TAMPERE UNIVERSITY OF TECHNOLOGY

JAAKKO PENTTINEN

COMPARISON OF HSPA INDOOR CONFIGURATIONS WITH MULTIPLE USERS

Master of Science Thesis

Examiners: Prof. Jukka Lempiäinen
M.Sc. Tero Isotalo
Examiners and topic approved in the Faculty of Computing and Electrical Engineering Council meeting on 9 December 2009

TIIVISTELMÄ

TAMPEREEN TEKNILLINEN YLIOPISTO
Signaalinkäsittelyn ja tietoliikennetekniikan koulutusohjelma
PENTTINEN, JAAKKO: HSPA sisätilaverkkojen suorituskyky usealla käyttäjällä
Diplomityö, 60 sivua, 8 liitesivua
Toukokuu 2010
Pääaine: Tietokoneverkot ja -protokollat
Tarkastajat: Prof. Jukka Lempiäinen, DI Tero Isotalo
Avainsanat: Pikosolu, DAS, HSPA, UMTS, mittaus, sisäverkko.

Matkapuhelimien suosio viestinnässä on kasvanut 2000-luvun alusta lähtien. Myös samanaikaisesti internetin sekä sen suomien palveluiden, kuten sähköpostin ja erilaisten yhteisöpalveluiden kotikäyttö on levinnyt nopeiden ADSL-yhteyksien ansiosta. Näistä palveluista on ajan myötä monelle tullut yhtä tärkeä ominaisuus matkapuhelimessa kuin normaaleista puheyhteyksistä NMT:n ja GSM:n aikana.

Kasvava datakapasiteetin tarve on ajanut yritykset kehittämään kolmannen sukupolven matkapuhelinteknologioita. Euroopassa käyttöön valittu UMTS matkapuhelinteknologian ensimmäinen versio mahdollistaa käyttäjille 384 kbps datanopeuden. UMTS datayhteyksien päivitetty versio HSPA tarjoaa parhaimmillaan jopa 14.4 Mbps alalinkille ja vastaavasti 2 Mbps ylälinkille. 2010-luvun taitteessa HSPA on yleistynyt paremman päätelaitekannan sekä edullisten runkoverkon päivitysten ansiosta. Pakettiyhteyksien kapasiteetin ja sisätilakäyttäjien määrän kasvuennuste asettavat matkapuhelinoperaattoreille uusia haasteita. Sisätilakäyttäjien palveleminen ulkoverkoilla vaikeuttaa ulkoverkkojen suunnittelua sekä syö ulkotilakäyttäjien kapasiteettia. Eräs ratkaisu ongelmaan olisi dedikoitu sisätilaverkko pelkästään sisäkäyttäjien palvelemiseen.

Kapasiteetin jakaminen on mahdollista tehdä erilaisilla antennikonfiguraatioilla, joista yleisimmät ovat hajautettu antennijärjestelmä (DAS) ja useat pikosolut. Näiden konfiguraatioiden suurimmat erot löytyvät laitekustannuksista ja kapasiteetista, jota ne pystyvät tarjoamaan. Näiden kahden konfiguraation eroja on tutkittu, mutta tutkimukset ovat rajoittuneet vain yhden päätelaitteen mittauksiin.

Tässä työssä tutkitaan mittausten avulla DAS ja pikosolujen antennikonfiguraatioiden eroja sisätiloissa HSPA yhteyksillä. Mittauksissa käytettiin useaa päätelaitetta luomaan alhaista sekä korkeaa kuormaa verkkoon, jotta myös kuorman vaikutusta eri ratkaisujen suorituskykyyn voitiin verrata. Eroja havainnointiin myös kahdessa erilaisessa sisätilaympäristössä. Pääasiallinen vertailu antennikonfiguraatioiden välillä tapahtui verkon kokonaisdatasiirtonopeutta ja signaaliparametreja tutkimalla.

Tulosten perusteella alhaisella kuormalla DAS päihittää usean pikosolun konfiguraation. DAS:n antama jatkuva kuuluvuusalue ilman solunvaihtoja tekee siitä varteenotettavan vaihtoehdon pienille ja keskisuurille rakennuksille. Vastaavasti suuremmalla kuormalla useampi pikosolu tuottaa paremman suorituskyvyn, jonka yksiselitteinen toteaminen ei ole mahdollista mittausrajoituksien vuoksi.

ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
Master's Degree Programme in Signal Processing and Communications Engineering
PENTTINEN, JAAKKO: Comparison of HSPA indoor configurations with multiple users.
Master of Science Thesis, 60 pages, 8 Appendix pages
May 2010
Major: Computer networks and protocols
Examiners: Prof. Jukka Lempiäinen, M.Sc. Tero Isotalo
Keywords: Picocell, DAS, HSPA, UMTS, field measurements, indoor network

The popularity of mobile communication has grown exponentially since the beginning of the 21st century. At the same time, because of fast ADSL-connections, the use of internet and its services like e-mail and social networks has grown in households. These services have become as important as voice calls, during NMT and GSM, for mobile users.

The growing need for data capacity has forced companies to develop third generation mobile technologies. UMTS has been chosen for the mobile technology in Europe, which enables 384 kbps user data rate. HSPA is an upgraded version of UMTS providing 14.4 Mbps in downlink and 2 Mbps uplink data rate. Because of cheap upgrade costs and several HSPA-enabled user equipment, HSPA has become quite attractive choice for operators at the end of 2009.

The forecast for future data capacity requirements and the increase of indoor users set a new challenge for the mobile operators. Serving of indoor users by outside cells complicates the radio network planning and reduces the capacity from outdoor users. One solution is a dedicated indoor network system which serves only the indoor users.

Capacity distribution in indoors can be done by DAS or by multiple picocells, which are the most commonly used antenna configurations. Total capacity and equipment costs are the main differences between these two configurations. Research between them has been done, however it has been limited to a single terminal measurements.

The focus of the Thesis is to compare DAS and picocell configurations for HSPA with the aid of the measurements. Several terminals were used to generate low and high load to the network. In addition, two different indoor environments were used for the observation of differences. Comparison was made by analyzing total network throughput and several signal indicators.

According to the results, with low load the DAS outperforms picocell configuration. For small and medium sized buildings, DAS is a good choice due to the smooth coverage and handover-free regions. With higher load, pico configuration has better performance but because of measurement restrictions unambiguous conclusion could not be made.

PREFACE

This Master's Thesis, "Comparison of HSPA Indoor configurations with multiple users", has been written for Master of Science Degree in the Department of Communication Engineering in Tampere University of Technology, Finland. The work has been measured and written during the spring 2010.

Compliments for my co-worker Janne Palttala, instructor M.Sc. Tero Isotalo and supervisor prof. Jukka Lempiäinen about great advice, support and guidance for making this Thesis complete. I would also thank my great classmates, who have given me the escape place back to the reality and motivation towards graduation. In addition, thanks for my colleagues Usama and Ashok for not kicking me and Janne out of the office during our motivation gaps.

This Thesis is dedicated to my parents Leena and Urpo Penttinen, who have been constantly supporting me in my studies and life. Without their support and guidance, this point in my life would have been unreachable. Thanks for my aunt Sari Penttinen for the proofreading of this Thesis. Also the warmest thanks for my grandparents Elma and Kalevi Penttinen.

Tampere, May 11th, 2010

Jaakko Penttinen

jaska.penttinen@gmail.com
+358 45 277 67 60
Finland

TABLE OF CONTENTS

LIST OF SYMBOLS

S_{Φ}	Angular spread
$\bar{\tau}$	Average delay
h_{BTS}	Base station antenna height
B	Breakpoint distance
Δf_c	Coherence bandwidth
S_{τ}	Delay spread
d	Distance
$P(\Phi)$	Distribution of angular power
α	Downlink code orthogonality
E_b/N_0	Energy per bit to noise ratio
E_c/N_0	Energy per chip to noise ratio
θ	Incident angle of wave
η	Load factor percentage
$\bar{\Phi}$	Mean angle
h_{MS}	Mobile station antenna height
P_{noise}	Noise power
P_{other}	Other cell interference power
P_{own}	Own cell interference power
L	Path loss
$P_{\tau}(\tau)$	Power –delay profile
P_g	Processing gain
Δh	Rayleigh criterion
P_r	Received power
$P_{HS-DSCH}$	Received power of HS-DSCH
G_r	Receiving antenna gain
W_c	System chip rate
P_{Φ_tot}	Total received power
P_t	Transmitted power
G_t	Transmitting antenna gain
R	User bit rate
λ	Wavelength

LIST OF ABBREVIATIONS

16-QAM	16 Quadrature Modulation
2.5G	Enhanced 2nd Generation
2G	2nd Generation
3G	3rd Generation
3GPP	3rd Generation Partnership Project
4G	4th Generation
AC	Admission Control
ACK	Acknowledgement
ADSL	Asynchronous Digital Subscriber Line
AMC	Adaptive Modulation and Coding
AMPS	Advanced Mobile Phone System
BER	Bit Error Rate
BLER	Block Error Rate
BMC	Broadcast/Multicast Control Protocol
BPSK	Binary Phase Shift Keying
BS	Base Station
CDMA	Code Division Multiple Access
CN	Core Network
CQI	Channel Quality Indicator
CRC	Cyclic Redundancy Check
CS	Circuit Switched
D-AMPS	Digital Advanced Mobile Phone System
DAS	Distributed Antenna System
DCH	Dedicated Channel
DL	Downlink
DPDCH	Dedicated Physical Data Channel
DS-CDMA	Direct Sequence Code Division Multiple Access
E-AGCH	E-DCH Absolute Grant Channel
E-DCH	Enhanced Dedicated Channel
EDGE	Enhanced Data rates for Global Evolution GSM
E-DPCCH	E-DCH Dedicated Physical Control Channel
E-DPDCH	E-DCH Dedicated Physical Data Channel
E-HICH	E-DCH HARQ Indicator Channel
EIRP	Effective Isotropic Radiated Power
E-RGCH	E-DCH Relative Grant Channel
E-TFC	E-DCH Transport Format Combination
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
GERAN	GSM Radio Access Network

GGSN	Gateway GPRS Support Node
GMSC	Gateway MSC
GPRS	General Packet Radio Service
GSM	Global System for Mobile
HARQ	Hybrid Automatic Repeat Request
HLR	Home Location Register
HO	Handover
HSCSD	High Speed Circuit Switched Data
HSDPA	High Speed Downlink Packet Access
HS-DPCCH	High Speed Dedicated Physical Control Channel
HS-DSCH	High Speed Downlink Shared Channel
HSPA	High Speed Packet Access
HSPA+	High Speed Packet Access Evolution
HS-PDSCH	High Speed Physical Downlink Shared Channel
HS-SCCH	High Speed Shared Control Channel
HSUPA	High Speed Uplink Packet Access
HTTP	Hypertext Transfer Protocol
IMT-2000	International Mobile Telecommunications-2000
IP	Internet Protocol
IR	Incremental Redundancy
ITU	International Telecommunication Union
KPI	Key Performance Indicators
L1	Layer 1
L2	Layer 2
L3	Layer 3
LNA	Low Noise Amplifier
LOS	Line-of-sight
LTE	Long Term Evolution
MAC	Medium Access Control
ME	Mobile Equipment
MRC	Maximal Ratio Combining
MS	Mobile Station
MSC	Mobile Switching Centre
NACK	Negative Acknowledgement
NLOS	Non-line-of-sight
NMT	Nordic Mobile Telephone
OFDM	Orthogonal Frequency Division Multiple Access
OVSF	Orthogonal Variable Spreading Factor
PC	Power Control
P-CPICH	Primary Common Pilot Channel
PDC	Personal Digital Cellular
PDCP	Packet Data Convergence Protocol
PG	Processing Gain
PS	Packet Switched

PSTN	Public Switched Telephone Network
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
R4	Release 4
R5	Release 5
R99	Release 99
RAT	Radio Access Technology
RLC	Radio Link Control
RMS	Root Mean Square
RNC	Radio Network Controller
RNP	Radio Network Planning
RNS	Radio Network Subsystem
RRC	Radio Resource Control
RRM	Radio Resource Management
RSCP	Received Signal Code Power
RSSI	Received Signal Strength Indicator
SF	Spreading Factor
SfHO	Softer Handover
SGSN	Serving GPRS Support Node
SHO	Soft Handover
SIR	Signal-to-interference ratio
TB	Transport Block
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TP	Throughput
TTI	Transmission Time Interval
TUT	Tampere University of Technology
TX	Transmission
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System
USIM	UMTS Subscriber Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
WCDMA	Wideband Code Division Multiple Access

1. INTRODUCTION

The breakthrough in mobile communication came at the beginning of 1990's with successful Global System Mobile (GSM) technology, which started the era of the modern wireless communication. As the internet became more popular for the home users, the demand for the same services for mobile users grew rapidly. 2nd generation (2G) technology was not enough to fulfill the capacity need for operators and therefore more multi-service oriented technology was needed.

Early mobile data services could be provided by GSM with speed comparable to the modem connections. This was improved by High Speed Circuit Switched Data (HSCSD) and General Packet Radio Service (GPRS) technologies to provide higher data speeds with low-cost system upgrades. At the beginning of 21st century, this was improved even more by Enhanced Data rates for Global Evolution GSM (EDGE) technology, which is still ongoing development process towards higher data speeds with GSM.

Because of the need for even higher data rates and the technological boundaries of GSM, new 3rd Generation (3G) technology was needed. Wideband Code Division Multiple Access (WCDMA) was introduced by 3G Partnership Project (3GPP) as a new radio interface technology. In Europe, new 3G system was referred to as Universal Mobile Terrestrial System (UMTS). The initial release of UMTS provided 384 kbps data speed, which is upgradeable with High Speed Packet Access (HSPA) technology. The upgrade provides the data speeds of 14.4 Mbps in the downlink and 2 Mbps in the uplink direction. Even higher peak data rates in the future are provided by Enhanced HSPA (or HSPA+) and by new 4th Generation (4G) technologies like Long Term Evolution (LTE).

Along with the raising capacity demand, the operators face a new challenge in radio network planning because of the increasing trend of mobile indoor users. Studies about future data traffic demands have shown the increase in indoor data traffic. As illustrated in Table 1.1, the prediction about indoor user percentage in 2015 is around 70 % and thus the focus on efficient coverage planning for indoor users is justified.

Table 1.1. *Forecast for mobile traffic in developed and developing regions. [1]*

Traffic metric	2008 (developed)	2015 (developed)	2008 (developing)	2015 (developing)
Total traffic/month	57 PB	557 PB	50 PB	307 PB
Traffic/mobile/month	56 MB	455 MB	22 MB	83 MB
Percentage of total data traffic	49 %	94 %	7 %	79 %
Percentage of total indoor data traffic	54 %	74 %	34 %	62 %

Strategies for providing adequate coverage for indoor users range from outdoor-to-indoor coverage to the dedicated indoor systems. In addition, outdoor-to-indoor repeaters can be utilized to enhance the indoor coverage. As the indoor capacity requirement rises over the years, the dedicated indoor system is the most probable and reasonable choice for highly populated areas.

The dedicated indoor system capacity can be distributed by different antenna configurations. Distributed Antenna System (DAS) and multiple picocell configuration are commonly used antenna configurations to provide good coverage and user experience to indoor environment. As the construction expenses of DAS and pico configuration are different, research and measurements about the configuration differences have been made. Research has been made with single mobile and thus information about multiple user performance with different antenna configurations is still lacking.

In this Master of Science Thesis, verification about DAS and pico antenna configuration differences in indoor environment for HSPA is made by multiple user measurements. Thesis is divided into several parts, which is started with the essential background about mobile communications (Chapter 2), UMTS (Chapter 3) and HSPA (Chapter 4). In order to understand the overall planning process for UMTS and indoor systems, Chapter 5 describes the radio network planning for indoor systems in addition with performance indicators. Chapter 6 introduces the measurement campaign done for the Thesis and Chapter 7 presents the results acquired from the measurement campaign. Finally, conclusions and discussion about the results are done in Chapter 8.

2. MOBILE COMMUNICATION PRINCIPLES

Wireless communication has made big steps towards modern mobile communication during recent decade. The air interface with limited spectral resources poses challenges to develop, for example, a speech and data service for the masses without major movement restrictions. This chapter introduces the concept of modern mobile communication network with basic principles behind radio channel and propagation environment characterization. In addition, the most common access methods used by mobile techniques are briefly explained.

2.1. Cellular concept

Before the utilization of cellular concept the wireless phone services were provided by high masts with single antenna. These analog systems could serve only few users under the masts' big coverage area which was achieved by very high antenna positions and high power transmitters. [2] There were no handovers between masts so the calls were dropped if the user went outside of the coverage area. Demand for mobile telephony rise and due to the strict regulations in spectrum allocations the operators could not just increase capacity by adding new masts with different spectrum. Capacity enhancement with limited spectrum led to research a way to use coverage and capacity more efficiently.

The first design about cellular concept was made by AT&T and Bell Laboratories in the United States [2]. The concept introduced hexagonal cell structure, as illustrated in Figure 2.1, where the users could see the whole network as a homogenous service area. Each site is divided into cells (or sectors) with low power transmitters regarding to the capacity and coverage demand on the area. The concept is scalable for capacity or coverage limited areas like for rural or city environment. Bigger cells increase coverage and reduce the overall capacity and vice versa. With the new design the network structure became more complex, due to the multiple sites, and movement between cells introduced many new problems to solve. Cell selection and power control were the main issues to solve, before the mobility and interference free communication between cells could be ensured.

After sectorization each cell is granted with portion of total number of available system channels for creation of an independent service area. This way the channel reuse must be planned by groups over the whole network, targeting to minimize the interference between cells and users. The bigger proportion of total system channels, assigned to the cell, increases the cell capacity and reduces the total amount of channel groups. Smaller amount of channel groups create more co-channel interference to the network.

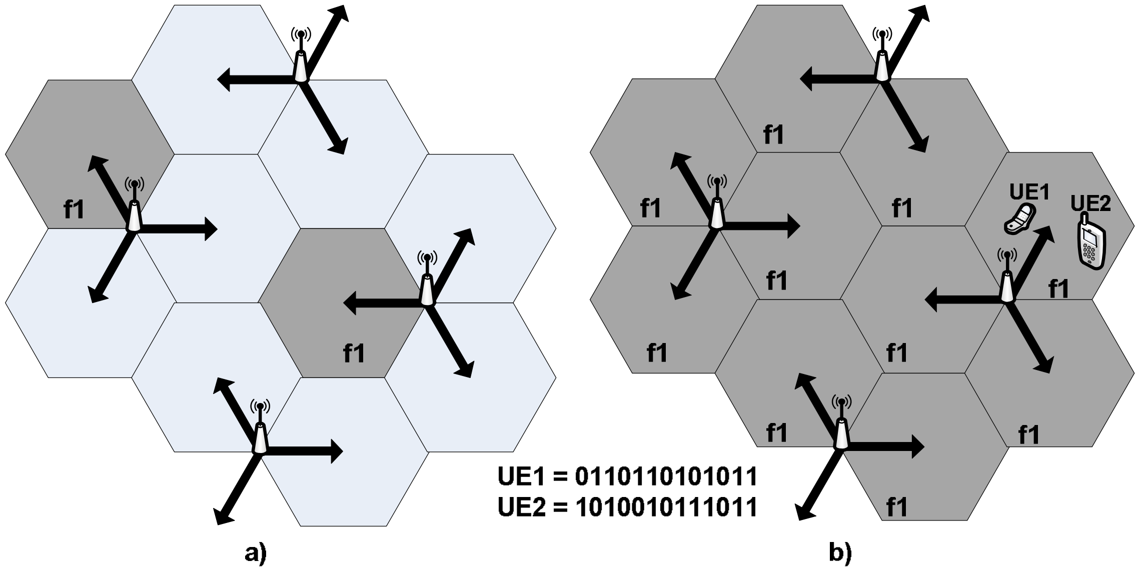

Figure 2.1. *Frequency reuse principle in a) FDMA and b) (W)CDMA hexagonal cellular concepts. Binaries of different User Equipments (UEs) represent example of the channel separation by different codes in (W)CDMA and f1 represents single carrier frequency. [3]*

Channel separation method amongst the users affects the way channel reuse must be planned. Capacity of Frequency and Time Division Multiple Access (FDMA and TDMA) (covered in Section 2.3) depend on the frequency reuse factor which states the average number of cells between co-channels [3]. In Code Division Multiple Access (CDMA) network the same bandwidth is used in every cell and the users are separated by different orthogonal codes. The difference of FDMA (also TDMA) and CDMA cellular concept is illustrated in Figure 2.1.

2.2. Mobile radio channel characteristics

Radio channel is characterized from the transmit antenna to the receiving antenna through the air interface as the transmit medium. Various obstacles affect the propagation path between transmitter and receiver differently, and movement of the receiver changes the path distance. This section describes basic phenomena affecting the radio propagation and presents different variables for the environment characterization.

2.2.1. Propagation principles

The behavior of radio wave propagation through the air interface can be understood as the combination of some basic mechanisms affecting the plane waves. These mechanisms provide information about direction, frequency and phase changes to the plane wave during the propagation and after the encounter with an obstacle. The mechanisms give also the tools to predict the signal power reduction during propagation from transmitter to receiver, which is also known as propagation loss.

2.2.1.1 Free space loss

The propagation can be treated as free space propagation when there are no obstacles near or relatively close to the propagation path between transmitter and receiver. The propagation loss can be calculated through Friis transmission formula [4]:

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2, \tag{2.1}$$

where P_r and P_t are the received and transmitted powers, respectively. Variables G_r and G_t are the antenna gains of receiver and transmitter which are affected by the structure of antennas. Wavelength of signal is signified to λ and d to distance between transmitter and receiver. More suitable form of free space loss can be expressed as [4]:

$$L = 32.4 + 20log\, d_{km} + 20logf_{MHz}, \tag{2.2}$$

where f_{MHz} denotes to frequency of signal in MHz and d_{km} to distance between transmitter and receiver in km. This equation is generally used due to its simplicity to give an estimate about path loss.

2.2.1.2 Reflection and refraction

In practice the propagation environment is never free of obstacles especially in land mobile systems. The plane wave can encounter various different obstacles like hills, trees and building walls which can alter the signal. From smooth surfaces one portion of signal energy gets reflected and the rest gets refracted. The boundary's electrical properties define the proportion of refracted and reflected signal energy and how the signal is affected by phase shift, polarization and the angle of reflected and refracted signal.

2.2.1.3 Diffraction

Diffraction is a phenomenon where signal propagates to a shadow region from a sharp edge obstacle and it is considered as a Non Line-of-sight (NLOS) situation. It can be explained by Huygen's principle which states that the each element of a wavefront can be considered as the centre of new secondary wavelets and that the previous wavelet is the envelope of new sources [4]. Knife-edge model with Huygen's principle is basic model to predict radio wave diffraction.

2.2.1.4 Scattering

Surfaces in reflection and refraction are considered as smooth boundaries for easier examination. In practice there are surfaces which are not ideally smooth and therefore the signal gets scattered when "reflected" from rough boundary. Scattering spreads the signal energy and the degree of scattering depends on the incident wave angle and on the roughness of boundary compared to the signal wavelength. Surface is considered as rough when the Rayleigh criterion [4]:

$$\Delta h < \frac{\lambda}{8cos\theta} \tag{2.3}$$

is fulfilled. Surface for the signal with the wavelength of λ and incident angle of θ can be considered as rough when the height difference of the surface is more than h.

2.2.2. Multipath propagation

Due the mobile nature of wireless communication it is difficult to predict signal propagation paths, from transmitter to receiver, in typical environment having many obstacles. As mentioned before, there are several phenomena affecting signal propagation which makes it nearly impossible to calculate exact values about signal propagation. Therefore statistical approach, to define propagation parameters, is a way to minimize problem and get relevant information about the effects on propagation paths [5;6]. Multipath propagation consists of multiple components which are received signals from different paths with the same information. At the receiving end, these components are utilized and fundamentals about this kind of receiver are discussed in Section 3.3.3.

2.2.2.1 Propagation slope

In practice, the signal does not always attenuate as in free space loss model which equals to 20 dB/dec. The environment affects also the level of attenuation which can vary between 25 – 40 dB/dec, according to the environment type. [7] The breakpoint distance B is a value calculated from base station to mobile from which the attenuation level starts to rise over the free space loss prediction. Importance of breakpoint distance in network planning is relevant for defining the cell's dominance area. Breakpoint distance is defined [7]:

$$B = 4\frac{h_{BS}h_{MS}}{\lambda}, \tag{2.4}$$

where h_{BS} and h_{MS} are the heights of the base station and mobile station.

2.2.2.2 Slow fading

Many scatterers, reflectors and diffractors in physical environment like buildings and hills cause received signal power level fluctuations at constant distance from transmitter. This phenomenon is referred as shadowing or as slow fading. Variation around the mean level is log-normally distributed and the standard deviation of it is called the location variability. Frequency, antenna height and the environment are the main aspects which affect the location variability. [4] Slow fading is a phenomenon which must be taken into account for better channel estimation accuracy.

2.2.2.3 Fast fading

Even slight movement of a mobile receiver changes channel conditions. In a multipath environment this causes very rapid fluctuations to the sum of received multipath components. This is due to the different phases and amplitudes of arriving components. Statistical approach is the only reasonable way to predict the fast fading phenomenon. Two probability density functions are used to predict different fast fading situations. For Line-of-sight (LOS) situation where at least one direct path reaches the receiver from transmitter the Ricean (or Rice) distribution function and in NLOS when there are only reflected and scattered waves to receive the Rayleigh distribution function describe the distribution of arriving signals.

