TAMPERE UNIVERSITY OF TECHNOLOGY

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COMPARISON OF PICOCELL AND DAS CONFIGURATION WITH HSPA EVOLUTION

Master of Science Thesis

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Examiners and topic approved in the Faculty of Computing and Electrical Engineering Council meeting on 8th September 2010

ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
Master’s Degree Program in RF Electronics
Shan, Haroon: Comparison of picocell and DAS configuration with HSPA Evolution.
Master of Science Thesis, 85 pages, 3 Appendix pages
March 2011
Major: RF Electronics
Supervisor: M.Sc. Tero Isotalo, Examiner: Professor Jukka Lempiäinen
Keywords: Picocell, DAS, HSPA+, UMTS, indoor network, field measurements.

As demand of mobile data services has grown exponentially, it has increased pressure on mobile operators to enhance capacity in dense urban areas. Usage of internet and services related to mobile network has grown up. UMTS specification has been updated in order to cope with an increased amount of mobile data traffic. These upgrades and releases are based on international standards. HSDPA and HSUPA technologies are previous upgrades of UMTS network but now HSPA Evolution (HSPA+) is the upgraded version for UMTS. HSPA+ improves performance of mobile data transmission in downlink direction.

Previously UMTS enabled user data of 384 kbps that was upgraded to 14.4 Mbps in downlink and 5.76 Mbps in uplink data rate by HSPA. But still the demand of data rate is increasing so HSPA+ upgraded UMTS to 21.1 Mbps in downlink and 5.76 Mbps in uplink. Due to these improvements in data rates, HSPA+ has become one of the striking choices for mobile operators. It has been forecasted that amount of data users will increase in future and this will set new challenges for mobile operators. The network is planned in such a way that more capacity is provided to places where more users are present. Most of the network traffic in dense urban area is generated by indoor users. Indoor planning is mostly done with multiple picocells or DAS configuration. The main differences between these two configurations are interference, total capacity, cost of the equipment and implementation.

In this Master’s thesis, the main focus is to compare picocells and DAS configuration for HSPA+ by simulations and measurements. Several mobile terminals were used to generate low and high loads for HSPA+ network. These comparisons were made by analyzing the results for signal to interference ratio, total network throughput and several other indicators. The results showed that DAS outperforms picocells in low/high load conditions in terms of SIR, cell throughput and modulation technique. DAS is good choice for medium sized building due to handover free regions and smooth coverage.

PREFACE

This Master of Science Thesis "Comparison of picocell and DAS configuration with HSPA Evolution" has been written for the completion of my Master of Science Degree in Radio Frequency Electronics. The research work has been done in the Department of Communication Engineering (DCE) in Tampere University of Technology (TUT), Finland. The measurement work and writing process were carried out during Fall 2010.

I would like to show gratitude to my examiner Prof. Jukka Lempiäinen, supervisor MSc. Tero Isotalo and MSc. Syed Fahad Yunas for providing me the topic for this thesis. I am really thankful to Tero Isotalo for his valuable guidance, help and support throughout my thesis period. Special thanks to MSc. Syed Fahad Yunas and my co-worker Rajadurai Subramaniam for their fruitful technical discussions and technical help throughout the course of thesis work.

I am extremely thankful to my parents Shan Uddin Shan and Shahida Shan; my brothers Sohail Shan, Shafqat Shan, Shahid Shan, Shahzad Shan and Farrukh Shan; and my sisters Shaheena Shan, Saima Shan and Ayesha Shan for their support, encouragement, endless love and countless prayers. Without their contribution this would not have been possible.

This thesis is dedicated to my grandfather late Islam Ul Haq without his effort I cannot reach this place.

