiver requiered signal power (dBm)	**-100,5360878**	**-108,4463878**
	O: Receiver cable loss (dB)	0	3
	P: Receiver body loss (dB)	0	0
	Q: Diversity gain (dB)	0	3
	R: Fast fading margin (dB)	0	4
	S: Maximum path loss (dB)	**123,0693645**	**136,4257879**
	T: Soft handover gain (dB)	1,2	1,2
	U: Shadow fading standard deviation (dB)	6	6
	V: Shadow Fading Margin (dB)	7,5	7,5
	W: Indoor penetration loss (dB)	0	0
	Allowed propagation loss (dB)	**110,7693645**	**124,1257879**
	Cell radius using ITU-R P. 1238 (meter)	**59,90999553**	**166,9988189**
	Cell covered area (m^2)	**9331,939667**	**72510,37438**
	Pico Node B amount for 78 300 m^2	8,390538602	1,07984548

WCDMA SERVICES SIMULTANEOUS MAXIMUM USERS (PNB)

VOICE SERVICE 12,2 Kbps

Pico Node B downlink Capacity per sector, only R99	3km/h
AMR Bit rate (kbps)	12,2
Processing gain, PG	**314,7540**
Processing gain, PG (dB)	**24,97971**
DL Eb/No (dB)	7,3
DL C/I (dB)	**-17,68**

Thermal Noise Density (dBm/Hz)	-174
Mobile Noise Figure (dB)	5
Thermal Noise (dBm)	**-103,16**

Antenna Gain (dBi)	8,0
Body loss	3,0
Average attenuation within the cell (dB)	107,79
Total Average attenuation within the cell (dB)	**110,79**

Orthogonality factor (%)	90%
DL average extracell to intracell interference ratio	0,65
Load due to SHO	0,3
Average Gain on DL Eb/No due to SHO (dB)	1,2

% of E-node max power dedicated to common channels	20%
E-node max Power (Watts)	0,25

DL load (%)	80%
Remaining E-node power for traffic channels (Watts)	**0,20**
Average E-node transmit power per link, for one user (Watts)	**0,0024985947**
Simultaneous connections with formula 1	**61,57**
Simultaneous connections with formula 2	**50,72**
Activity factor	**0,67**
User number in one sector, min of formulas 1 and 2	**75,70**
Real user number in a sector for 80% in the DL	**75,0**
Throughput per sector (kbps)	751,19

Erlang B à 2%	

Pico Node B downlink Capacity per sector, both R99 and HSDPA	3km/h
AMR Bit rate (kbps)	12,2
Processing gain, PG	**314,7540**
Processing gain (dB)	**24,97971**
DL Eb/No (dB)	7,3
DL C/I (dB)	**-17,68**

Thermal Noise Density (dBm/Hz)	-174
Mobile Noise Figure (dB)	5
Thermal Noise (dBm)	**-103,16**

Antenna Gain (dBi)	8,0
Body loss	3,0
Average attenuation within the cell (dB)	107,79
Total Average attenuation within the cell (dB)	**110,79**

Orthogonality factor (%)	90%
DL average extracell to intracell interference ratio	0,65
Load due to SHO	0,3
Average Gain on DL Eb/No due to SHO (dB)	1,2

% of E-node max power dedicated to common channels	20%
E-node max Power (Watts)	0,25
R99 to HSDPA power ratio	25%
DL load (%)	20%
Remaining power for traffic channels (Watts)	**0,05**
Average transmit power per link (Watts)	**0,0024985947**
Simultaneous connections with formula 1	**15,39**
Simultaneous connections with formula 2	**12,68**
Activity factor	**0,67**
User number in one sector, min of formulas 1 and 2	**18,92**
Real user number in a sector for 80% in the DL	**18,0**
Throughput per sector (kbps)	187,80