2.2.2.4 Angular spread

Angular spread is a variable which describes the deviation of the signal incident angle. It is used to describe different propagation environment types. The calculation can be done for both horizontal and vertical planes and it is based on the incident angles of received signal powers. Angular spread is defined [3]:

$$S_{\Phi} = \sqrt{\int_{\bar{\Phi}-180}^{\bar{\Phi}+180} (\Phi - \bar{\Phi})^2 \frac{P(\Phi)}{P_{\Phi\_tot}} d\Phi}, \qquad (2.5)$$

where $\bar{\Phi}$ is the mean angle of incident wave, P(Φ) is the angular power distribution and P_{Φ_tot} is the total received signal power.

2.2.2.5 Delay spread

In multipath environment, multipath components of same transmitted signal may have different arrival times due to different propagation paths. The arrival time difference calculated from first received component to last one is described as excess delay spread. It is used as one parameter to characterize different propagation environments. In indoor environment the delay spread is small due to small component path length differences compared to rural environment. The Root Mean Square (RMS) delay spread S_{τ} can be calculated from the channel power delay profile $P_{\tau}(\tau)$ and average delay $\bar{\tau}$ as [7]:

$$S_{\tau} = \sqrt{\frac{\int_0^{\infty} (\tau-\bar{\tau})^2 P_{\tau}(\tau) d\tau}{\int_0^{\infty} P_{\tau}(\tau) d\tau}}. \qquad (2.6)$$

2.2.2.6 Coherence bandwidth

The delay spread represents multipath component spread in time domain, whereas coherence bandwidth represents it in frequency domain. Coherence bandwidth describes the separation of different frequencies, in multipath environment, whose fading are correlating by each other and thus, affected by frequency selective fading. This separation Δf_c, is a function of the delay spread S_τ [7]:

$$\Delta f_c = \frac{1}{2\pi S_\tau}. \tag{2.7}$$

In multipath environment, separation greater than Δf_c of two different frequencies can be considered as uncorrelated. By this, the channel can be considered as flat for these frequencies. In addition, system can be considered as wideband, when the signal bandwidth is greater than the coherence bandwidth. For wideband systems frequency selective fading does not affect the system as much for the narrowband system.

2.3. Propagation environments and characteristics

Separation and characterization of different propagation environments is important in the sense of radio network planning. Different environments affect differently on radio wave propagation and therefore classification of environments is sensible.

In literature there are some different mixtures of classifications for propagation environments and in this work the main separation is done from the system point of view to macrocellular, microcellular and indoor. Macrocellular environments consist of urban, suburban, rural and hilly terrains which all have their own characteristics. Urban environment is also included in the microcellular environment in smaller scale as illustrated in Figure 2.2. Indoor can be separated into pico- and femtocellullar according to their sizes [7]. Characterization of different environments is presented in Table 2.1 which shows the differences between outdoor and indoor environment with 900 Mhz carrier. The presented values do not change with higher carrier frequencies because the wavelengths are much less than the sizes of human-made structures [8].

Table 2.1. *Attributes for different propagation environments with 900 MHz carrier. [3;4;7]*

Environment type	Angular spread of multipath components (°)	Delay spread of multipath components (μs)	Slow fading std. deviation (dB)	Propagation slope (dB/dec)	Coherence bandwidth (MHz)
Macrocellular					
Urban	5-10	0.5	7-8	40	0.32
Suburban	5-10	0.1	7-8	30	1.60
Rural	5	0.1	7-8	25	1.60
Hilly rural		3	7-8	25	0.05
Microcellular	40-90	< 0.5	6-10		< 16
Indoor	90-360	< 0.5	< 10		< 16

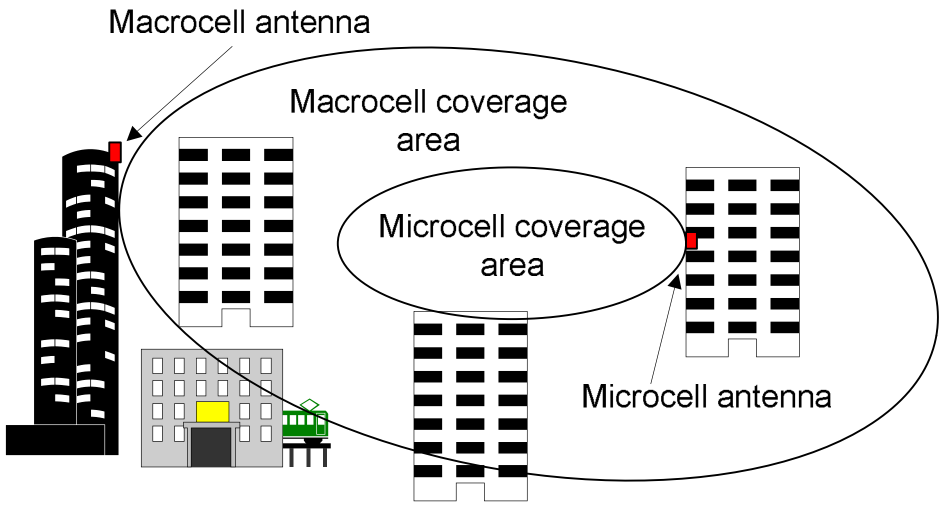

Figure 2.2. *Macro and microcellular radio propagation environment.*

2.3.1. Indoor propagation environment

As Thesis measurements are carried out only in indoor environment the closer observation to reasons of indoor environment variables is essential. Main outdoor and indoor characteristics are presented on Table 2.2.

In outdoor environment the channel can be considered as stationary in time because the environment changes are minor compared to indoor where for example doors and people movement affect more the channel conditions in overall. This causes higher fluctuation in mean signal level in indoors rather than outdoors. The distances in propagation paths are shorter in indoors than outdoors which can be seen in much lower delay spread values and lower UE power consumption. Systems which are wideband in outdoor can no longer consider channel as flat and are therefore regarded as narrowband in indoor due to high coherence bandwidth. High angular spread in indoor is caused by the walls and floors whereas in outdoors such elements does not affect so much.

Table 2.2. *Main outdoor and indoor propagation environment properties. [9]*

Indoor	Outdoor
• Non-stationary in time and space • Quick deep drops in mean signal level • No universally established path loss model • Negligible Doppler shifts • Small delay spread • Large angular spread • Lower mobile power consumption	• Stationary in time and non-stationary in space • Slow changes in mean signal level • Well established path loss model • Large Doppler shifts due to high UE velocity • Large delay spread • Small angular spread • Higher mobile power consumption

2.4. Multiple access techniques

In wireless communication, all users share the same finite radio spectrum so the separation and resource sharing for multiple users must be done in frequency, time or code domain. Methods behind user separation in air interface are called multiple access techniques which are introduced in this section and depicted in Figure 2.3. Uplink and downlink duplexing can be done by the same principles. Domains, in which the separation is done, are time, frequency and code domains which can be grouped as narrowband or wideband systems, depending on the amount of bandwidth allocation to the users [10]. As discussed in Section 2.2.2.6, the wideband system is not affected as much by frequency selective fading as narrowband systems, in which the bandwidth of the single user channel can be the same as coherence bandwidth.

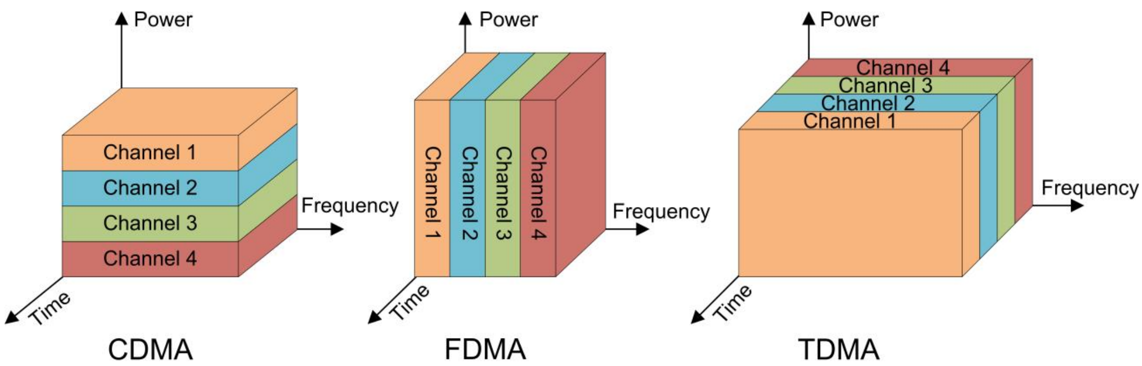

Figure 2.3. *Multiple access techniques.*

2.4.1. Frequency division multiple access

Method by which for example the FM radio channels are divided is frequency division. In FDMA user channels are separated from each other by different frequency bands and in mobile communication, one FDMA channel carries only one phone circuit at a time [10]. With this method the users cannot interfere each other in the same cell and therefore power control is not needed which makes the system much simpler. Drawback of the method is that the channel is reserved for the whole duration of a call and therefore the silent periods of the call is waste from total system capacity point of view.

2.4.2. Time division multiple access

In TDMA the service is divided into smaller periods which are sent at the specified time instants granted for the users on the same frequency. By this way, the spectral efficiency in TDMA is better than in FDMA [10]. Without proper synchronization the TDMA system creates interference to adjacent channels. TDMA also suffers from multipath propagation due to delay spread caused by the environment.

2.4.3. Code division multiple access

Along with the frequency and time domain, the separation can be also done by codes where every user uses the same frequency band and timeslot simultaneously. CDMA is based on spread spectrum multiple access technique (covered in Section 3.3.2) where the total information from every user is spread by the wideband spreading signal from which the separation itself is done by almost orthogonal pseudorandom codes [10]. Other type of spread spectrum multiple access based technique is frequency hopped multiple access where carrier frequencies of individual users are varied in a pseudorandom fashion [10]. With these codes the user can extract the indicated information from the total spread signal. In CDMA technique, every new user adds in its own share of interference or power to the shared medium. In that sense CDMA technique is more flexible to capacity changes than FDMA and TDMA where there are cut-offs when every slot is reserved.

3. UNIVERSAL MOBILE TELECOMMUNICATION SYSTEM

As the cellular concept covers the flexible planning for different environments there must be also a new access network which has an adjustable capacity distribution mechanism. In other words, the system must be also flexible to ensure Quality of Service (QoS) for different services like voice and data. UMTS is a 3G system which has variable data rates on the air interface with independent radio access infrastructure. In this chapter, the initial design of UMTS with the background, system architecture and its functionalities are covered. In addition the WCDMA air interface of UMTS with RAKE receiver architecture is introduced.

3.1. Evolution and standardization

Evolution steps of mobile communication are divided into generations. Analog mobile network systems like Advanced Mobile Phone System (AMPS) in the U.S. and Nordic Mobile Telephone (NMT) in the Nordic countries are referred to the first-generation (1G) systems which were introduced in the 1980's [3;11].

During the 90's mobile communication grew rapidly due to successful 2G digital mobile networks like GSM in Europe, Digital AMPS (D-AMPS) in North-America and Personal Digital Cellular (PDC) in Japan [2;11]. The development of internet brought the demand to integrate the internet into mobiles with the same services as at home with Asynchronous Digital Subscriber Line (ADSL) connection. This phenomenon introduced applications such as e-mail, video call and multimedia services to mobile which required much higher data rates than basic voice services. The need for higher data rates brought GPRS and EDGE enhancements for GSM system and are referred to Enhanced 2G (2.5G) [11].

In the beginning of 21st century focus of the industry shifted from the 2G systems towards 3G. In Europe, UMTS technology was chosen which is one part of the mobile network families from 3GPP standardization group. The 3GPP was established in 1998 by different telecommunication associations to develop 3G mobile systems based on evolved GSM core networks and radio access technologies [12]. The standardization process of 3GPP is divided into releases which provide new features and stable platform for implementation to the market. Release 99 (R99) was the initial Release of UMTS and it is followed by Releases 4, 5 and so on. International Mobile Telecommunications-2000 (IMT-2000) is the name defined for all 3G systems by International Telecommunication Union (ITU). ITU is responsible for specification work which is formed by several associates around the world for information and communication technology issues. As seen in Figure 3.1, the UMTS system is divided into Frequency and Time Division Duplex (FDD and TDD), depending on the separation method of uplink and downlink in the air interface.

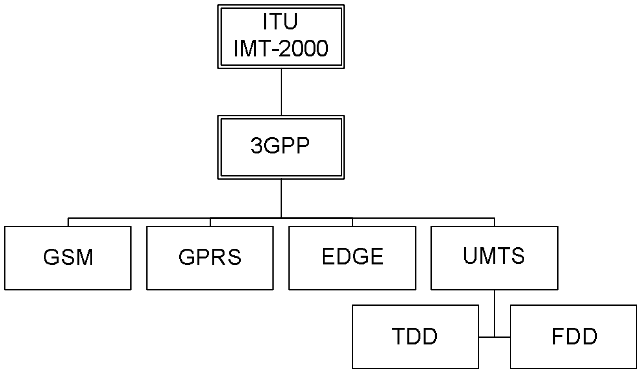

Figure 3.1. *Structure of mobile network family. [3]*

During the first decade of the 21st century the 3G system gained upgrades similar to EDGE and GPRS for GSM. Releases 5 and 6 featured High Speed Downlink and Uplink Packet Access (HSDPA and HSUPA) upgrades. For UMTS it provided better performance on WCDMA air interface and Internet Protocol (IP) based access network. Later releases introduce HSPA+, more IP-based network entities for access and core network to meet the requirements for higher data rates.

3.2. Architecture

On high-level architecture (as illustrated in Figure 3.2) the UMTS network is divided into three sub-networks based on the similarities of network element functionalities. UE is the terminal for user to access the network services through the radio interface. All the radio interface features are handled by UMTS Terrestrial Radio Access Network (UTRAN). Voice and data connections are Circuit Switched (CS) and Packet Switched (PS) by Core Network (CN) to the external networks like the internet. [3]

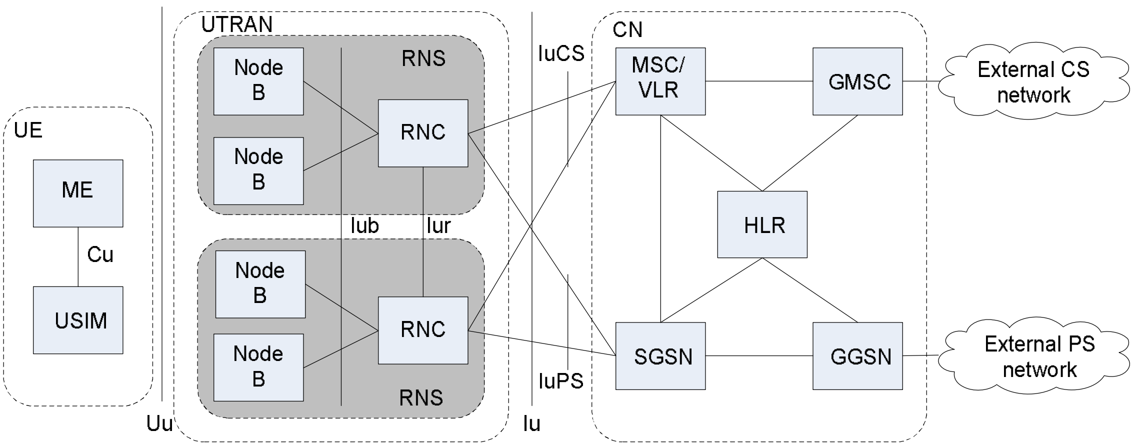

Figure 3.2. *Architecture of UMTS network. [6]*

The groups are connected by interfaces from which some are open. Open interfaces do not require the endpoint equipments to be from the same manufacturer like the U_u interface between the UE and UTRAN. UMTS is developed alongside with the GSM architecture and thus both of the systems have similarities in architecture. GSM Radio Access Network is referred as GERAN which is not covered in this Thesis.

3.2.1. UE

UE (or Mobile Station in GSM) is a combination of two elements: Mobile Equipment (ME) and UMTS Identity Module (USIM) (see Figure 3.2). ME allows the communication through U_u interface with the UTRAN. UE can consist from one or several USIMs which identifies the subscriber unambiguously and securely to the network [13]. ME and USIM(s) are connected together via C_u interface.

3.2.2. UTRAN

The aggregation point of users in the UMTS is UTRAN (see Figure 3.2) which handles the Radio Resource Management (RRM) and provides the connection to the CN for the users. The UTRAN is divided into several Radio Network Subsystems (RNS) which consist from Radio Network Controller (RNC) connected through I_{ub} interface to base stations referred as Node Bs [14]. For UE, Node B is the termination point towards RNC and it handles the transmission of one or more cells between the users. RRM in the RNS is done by the combination of Node Bs and RNC from which the RNC is in the control of the radio resources. RNCs can be divided into drift and serving RNCs where the drift RNC is the initial RNC of UE’s RNS and serving RNC is connected to the CN [14]. RRM functionalities are covered in more detail in Section 3.4. RNCs in UTRAN are connected amongst themselves via I_{ur} interface and to the CN via I_{uCS} or I_{uPS} interfaces depending on the data flow.

3.2.3. CN

The structure of CN is almost the same as in GSM on initial release of UMTS. The same network elements from GSM CN are utilized for UMTS, where both UTRAN and GERAN are connected. Division of CN can be done to PS and CS domains with different network elements (see Figure 3.2). Circuit switched domain contains following elements: Mobile Switching Centre (MSC), Visitor Location Register (VLR), Home Location Register (HLR) and Gateway MSC (GMSC). Packet switched domain contains Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) elements. [6;13-15]

MSC/VLR is a first CS access point from UTRAN to CN. It contains the database of visiting UE service profiles and handles the switching of CS services [15]. All CS traffic goes through GMSC to the external CS networks like Public Switched Telephone Network (PSTN). For UE service allocation and routing purposes, HLR contains the service profile of the user. The profile has information like allowed services and routing information on MSC/VLR level. [15] SGSN and GGSN functionalities are quite similar to MSC/VLR and GMSC respectively on packet switched services.

3.3. WCDMA for UMTS

UMTS Terrestrial Radio Access (UTRA) is the definition for WCDMA air interface technology in UMTS which is the most adopted one for the current 3G systems. WCDMA can be utilized on FDD or TDD but in this Thesis the focus is only on the FDD and from now on the terms UMTS, UTRA and WCDMA denote to the FDD method.

3.3.1. Main parameters of WCDMA

The information bits on the WCDMA physical layer are spread over the bandwidth with a variable spreading factor which is referred as Direct-Sequence CDMA (DS-CDMA). In WCDMA the spread quasi-random bits are called chips. WCDMA also supports multicode connections where the allocation of data rates can be done simultaneously by multiple fixed or variable spreading factors. The bandwidth of WCDMA channel is approximately 5 MHz with the chip rate of 3.84 Mcps. Definition of wideband system is more sensible when comparing the system bandwidth to the coherence bandwidths in different environments, shown in the Table 2.1. Carrier spacing can be selected from a 200 kHz grid between 4.4 and 5 MHz depending on how much interference is allowed between carriers [6]. This is due to the unideal shape of the bandwidth power distribution. UTRA FDD operating bands for uplink (UL) and downlink (DL) are 1902 – 1980 MHz and 2110 – 2170 MHz, respectively [16]. In Table 3.1 the summary of WCDMA physical layer parameters is presented.

Table 3.1. *Summary of the main WCDMA parameters. [6]*

Access technology	DS-CDMA
Chip Rate	3.84 Mcps
Channel bandwidth	5 MHz
Frequency band	UL: 1920-1980 MHz DL:2110-2170 MHz
Modulation	Quadrature Phase Shift Keying (QPSK)
Frame length	10 ms
Frame structure	15 slots
Spreading factor	UL: 4-256 DL: 4-512

3.3.2. Spreading and despreading

Spreading in the DS-CDMA system is done by multiplying each modulated information bit with another bit sequence. This spreads the information according to the size of spreading sequence which is also called spreading code. Despreading is done at the receiver end by multiplying the spread signal with the very same spreading code which was used for the spreading. The benefit of spreading the narrowband signal to a wideband is to increase the robustness against narrowband interferences as illustrated in the Figure 3.3.

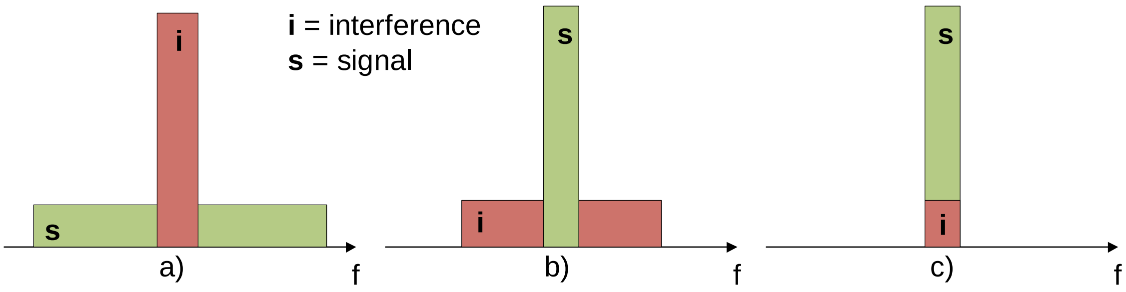

Figure 3.3. *Spread spectrum tolerance against narrowband interference. a) Received information signal with narrowband interference before despreading, b) same received signal after despreading c) and after narrowband filtering. [17]*

The despreading process at the receiving end spreads the narrowband interference to the level from which the actual information signal can be extracted after filtering the spread interference. Gain achieved from spreading is called Processing Gain (PG) and it is a fundamental factor of all CDMA systems [6;10]. Spreading Factor (SF) is the ratio of system chip rate W_C and user data rate R. The processing gain P_g in dBs is defined in the Equation (3.1) [17].

$$P_g = 10log_{10}(\frac{W_C}{R}) \tag{3.1}$$

For an example, for UMTS system with speech service at bit rate of 12.2 kbps the processing gain is 25 dB.

As the spreading codes are used to spread information to a wider bandwidth codes are also used to separate the different channels from each other. This is done by utilizing Orthogonal Variable Spreading Factor (OVSF) codes [3]. Variable bit rates can be created by using variable spreading factors.

In military applications scrambling is used to encrypt signal to avoid detection of adversaries. In WCDMA systems scrambling codes are used to separate different cells and users from each other. Scrambling is the final operation after spreading and does not affect the bandwidth of the signal.

3.3.3. RAKE receiver

In a multipath propagation environment, every delayed multipath component is used to achieve performance gain for the system. With basic receiver the worst case scenario is that every component, due to different phases, degrades the total energy of the received signal so it cannot be interpreted correctly. In RAKE receiver multipath components are treated individually and combined to achieve the best possible symbol value for interpretation.

RAKE receiver consists of different fingers (or branches) which separately handle the different multipath components as illustrated in Figure 3.4. After receiving the signal the most significant multipath components are collected and decoded by correlation receivers at the corresponding finger which modifies decoded signals according to the channel estimation from the carrier signal. After decoding, the signal is phase-adjusted before the combination of all fingers. [6] Combination methods can vary according to the vendor implementation but usual combining method is Maximal Ratio Combining (MRC). More about other combination methods are explained in detail in [5].

The performance of RAKE receiver is almost equal to the simple receiver structure in LOS situations. This is due to the relatively high power LOS component which is not affected by much lower power multipath components. In NLOS situations, RAKE receiver excels because of the exploitation of different multipath components. This though requires the time separation of different multipath components to be higher than the duration of one chip which equals to 0.26 µs in WCDMA system. In that time the radio signal can propagate a distance of 78 metres. This distance difference between two multipath components' propagation paths is more probable in NLOS than in LOS environment.

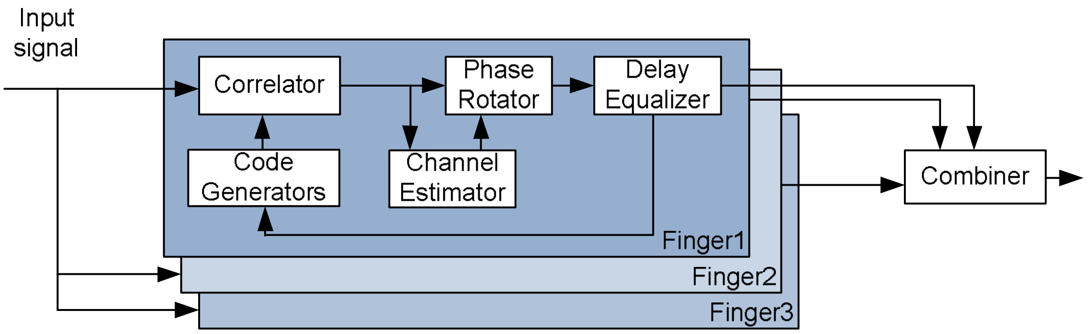

Figure 3.4. *RAKE receiver structure. [17]*

3.4. Radio resource management

Along with the other systems, in the UMTS the management and sharing of the common resources must be planned accurately to guarantee fair QoS along with the high capacity for the users. This is called radio resource management which can be divided into handover control, Power Control (PC), Admission Control (AC), load control, packet scheduling and resource management. Functionalities and locations of initial UMTS RRM differ from the HSPA RRM and therefore more detailed description is provided in Chapter 4. The principles of different RRM functions are presented later in this section and location of these elements in network structure is illustrated in Figure 3.5.

3.4.1. Handovers

Handovers (HO) provide mobility between or within service cells without connection breaks for the ongoing service. The handovers are divided by their types and procedures. Types are intra- and intersystem HO from which the intrasystem HO is subdivided into the intra- and interfrequency HO. Moreover, the procedures are divided into three categories: hard, soft (SHO) and softer handover (SfHO).