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List of Abbreviations

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
AC	Admission control
ACK	Acknowledgment
AMC	Adaptive modulation and coding
BLER	Block error rate
BS	Base station
CDMA	Code division multiple access
C/I	Carrier to interference ratio
CN	Core network
CQI	Channel quality indicator
CS	Circuit switched
DAS	Distributed antenna system
DCH	Dedicated channel
DC	Data card
DL	Downlink
DS-CDMA	Direct sequence CDMA
DPDCH	Dedicated physical data channel
E-DCH	Enhanced dedicated channel
EIRP	Effective isotropic radiated power
E-AGCH	E-DCH absolute grant channel
E-DPDCH	E-DCH physical data channel
E-HICH	E-DCH HARQ indicator channel
E-RGCH	E-DCH relative grant channel
EDGE	Enhanced Data rates for Global Evolution GSM
E-TFC	Enhanced transport format combination

FDD	Frequency division duplex
FDMA	Frequency division multiple access
FTP	File transfer protocol
GSM	Global System for Mobile
GPRS	General Packet Radio Service
GMSC	Gateway MSC
GGSN	Gateway GPRS support node
GoS	Grade of service
GPS	Global Positioning System
HARQ	Hybrid automatic repeat request
HC	Handover control
HHO	Hard handover
HLR	Home location register
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-SCCH	High speed shared control channel
HSUPA	High Speed Uplink Packet Access
HTTP	Hypertext transfer protocol
ISDN	Integrated services digital network
ITU	International Telecommunication Union
KPI	Key performance indicator
LC	Load control
LOS	Line of sight
LTE	Long Term Evolution
MAC	Medium access control
MRC	Maximal ratio combining
MS	Mobile station
MSC	Mobile switching centre

NACK	Negative acknowledgment
NLOS	Non line of sight
NPSW	Network planning strategies for Wideband CDMA
OFDMA	Orthogonal frequency division multiple access
PC	Power control
P-CPICH	Primary common pilot channel
PAM	Pulse amplitude modulation
PG	Processing gain
PC	Power control
PSTN	Public switched telephone network
QoS	Quality of service
R5	Release 5
R6	Release 6
R7	Release 7
RNC	Radio network control
RNP	Radio network planning
RRM	Radio resource management
RSCP	Received signal code power
RSSI	Received signal strength indicator
SF	Spreading factor
SfHO	Softer handover
SHO	Soft handover
SGSN	Serving GPRS support node
SIR	Signal-to-interference ratio
SSB	Single sideband modulation
SBR	Shooting and bouncing ray method
TB	Transport block
TDD	Time division duplex
TDMA	Time division multiple access
TP	Throughput
TPC	Transmit power control

TFC	Transport format combination
TTI	Transmission time interval
UE	User equipment
UMTS	Universal Mobile Telecommunications System
UTRAN	Universal terrestrial radio access network
VLR	Visitor location register
WCDMA	Wideband code division multiple access

List of Symbols

λ	Wavelength
$\bar{\tau}$	Average delay
c_m	Area correction factor
$P(\phi)$	Angular power distribution
k	Boltzmann constant
f_c	Center frequency
q	Co-channel interference reduction factor
R	Cell radius
S_τ	Delay spread
E_c/N_0	Energy per chip to noise ratio
E_b/N_0	Energy per bit to noise ratio
h_{BTS}	Height of base station
h_{MS}	Height of mobile station
$a(h_m)$	Mobile station antenna correction factor
F_B	NodeB noise factor
G_B	NodeB antenna gain
T	Noise equivalent temperature
i	Other to own cell Interference
I_{other}	Other cell interference
I_{own}	Own cell interference
L_p	Path loss
G_R	Receiver antenna gain
P_{rx}	Received signal power
P_{τ_tot}	Received power
SF	Spreading factor
G_T	Transmitter antenna gain
N_{TH}	Thermal noise density
P_{tx}	Transmitted signal power
P_{ϕ_total}	Total received power.

1. Introduction

Mobile telecommunication has faced rapid changes during past decades due to increasing demands of packet switched data. Internet access has become necessity for most of the mobile users. This change in mobile communication came after successful launch of 2G network. GSM is considered to be 2G and main purpose of GSM was to provide speech services in macro cells [5]. As the mobile user capacity increased, 2G network was unable to fulfill the capacity needed for network operators.

Mobile network operators require cost effective coverage and capacity solutions to get a profitable network. Services like video telephony, multimedia content streaming, positioning services and multimedia messages have become major sources of revenue. The capacity demand is growing due to increasing trend of mobile indoor users. Such a situation leads to deploy most of the base stations in traffic generating areas. This strategy is not economically feasible for operators as operators face a new challenge in radio network planning and new solutions should be examined.