Erlang B à 2%	

VIDEO CALL CS 64 Kbps

Pico Node B downlink Capacity per sector, only R99	**3km/h**
CS 64 Bit rate (kbps)	**64**
Processing gain, PG	**60,00**
Processing gain, PG (dB)	**17,78151**
DL Eb/No (dB)	**4,9**
DL C/I (dB)	**-12,88**
Thermal Noise Density (dBm/Hz)	**-174**
Mobile Noise Figure (dB)	**5**
Thermal Noise (dBm)	**-103,16**
Antenna Gain (dBi)	**8,0**
Body loss	**3,0**
Average attenuation within the cell (dB)	**107,79**
Total Average attenuation within the cell (dB)	**110,79**
Orthogonality factor (%)	**90%**
DL average extracell to intracell interference ratio	**0,65**
Load due to SHO	**0,3**
Average Gain on DL Eb/No due to SHO (dB)	**1,2**
% of E-node max power dedicated to common channels	**20%**
E-node max Power (Watts)	**0,25**
DL load (%)	**80%**
Remaining E-node power for traffic channels (Watts)	**0,20**
Average E-node transmit power per link, for one user (Watts)	**0,0075228811**
Simultaneous connections with formula 1	**20,45**
Simultaneous connections with formula 2	**16,80**
Activity factor	**0,67**
User number in one sector, min of formulas 1 and 2	**25,08**
Real user number in a sector for 80% in the DL	**25,0**
Throughput per sector (kbps)	1308,83
Erlang B à 2%	

Pico Node B downlink Capacity per sector, both R99 and HSDPA	**3km/h**
CS 64 Bit rate (kbps)	**64**
Processing gain, PG	**60,00**
Processing gain (dB)	**17,78151**
DL Eb/No (dB)	**4,9**
DL C/I (dB)	**-12,88**
Thermal Noise Density (dBm/Hz)	**-174**
Mobile Noise Figure (dB)	**5**
Thermal Noise (dBm)	**-103,16**
Antenna Gain (dBi)	**8,0**
Body loss	**3,0**
Average attenuation within the cell (dB)	**107,79**
Total Average attenuation within the cell (dB)	**110,79**
Orthogonality factor (%)	**90%**
DL average Extracell to intracell interference ratio	**0,65**
Load due to SHO	**0,3**
Average Gain on DL Eb/No due to SHO (dB)	**1,2**
% of E-node max power dedicated to common channels	**20%**
E-node max Power (Watts)	**0,25**
R99 to HSDPA power ratio	**25%**
DL load (%)	**20%**
Remaining power for traffic channels (Watts)	**0,05**
Average transmit power per link (Watts)	**0,0075228811**
Simultaneous connections with formula 1	**5,11**
Simultaneous connections with formula 2	**4,20**
Activity factor	**0,67**
User number in one sector, min of formulas 1 and 2	**6,27**
Real user number in a sector for 80% in the DL	**6,0**
Throughput per sector (kbps)	327,21
Erlang B à 2%	

DATA SERVICE PS 64 Kbps

Pico Node B downlink Capacity per sector, only R99	3km/h
PS 64 Bit rate (kbps)	64
Processing gain, PG	60,00
Processing gain, PG (dB)	17,78151
DL Eb/No (dB)	3,8
DL C/I (dB)	-13,98
Thermal Noise Density (dBm/Hz)	-174
Mobile Noise Figure (dB)	5
Thermal Noise (dBm)	-103,16
Antenna Gain (dBi)	8,0
Body loss	3,0
Average attenuation within the cell (dB)	107,79
Total Average attenuation within the cell (dB)	110,79
Orthogonality factor (%)	90%
DL average extracell to intracell interference ratio	0,65
Load due to SHO	0,3
Average Gain on DL Eb/No due to SHO (dB)	1,2
% of E-node max power dedicated to common channels	20%
E-node max Power (Watts)	0,25
DL load (%)	80%
Remaining E-node power for traffic channels (Watts)	0,20
Average E-node transmit power per link, for one user (Watts)	0,0058447044
Simultaneous connections with formula 1	26,32
Simultaneous connections with formula 2	21,64
Activity factor	0,20
User number in one sector, min of formulas 1 and 2	108,22
Real user number in a sector for 80% in the DL	108,0
Throughput per sector (kbps)	1684,63
Erlang B à 2%	