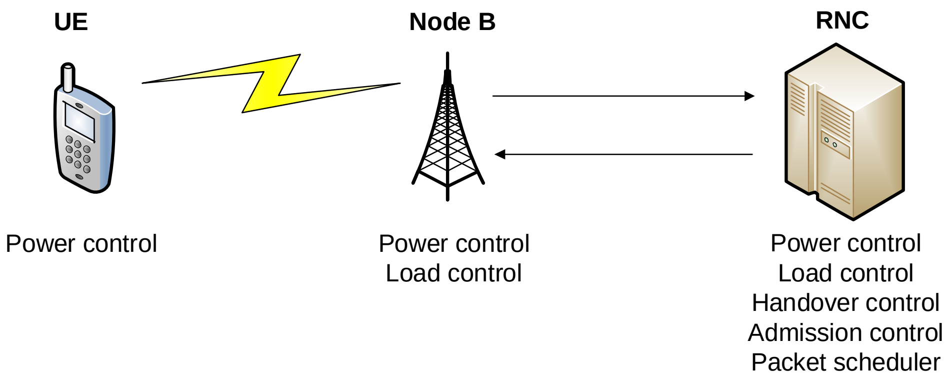

Figure 3.5. *Release 99 RRM functionality placement.*

The intrasystem handovers take place within the WCDMA system with the definition on how the behavior between carriers is done. If the different cells belong to the same carrier frequency the HO is called Interfrequency HO and for the different carriers it is called interfrequency HO. Intersystem handovers occur if the Radio Access Technology (RAT) or Radio Access Mode is changing during the HO like between WCDMA and GSM or between UTRA FDD and UTRA TDD [6].

In hard handover the service for the user data transfer between UE and UTRAN (also known as radio bearer) must be disconnected in order to establish a new one. This introduces a short disconnection on real-time services like voice but for non-real-time services the hard handover is usually lossless as the retransmissions can fix the short break in the connection [11]. Soft handover does not interrupt ongoing service because of multiple simultaneous connections on different base stations controlled by the same RNC. In softer handover the MS is simultaneously connected to the different cells on same base station. Simultaneous connections in SHO and SfHO are called active set and monitored set contains the measured neighboring cells which are not currently in the active set [6].

3.4.2. Power control

In WCDMA, where the users communicate simultaneously on the same frequency, it is crucial that the power control keeps the transmission power at minimum level within the limits of guaranteed QoS. In uplink, PC diminishes the near-far problem where the MS, closer to BS, blocks the further one because the BS receives more power from the nearer MS. In cellular concept the cells are overlapping each other and therefore in DL the other-cell interference must be minimized by keeping the transmit power of BS in minimum. The different power control mechanisms are presented in Figure 3.6.

Fast inner loop power control combats against the fast fading phenomenon by fast closed-loop PC between MS and BS. The BS estimates and compares the received SIR to the target SIR and sends PC commands at the rate of 1.5 kHz [6]. These commands are basic power up or down commands to the relative power level. The initial power for the MS when entering network is done by open-loop PC where the MS evaluates the transmission power from the measured downlink power level. Open-loop PC is utilized also to DL transmission power for BS from MS DL channel power measurement reports.

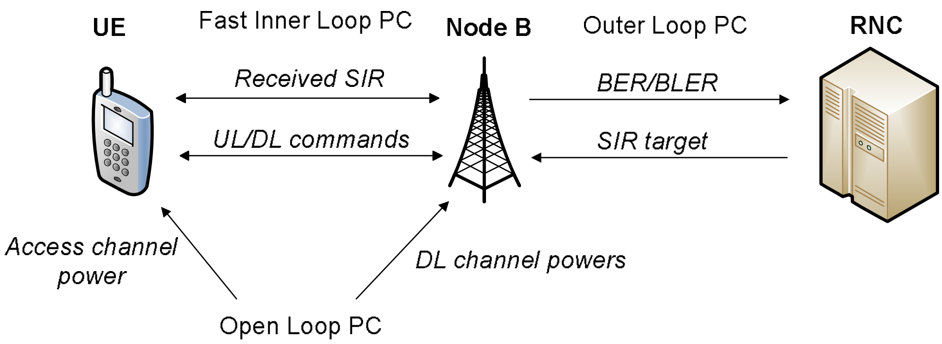

Figure 3.6. *Release 99 power control.*

Outer loop PC is between the BS and RNC where the RNC sets the target SIR for fast power control at the level of required communication quality. The quality for different services is defined by the Bit Error Rate (BER) or Block Error Rate (BLER) percentages [17]. The main goal of outer-loop PC is to keep the lowest possible SIR target for the desired quality level. This functionality prevents waste of capacity from other users by reducing excess interference from the network.

3.4.3. Admission and load control

As discussed, the WCDMA network capacity is more flexible than in fixed channel systems. To ensure sufficient QoS for existing connections, there is need to limit new connections to prevent excess interference into the system. Admission and load control works in parallel and they optimize the usage and quality of resources. Admission control handles requested connections and load control ensures the ongoing quality of connections. [3]

Before acquiring new connections the admission control evaluates the impact of new connection to the existing connections. This is done for both UL and DL from the information of several cells and both have to be acceptable before any new connections can occur. One scheme is to compare UL and DL transmission power rise (or noise rise) to the planned threshold [6].

In the situations where the admission control and packet scheduler fail to keep load below the planned overload threshold the load control acts as a ‘fail-safe’ mechanism to reduce load below the threshold [6]. Usual behavior of load control is to reduce load from PS services and handover connections to other carriers or RATs.

3.4.4. Packet scheduling

Packet scheduling consists of many different scheduling scenarios like routing in core network. In this Thesis, packet scheduling is considered as cell-specific packet scheduling where the resources are shared over a cell (or a Node B). Main function of the packet scheduler is to share the remaining capacity from non-scheduled real time connections. As the remaining capacity is shared, the scheduler must maintain the load under planned interference level without interfering real time connections. In multi-user packet data scenarios the packet scheduler is one of the main factors on performance and is mainly vendor-specific [6].

3.4.5. Resource management

As the amount and type of connections change in the network, the dynamic allocation of resources is utilized by RNC and Node B. Resource management operates with OVSF codes by allocating variable code lengths for different services and users with the information acquired from AC and packet scheduler [3;17]. Scrambling code distribution for uplink is also handled by resource management.

4. HIGH SPEED PACKET ACCESS

Development for evolved 3G technologies by 3GPP has brought two separate evolution paths: LTE and HSPA. The LTE is all-new RAT which in media is usually defined as 4G technology. Main difference between UMTS and LTE is that LTE utilizes Orthogonal Frequency Division Multiple Access (OFDMA) as an air interface technology. HSPA is a cost-efficient solution for existing UMTS network with a target to provide higher peak data rates and lower latency with same 5 MHz WCDMA carrier.

The PS enhancements featured by Release 4 for the UMTS were the base for HSPA development. The HSPA is divided into HSDPA and HSUPA which were introduced in Releases 5 and 6, respectively. The timeline of releases and the evolution of UMTS are presented in Figure 4.1. First commercial launch for HSDPA was at the end of 2005 and for HSUPA in early 2007. HSPA brought many new features involved with air interface but also other UTRAN functionalities have been modified. Higher order modulation, fast link adaptation, lower Transmission Time Interval (TTI), Layer 1 retransmission and combining are few to mention of features driving HSPA to higher peak data rates.

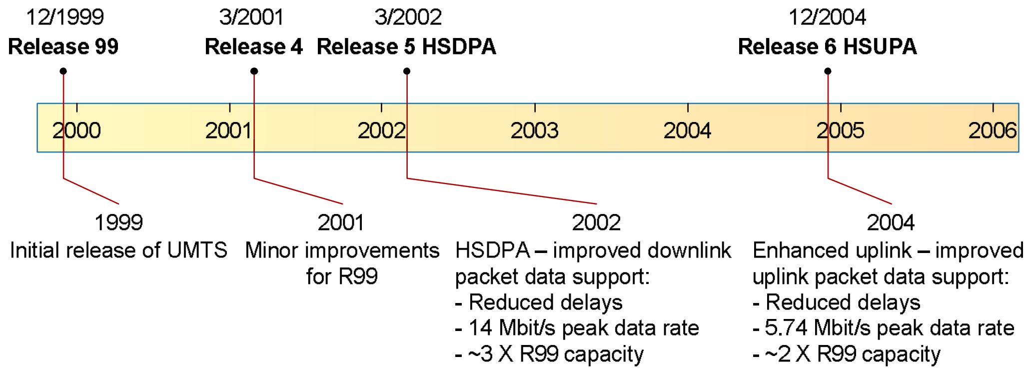

Figure 4.1. *Evolution of WCDMA. [11;18]*

This chapter presents in detail different aspects and features of HSPA by presenting changes in architecture and features dividing them to DL and UL parts. Furthermore the performance evaluations and scheduling for multiple users are covered.

4.1. HSPA architecture and protocols

With the HSPA many RRM functionalities are moved from RNC to Node B and interface capacity enhancements performed. This obviously requires much higher processing for the entire network elements, especially for Node Bs and therefore basic software update is not possible for too old equipment. On Release 99 the RNC was the main RRM element whereas the Node B featured only fast power control. Scheduling, dynamic resource allocation, QoS provisioning, load and overload control are new functionalities presented for Node B by Releases 5 and 6. The overall picture of different RRM functionality placements in UTRAN with HSPA Release 6 is illustrated in Figure 4.2 and covered briefly in following sections.

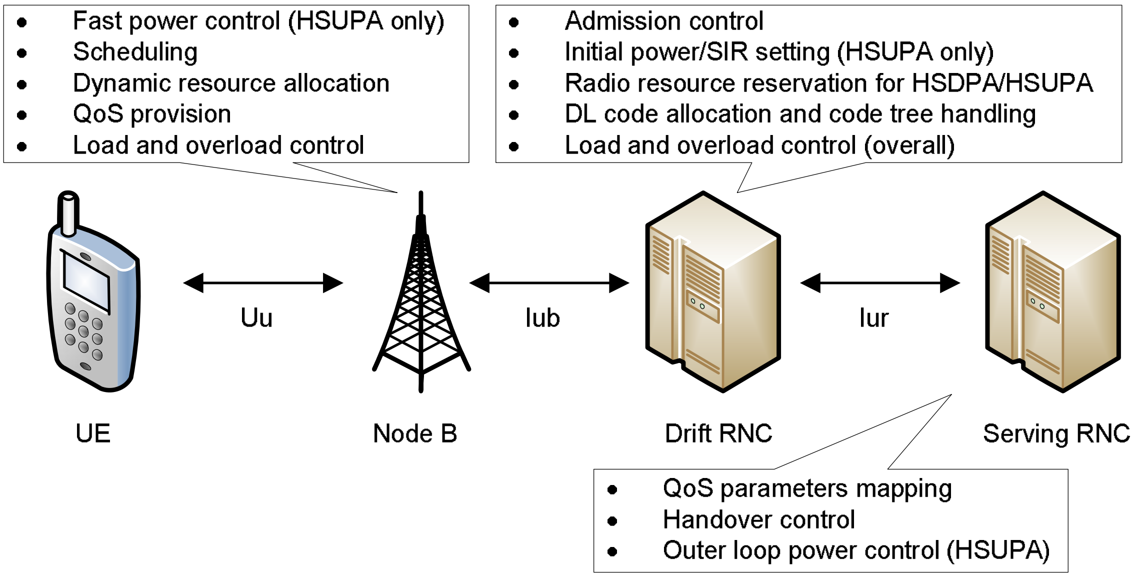

Figure 4.2. *HSDPA and HSUPA RRM architecture in Release 6. [18]*

Layer structure of UMTS protocol stack is base for understanding the interoperability between different network elements. Each layer is responsible for specific part of radio-access functionalities and they are connected to each other by several channels. Main layers can be divided in: application, Radio Resource Control (RRC) (L3), Radio Link Control (RLC) (L2), Medium Access Control (MAC) (L2) and physical layer (L1) [11;18]. RRC is responsible for signaling, channel configuration, mobility and resource management or in brief everything that is needed to establish and maintain the connections for applications. For user plane radio bearers Packet Data Convergence Protocol (PDCP) and Broadcast/Multicast Control Protocol (BMC) are utilized. Main functionality of PDCP is header compression and BMC conveys messages from Cell Broadcast Centre. [6] RLC handles the segmentation, reassembly and retransmission of user and control plane data with an addition of logical channel mapping for lower layers. Data rate selection, prioritization, transport channel mapping and transport format selection are the main tasks of a MAC layer. Physical layer is the last layer before sending data to air interface. Coding, interleaving, multiplexing, spreading and mapping to physical channels are the main tasks of physical layer. The architecture of UMTS protocols is illustrated in Figure 4.3.

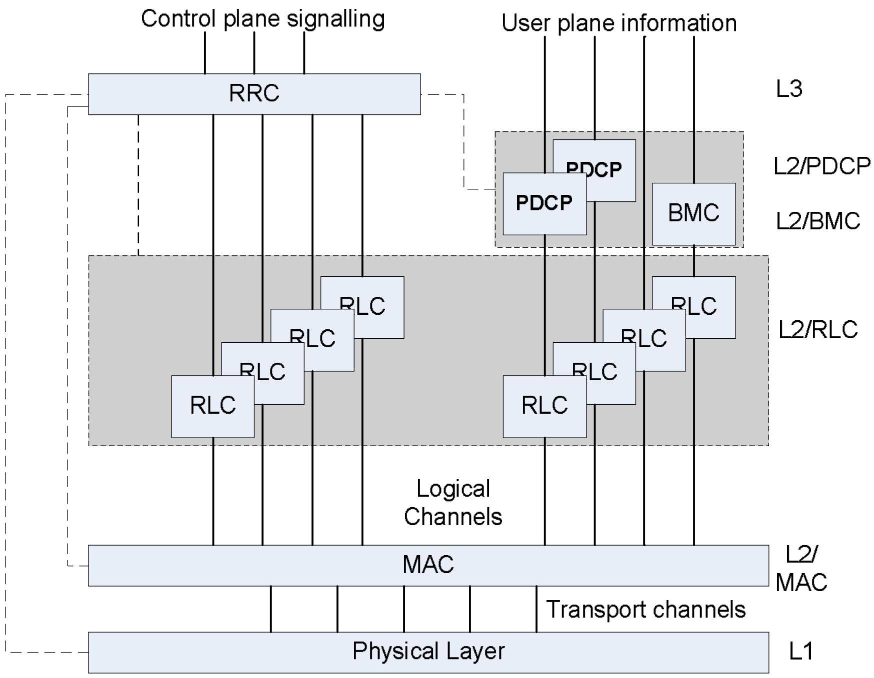

Figure 4.3. *Protocol stack of UMTS. Dotted lines represents the control channels and solid lines service access points between different layers. [18]*

4.2. HSDPA

Several technical improvements and added features to WCDMA from Release 5 bring higher downlink packet data rates for users with HSDPA capable UE. Main features enabling higher throughput on downlink are introduced in this section which are as follows: new shared common channel, higher order modulation, L1 Hybrid Automatic Repeat and request (HARQ), channel adaption and fast scheduling.

4.2.1. Shared-channel data transmission

Main difference of HSPA data transmission in comparison to R99 dedicated transmission channels is shared channel transmission. This approach occupies certain amount from overall downlink capacity and shares it for the users based on priority levels and QoS requirements. The downlink capacity is reserved by a fixed spreading factor of 16 from where up to 15 codes can be used for the HSDPA data transmission and rest (with a higher SF) for signaling and CS traffic [11;18]. All of the 15 codes can be assigned for only one user if the UE supports total amount of the codes. Different users are separated dynamically by assigned blocks (or codes) for every TTI. By this fast channel-dependent scheduling for two or more users can be utilized on physical layer by Node B. The division of codes and example of user separation in HSDPA is illustrated in Figure 4.4.

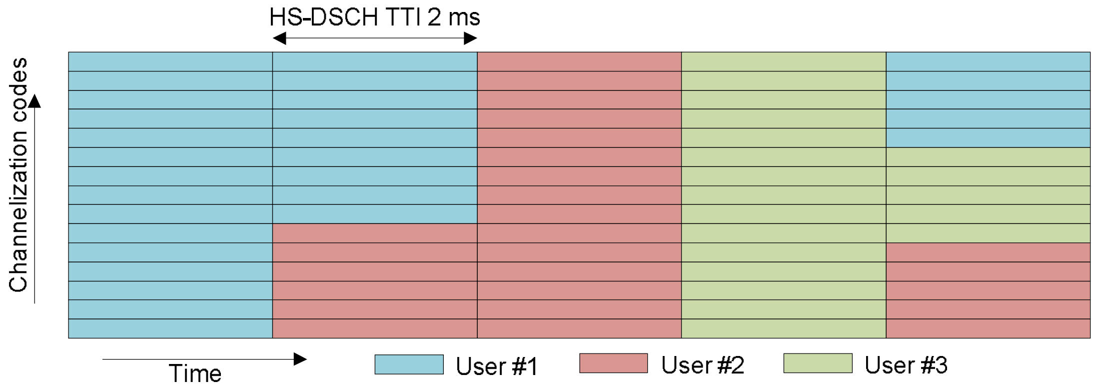

Figure 4.4. *Time-and code-domain structure of High Speed Downlink Shared Channel. [18]*

TTI is the duration of encapsulation from MAC layer data to the physical layer before any coding, modulation or spreading. In Release 99 TTI for Dedicated Channel (DCH) is 10-80 ms, depending on the configuration, and in HSPA the TTI reduced to 2 ms for latency reduction in the system.

The new transport channel presented in HSDPA is a High Speed Downlink Shared Channel (HS-DSCH) which is mapped up to 15 physical layer channels called High-Speed Physical Downlink Shared Channel (HS-PDSCH). Each user is assigned by common HS-DSCH with variable amount of HS-PDSCHs every TTI. HS-DSCH has many features which differ from R99 DCH downlink packet-data operation. These features are summarized in Table 4.1.

Table 4.1. *Comparison between DCH and HS-DSCH. [18]*

Feature	**DCH**	**HSDPA (HS-DSCH)**
Variable spreading factor	Yes	No
Fast power control	Yes	No
Adaptive modulation	No	Yes
BTS based scheduling	No	Yes
Fast L1 HARQ	No	Yes
Soft handover	Yes	No
TTI length [ms]	80,40,20,10	2
Modulation	QPSK	QPSK, 16-QAM

For efficient usage of HS-DSCH transport channel with every TTI there must be also fast signaling channel to carry information about code allocation, transport format and HARQ process for the user. High-Speed Shared Control Channel (HS-SCCH) is a physical channel for downlink signaling purposes. It is a shared channel which is UE independently encoded. For multiuser scheduling purposes the UE must support up to 4 HS-SCCHs for code-domain scheduling. The amount of available HS-SCCH describes the maximum amount of simultaneous codes on the same TTI.

Uplink signaling is performed by High-speed Dedicated Physical Control Channel (HS-DPCCH) which carries Acknowledgement (ACK/NACK) information about received HS-DSCH block for HARQ process. Also information about downlink quality is sent through HS-DPCCH in the form of Channel Quality Indicator (CQI). [11;18] CQI is affected also by the quality of receiver and by the performance of supported data rates which can therefore differ between two different mobiles with the same exact channel conditions. Rather than plain channel condition information, CQI is expression about the recommended Transport Block (TB) size for the UE at the given moment. Report interval of CQIs is configured by UTRAN and the decision of transport format is made by Node B for HS-PDSCHs according to channel conditions.

The throughput of the UE is directly proportional to the transport block size. It can be calculated by multiplying the transport block size by 500 (2 ms TTI). Of course this presumes that only one TB size is used.

4.2.2. HS-DSCH link adaptation

The transmit power of HSDPA data channels is constant and therefore fast power control is substituted by HS-DSCH link adaptation [11;18]. As the channel conditions can vary independently in terms of fast fading, each user may experience peaks in channel quality. Utilization of these peaks with higher data rates, as illustrated in Figure 4.5, increases significantly capacity in highly loaded networks. Link adaptation controls rate control function by the CQIs gathered from UEs in addition to the scheduling decisions. The rate control is utilized by Adaptive Modulation and Coding (AMC) process. It changes the modulation and coding rate for matching transport block size.

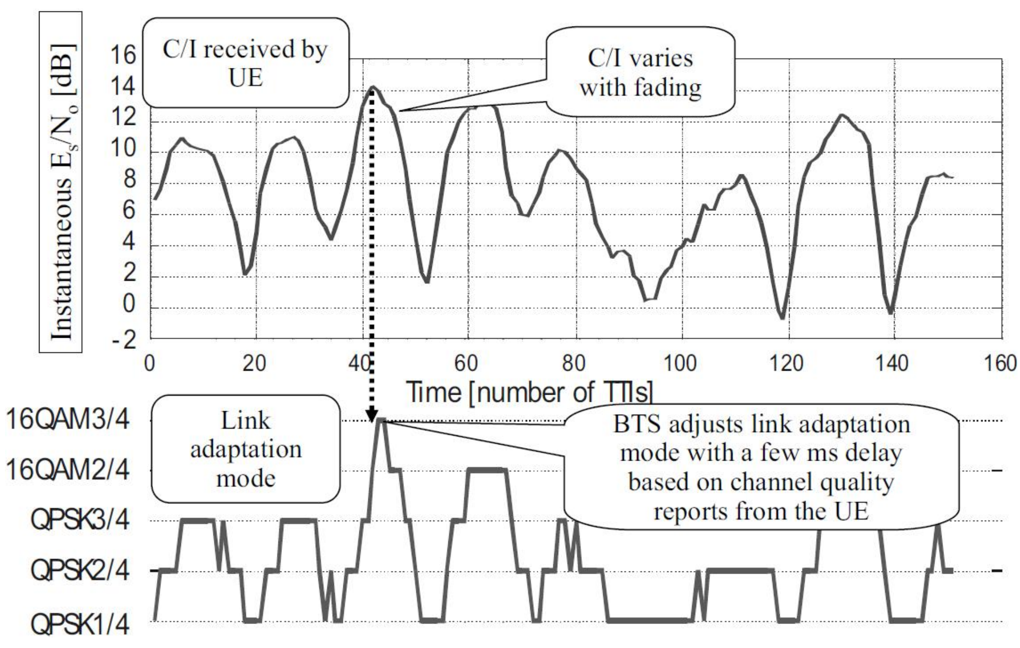

Figure 4.5. *HS-DSCH link adaptation. [18]*

For conditions where the reception of UE is good, the higher order of modulation is introduced to increase data rates through air interface. 16-QAM doubles the number of bits carried per symbol from QPSK 2 bits/symbol. In addition to modulation, HSDPA uses Turbo coding as Forward Error Correction (FEC) on larger transport blocks which outperforms convolutional coding at higher data rates [18]. For example coding rate 1/3 represents triple redundancy to data by added parity bits and therefore it is more resilient for bit errors at low channel conditions when signal may be affected by more errors.

The maximum HS-DSCH data rate can be calculated with few assumptions: Link adaptation mode with 16-QAM (4 bits/symbol) and 1/1 coding (no redundancy), empty cell and UE capable of using all 15 OVSF codes. As the chip rate of the system is 3.84 Mcps and the TTI is 2 ms. The maximum theoretical physical layer downlink bit rate can be calculated as in Table 4.2.

Table 4.2. *Calculation of maximum physical throughput for HS-DSCH. [18]*

$R_{chip} = 3.84\ Mcps * 2ms = 7680\ chips/TTI$	System chip rate times TTI.
$R_{symbol} = \frac{R_{chip}}{16\ SF} = 480\ symbols/TTI$	Amount of chips per TTI divided by the fixed spreading factor.
$R_{bit} = \frac{R_{symbol}}{4\frac{bits}{symbol}} = 1920\ bits/TTI$	Number of maximum user bits per code when utilizing the 16-QAM modulation.
$R_{HSDPA\_max} = \frac{R_{bit} * 15\ codes}{2\ ms} = 14.4\ Mbps$	Maximum HSDPA physical layer throughput by 15 codes with 1920 bits every TTI.

4.2.3. HARQ process

As the link adaptation tries to maintain sufficient data rates according to the current channel quality, there is still a change for errors due to the small delay in adaptation process as shown in Figure 4.5. Fine-tuning to correct these errors is made by HARQ process with soft combining. HARQ is a Layer 2 process where the UE sends ACK/NACK reports to Node B about successful transport block decoding which is detected by Cyclic Redundancy Check (CRC) [11]. Layer 2 retransmissions are much more rapid between UE and Node B rather than at Layer 3 by RNC in R99.

More sophisticated method, rather than plain re-transmission of data packet, is soft combining which works alongside the HARQ process. Soft combining does not discard the soft information from previous transmission attempts but uses them to increase the probability of successful decoding of retransmissions. Two different methods for soft combining are presented: Chase combining and Incremental Redundancy (IR). For soft combining process in HSDPA, IR is generally utilized. It increases the amount of parity bits (higher coding rate) for retransmitted packets which may not be included on initial packet. UE uses the initial data and retransmitted data with different amount of parity bits and applies them to reconstruct corrupted data. If HARQ process fails to transmit packet correctly with maximum retransmissions (usually after 3rd failed retransmission) the retransmission process is moved for upper layer [18].

4.2.4. Scheduling

As the scheduling process is moved to Node B, the scheduling decisions can be made with much less delay and therefore channel-dependent scheduling is utilized to maximize highly loaded cell throughput. Because the link conditions vary independently for every user, the scheduling decision is made in the same manner as in AMC: schedule users with the instantaneously best channel conditions. This scheduling method is referred as the Maximum C/I scheduling. The principle of the Maximum C/I scheduling method can be seen in Figure 4.6.