Improvements are made in packet transmission by enhancing GSM (Global System for Mobile communication) with techniques such as GPRS (General Packet Radio Service) and later with EDGE (Enhanced Data Rates for GSM Evolution). Since capacity demands are increasing with passage of time, GSM network got some technical boundaries. To overcome this problem, new 3G technology was needed. 3GPP introduced WCDMA as a new radio interface technology for packet transmission. Key technologies in 3G include UMTS that later became standard. According to growing performance requirements, current UMTS network needs to be upgraded. Initially data speed of UMTS provides 384Kbps that has been upgraded with HSPA (High Speed Packet Access) technology. Up gradation provides data speed to 14.4 Mbps in downlink and 5.76 Mbps in uplink direction. Further up gradation with HSPA+ (High Speed Packet Access Evolution) provides data speed of 21.1 Mbps in downlink and 5.76 Mbps in uplink direction. Throughputs can be achieved to 42.2 Mbps with 2x2 MIMO (Multiple Input Multiple Output) concepts used in HSPA+. Higher data rates in future can be achieved by new 4G (4^{th} Generation) technology known as LTE (Long Term Evolution).

Most of the traffic generated in urban environment is indoor traffic. As indoor capacity demands are getting higher, mobile operators must consider efficient solution to provide enough indoor coverage and capacity. The majority of the indoor places include cafes, hot spots, offices and educational institutions [1]. In near future, data traffic has increased in indoor environment. Outdoor microcells providing indoor coverage using outdoor-to-indoor scheme resulted in poor end user performance. This problem can be solved by using dedicated indoor network solution. Using repeaters, capacity and coverage can be enhanced in indoor area.

Indoor radio network planning includes dedicated indoor system capacity that is distributed by different antenna configurations. This includes outdoor-to-indoor repeaters to enhance the indoor coverage. As indoor capacity requirement is rising, dedicated indoor system is most reasonable choice for high populated areas. Multiple picocell and distributed antenna system are commonly used antenna configurations to provide better coverage and capacity to indoor environment. A large amount of the research [10; 24] is based on single mobile measurement and thus comparison measurements on multiple user performance in picocell and DAS are still not available. As the deployment costs of DAS and picocell configurations are different, research on comparing both configurations are made in this thesis.

This Master of Science thesis provides both analytical part and measurement part. Chapter 2 provides the basic principles of wireless communication and Chapter 3 describes the background study of WCDMA cellular network. Chapter 4 depicts the concept of HSDPA (R5), HSUPA (R6) and HSPA+ (R7). A practical deployment of WCDMA network with radio network planning process and parameters are described in Chapter 5. In Chapter 6, analytical study is described on the basis of simulations. The measurement campaign and measurement results are presented in Chapter 7. Finally chapter 8 provides the conclusions, made on the basis of analytical study and measurements results.

2. Principles of Wireless Communication

The need for efficient communication between people has increased dramatically during last two decades. The wireless communication systems have opened new doors for people to communicate. This communication provides high data rate and reliable mobility. The general concept describes that an independent mobile should be connected to a service provider. This chapter provides understanding to the basic principles of cellular communication and radio propagation related issues.

2.1 Evolution of Cellular Networks

Before the cellular concept, wireless services were provided by high masts antennas with single high power transmitter. As there was no handovers between masts, calls were dropped if user was out of coverage area. The early concept for the cellular network took place in the 1960s and 1970s by Bell Laboratories in New York. This concept includes a hexagon cell structure, providing design for large coverage area. But the capacity of the system was poor because of the spectral congestion in that large area. Each site was divided into sectors (or cells) with power transmitters depending on the coverage and capacity demand of that area. Power of transmitters was adjustable according to capacity and coverage area like rural or urban environment. Bigger cells increased coverage area but decreased capacity and with the new design network structure became more complex as there were multiple sites. So the movements between cells introduced many new problems to be solved [4].