Pico Node B downlink Capacity per sector, both R99 and HSDPA	3km/h
PS 64 Bit rate (kbps)	64
Processing gain, PG	60,00
Processing gain (dB)	17,78151
DL Eb/No (dB)	3,8
DL C/I (dB)	-13,98
Thermal Noise Density (dBm/Hz)	-174
Mobile Noise Figure (dB)	5
Thermal Noise (dBm)	-103,16
Antenna Gain (dBi)	8,0
Body loss	3,0
Average attenuation within the cell (dB)	107,79
Total Average attenuation within the cell (dB)	110,79
Orthogonality factor (%)	90%
DL average Extracell to intracell interference ratio	0,65
Load due to SHO	0,3
Average Gain on DL Eb/No due to SHO (dB)	1,2
% of E-node max power dedicated to common channels	20%
E-node max Power (Watts)	0,25
R99 to HSDPA power ratio	25%
DL load (%)	20%
Remaining power for traffic channels (Watts)	0,05
Average transmit power per link, for one user (Watts)	0,0058447044
Simultaneous connections with formula 1	6,58
Simultaneous connections with formula 2	5,41
Activity factor	0,20
User number in one sector, min of formulas 1 and 2	27,05
Real user number in a sector for 80% in the DL	27,0
Throughput per sector (kbps)	421,16
Erlang B à 2%	

DATA SERVICE PS 128 Kbps

Pico Node B downlink Capacity per sector, only R99	3km/h
PS 128 Bit rate (kbps)	128
Processing gain, PG	30,00
Processing gain, PG (dB)	14,77121
DL Eb/No (dB)	3
DL C/I (dB)	-11,77
Thermal Noise Density (dBm/Hz)	-174
Mobile Noise Figure (dB)	5
Thermal Noise (dBm)	-103,16
Antenna Gain (dBi)	8,0
Body loss	3,0
Average attenuation within the cell (dB)	107,79
Total Average attenuation within the cell (dB)	110,79
Orthogonality factor (%)	90%
DL average extracell to intracell interference ratio	0,65
Load due to SHO	0,3
Average Gain on DL Eb/No due to SHO (dB)	1,2
% of E-node max power dedicated to common channels	20%
E-node max Power (Watts)	0,25
DL load (%)	80%
Remaining E-node power for traffic channels (Watts)	0,20
Average E-node transmit power per link, for one user (Watts)	0,0097033590
Simultaneous connections with formula 1	15,85
Simultaneous connections with formula 2	13,01
Activity factor	0,20
User number in one sector, min of formulas 1 and 2	65,05
Real user number in a sector for 80% in the DL	**65,0**
Throughput per sector (kbps)	2029,43
Erlang B à 2%	

Pico Node B downlink Capacity per sector, both R99 and HSDPA	3km/h
PS 128 Bit rate (kbps)	128
Processing gain, PG	30,00
Processing gain (dB)	14,77121
DL Eb/No (dB)	3,0
DL C/I (dB)	-11,77
Thermal Noise Density (dBm/Hz)	-174
Mobile Noise Figure (dB)	5
Thermal Noise (dBm)	-103,16
Antenna Gain (dBi)	8,0
Body loss	3,0
Average attenuation within the cell (dB)	107,79
Total Average attenuation within the cell (dB)	110,79
Orthogonality factor (%)	90%
DL average Extracell to intracell interference ratio	0,65
Load due to SHO	0,3
Average Gain on DL Eb/No due to SHO (dB)	1,2
% of E-node max power dedicated to common channels	20%
E-node max Power (Watts)	0,25
R99 to HSDPA power ratio	25%
DL load (%)	20%
Remaining power for traffic channels (Watts)	0,05
Average transmit power per link (Watts)	0,0095581606
Simultaneous connections with formula 1	4,02
Simultaneous connections with formula 2	3,25
Activity factor	0,20
User number in one sector, min of formulas 1 and 2	16,26
Real user number in a sector for 80% in the DL	**16,0**
Throughput per sector (kbps)	515,07
Erlang B à 2%	

DATA SERVICE PS 384 Kbps

Pico Node B downlink Capacity per sector, only R99	3km/h
PS 384 Bit rate (kbps)	384
Processing gain, PG	10,00
Processing gain, PG (dB)	10,00
DL Eb/No (dB)	3,6
DL C/I (dB)	-6,40

Thermal Noise Density (dBm/Hz)	-174
Mobile Noise Figure (dB)	5
Thermal Noise (dBm)	-103,16

Antenna Gain (dBi)	8,0
Body loss	3,0
Average attenuation within the cell (dB)	107,79
Total Average attenuation within the cell (dB)	110,79

Orthogonality factor (%)	90%
DL average extracell to intracell interference ratio	0,65
Load due to SHO	0,3
Average Gain on DL Eb/No due to SHO (dB)	1,2

% of E-node max power dedicated to common channels	20%
E-node max Power (Watts)	0,25