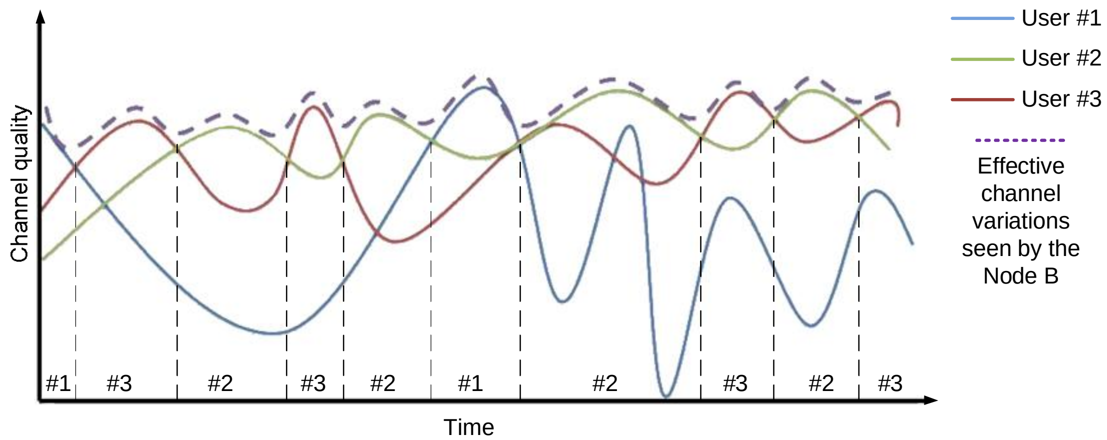

Figure 4.6. *Channel-dependent scheduling for HSDPA with the Maximum C/I method. [11]*

Scheduling techniques can vary as they are not specified by 3GPP and therefore they are vendor specific. As the distribution of users is not always homogenous the scheduling decision must be adjusted so that also the users with worse conditions would be served. Proportional fair scheduling method takes account along with the channel conditions also the average offered data rate. This approach provides resources for poor radio condition users and still maintains a reasonable data rate for good radio condition users.

4.2.5. Mobility

Release 99 introduced soft handover between cells to enhance the mobile user experience in cell changes. As the data transmission in HSDPA at serving cell is done by one shared channel the soft handover procedure is not possible. When changing the best cell, UE sends the measurement report to RNC which makes the decision and initiates the hard handover procedure. It configures target Node B and instructs the UE to change serving cell. When the UE makes cell change the data flow between source cell and UE is terminated and MAC layer functions are reset.

Reconfiguration of radio bearer to new cell terminates the data traffic and begins the new one on target cell. This process can happen before the UE has connected to the cell and therefore packet losses may occur. All the packet losses during handover are controlled by RLC protocol before new HARQ process is activated.

4.3. HSUPA

HSUPA, also referred as Enhanced Uplink, is the main feature introduced in Release 6. It provides higher data rates, reduced latency and higher system capacity with same mobility as in R99 [18]. HSUPA is an upgrade to the R99 UMTS and it uses most of the basic features from it like soft handover and fast power control. In this section new features and functionalities of HSUPA are introduced and principles of UL RRM are covered.

The main added feature for HSUPA is a new Enhanced Dedicated Channel (E-DCH) as a transport channel with 2 ms TTI, HARQ and fast scheduling. Also new signaling and physical channels are introduced with some scheduling and HARQ process related channels. These channels are as follows and are presented in more detail on following sections: E-DCH Dedicated Physical Data Channel (E-DPDCH), E-DCH Dedicated Physical Control Channel (E-DPCCH), E-DCH Absolute Grant Channel (E-AGCH), E-DCH Relative Grant Channel (E-RGCH) and E-DCH HARQ Indicator Channel (E-HICH) [19].

4.3.1. Transmission channel mapping

E-DPDCH is a new physical layer channel which transmits the data through air interface. It has almost same characteristics as DPDCH (R99 physical channel for DCH) with variable SF and BPSK modulation. Comparison of these two channels is presented in Table 4.3. E-DCH can utilize in maximum of 4 E-DPDCH at 2 or 10 ms TTI simultaneously with SFs 2 and 4 which leads to maximum physical layer bit rate of 5.76 Mbps [18]. Multiple physical channel transmission enables higher data rate for HSUPA and is referred as multicode operation. One has to notice that multiple DPDCHs from one UE could be also transmitted but in practice it has not been utilized in R99.

Table 4.3. *Comparison between DPDCH and E-DPDCH. [18]*

Feature	DPDCH	E-DPDCH
Maximum SF	256	256
Minimum channel data rate	15 kbps	15 kbps
Minimum SF	4	2
Maximum channel data rate	960 kbps	1920 kbps
Fast Power Control	Yes	Yes
Modulation	BPSK	BPSK
Soft Handover	Yes	Yes
TTI lengths [ms]	80, 40, 20, 10	10, 2
Maximum no. of parallel codes	6 x SF4 (1 x SF4)	2 x SF2 + 2 x SF4

As E-DPDCH transmission format can vary between simultaneous channels there is also need for signaling channel parallel with every physical channel. E-DPCCH carries decoding information about upcoming E-DPDCH payload for Node B and a happy bit which indicates whether the UE is satisfied with current data rate or not [11;18]. Also retransmission sequence number for HARQ process is indicated by 2 bits.

4.3.2. Mobility

For E-DCH the mobility works likewise as in R99. Measurements about neighboring cells are done by UE and the decision about active set updates are done by the RNC. Only difference is that the E-DCH active set is a subset of the DCH active set. Due to the multicode functionality the maximum required active set size for E-DCH is four apart from six for DCH.

4.3.3. HARQ

In principle, the HARQ process with soft combining is similar to the HSDPA HARQ process with the difference that HSUPA HARQ process is synchronous. This is because the need of simultaneous HARQ processes (maximum of 4) for individual E-DPDCH stream in multicode operation [18]. With synchronous HARQ process there is no need for separate signaling for retransmissions. The timing of transmission has the information of which HARQ process is being used and only indication is needed to inform whether the data is new or a retransmission [18]. The indication about the packet decoding success, from Node B, is transmitted by E-HICH in the form of ACK or NACK.

During the soft handover the HARQ process is active between UE and multiple Node Bs. From UE point of view it is sufficient that even one Node B receives the packet successfully. Therefore the transmitted packet can be considered successfully sent when UE receives even one ACK. As different Node Bs handle the ongoing soft handover HARQ process the packet reordering must be done in RNC.

4.3.4. Scheduling

In comparison to HSDPA, the HSUPA is many-to-one scenario where the scheduling functionality must work differently. In HSDPA the shared resource is transmission power and code space from one node but in HSUPA the shared resource is allowed amount of uplink interference from several nodes with unequal transmit powers. Increased UL load represents growing interference at Node B and therefore scheduling is based on requested and granted transmit powers to keep the interference below planned threshold.

UL scheduling is a three phase request and grant process. The request from UE is based on the UE’s power and buffer data availability. Node B combines the request, UE satisfaction (happy bit) and uplink interference information and evaluates the grant for the UE. Received grant in UE is used to evaluate the transport format and transmit power to use for the current data which is transmitted along with the corresponding control information.

Serving grant is a value from which UE determines current uplink data rate. It is expressed as E-DPDCH-to-DPCCH ratio. This is because of the fast power control mechanism which adjusts the E-DPCCH power level so there is no need for signaling absolute power levels [18]. As illustrated in Figure 4.7, the E-DPDCH-to-DPCCH ratio remains unchanged, until Node B grants more transmission power. Node B adjusts serving grant by using two different DL grant channels: E-AGCH and E-RGCH. Latter one is used for transmitting single up/down scheduling power commands which affects on the UE's relative transmission power allowed to use for E-DPDCH. The E-AGCH indicates the relative transmission power value for UE and is usually utilized for high data rate requests. Both E-AGCH and E-RGCH are used for evaluating the serving grant, from which the E-DCH Transport Format Combination (E-TFC) is determined. Uplink data rate evaluation process is illustrated in Figure 4.8.

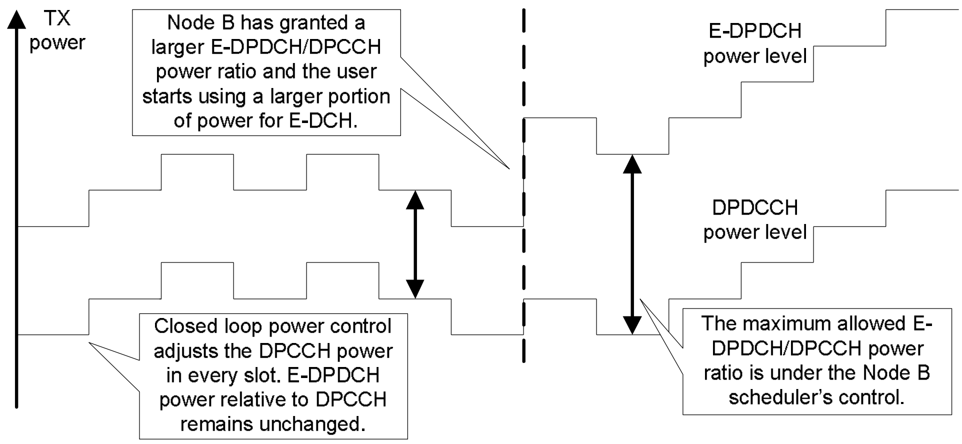

Figure 4.7. *E-DPDCH-to-E-DPCCH power ratio control by Node B scheduler. [18]*

During soft handover process only one of the active set base stations act as a serving E-DCH cell which controls the overall scheduling with the absolute and relative grants. Other cells in active set send only relative grant down or hold commands to UE so they act as part of the overload control mechanism. [18]

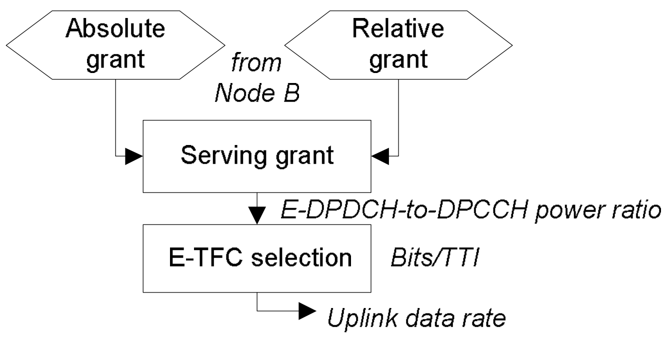

Figure 4.8. *Uplink data rate evaluation process by grants. [11]*

5. INDOOR RADIO NETWORK PLANNING

Radio Network Planning (RNP) is the main tool for operators to achieve a cost-efficient and high QoS radio network [7]. It requires good knowledge about implemented technology and the interoperability of three main aspects: coverage, capacity and quality. In addition, good planning process is required to meet current and future standards and demands from the market.

Because of WCDMA, where the capacity and coverage are bind together, the planning is constantly evolving process and the old planning philosophy from GSM and NMT networks: 'coverage first, capacity later' had to be abandoned. Therefore UMTS network requires constant feedback from the operating network for optimizing process. [17] In this chapter, the principles of radio network planning for UMTS is covered.

The following planning guidelines are mainly for outdoor network planning which can be also used for indoor network planning, in some degree. Principles remain the same but with the few differences due to the entirely different planning environment. More detail about indoor planning is covered in Section 5.2 and the main performance indicators for network evaluation in Section 5.4.

5.1. Planning process in UMTS

The UMTS network planning can be divided into three logical phases as illustrated in Figure 5.1. These phases are pre-planning (dimensioning), detailed planning and post-planning (optimization and monitoring) phase [3]. The dimensioning phase is the same for 2G network planning where the similarity to UMTS planning ends. As mentioned, the planning for UMTS is a constant process. In the detailed planning and post-planning phase, the planning is a continuous cycle to meet the current situation of network.

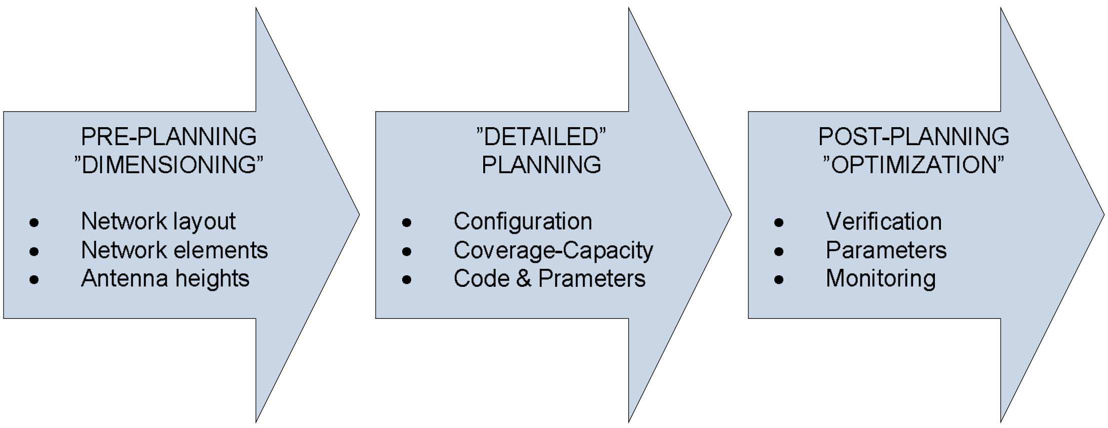

Figure 5.1. *WCDMA planning process. [3]*

5.1.1. Dimensioning

In the initial planning phase the rough estimate about current environment and capacity requirement are evaluated. It uses hypothetical data to evaluate the layout and the amount of elements, like base stations to cover capacity need on the region. In addition, the average antenna height is estimated in order to define the characteristics of the radio propagation channel for later planning phases. For example in optimization phase more sophisticated planning for antenna orientation is done for the current environment.

5.1.2. Detailed planning

With the help of initial results from dimensioning phase the detailed planning phase uses actual data to provide exact configuration of base stations. The base station, antenna lines and gains, slow fading margins et cetera are used to calculate link budget (or power budget) for more realistic information about current configuration.

Topology planning covers the coverage-capacity relative planning for the network. The coverage of the network is calculated by different path loss prediction models like Okumura-Hata where the information about average antenna height is used form initial planning [3]. But as the coverage in UMTS is affected by the load of the network (cell-breathing), the coverage and capacity have to be simulated simultaneously. Phases of topology planning are illustrated in Figure 5.2 and more about subject can be found from [3;7].

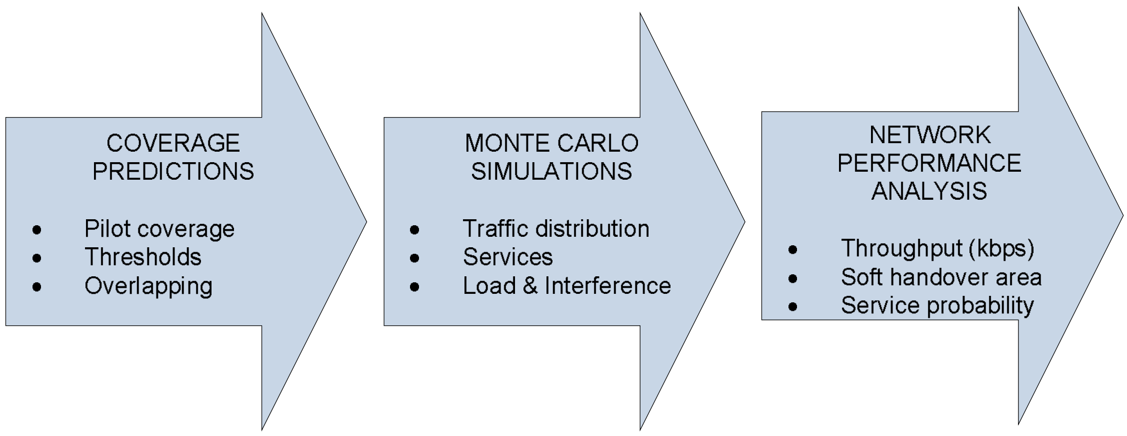

Figure 5.2. *WCDMA topology planning. [3]*

Code and parameter planning process covers the scrambling code allocation for cells and radio interface parameter optimization. In 3GPP specification there are enough codes for cells and therefore the scrambling code allocation planning is straightforward [3]. Radio interface parameter optimization includes parameters for like handover control, power control and signaling et cetera.

5.1.3. Post-Planning

In the final stage of RNP, verifications and measurements about current plan is performed. These tests provide information about coverage, dominance and handover areas. By this information fine-tuning of parameters can be done during the optimization phase.

After the network launch the monitoring of network is essential to compensate capacity demand variation in current environment [3]. Statistics about call success and drop rates are referred as Key Performance Indicators (KPI) and are used for QoS management. KPIs can be also used for post-planning and optimization phase.

5.2. HSPA indoor configuration planning

The first cellular networks provided coverage for indoor users by outdoor cells. This approach required planners to take account building penetration loss margin, which can vary from 15 to 20 dB, to ensure sufficient coverage for the users also in the inner parts of the building [9]. As building locations can vary from near the base station to the cell edge, the bigger coverage overlapping and therefore higher other cell interference is a result of this approach. The difference of outdoor and indoor coverage planning can be seen from missing planning margins at indoor case in Figure 5.3.

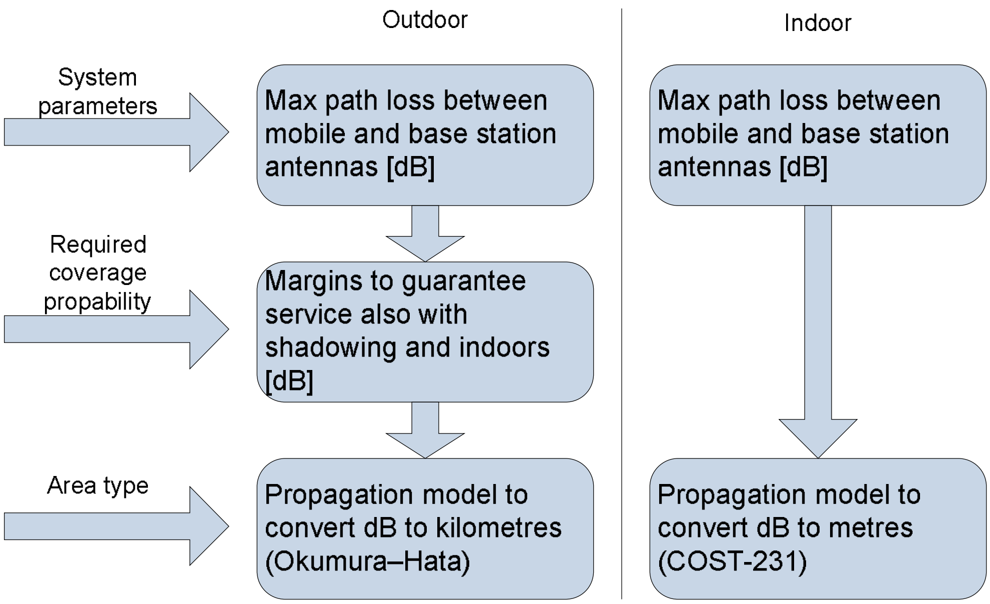

Figure 5.3. *Difference of indoor and outdoor coverage planning. [20]*

Because the traffic generation from indoor mobile users has been raised, in the past decade, different approaches to provide sufficient coverage and capacity are reasonable [2]. These approaches are dedicated indoor system and outdoor-to-indoor repeater where both of them can have the same cell configuration strategies to provide coverage for indoors.

5.2.1. Strategies for indoor coverage

For small and medium sized buildings with low amount of traffic, single cell strategy is good option to enhance coverage and provide decent signal quality for indoor users. As illustrated in Figure 5.4a) the single cell strategy utilizes only one base station (or cell) with different antenna configurations which are depicted in more detail in Section 5.2.2. While planning indoor coverage for one cell, for example with Distributed Antenna System (DAS), one has to remember that cell size cannot be infinitely increased due to the antenna line losses from example cables, splitters and connectors.

When one cell does not meet the required capacity need in the building, a multi-cell strategy (Figure 5.4b)) for indoors should be considered. Therefore to ensure mobility inside the building, the overlapping of the cells must be planned to provide continuous coverage with handover areas. This of course results in other cell interference, which must be taken into account when planning antenna placements.

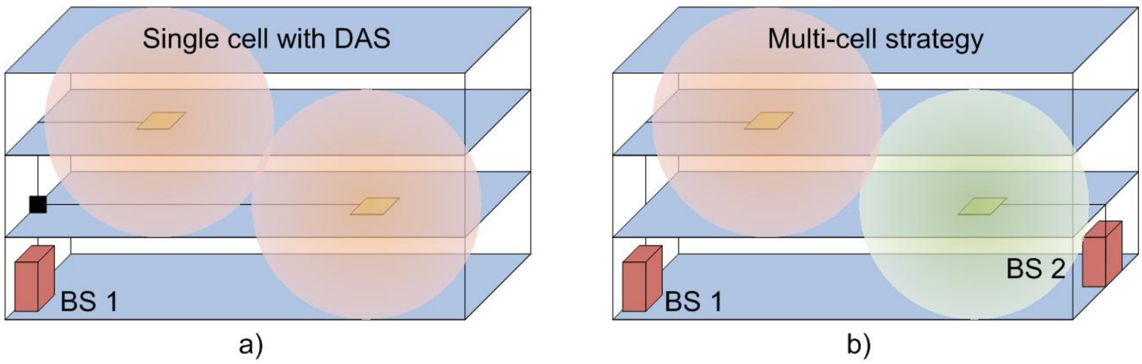

Figure 5.4. *Principle of a) single and b) multi cell strategy to provide indoor coverage.*

The initial antenna placement planning is important for the evolution of indoor networks [2]. As there might not be any exact numbers about current or future capacity requirements, the network can be planned by the old ‘coverage first, capacity later’ approach. As for the first solution, repeaters can be used to provide initial capacity for the building, and later on upgraded by the dedicated indoor system to meet current demand.

5.2.2. Indoor coverage configuration types

For dedicated indoor systems, DAS is the main strategy for planning indoor coverage and it can be classified as passive or active. Passive DAS distributes the same RF signal from the base station to several antennas with passive components like splitters and tappers. As mentioned, it is limited by the higher losses of increasing antenna line components and should be taken into account in link budget. Active DAS utilizes internal calibrating signals and amplifiers (like hubs for Ethernet) to compensate antenna line losses, where the distance between antennas and base station does not affect the antenna performance. Because of simplicity and cheaper components, passive DAS is generally used.

Base stations with relatively small transmit powers are called pico or femto cells regarding to their sizes. Exact definition when the system can be regarded as pico or femto cell, have not been standardized. Whereas picocells provide coverage for the entire floor, femto cells are planned to be even user-deployable for example to one office room. Pico and femto cell systems can be compared to Wi-Fi access points with the in-built antenna which can be mounted on indoor wall like antennas.

When the cost of the dedicated indoor system does not meet the demand for current capacity, the outdoor-to-indoor repeater system may be considered. With the repeaters, the received macro cell signal is amplified, transferred and distributed by the single antenna or DAS, inside the building [2]. By this, the outdoor cell signal does not need to penetrate building and the power budget demands for building penetration can be ignored. Therefore indoor users at the cell edge can be provided with adequate service coverage without excessive cost and influence on outdoor cell planning.

5.3. Indoor HSPA link budget

Link budget and propagation models are the main tools for radio network planning. By these tools, through the maximum allowed path loss, the maximum cell distance can be calculated. This information helps planners to decide the exact locations of antennas and base station equipment. The main problem for calculating the maximum cell distance is that there is no reliable propagation prediction for indoors. As there are several empirical models available to use, like COST-231 multi-wall model and Ericsson model, the accuracy of these can be very poor due to very different building types.

Ray tracing is also one method to provide accurate radio channel characteristics for different environments. Especially for indoors, it provides high level of detail for the characterization of multipath channels. Ray tracing utilizes geometrical optics, where propagation of discrete ray from transmitter to receiver is simulated. This technique demands though high computing, very accurate layout of the environment and its properties like material types, location of different objects et cetera.

In the link budget, all the equipment, from both transmitting and receiving end, and the general radio interface parameters are taken into account when evaluating the maximum path losses for both uplink and downlink. As the WCDMA coverage is affected by the load, also the service profile of the system must be considered. Depending on the service profile and planned parameters, the cell range can be uplink or downlink limited. The example HSDPA link budget and the main parts of it with calculations are presented in Table 5.1. The following sections present the different parts of link budget and explain the origin of different values used in link budget.

Table 5.1. *Example indoor network link budget for Release 5 HSPA with equations. Different parameters and calculations collected from [3;17;18;20].*

	Parameter	Unit	Value		
	General parameters		**Uplink**	**Downlink**	
	Chip rate	cps	3.84E+06		
A	Noise bandwidth (α=1.22)	Hz	4.68E+06		
B	Temperature	K	293		
C	Boltzmann's constant	J/K	1.38E-23		
	Frequency	Mhz	1950	2150	
	Service profile	**Unit**	**Uplink**	**Downlink**	
D	Load	%	50	50	
	Number of HS-DSCH codes			15	
	Required bit rate (physical layer)	kbps	240	4000	
E	Spreading Factor		8	16	
	Receiving end		**Node B**	**Mobile**	
F	Noise figure	dB	4	8	
G	Noise power	dBm	-103.2	-99.2	$10log_{10}\left(\frac{ABC}{0.001}\right) + F$
H	Interference margin	dB	3.0	3.0	$10log_{10}\left(\frac{100}{100 - D}\right)$
I	**Total interference level**	**dBm**	**-100.2**	**-96.2**	$G + H$
J	Required Eb/N0 (UL) / SIR (DL)	dB	4	17	
K	Processing Gain	dB	9.0	12.0	$10log_{10}E$
L	Antenna diversity gain	dB	0	0	
M	SHO diversity gain	dB	1	0	
N	Power control headroom	dB	3	0	
O	**Required C/I**	**dB**	**-3.0**	**5.0**	$J - K - L - M + N$
P	**Receiver sensitivity**	**dBm**	**-103.3**	**-91.3**	$I + O$
Q	Receiver antenna gain	dBi	7	0	
R	LNA gain	dB	0	0	
S	DAS antenna line losses	dB	45	0	
T	**Required signal power**	**dBm**	**-65.3**	**-91.3**	$P - Q - R + S$
	Transmitting end		**Mobile**	**Node B**	
U	Indoor Node B total power	W		0.8	
V	Indoor Node B total power	dBm		29.0	$10log_{10}\left(\frac{U}{0.001}\right)$
W	HS-DSCH Power	W	0.13	0.8	
X	HS-DSCH Power	dBm	24.0	29.0	$10log_{10}\left(\frac{W}{0.001}\right)$
Y	Antenna gain	dBi	0	2	
Z	DAS antenna line losses	dB	0	45	
ZZ	**Peak EIRP**	**dBm**	**24.0**	**-14.0**	$X + Y - Z$
	Maximum path loss	**dB**	**89.3**	**77.3**	$ZZ - T$

5.3.1. General parameters and service profiles

The general parameters introduce the fundamental parameters of the radio interface like chip rate and operating frequencies which are the same for every configuration. The service profile defines the network load limits on the air interface before load and admission control starts to constrain current and new connections. To provide accurate plans for the network, link budgets should be calculated separately for every service profiles available, from where the worst case scenarios (the lowest maximum path loss) can be obtained.