Two most important things in a cellular network are better coverage and mobility. But at the same time, enough user capacity should be achieved without compromising the quality of the services provided by the system. This target of high capacity and better coverage can be accomplished by dividing a large geographical area into multiple smaller regions (known as cells) each containing its own set of allocated resources. A layout of cellular network is illustrated in Figure 2.1.

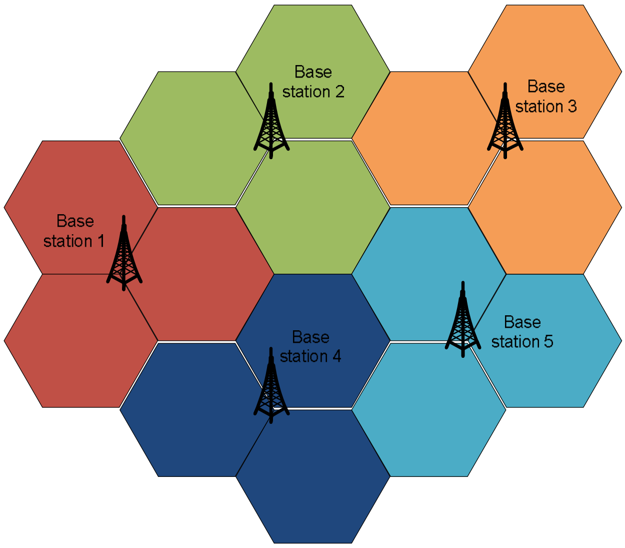


***Figure 2.1** Five base station cellular layout.*

Main issues that had to be solved were power control and cell selection. To ensure better user mobility, less interference should be present between cells. Each sector was allocated a number of channels for creating an independent service area. Due to this channel reuse concept was evolved. Channel reuse is design process of selecting and allocating available frequency channel groups to all base stations in sensible manner. Channel reuse concept target is to minimize the interference level between users and cells. Allocating bigger proportions of channels to a bigger area, decreases the amount of channel groups but increases the capacity of that area. Smaller amount of channel groups increases co-channel interference in the network [4]. Channels reuse principle in frequency division multiple access (FDMA) and wideband code division multiple access (WCDMA) is given in Figure 2.2.

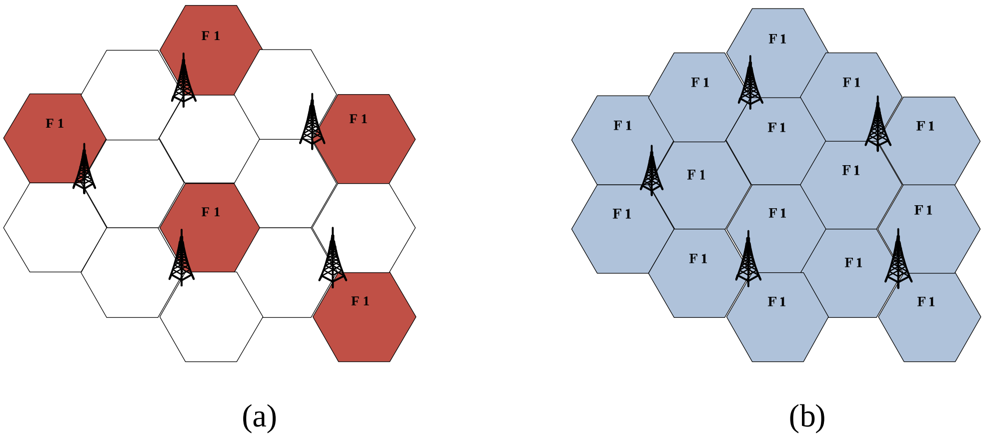


***Figure 2.2** (a) Frequency reuse concept used in FDMA (b) code division multiple access used in CDMA having same carrier frequency is used for whole cluster but with different spreading codes.*