DL load (%)	80%
Remaining E-node power for traffic channels (Watts)	0,20
Average E-node transmit power per link, for one user (Watts)	0,0325236162
Simultaneous connections with formula 1	4,73
Simultaneous connections with formula 2	3,78
Activity factor	0,20
User number in one sector, min of formulas 1 and 2	18,89
Real user number in a sector for 80% in the DL	18,0
Throughput per sector (kbps)	1816,4

Erlang B à 2%	

Pico Node B downlink Capacity per sector, both R99 and HSDPA	3km/h
PS 384 Bit rate (kbps)	384
Processing gain, PG	10,00
Processing gain (dB)	10,00
DL Eb/No (dB)	3,6
DL C/I (dB)	-6,40

Thermal Noise Density (dBm/Hz)	-174
Mobile Noise Figure (dB)	5
Thermal Noise (dBm)	-103,16

Antenna Gain (dBi)	8,0
Body loss	3,0
Average attenuation within the cell (dB)	107,79
Total Average attenuation within the cell (dB)	110,79

Orthogonality factor (%)	90%
DL average Extracell to intracell interference ratio	0,65
Load due to SHO	0,3
Average Gain on DL Eb/No due to SHO (dB)	1,2

% of E-node max power dedicated to common channels	20%
E-node max Power (Watts)	0,25
R99 to HSDPA power ratio	25%
DL load (%)	20%
Remaining power for traffic channels (Watts)	0,05
Average transmit power per link (Watts)	0,0325236162
Simultaneous connections with formula 1	1,18
Simultaneous connections with formula 2	0,94
Activity factor	0,20
User number in one sector, min of formulas 1 and 2	4,72
Real user number in a sector for 80% in the DL	4,0
Throughput per sector (kbps)	454,11

Erlang B à 2%	

DATA SERVICE PS 512 and 1024 Kbps

Pico Node B downlink Capacity per sector, only HSDPA	3km/h
PS 512 Bit rate (kbps)	512
DL Eb/No (dB)	3,4
Processing gain (dB)	8,75
DL C/I (dB)	-5,35

Thermal Noise Density (dBm/Hz)	-174
Mobile Noise Figure (dB)	5
Thermal Noise (dBm)	-103,16

Antenna Gain (dBi)	8,0
Average attenuation within the cell (dB)	107,79

Orthogonality factor (%)	90%
DL average Extracell to intracell interference ratio	0,65
Load due to SHO	0,0

% of E-node max power dedicated to common channels	20%
E-node max Power (Watts)	0,3
E-node power dedicated to 3G+ services	75%
DL load (%)	60%
Remaining E-node power for traffic channels (Watts)	0,15
Average E-node transmit power per link (Watts)	0,0539675529
Simultaneous connections with formula 1	2,78
Simultaneous connections with formula 2	3,66
Throughput per sector (kbps)	1872,23

Erlang B à 2%	

Pico Node B downlink Capacity per sector, only HSDPA	3km/h
PS 1024 Bit rate (kbps)	1024
DL Eb/No (dB)	4
Processing gain (dB)	5,74
DL C/I (dB)	-1,74

Thermal Noise Density (dBm/Hz)	-174
Mobile Noise Figure (dB)	5
Thermal Noise (dBm)	-103,16

Antenna Gain (dBi)	8,0
Average attenuation within the cell (dB)	107,79

Orthogonality factor (%)	90%
DL average Extracell to intracell interference ratio	0,65
Load due to SHO	0,0

% of E-node max power dedicated to common channels	20%
E-node max Power (Watts)	0,3
E-node power dedicated to 3G+ services	75%
DL load (%)	60%
Remaining E-node power for traffic channels (Watts)	0,15
Average E-node transmit power per link (Watts)	0,1195341908
Simultaneous connections with formula 1	1,25
Simultaneous connections with formula 2	1,59
Throughput per sector (kbps)	1630,65

Erlang B à 2%	

Erlang B Table

CURRICULUM VITAE

PERSONAL INFORMATION

Name Surname	: DIBY JEO RAOUL AMARA
Date of birth and place	: 27 – 04 – 1984 at M’BAHIAKRO
Foreign Languages	: FRENCH, ENGLISH, TURKISH
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EDUCATION

Degree	**Department**	**University**	**Date of Graduation**
Undergraduate	Computer Sciences	Nangui Abrogoua	2008
High School	Sciences	G.S. Frantz Fanon	2003