Because of the link adaptation and shared channel concept of the HSDPA, the performance evaluation for it is slightly different from R99 DCHs received-energy-per-user-bit-to-noise ratio (E_b/N_0). For HSUPA's E-DCH, E_b/N_0 is still used because of similar behavior of R99 DCH. The E_b/N_0 corresponds to a certain BLER for a given data rate where the only adaptation parameter is spreading gain. [18] Therefore it is not sensible parameter to measure HSDPA bit rate performance, because HSDPA can change modulation, coding rate and the amount of HS-PDSCH codes for each TTI with constant SF of 16. Signal-to-interference ratio (SIR) is more appropriate evaluator for HSDPA performance, because it takes account received power from every received HS-PDSCH ($P_{HS-DSCH}$) and the interference from own (P_{own}) and other cells (P_{other}) with the addition of received noise power (P_{noise}). In Equation 5.1 α denotes to the code orthogonality factor in downlink [18].

$$SIR = SF_{16} \frac{P_{HS-DSCH}}{(1-\alpha)P_{own} + P_{other} + P_{noise}} \tag{5.1}$$

One of the main issues in service profile is to define the load factor for the current link budget. As the WCDMA interface is interference limited, some estimation about interference generated from load must be done. The interference margin (IM), in the receiving end, is derived by the Equation 5.2, where η denotes to the load factor percentage [17].

$$IM = -10log_{10}(\frac{100 - \eta}{100\,\%}) \tag{5.2}$$

More about load factor calculations for HSDPA and HSUPA can be found in [17;20;21].

5.3.2. Receiving and transmitting ends

For accurate link budget, also the operating equipment with some assumptions and specifications about network behavior must be taken into account. UE, Node B and antenna equipment (with antenna line) losses and gains are mostly vendor specific and general values (at least for UE part) should be used. For example, the noise figure of the equipment can be estimated, measured or by using literature values.

Required E_b/N_0 and SIR values are the result of simulations for desired QoS. The quality of the service can be defined and then simulated to acquire required performance indicator for the current service. One quality meter is BLER. For example, for 15 HS-DSCH codes with the bit rate of 4 Mbps and 10 % BLER the required SIR is 17 dB [18].

Some values of link budget can be calculated based on values given in general parameters and service profile. Noise power represents the constant thermal noise in the system and can be calculated as presented in the example power budget. As discussed in Section 3.3.2 processing gain can be calculated from the used service profile SF. HSDPA, for example, with fixed SF of 16 gives 12 dB processing gain.

Antenna diversity gain and SHO diversity gain values are mainly estimates from literature or system simulations, due to its statistical nature. Multiple antenna reception scheme is mainly utilized in macro cellular networks, where the effect of diversity gain is more cost-efficient, rather than indoors. Research about HSUPA antenna diversity gain in indoors can be found in [22]. The soft handover gain (or macro diversity gain) can only be used for HSUPA because the HSDPA does not support soft handover, as discussed in Section 4.2.5. Power control headroom (or fast fading margin) is a planning margin for technologies which utilize closed loop fast power control, and thus only HSUPA and R99 is affected by this. It is taken into account, especially for slow-moving mobiles which are able to compensate the fast fading with typical margin values of 2.0 – 5.0 dB [20].

Transmit power of UE is mostly vendor specific but some approximation specification values [16], like +21 dB can be used. Node B transmission (TX) power is usually adjustable, according to the desired cell size. For path loss calculations, the Primary Common Control Channel (P-CPICH) is generally used. Typical P-CPICH transmit power values for indoor networks lay around +27 dBm and less. Even +15 dBm can be used in femto cells. For services like HSDPA, more reasonable is to estimate transmit channel power and use that for path loss calculations. The amount of power allocated for transport channel (HS-DSCH for HSDPA) can vary according to the settings in Node B and in the example 80 % allocation is used. After calculation of Effective Isotropic Radiated Power (EIRP) and required signal power, the maximum path loss can be then derived and the estimation of cell range can be calculated based on the propagation models.

5.4. Performance indicators

In the last planning phase, the verification measurements must be done after the network launch. Several indicators, for example about network coverage and performance are evaluated by commonly used performance indicators. These indicators provide a good picture about network behavior and sufficient information for later optimizing process.

For air interface, different performance indicators can be divided into signal quality and cell capacity indicators. One of the signal quality indicators can be evaluated from downlink P-CPICH received power level at UE. This measurement is called Received Signal Code Power (RSCP) and it is mainly used as coverage indicator for the cell. Received Signal Strength Indicator (RSSI) measures the total wideband received signal power with interferences at UE. It is used along with RSCP to calculate coverage quality indicator E_c/N_0 with the Equation (5.3) which expresses the interference level in the current cell.

$$\frac{E_c}{N_0} = \frac{RSCP_{P-CPICH}}{RSSI} \tag{5.3}$$

Signal quality can also be measured by other indicators than E_c/N_0. CQI is channel quality indicator which is, in addition to the signal quality, affected by the capabilities of UE, like transmit power and maximum data rate properties. It can be used to evaluate transport block size from specifications and to compare different measurements done by the same type of UEs. But it should be taken into consideration that even the same type of UEs might have slightly different components or firmware versions installed which might affect the CQI calculations done by UE.

As discussed earlier, the HSDPA performance is mainly affected by the SIR. Simulations done in [18] show the dependence between SIR and HSDPA performance and thus it is reasonable to measure SIR to get relevant information about conditions affecting HSDPA performance.

To evaluate performance of mobile and cell data throughput, the MAC-layer throughput is used. As MAC-layer has about 5 % overhead from the physical layer, the MAC-layer throughput provides quite accurate estimate of the physical layer performance. In addition to throughput, BLER value indicates the performance of link adaption process. High BLER value indicates poor performance of link adaptation, due to the too optimistic transport block size selection in relation to the channel quality. [17;18]

6. MEASUREMENT CAMPAIGN

The purpose of the measurements was to provide a verification to earlier studies [23;24] about differences between multiple picocells and DAS indoor network configurations for HSPA. The motivation of this Thesis measurement campaign is presented in next section and in addition, the measurement setup, location and configurations are presented in this chapter.

6.1. Preliminary reference measurements

Earlier studies about different configurations for indoor HSPA network presented that coverage from multiple picocells and DAS was superior compared to radiating cable antenna configuration. By this the radiating cable configuration was abandoned and the network performance measurements were conducted for multiple picocell and DAS configurations in [24]. Results in Table 6.1 verified the more coverage/capacity dependent planning for HSDPA.

Table 6.1. *HSDPA measurement results from [24].*

Antenna configuration	1 pico cell	2 antennas DAS	3 antennas DAS	4 antennas DAS	2 pico cells
RSCP (dBm)	-86.04	-82.41	-84.17	-82.68	-79.43
E_c/N_0 (dB)	-7.46	-7.92	-8.17	-7.96	-7.99
CQI	15.70	15.89	15.81	16.37	16.02
MAC BLER	6.62	6.06	6.60	6.06	7.03
MAC throughput (kbps)	1403.00	1397.40	1468.80	1502.00	1302.90

According to the results, the relation of good coverage and HSDPA performance plays important role in indoor network planning. By keeping the signal level above the threshold level, with smooth coverage, the HSDPA performance increases and thus the measurements with DAS configuration provides better results. Even though 2 picocells configuration has higher average RSCP (higher EIRP) than any DAS configuration, the throughput is still the lowest in 2 picocells configuration. Main issue for poor multiple picocell configuration performance is the handover functionality of HSDPA.

The measurements in [24] were performed by single category 12 HSDPA UE [25] with maximum physical layer throughput of 1.8 Mbps in open corridor environment, and therefore the question about the impact of different environments and loaded network with more capable UEs remains. In addition, the HSUPA performance should be also measured to provide more information about the effect of different configurations to the uplink technology as well.

6.2. Measurement setup

6.2.1. Measurement environment

Measurements were performed in a modern office building in Tampere, (Department of Communications Engineering, Tampere University of Technology). Open and dense corridors were chosen to provide measurement verification with different environments. The open corridor environment (the maximum length of 100 m and width 10 m) represents concentrated antenna placement with omnidirectional antennas. Antennas were placed by 20 m separation and the measurement routes were just below antennas as illustrated in Figure 6.1. The narrower dense corridor (2.5 m wide) represents practical implementation with directional antennas at the end of each side corridor. As illustrated in Figure 6.2, the isolation of antenna coverage areas are better, than in the open corridor environment.

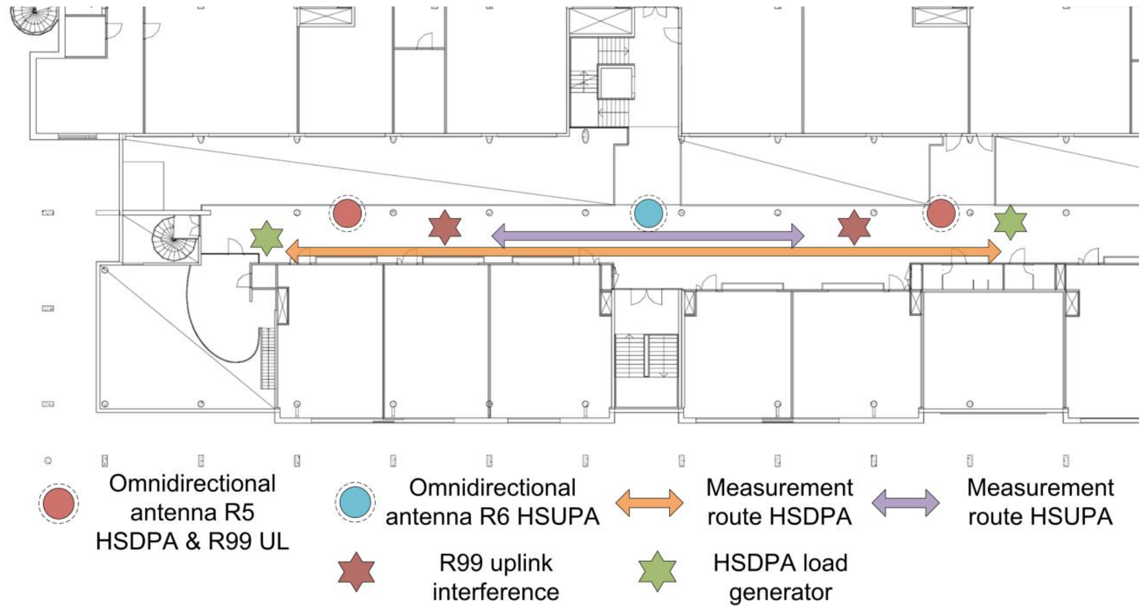

Figure 6.1. *Layout of the open corridor environment with antenna placements, measurement routes and load generators.*

To prevent handovers between HSUPA and R99 cells in HSUPA measurements, the measurement routes were planned to the dominance area of HSUPA cell. This was achieved by preparative measurements inside HSUPA cell's coverage area. Handover areas, between HSUPA and R99 cells, were discovered and measurement routes were planned between these areas. By this, measurement cases were authentic as possible, even though it was possible to lock measurement equipment only to the HSUPA cell.

6.2.2. Measurement system

The network was built from three different base stations which were connected to the same RNC. One of the Node Bs supports Release 6 HSPA and the rest of Node Bs support only Release 5 HSDPA. Summary of Node Bs is presented in Table 6.2.

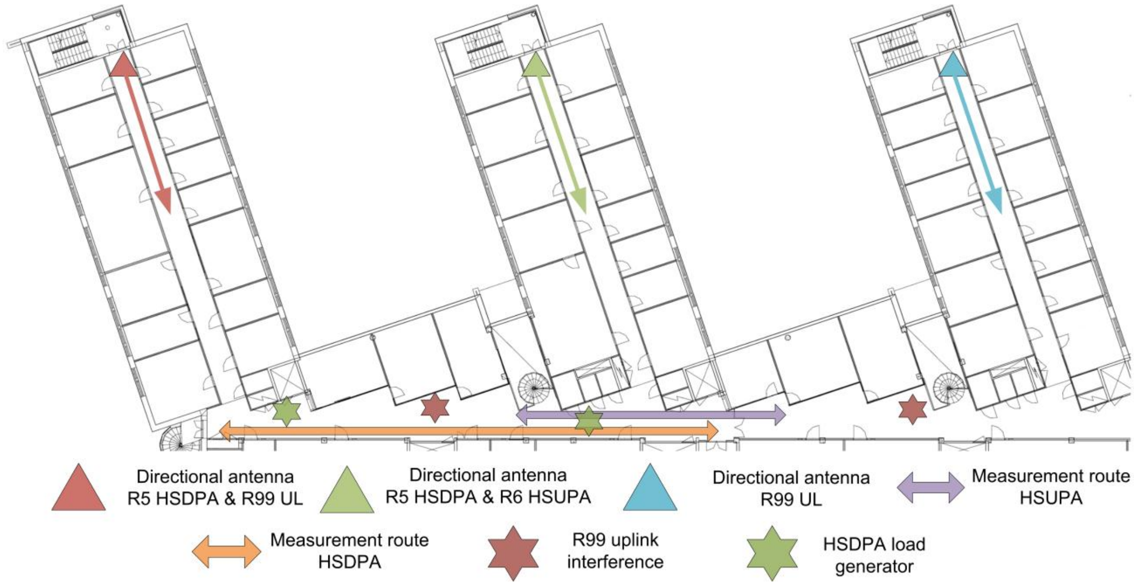

Figure 6.2. *Layout of the dense corridor environment with antenna placements, measurement routes and load generators.*

The antenna line between Node Bs and antennas consisted of ½" feeder cables, 2- and 3-way splitters and various amount of connectors and attenuators. Antenna lines were built so that the antenna line losses, between pico and DAS configuration, had the difference only from the splitters: 3 dB from 2-way splitter and 5 dB from 3-way splitter. By this, measurements were comparable because either of configurations could not get the leverage from higher EIRPs. The best way to achieve this was to attach splitters to Node B. The antennas used for measurement were omni- and directional antennas which gains are 2 dBi and 7 dBi, respectively. The block diagram of antenna line configurations for HSDPA and HSUPA in open corridor with EIRPs are shown in Figure 6.3 and 6.4. EIRPs for every configuration are presented in Table 6.3.

Table 6.2. *Capabilities of Node Bs used in measurements with transmit powers.*

	HSDPA	HSUPA	Max. TX power	P-CPICH power	I_{ub} interface
Node B #1	X	X	46 dBm	30 dBm	Fibre
Node B #2	X		39 dBm	29 dBm	3 x E1
Node B #3	X		39 dBm	29 dBm	3 x E1

As HSDPA pushes air interface data speeds higher, the requirement also for I_{ub} interface transport capacity raises. The Node Bs, with the only capability of Release 5 HSDPA, were connected to the RNC only by 3 E1 lines *(3 x 1920 kbps=5760 kbps,* *including overhead up to 35 %)* [20] connections and therefore the case became I_{ub} interface limited scenario. As the focus of the measurement was to provide information about the air interface performance, the antenna lines were attenuated so that the total HSDPA throughput per cell would be under I_{ub} limitations.

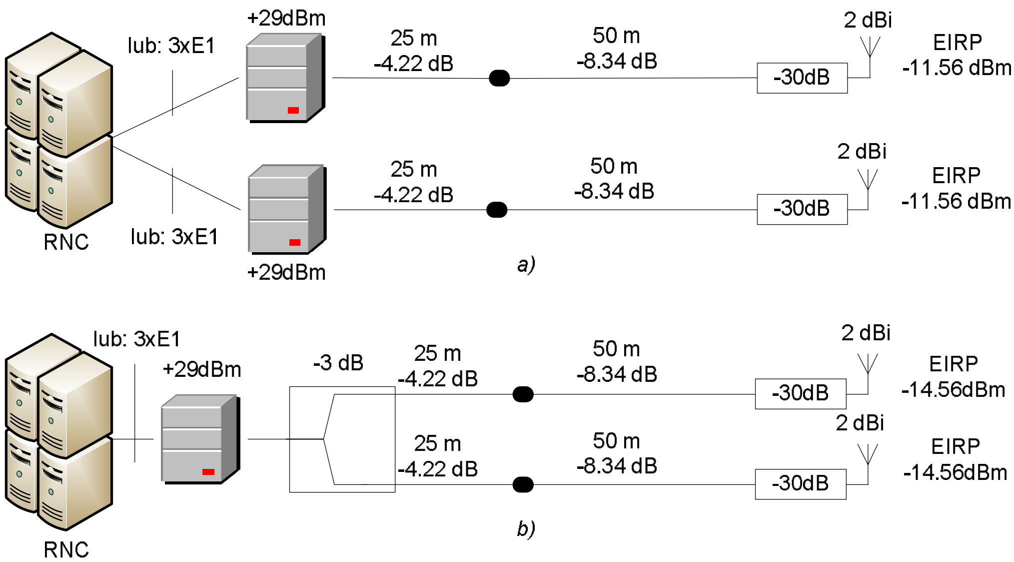

Figure 6.3. *Block diagram of antenna line configuration for a) 2 picocells and b) 2 antennas DAS HSDPA configurations in open corridor environment.*

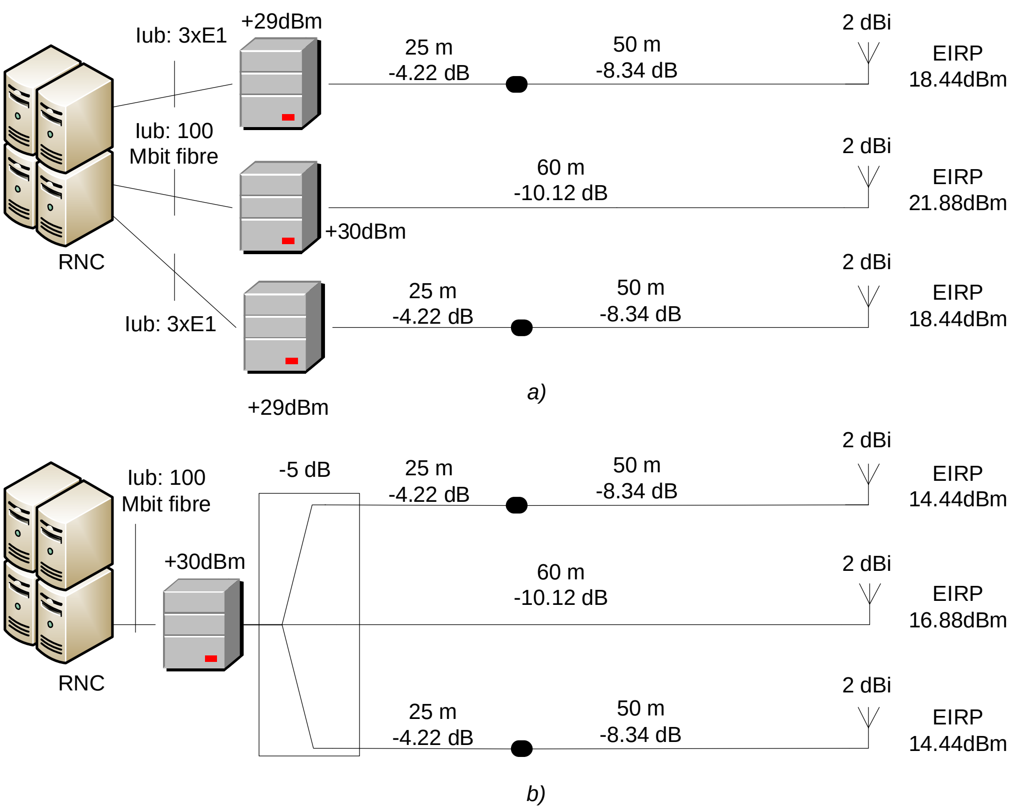

Figure 6.4. *Block diagram of antenna line configuration for a) 3 picocells and b) 3 antennas DAS HSUPA configurations in open corridor environment.*

Measurement equipment consisted of three category 9/5 (HSDPA/HSUPA) mobiles with theoretical maximum physical layer throughput of 10.1/2 Mbps. Also category 8/5 data card connected to a laptop with theoretical maximum physical layer throughput of 7.2/2 Mbps was used [25]. Two of category 9/5 mobiles were used for actual measurements and rest were used as stationary load generators.

Table 6.3. *Calculated EIRP values for different measurement configurations.*

All Measurement Configurations	Open corridor (dB)	Dense corridor (dB)
2 antennas DAS	-11.56	-11.44
HSDPA low/high load	-11.56	-11.44
2 picocells	-14.56	-8.44
HSDPA low/high load	-14.56	-8.44
3 antennas DAS	14.44	-13.44
HSUPA	16.88	-10.44
	14.44	-19.34
3 picocells	18.44	-8.44
HSUPA	21.88	-5.44
	18.44	-14.34

6.3. Measurements

In total of six different cases were performed for both environment types: 4 HSDPA and 2 HSUPA cases. For HSDPA two antennas were used for both DAS and multiple picocell cases. Two HSDPA measurements with the same measurement route were performed for both configurations: with low and high load. In the high loaded case, stationary mobiles generated load by Hypertext Transfer Protocol (HTTP) file transfer at both ends of the measurement route. Rest of the mobiles was man-carried at the height of 1.3 metres, with HTTP file transfer, between antenna coverage areas as illustrated in Figure 6.1. In the low loaded case there were no stationary load generators and only two moving mobiles were used with the same measurement setups as in high loaded cases.

All HSUPA measurements were performed with load, to measure effect of the interference into the HSUPA performance. As two of the base stations did not support HSUPA, the load (UL interference) was generated by two R99 data streams at both ends of the measurement route to maximize HSUPA cell's interference level. Rest of the HSUPA mobiles, with FTP file transfer, moved in the dominance area of HSUPA cell. In multiple picocell case the HSUPA cell was placed in the middle and other R99 cells next to it as presented in Figure 6.1. In DAS case, HSUPA Node B was used.

7. RESULTS

After the measurement campaign, the results were gathered and combined. In every measurement, data from moving mobiles is considered, except the total network throughput (TP) in the high loaded network case for HSDPA, where also the TP of the stationary mobiles is summed up. Measurement equipment provides data with different sized averaging windows for different values. Before the first analysis the data is averaged over the whole measurement route for moving mobiles.

In this chapter, different cases are divided by the environment and radio technology. The averaged results are analyzed according to the environment and configuration in the next sections and deeper analysis of the impact of high load is covered in Section 7.3. Error analysis of the measurements is covered in the last section of this chapter. All measured throughput graphs with cumulative distribution functions can be found from the Appendix A and the RSCP/SIR/TB comparisons from high loaded cases are shown in the Appendix B.

7.1. Open corridor measurements

Averaged results from open corridor environment measurements in Tables 7.1 and 7.2 verify measurements in [24] about better RSCP values for the picocell configuration. The RSCP values are about 3-5 dB better in the picocell configuration than in DAS which is due to the higher EIRP values for each antenna, as there are 2-way (-3 dB) or 3-way (-5 dB) splitters in DAS configuration.

7.1.1. HSDPA

The results of open corridor measurements for HSDPA are presented in Table 7.1. As mentioned, the pico configuration has higher RSCP values than DAS which also affects the other indicators. Averaged signal quality indicators like E_c/N_0 and SIR indicate slightly better radio conditions for pico configuration but as the difference of these two are less than 1 dB, the radio conditions can be treated as equal.

Although both configurations have almost equal values for signal strength and quality indicators, the network throughput is about 450 kbps (12 %) better in DAS configuration with low load. This verifies the measurements in [24] and can be explained by drops during the cell changes. The drop in network throughput is clearly visible during the cell change which can be seen in Figure 7.1. These drops on the measurement route decrease the overall performance of the pico configuration. In addition to the handovers, the pico configuration has slightly higher overall interference levels between cells which degrades the signal quality and thus reduces the throughput. These two phenomena can be considered as major disadvantages of pico configuration.