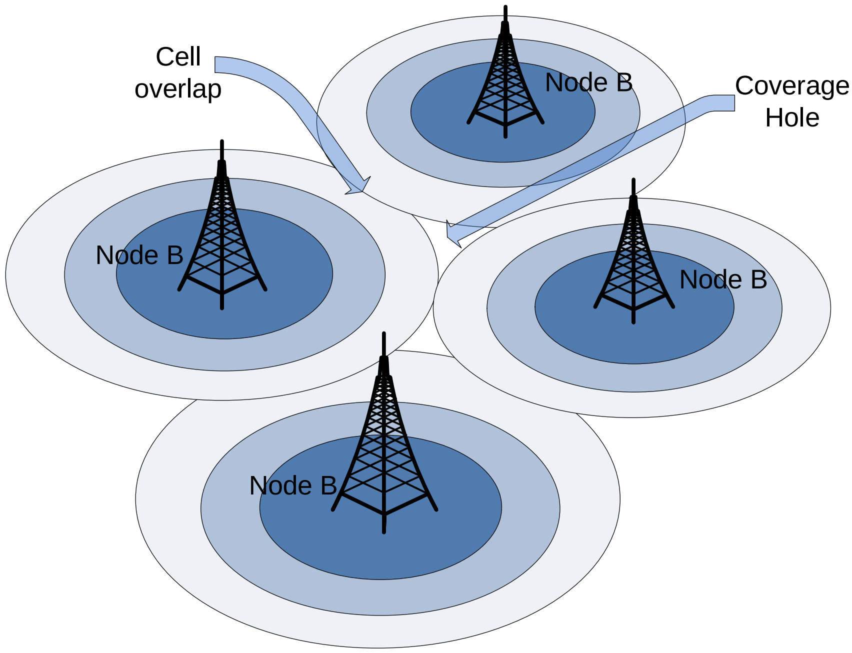


Figure 2.3 *Cell overlap and coverage hole in network.*

Figure 2.3 shows the cell coverage and gives the idea about coverage holes and cell overlap. In order to increase the capacity of cellular network, more frequency channels are added. This decreases the cell area and as a result, interference and system complexity increases. Addition of channels creates new challenges in terms of traffic distribution and mobility. To ensure roaming within cellular networks, handovers between cells are required. Handover functions require sophisticated measuring tasks and algorithms. These measurements are used to evaluate the cell in which mobile can obtain the best possible service but this increases the complexity of the network.

2.2. Multiple Access Techniques

For a reliable communication among the users and channels there is a need to separate them from each other in the air interface. The most important schemes used for user separation are:

- Frequency division multiple access (FDMA)
- Time division multiple access (TDMA)
- Code division multiple access (CDMA).

Figure 2.4 shows the principle of different multiple access techniques.

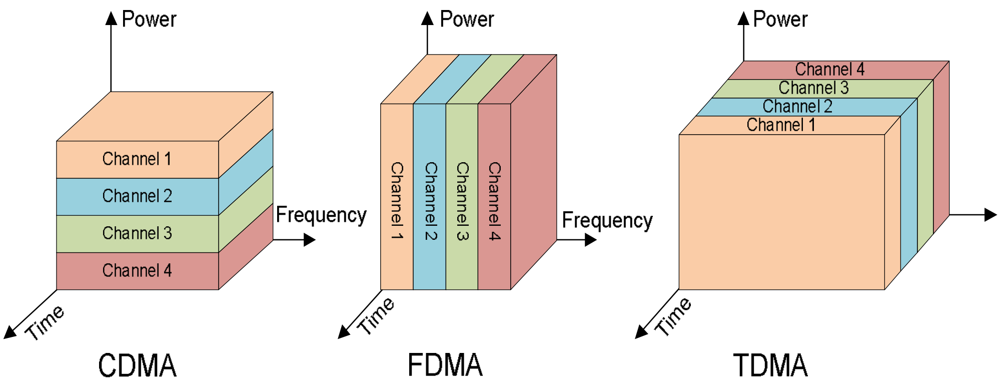


Figure 2.4 *CDMA, FDMA and TDMA multiple access schemes.*

In FDMA, total bandwidth is divided into the number of frequency channels. Transmission and reception are simultaneous and continuous so RF duplexers are required at the mobile end [6] and carrier bandwidth is narrow so equalizers are not needed. In modern communication, FDMA technique is most commonly used due to high efficiency. FDMA is immune to power dynamic faults and timing problems. To avoid the effect of delay spread is simply to reduce the modulated data rate by transmitting the data simultaneously on large number of carriers. OFDMA is a spread spectrum technique based on spreaded multi tone modulation and it divides the allocated spectrum to groups of subcarriers.