Table 7.1. *Averaged results from moving mobiles in open corridor environment.*

HSDPA	Open corridor	DAS configuration	Pico configuration
RSCP (dBm)	Low load	-83.2	-81.6
	High load	-83.3	-81.5
E_c/N_0 **(dB)**	Low load	-8.8	-8.5
	High load	-11.2	-8.8
SIR (dB)	Low load	4.4	4.9
	High load	2.0	4.0
BLER (%)	Low load	15.4	14.1
	High load	18.4	16.6
CQI	Low load	19.4	20.5
	High load	15.2	18.3
Network TP (kbps) All 4 UEs	Low load	3695	3251
	High load	4730	5830

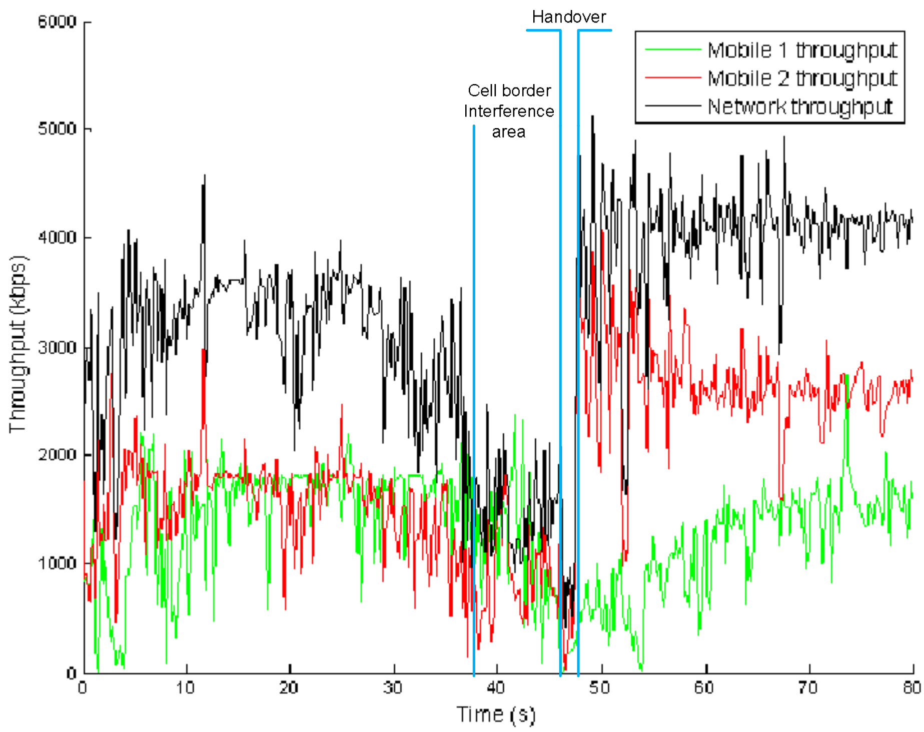

Figure 7.1. *Example of mobiles and network TP from pico configuration measurement with low load. Gap illustrates interference area and HHO during the cell change.*

Throughput CDF from pico and DAS configuration (see Figure 7.2) confirms the superiority of DAS configuration in low loaded network. In overall, DAS achieves higher TP values than pico configuration and the biggest difference can be seen from TP values under 4.2 Mbps. The DAS configuration though could achieve even higher network TP without I_{ub} interface limitation as there are quite low amount of values under 4 Mbps. TP values over 90 % distribution in Figure 7.2 are from the bursts when

Node B empties its buffer for scheduled mobile with good channel conditions after silent period caused by poor channel conditions. Therefore DAS can be considered as a better solution for low loaded areas.

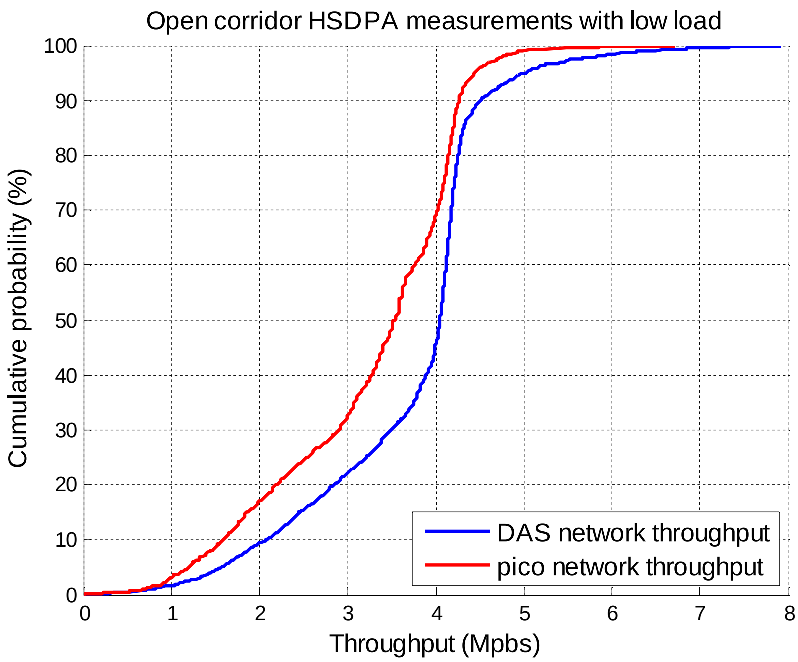

Figure 7.2. *Throughput CDF of pico and DAS configuration measurement with low load.*

In the high loaded case (see Table 7.1), all values indicate the superiority of pico configuration. The results show that the throughput of pico configuration is about 23 % better when increasing the network load. Therefore the disadvantages of pico configuration, like higher inter-cell interference than in low load case, do not affect the network TP so much when the load is distributed evenly. More about the impact of high load on the system performance is analyzed in Section 7.3 from the radio network planning point of view.

7.1.2. HSUPA

Results from HSUPA measurements in Table 7.2 indicate lower TX power and higher RSCP when utilizing the pico configuration. The difference between the DAS and the pico configuration TX power and RSCP values are about the same as 5 dB attenuation from the 3-way splitter. Whereas the TX power between two configurations is self-explanatory, the network TP needs deeper analysis.

Table 7.2. *Averaged results from HSUPA mobiles in open corridor environment.*

HSUPA	DAS configuration	Pico configuration
RSCP (dBm)	-55.5	-51.9
TX Power (dBm)	-24.7	-29.6
Network TP (kbps)	1370	919

Quite big throughput difference for the pico configuration can be explained by the UL interference limited scenario. There are no clear indicators from measurements which can show rising UL interference, as there was no way to get data from base stations, however the UL interference limitation can be seen from the mobiles' TX power and TP graphs as illustrated in Figure 7.3.

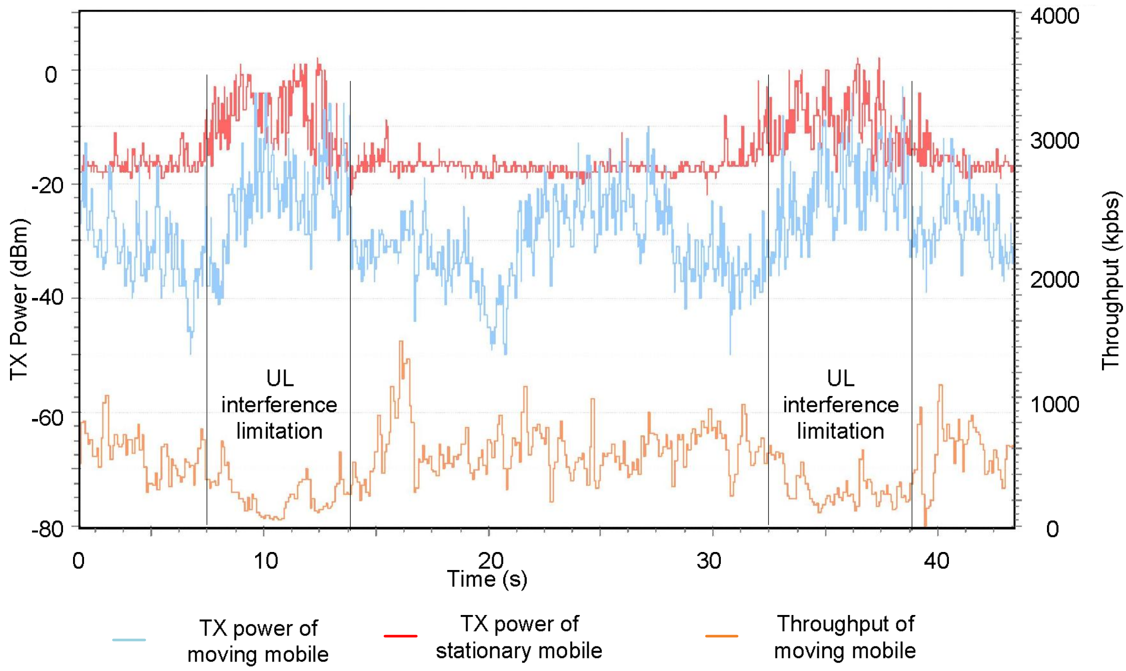

Figure 7.3. *UL interference limited scenario illustration by TX powers of moving and stationary mobiles. In addition, the effect of UL interference limitation to the mobile's TP is visible.*

When moving mobiles arrive near the cell border, they increase their TX power to combat against increasing path loss. This also increases own-to-other cell UL interference, which can be seen from the increasing TX power of the stationary mobile, which again adds more interference to the middle cell. Because the mobiles' TX powers are still in the dynamic area, it can be presumed, that the UL interference limitation from Node B stops granting more TX power. Instead of it, Node B reduces the UL interference by lowering mobiles' throughput. Because of this behavior the DAS configuration can be kept as a better solution for open corridor environment, where the cells are not so well isolated and the uplink interference is the limiting factor for the HSUPA performance.

7.2. Dense corridor measurements

Results gathered from dense corridor environment differ from preliminary reference measurements due to the different environment. Also differences between DAS and pico measurements are more distinct when the cell isolation is better.

Impact from the different environments and measurement configurations on the RSCP can be seen from Figure 7.4. In the open corridor case there was a high probability for LOS environment for the whole measurement route. Difference to the open corridor environment can be seen from overall lower RSCP values. In dense corridor, there was a high probability for NLOS environment (RSCP < - 80 dBm) on the measurement route, only around the highest RSCP peaks (over -80 dBm) there was a moderate probability for LOS.

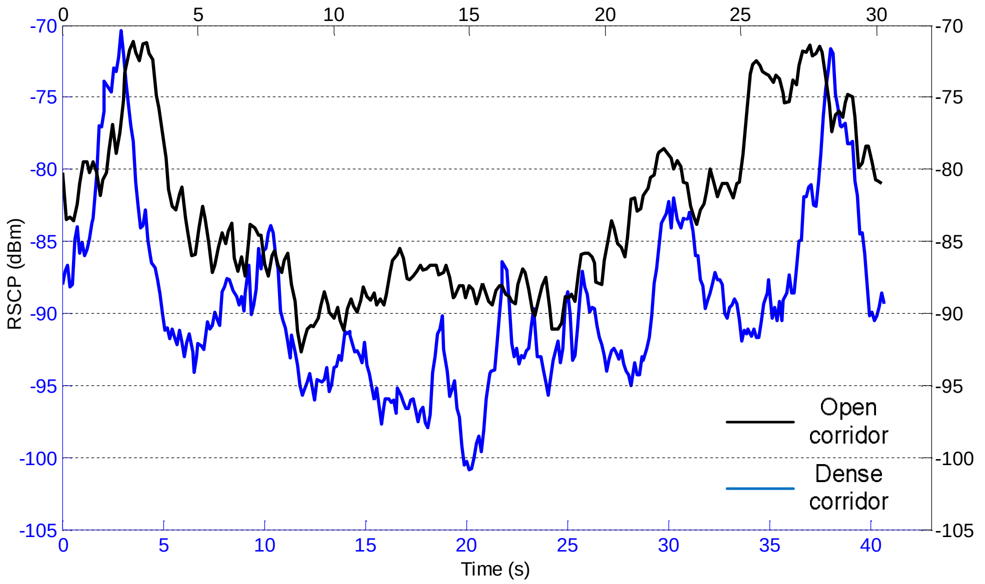

Figure 7.4. *HSDPA measurement route from open and dense corridor with DAS configuration.*

7.2.1. HSDPA

As presented in Table 7.3. for the low load case, the DAS outperforms the pico configuration by 1 Mbps (38 %) better network throughput. However, the average RSCP is the same for both configurations which gives small leverage for DAS performance. It should have about 3 dB lower RSCP than pico configuration, like in open corridor HSDPA measurements. But as the throughput difference is so high it can be considered that the RSCP difference does not affect the conclusion about configuration differences. For example CQI and SIR values indicate much better performance for DAS than pico configuration. Reasons behind better performance for DAS are the same as in the open corridor case: smoother cell coverage without handovers and other-to-own cell interference. Therefore DAS can be considered as a good choice also in low load areas where the cell isolation is better.

In the high loaded case, conclusions between two configurations cannot be made just by average network throughput. SIR and CQI values are higher in DAS configuration but the network TP of pico configuration states about 1.7 Mbps better TP than DAS configuration. As discussed in Section 6.2.2 the DAS configuration might be I_{ub} interface limited and thus, speculations about network TP should be made due to over 4 Mbps network TP in DAS configuration.

Table 7.3. *Averaged results from moving mobiles in dense corridor environment.*

HSDPA	Dense corridor	DAS configuration	Pico configuration
RSCP (dBm)	Low load	-89.8	-90.4
	High load	-90.5	-90.3
E_c/N_0 (dB)	Low load	-6.6	-8.8
	High load	-7.8	-6.6
SIR (dB)	Low load	6.0	4.7
	High load	5.2	3.6
BLER (%)	Low load	15.4	14.4
	High load	14.6	16.4
CQI	Low load	23.3	19.4
	High load	23.3	16.3
Network TP (kbps) All 4 UEs	Low load	4034	2948
	High load	4139	5869

For the pico configuration, average SIR values range from 3.5 dB to 4.7 dB and the network TP from 2.9 Mbps to 5.9 Mbps for low and high loaded case, respectively. As HSDPA TP is bind to the SIR [18], the 4 Mbps TP and 5.2-6.0 dB SIR indicates that DAS configuration could achieve higher TP without I_{ub} interface limitations. As illustrated in Figure 7.5, the SIR distribution in DAS configuration is much smoother than for pico configuration. In pico configuration, SIR values in Figure 7.5 and 7.6 from 0 to 7 dBs are probable in the middle of measurement route due to the other-to-own cell interference and values above 8 dBs are mainly from the LOS part of the measurements. These values from LOS part in pico configuration measurement are higher than in DAS because of higher EIRPs. This indicates that in areas with good cell isolation, DAS configuration could provide better SIR quality and thus higher TP. In addition, average reported CQI values of 23 indicate the ability to achieve 9719 bit Transport-block size for category 10 UEs [26], which equals 4.86 Mbps TP per mobile. This can be compared to average CQI values of 16 from pico configuration which equals to 1.78 Mbps TP per mobile.

By previous analysis the disadvantages of pico configuration seems to decrease the performance more in dense than in open corridor environment so that the DAS configuration achieves higher overall TP. This indicates that DAS configuration should be considered also in the high loaded areas where the cell isolation is better. Deeper analysis of higher load cases is discussed in Section 7.3 where all the relative signal parameters and limitations are taken into consideration when comparing different cases from the radio network planning point of view.

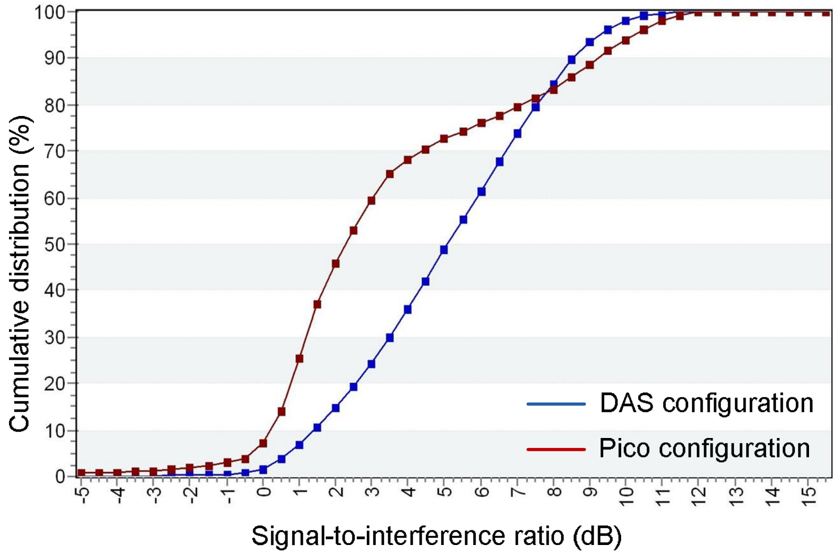

Figure 7.5. *Cumulative distribution of SIR in DAS and pico configuration with high load.*

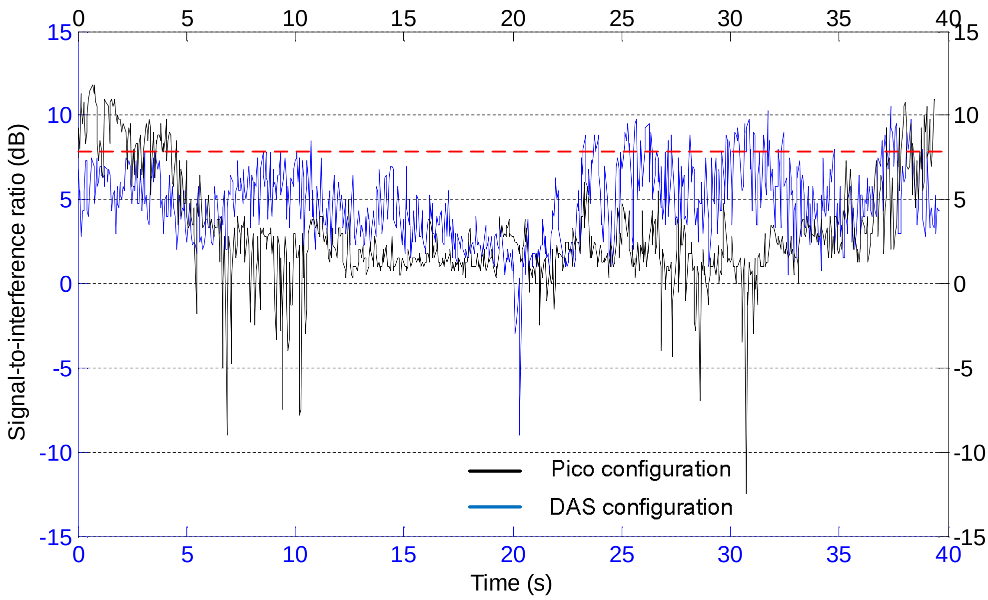

Figure 7.6. *Example from the high loaded dense corridor SIR measurements for pico and DAS configuration with 8 dB reference line (red).*

7.2.2. HSUPA

Table 7.4 presents the averaged HSUPA results gathered from the dense corridor measurements. RSCP and TX power differences between DAS and pico configurations are about 5 dB as expected because of the 3-way splitter. Even though the EIRPs were much higher, the RSCP values were lower than in open corridor cases because the measurement route had more NLOS and the distance to the antennas was also higher. Therefore it is expected that also network TP would be lower or almost equal as in the open corridor case. However, in dense corridor case the network TP is about 0.5-0.8 Mbps better than in open corridor case so deeper analysis on the WCDMA system behavior should be done.

Table 7.4. *Averaged results from HSUPA mobiles in dense corridor environment.*

HSUPA	DAS configuration	Pico configuration
RSCP (dBm)	-83.5	-79.0
TX Power (dBm)	-1.5	-7.4
Network TP (kbps)	1761	1699

The WCDMA system performance can be limited by lack of coverage or due to excess interference. As discussed in Section 7.1.2, the performance degradation at pico configuration in open corridor case can be explained by interference limited scenario as the interferer mobiles had much more effect on poorly isolated cells. Therefore better cell isolation and lower UL interference are the reasons behind better performance in dense corridor environment. In addition, the case could not be coverage limited scenario because the HSUPA mobiles TX power were in the dynamic area, in other words the maximum TX powers were under +21 dBm.

Odd system level behavior can be seen from DAS HSUPA measurements between open and dense corridor environments. As seen from Tables 7.2 and 7.4 the network TP is better in dense corridor even though it has worse average RSCP than in open corridor measurements. This cannot be explained by inter-cell interference as there are no other cells in DAS configuration and when analyzing different performance indicators, clear explanation about unexpected results cannot be given. However, one reason about current behavior could be better Node B’s RAKE receiver performance in dense corridor environment. In open corridor environment, there was almost all of the time LOS between UE and antennas. As discussed in Section 3.3.3, the performance of RAKE receiver is better in NLOS situation when the delay separation of multipath components is greater than 0.26 μs (or 78 m). This though cannot be verified by current measurement equipment because it was not possible to get data about power delay spread of the environment. Verification measurements, for example by WCDMA scanner could provide accurate information about this behavior, whether the current measurement should be discarded or if the environment is really affecting that much the performance of HSUPA.

7.3. Impact of high load

Previous sections covered analysis between different cases from the total network throughput point of view, by taking account every mobile in the measurement. It has to be noted however, that the true performance of different configurations can be acquired by comparing moving mobiles' performance, when the network is loaded by stationary mobiles. The reason why only moving mobiles can be analyzed is that the propagation channel of the stationary mobiles is quite static. Therefore the influence of stationary mobiles does not affect the moving mobiles' performance as the channel dependent scheduler treats moving mobiles according to the channel variations. This approach also represents more general user behavior within the high loaded network and can be used to analyze differences between configurations.

The impact of stationary mobiles on the network throughput analysis can be seen from Figure 7.7. The total network throughput in pico configuration consists more from stationary mobiles rather than in DAS configuration, where all of the mobiles share almost the same amount of capacity. In pico configuration, the greater throughput from stationary mobiles is from the periods of the measurement route when the stationary mobiles could use alone the whole capacity of single cell, when the other cell is occupied by the moving mobiles.

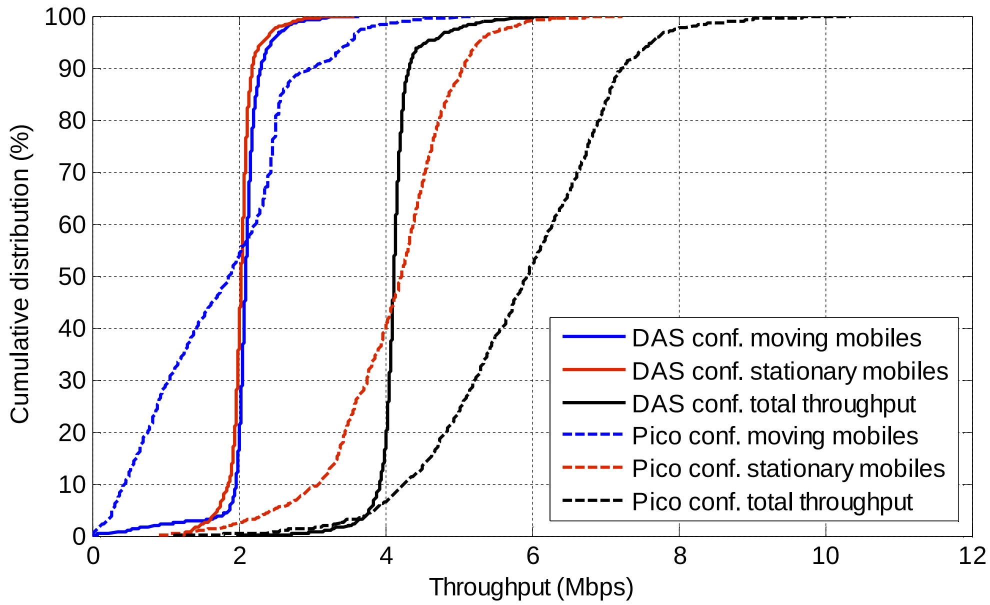

Figure 7.7. *Throughput CDFs of moving and stationary mobiles with total network throughput from high loaded dense corridor measurements.*

To evaluate configuration differences of moving mobiles, in radio network planning point of view, it is sensible to compare throughput to the cell coverage. In other words, in what kind of coverage one can get (at least) certain throughput. But as the total network throughputs are different in every configuration, in addition to the I_{ub} interface limitation, it is not reasonable to compare absolute values of moving mobiles throughputs. Also with multiple mobiles this comparison does not give accurate results as the channel dependent scheduler can affect the results. Therefore transport block size is a good estimator of configuration performance as it is not affected by channel dependent scheduler. All graphs used in following analyses can be found from Appendix B.

In Figures 7.8 and 7.9 the RSCP/TB comparison shows the relation of coverage and true throughput capability of different configurations in open and dense corridors. In open corridor environment, with RSCP values below -80 dBm the pico configuration achieves the same TB size with around 3 dB lower RSCP value than DAS configuration. With RSCP values higher than -75 dBm, DAS configuration achieves higher TB than pico configuration which may be considered as a statistical error due to the low amount of samples over that area. In dense corridor environment, DAS configuration achieves much higher TB size with the same coverage than pico configuration. But in dense corridor environment (Figure 7.9) the saturation of TB sizes in different configurations are on the different levels (7200 and 9800 bits) and therefore effect of the system should be revised with a SIR/TB relation.

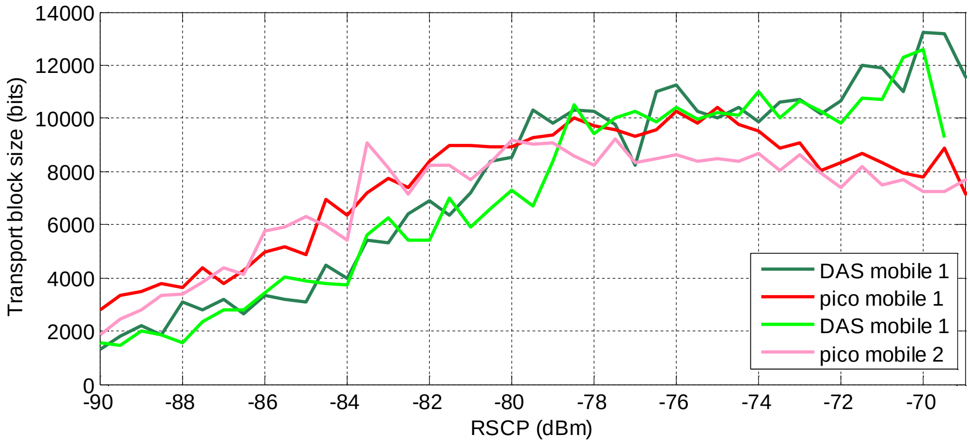

Figure 7.8. *RSCP and TB size comparison in the open corridor environment.*

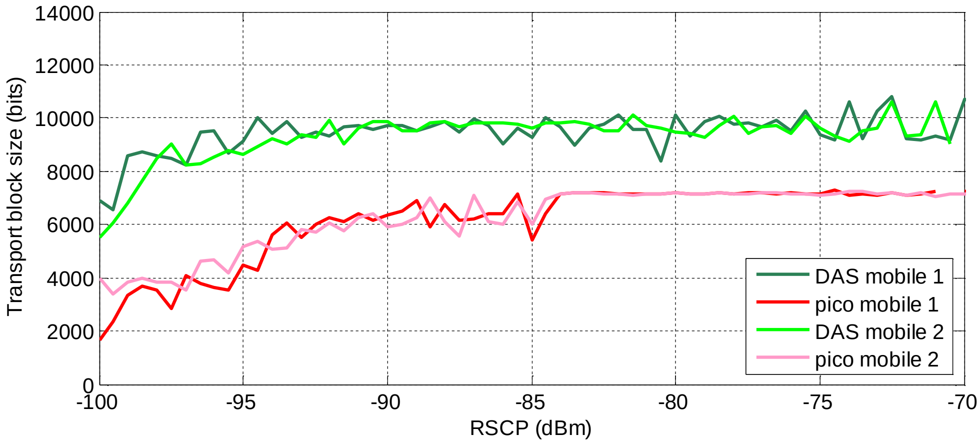

Figure 7.9. *RSCP and TB size comparison in the dense corridor environment.*

Figures 7.10 and 7.11 illustrate the SIR and TB relation to each other in the different environments. According to the theory [18], the SIR and TB relation should be equal with the same channel properties. In open corridor environment SIR/TB relation is as it should be but as seen in Figure 7.11, the TB size saturates around 7200 and 9800 bits in dense corridor environment. This behavior evidences that the system affects the results and more analysis should be done by minimizing the system influence. This can be done by analyzing the signal quality to the coverage without taking account the throughput of the system. The system influence can be seen from the scatter plots in the Appendix B by which the SIR/TB size comparison figures are done.

One interesting point can be seen from the saturation starting points of TB size in dense corridor measurements (Figures 7.9 and 7.11). For the DAS configuration saturation starts around the RSCP value of -93 dBm and 4 dB SIR and for the pico configuration same values are -85 dBm and 5 dB. This shows that the differences of configurations can be seen from the RSCP/SIR relation. It is also sensible comparison as the TP of the system is heavily dependent of the SIR.

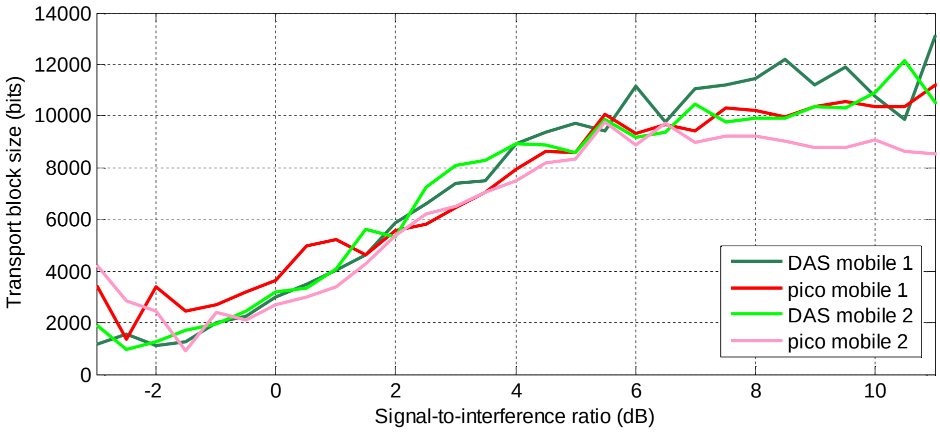

Figure 7.10. *SIR and TB size comparison in the open corridor environment.*

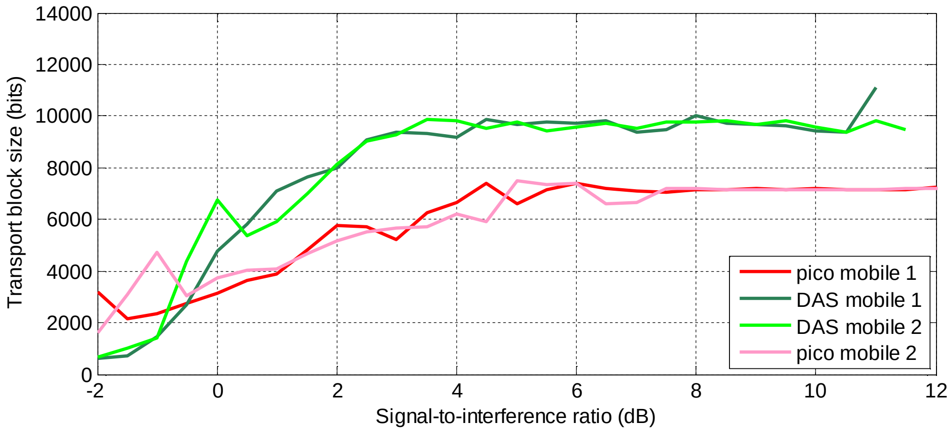

Figure 7.11. *SIR and TB size comparison in the dense corridor environment.*

In open corridor case the TB sizes for both configurations were almost the same with the same SIR and RSCP values. This can also be seen from Figure 7.12 which illustrates the signal quality comparison to the coverage. It shows that the pico configuration has around 1 dB better SIR with RSCP values lower than -80 dBm. With higher RSCP values the RSCP/SIR relation is not so reliable due to the possible statistical error from low amount of samples.

The RSCP/SIR comparison for dense corridor environment in Figure 7.13 shows quite high difference in SIR with RSCP values lower than -85 dBm to DAS configuration's advantage. The RSCP values over -84 dBm are from the LOS part of the measurement route which can be seen from the Figure 7.6 at the SIR values over 8 dB with pico configuration.

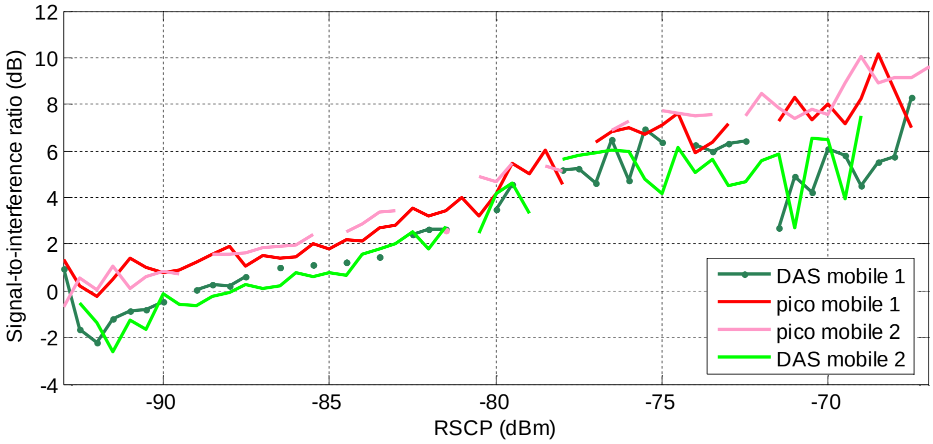

Figure 7.12. *RSCP and SIR comparison in the open corridor environment.*

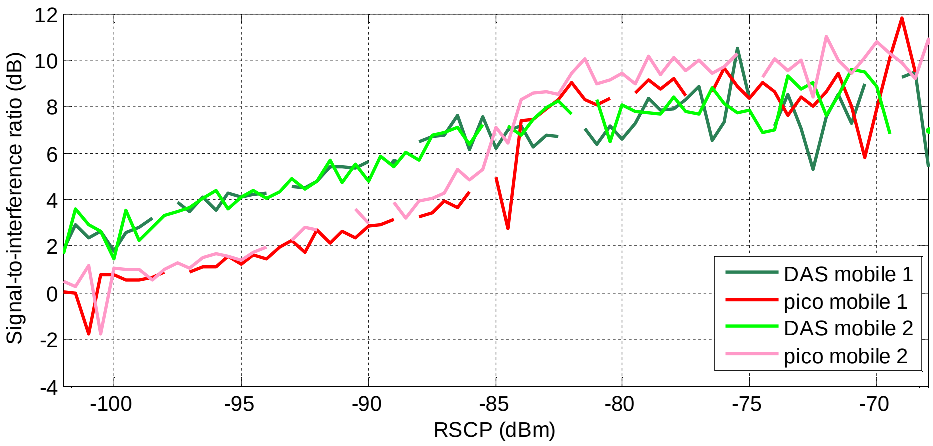

Figure 7.13. *RSCP and SIR comparison in the dense corridor environment.*

According to the measurement results in poor coverage areas of the dense corridor environment (RSCP around -100 and -90 dBm), DAS provides the same signal quality with over 7 dB lower RSCP. Therefore it seems that the DAS configuration provides better performance when the cell isolation is taken into account in the indoor network planning. In open corridor environment, the situation is other way around even though the difference is smaller. In the poor coverage area of open corridor environment with the RSCP values around -90 and -83 dBm, the pico configuration provides the same signal quality with around 3 dB lower RSCP value. In radio network planning point of view, lower RSCP indicates larger cell coverage or capacity with the same signal quality or planning margins.

As the result, it is sufficient to say that the DAS configuration provides overall the best coverage and capacity in the areas where the network load is low or moderate, despite the environment. In high loaded areas, the pico configuration should be chosen due to the higher overall capacity even though the performance is degraded by handovers and inter-cell interference. These results though should not be taken as a fundamental guideline for the indoor network planning, as the environment and antenna placement affects also greatly to the different configurations performances. Most of all, information about these configurations should be used as an evolution steps for the network after proper antenna placement.

7.4. Error analysis

Results contain some errors from the measurement and analysis phases. Every measurement is done by walking along the same measurement route so it is never exactly identical with other measurements and also the walking speed is varying. Therefore the mobiles in different measurements can spend more time in bad coverage conditions than in others. In addition, the antennas were situated in the office corridor where the movement of people, doors or even antenna may affect the signal in different measurements. These can have significant impact on average network throughput.

When evaluating the overall network throughput with multiple UEs, the time synchronization of measurement equipment is important. This is due to the dynamics of channel dependent scheduling which distributes resources by the speed of 2 ms and 10 ms TTI. This restriction though is not as strict as the measurement software averages the data over 200 ms. However the unsuccessful time synchronization of mobiles can make some error to the overall results when combining the measurement data and calculating cell throughput.

After the measurements, the data were combined and summed up to acquire overall network throughput. As the synchronization of mobiles may be incorrect, the overall network throughput is a sum of 200 ms window from every measurement. This operation also sums up the errors from the measurements and should be taken into account when analyzing the overall results.

As mentioned, the main limitation of HSDPA performance with DAS configuration was the I_{ub} interface. Every result, where the network throughput with single Node B was around 4 Mbps or more, should be considered as faulty in a sense that the real result may be higher but not less. In those cases the analysis of signal quality indicators is reasonable.

Results from RSCP/SIR/TB comparisons are quite unexpected as in the open corridor case the SIR values for pico configuration are somehow better than for DAS configuration. It is presumed that the SIR values would be other way around in DAS configuration as there are no other cells adding interference to the system. In addition, the cell isolation in open corridor is poorer than in dense corridor environment and thus, the SIR values should be much lower for pico configuration in open corridor case.

However, in dense corridor measurements the results are as expected with the RSCP values under -85 dBm. Reasons behind the unexpected results remain unexplainable and therefore additional measurements in more controllable environment should be considered.

8. CONCLUSIONS AND DISCUSSION

In this Master of Science Thesis, the differences between indoor DAS and multiple picocell configurations are measured by multiple users for HSDPA and HSUPA. The measurements were conducted in modern office building at TUT with open and dense corridor environments. In different environments also different load types were utilized to see the impact of different antenna configurations into several mobile's performance.

Table 8.1. *Summary of different measurement cases with total network throughputs.*

Network throughput (kbps)		**Open corridor**		**%**	**Dense corridor**		**%**
Case/configuration		**DAS**	**pico**		**DAS**	**pico**	
HSDPA	low load	3700	3300	12	4000	2900	38
	high load	4700	5800	23	4100	5900	44
HSUPA		1400	900	56	1800	1700	6

As shown in Table 8.1, the DAS configuration outperforms pico configuration with low loaded HSDPA cases by 12-38 % better network throughput, depending on the environment. Handovers and higher inter-cell interference in pico configuration and smoother coverage provided by DAS are the reasons for the differences. With higher load, pico configuration seems to provide about 23-44 % better network throughput performance, because of higher total capacity. In high loaded cases explicit conclusions from DAS results cannot be done, as the measurement configuration appeared to be I_{ub} interface limited for HSDPA. But it can be expected, that at least in dense corridor environment, the DAS performance could be higher when examining the signal quality indicators. As this limitation for these measurements affects the performance results, it would be reasonable to repeat measurements in the air interface limited scenario. By this, more accurate results about DAS and pico configuration differences for HSDPA could be shown and more explicit conclusion could be made.

For HSUPA, DAS configuration gives 6-56 % better results because the UL interference is shared amongst the all antennas and there is no other-to-own cell interference, as in pico configuration. But because the HSUPA supports soft handover, which results macro diversity gain, measurements with multiple HSUPA capable base stations should be considered.

From these results, the conclusion is that DAS configuration is the best option for low traffic areas like small and medium sized buildings. This verifies also the results from preliminary research [24] about DAS and pico configuration differences. The pico configuration excels in high loaded cases, when increasing the capacity with several base stations even though the performance is degraded by handovers and inter-cell interference. Therefore it fits better for bigger buildings with higher capacity requirements.

Even though different antenna configurations have impact on the coverage or the capacity, the importance of antenna placement should not be forgotten. After good planning of antenna placement, the upgrade of system is much more cost efficient as there are no need to move antenna locations and antenna lines. Evolution on indoor network can be done by simple equipment upgrades and minor antenna line configuration changes.

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[26] 3GPP TS 25.214, V6.0.0, Release 6, Physical layer procedures (FDD).

APPENDIX A

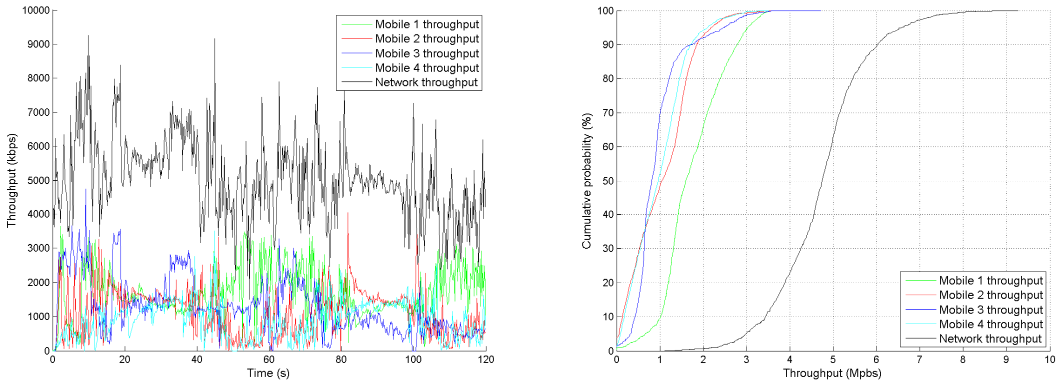

Figure 1. *Part of the measurement route and cumulative distribution function of mobile and network throughputs from (Open corridor/DAS/HSDPA/high load) measurement.*

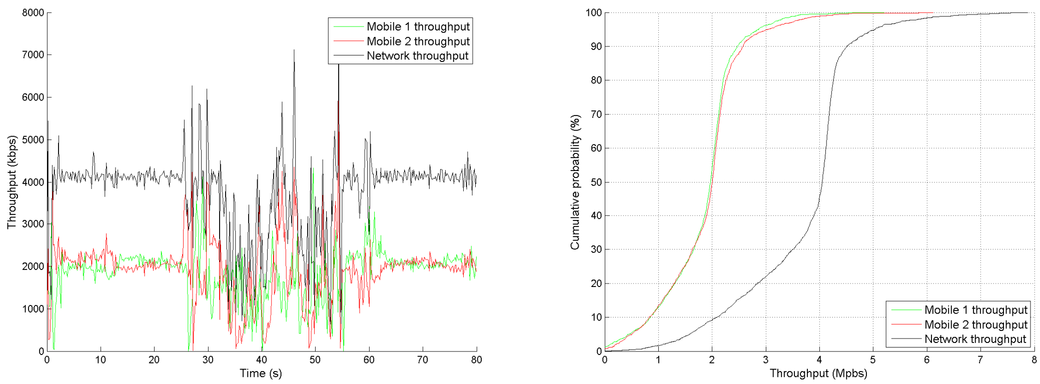

Figure 2. *Part of the measurement route and cumulative distribution function of mobile and network throughputs from (Open corridor/DAS/HSDPA/low load) measurement.*

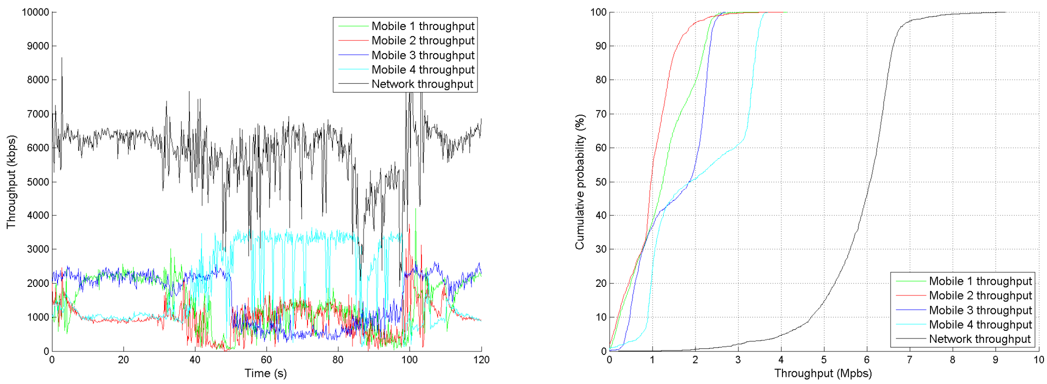

Figure 3. *Part of the measurement route and cumulative distribution function of mobile and network throughputs from (Open corridor/pico/HSDPA/high load) measurement.*

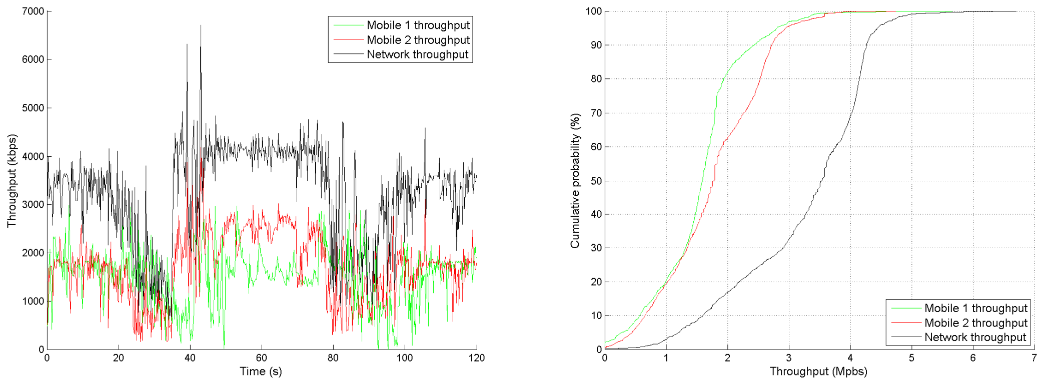

Figure 4. *Part of the measurement route and cumulative distribution function of mobile and network throughputs from (Open corridor/pico/HSDPA/low load) measurement.*

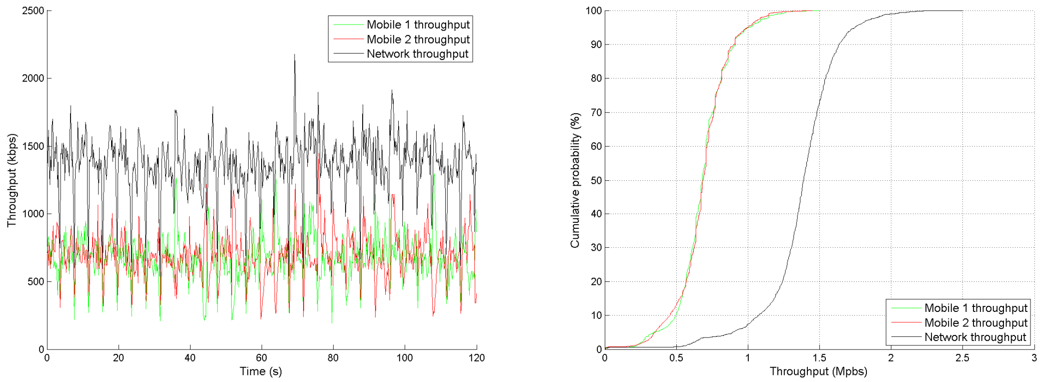

Figure 5. *Part of the measurement route and cumulative distribution function of mobile and network throughputs from (Open corridor/DAS/HSUPA) measurement.*

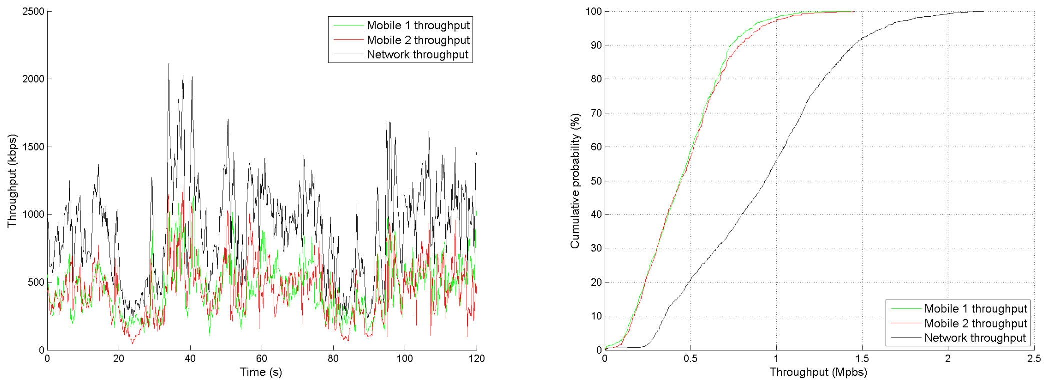

Figure 6. *Part of the measurement route and cumulative distribution function of mobile and network throughputs from (Open corridor/pico/HSUPA) measurement.*

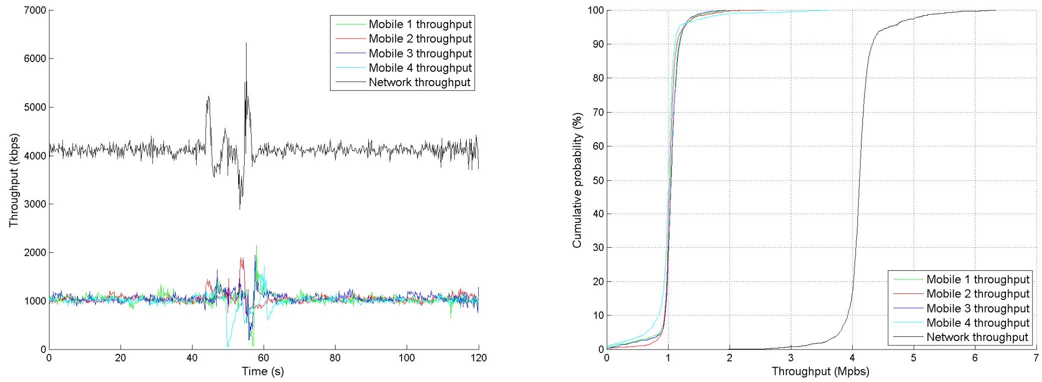

Figure 7. *Part of the measurement route and cumulative distribution function of mobile and network throughputs from (Dense corridor/DAS/HSDPA/high load) measurement.*

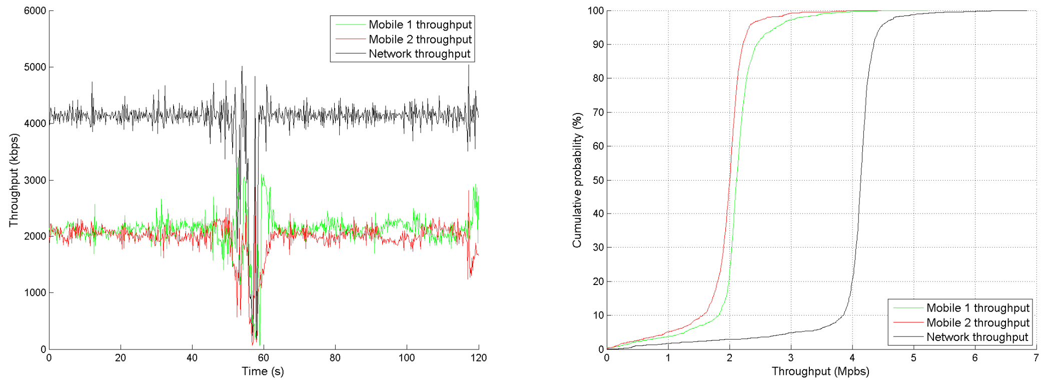

Figure 8. *Part of the measurement route and cumulative distribution function of mobile and network throughputs from (Dense corridor/DAS/HSDPA/low load) measurement.*