TDMA systems separate the time into frames and each frame is further divided into the number of slots. Each mobile is allocated a pair of time slots, one in uplink frequency and other one in downlink frequency. This choice is made such that they do not coincide in time [6].

CDMA is a spread spectrum system where each user occupies a bandwidth that is much wider than needed to accommodate their data rate. A narrow information signal is widened for transmission in the frequency domain by multiplying it with a wide spreading signal. Each code is almost orthogonal which enables simultaneous transmission in the shared frequency band. These days CDMA technique is mostly used in modern cellular systems such as UMTS systems.

2.3 Radio Propagation Environment

One of the important things which affect the radio propagation of signal is 'environment'. In human made environment, the main scatters that affect signal propagation are houses and building found in suburban areas. The building sizes are equivalent over many wavelengths of propagation frequency, creating reflected signals of transmitted signal [7]. Combination of some basic mechanisms affecting the plane waves provide better understanding about the propagation behavior of radio waves. Propagation models are needed to estimate path loss between the mobile station and base station. Propagation models are divided into empirical, semi-empirical and deterministic models. Empirical models are based on measurement campaigns that change the measurement statistics into mathematical models. Semi-empirical models rely on physical phenomena's such as refraction, reflection and diffraction. Deterministic models includes ray tracing and ray launching methods, having basis of electromagnetic theory to provide accuracy in path loss calculation in cost of computational power requirement.

2.3.1. Free Space Loss Environment

When there are no obstacles near or relatively close to the propagation path between the transmitter and receiver then this type of propagation environment is known as the free space loss environment. P_R can be calculated from Friis formula for transmission also known as free space loss. [8]

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d} \right)^2 , \qquad (2.1)$$

where P_T is transmitted and P_R is received power. Wavelength is denoted by λ and d is the distance between the transmitter and receiver. The formula of path loss in logarithmic form is given

$$L = 32.4 + 20\log d_{Km} + 20\log f_{MHz} , \qquad (2.2)$$

where d_{Km} is distance in kilometers and f_{MHz} is frequency in MHz.

2.3.2. Diffraction

In diffraction, the signal propagates to a shadow region behind an obstruction that gives an infinitely sharp signal transitions. However, some energy does propagate into the shadow region. Diffraction can be said as non line-of sight (NLOS) situation. The Huygens principle describes the diffraction which states that each element of a wavefront at a point in time may be regarded as the center of new secondary wavelet and that previous wavelet is to envelop of new sources [6]. Figure 2.5 gives general idea of diffraction.

2.3.3. Scattering

The reflected wave is scattered from a number of positions when the surface is quite rough. In practice there are surfaces which are not ideally smooth and signal gets scattered when reflected from rough boundary. Signal energy is spreaded due to scattering and the degree of scattering depends on the incident wave angle and on the roughness of the surface in comparison to wavelength [6]. For a surface to be rough, it must satisfy the Rayleigh criterion given in equation 2.3

$$\Delta h < \frac{\lambda}{8cos\theta}. \qquad (2.3)$$

Signal surface with the wavelength of λ and incident angle of θ can be considered as rough when height difference of the surface is more than *h*.

2.3.4. Reflection and Refraction

When an incident plane wave encounters a boundary, reflection occurs. A plane wave encounters different obstacles such as buildings, hills and trees which changes the shape of the signal. From smooth surfaces one portion of signal energy gets reflected and rest gets refracted [6]. Signal strength depends on the boundaries from which a signal is reflected and refracted. A signal is affected in terms of phase shifts, the angle of reflection, refracted signal and polarization. Figure 2.5 shows the idea of reflection and refraction.

2.3.5. Propagation Slope

In free space loss, the propagation slope for attenuation is 20 dB/dec. The environment also affects the level of attenuation which can vary between 25 and 40 dB/dec. It gives total attenuation between base station and the mobile station antennas as a function of time. The distance where higher signal degradation occurs is called breakpoint distance and is denoted by *B*. Value of *B* can be calculated as:

$$B = 4\frac{h_{BTS}h_{MS}}{\lambda}, \qquad (2.4)$$

where h_{BTS} is the base station antenna height, h_{MS} is the mobile station antenna height (mostly considered 1.5 meter) and λ is the wavelength [1].