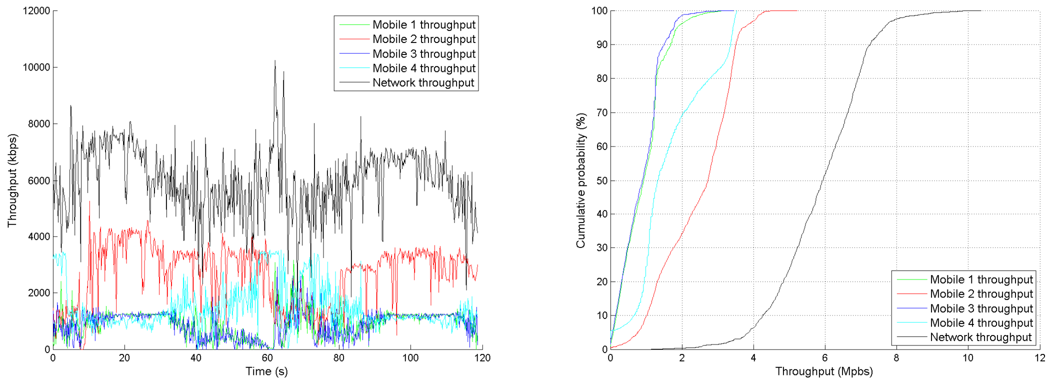

Figure 9. *Part of the measurement route and cumulative distribution function of mobile and network throughputs from (Dense corridor/pico/HSDPA/high load) measurement.*

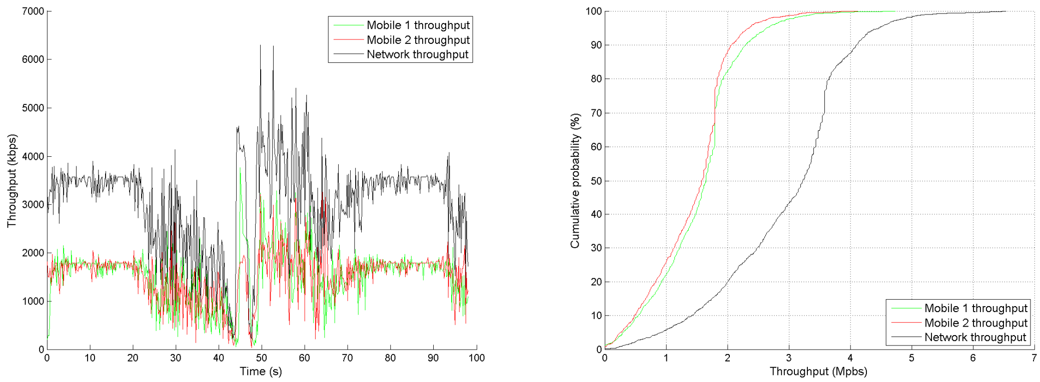

Figure 10. *Part of the measurement route and cumulative distribution function of mobile and network throughputs from (Dense corridor/pico/HSDPA/low load) measurement.*

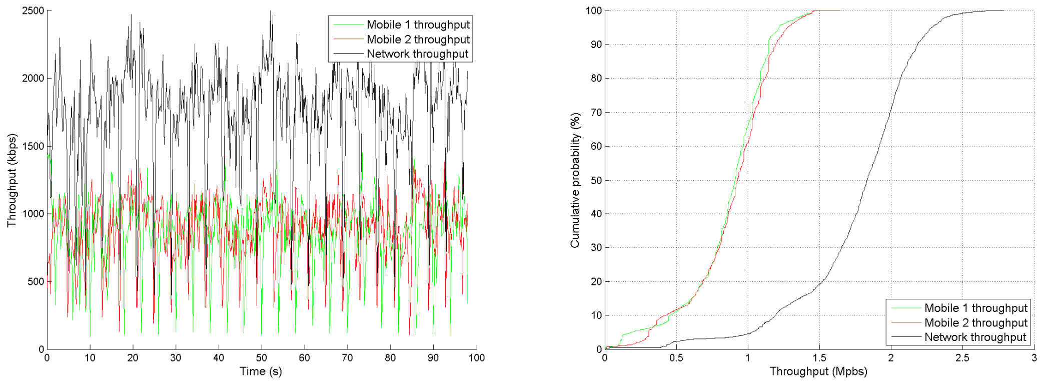

Figure 11. *Part of the measurement route and cumulative distribution function of mobile and network throughputs from (Dense corridor/DAS/HSUPA) measurement.*

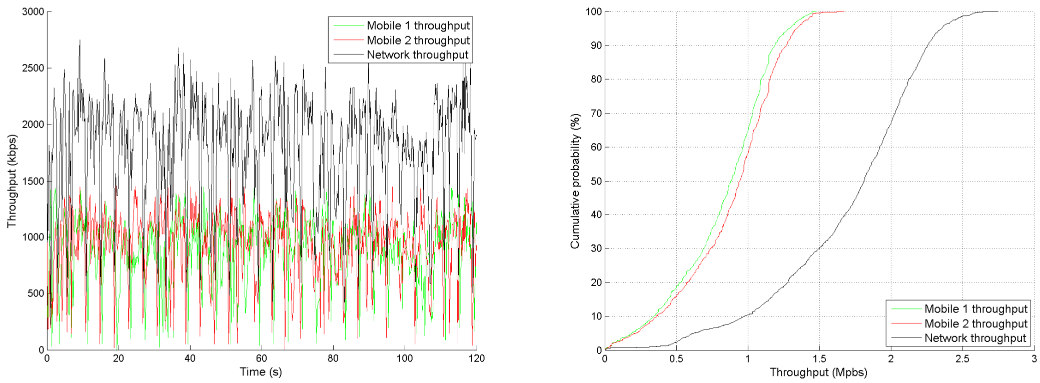

Figure 12. *Part of the measurement route and cumulative distribution function of mobile and network throughputs from (Dense corridor/pico/HSUPA) measurement.*

APPENDIX B

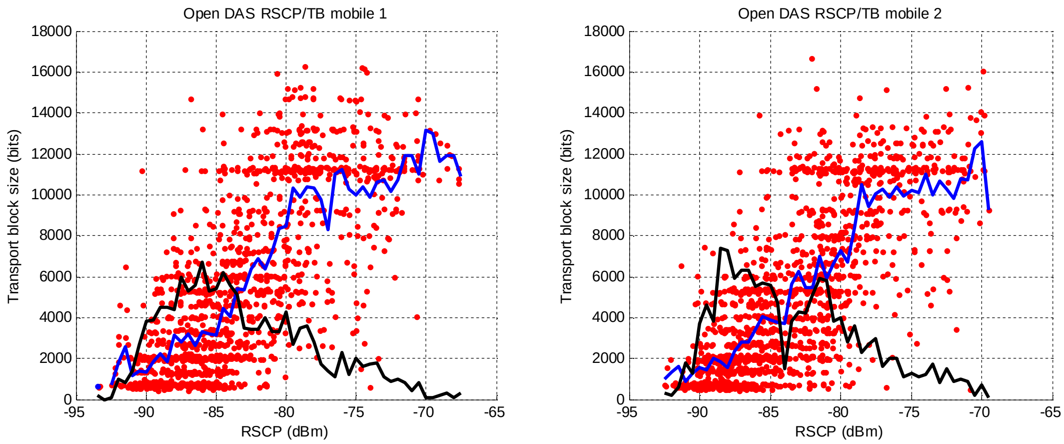

Figure 1. *RSCP and transport block size comparison with actual data (red), average (blue) and relative amount of samples (black).*

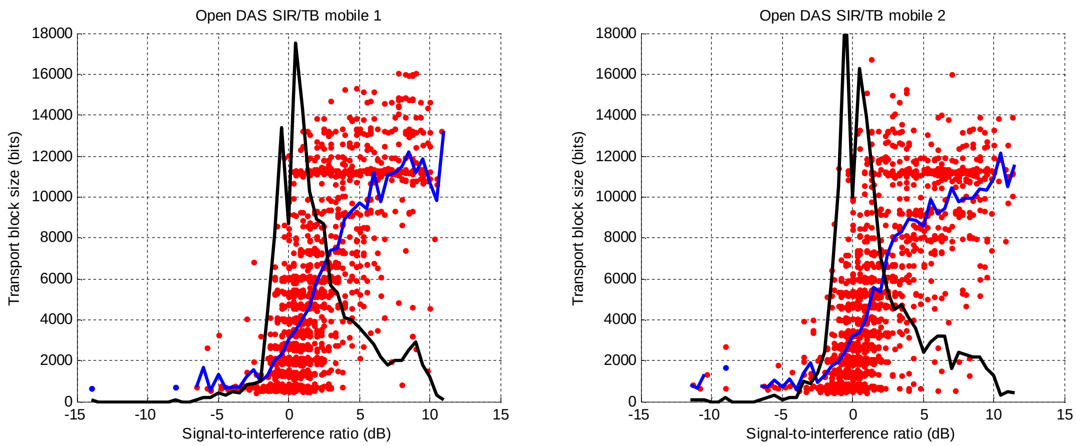

Figure 2. *SIR and transport block size comparison with actual data (red), average (blue) and relative amount of samples (black).*

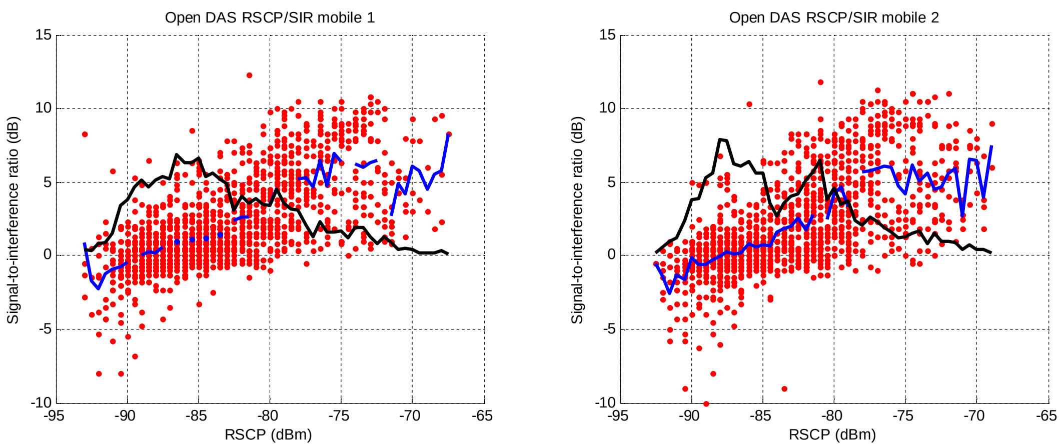

Figure 3. *RSCP and SIR comparison with actual data (red), average (blue) and relative amount of samples (black).*

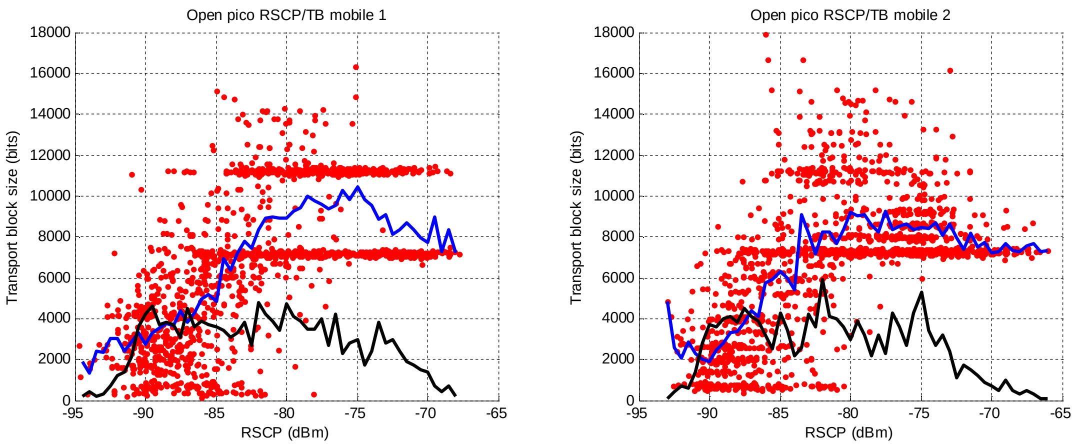

Figure 4. *RSCP and transport block size comparison with actual data (red), average (blue) and relative amount of samples (black).*

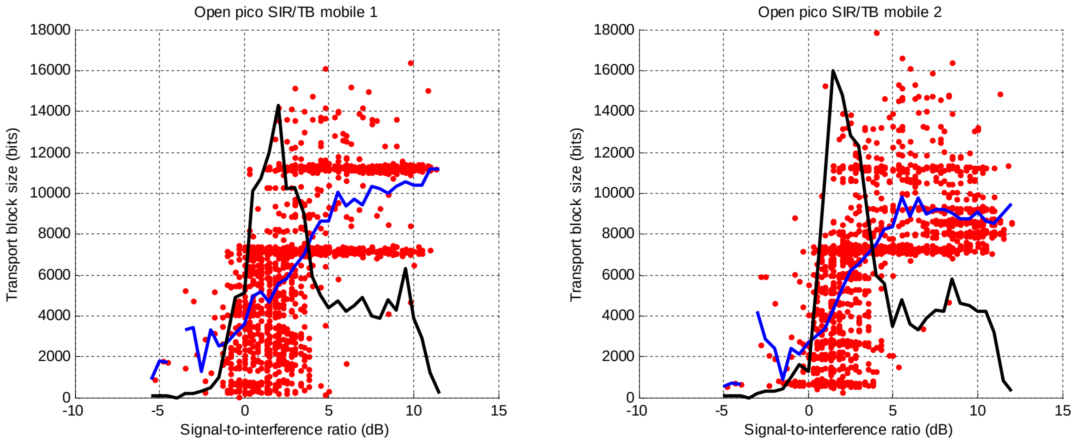

Figure 5. *SIR and transport block size comparison with actual data (red), average (blue) and relative amount of samples (black).*

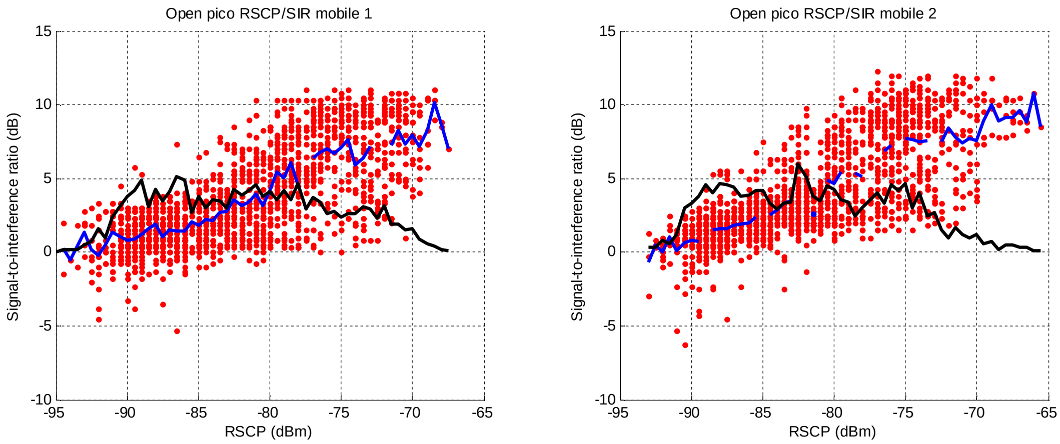

Figure 6. *RSCP and SIR comparison with actual data (red), average (blue) and relative amount of samples (black).*

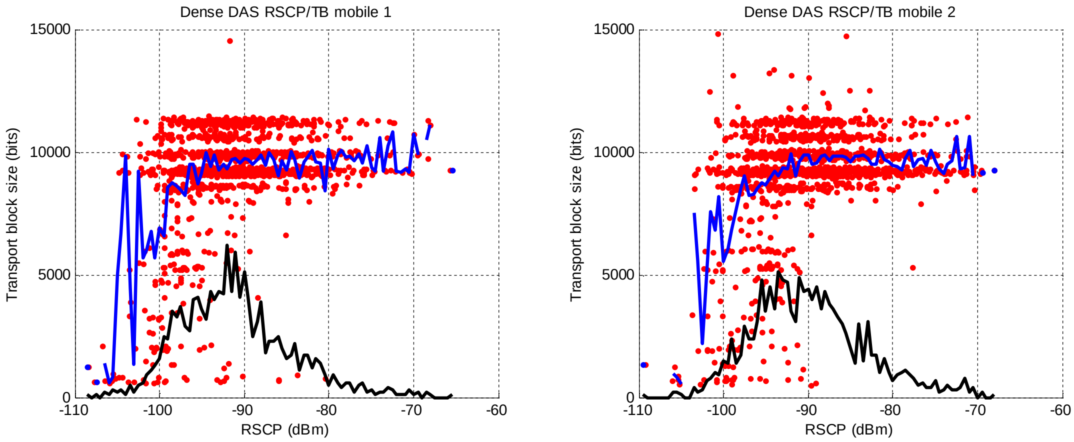

Figure 7. *RSCP and transport block size comparison with actual data (red), average (blue) and relative amount of samples (black).*

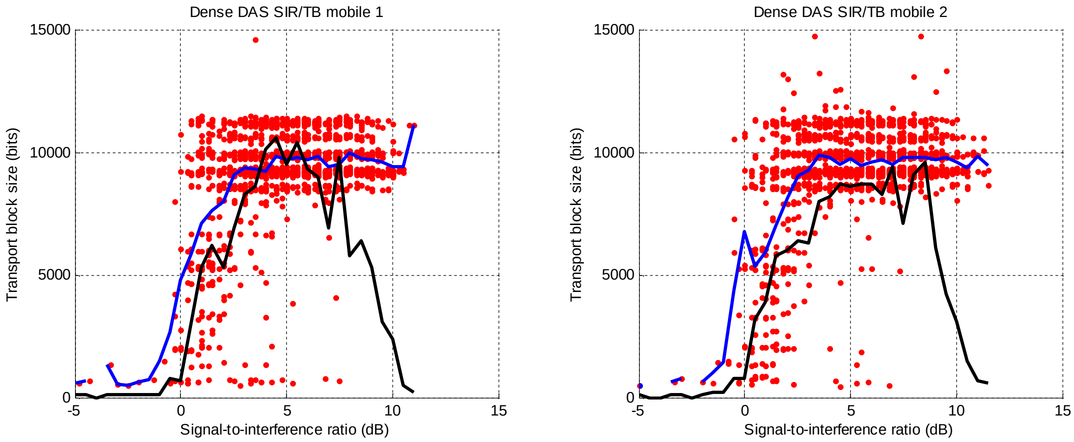

Figure 8. *SIR and transport block size comparison with actual data (red), average (blue) and relative amount of samples (black).*

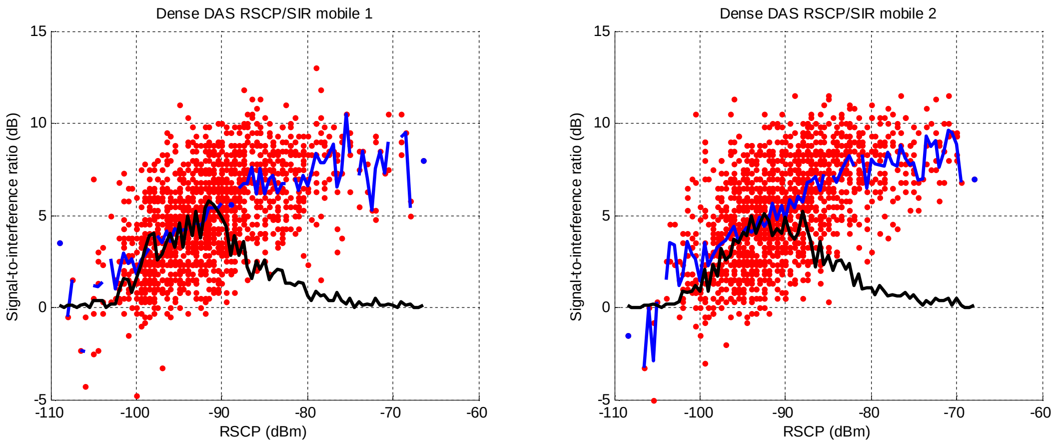

Figure 9. *RSCP and SIR comparison with actual data (red), average (blue) and relative amount of samples (black).*

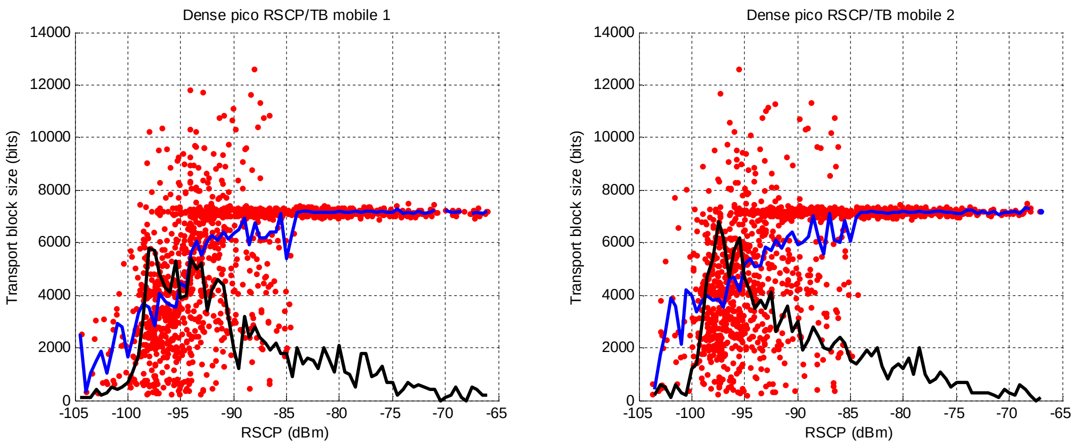

***Figure 10.** RSCP and transport block size comparison with actual data (red), average (blue) and relative amount of samples (black).*

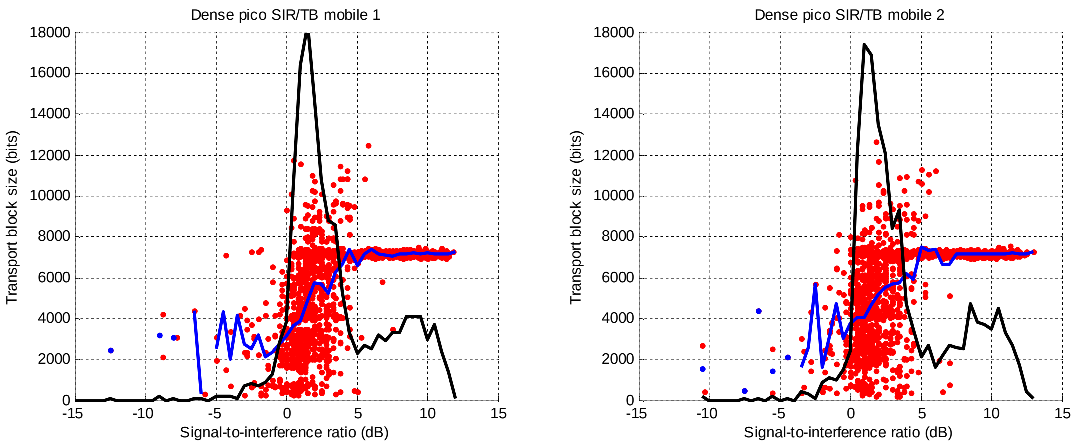

***Figure 11.** SIR and transport block size comparison with actual data (red), average (blue) and relative amount of samples (black).*

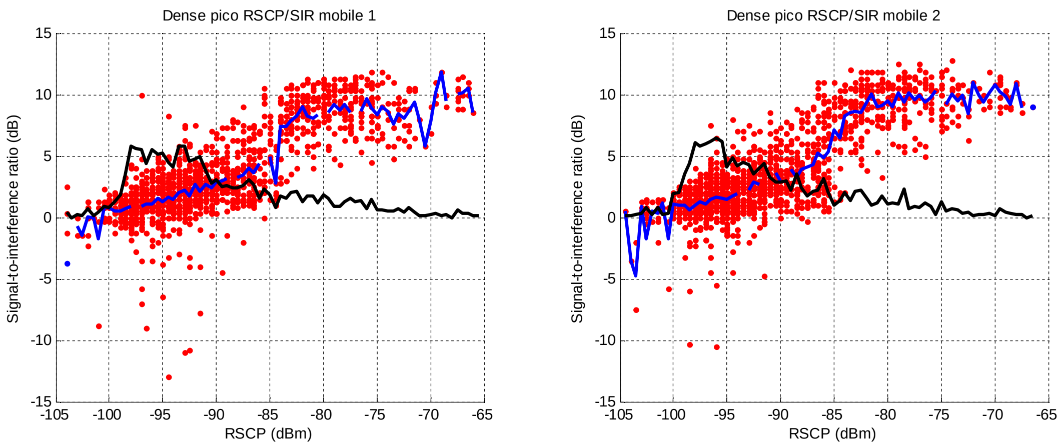

***Figure 12.** RSCP and SIR comparison with actual data (red), average (blue) and relative amount of samples (black).*