2.4 Multipath Propagation Principles

When a received radio signal consists of several diffracted, reflected and attenuated components of original transmitted signal, then it is called multipath signal. While receiving the signal, each signal component may have different amplitudes and phase due to multipath environment. Multipath propagation can be characterized in terms of angular spread, delay spread, coherence bandwidth and the propagation slope. Figure 2.5 gives a general idea of multipath propagation. Received signal component may have travelled different paths with different path lengths and thus delayed at the reception.

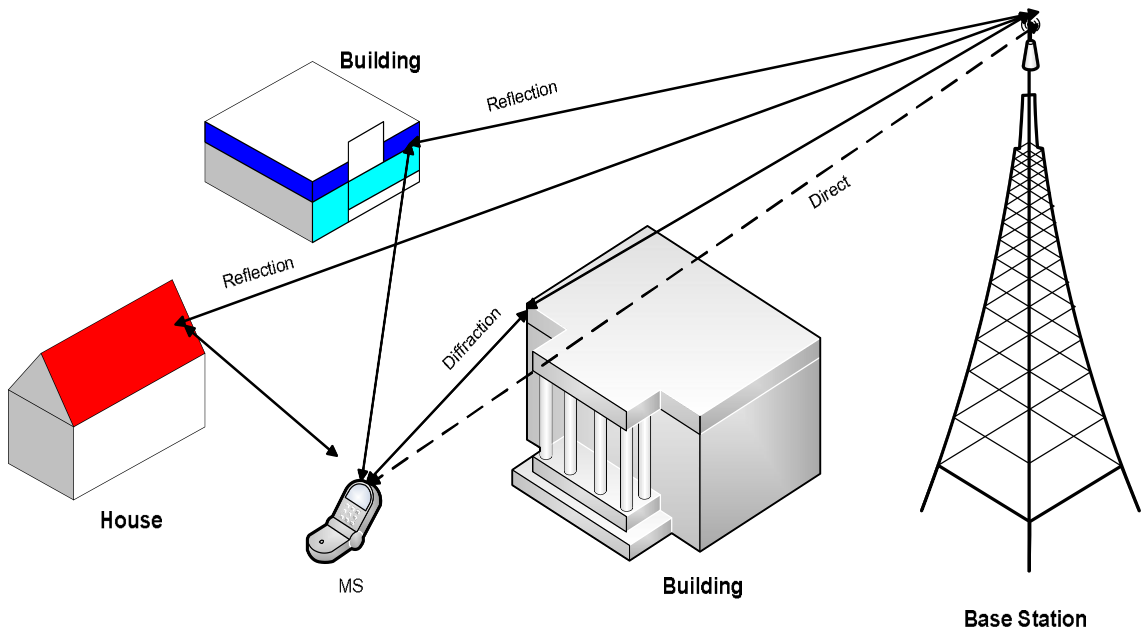


Figure 2.5 *Multipath propagation environment.*

2.4.1 Angular Spread

Angular spread is a variable which describes the deviation of the signal incident angle. It defines the power distribution as a function of the angular shift in horizontal and vertical planes [1]. It is used to describe different propagation environment types. Angular spread is defined as:

$$S_{\phi} = \sqrt{\int_{\phi-180}^{\phi+180} \left(\phi - \bar{\phi}\right)^2 \frac{P(\phi)}{P_{\phi\_total}} d\phi} \,, \qquad (2.5)$$

where ϕ means angle, P (ϕ) is the angular power distribution and P_{ϕ_total} is the total received power [1].

2.4.2 Delay Spread

The arrival time difference from the first received signal to the last one is described as excess delay spread. It occurs in multipath environment where multipath components of the same transmitted power may have different arrival times due to different propagation paths [1]. Small delay spread is present for indoor environment and large for rural areas. Delay spread can be defined as:

$$S_{\tau} = \sqrt{\frac{\int_{0}^{\infty} (\tau - \bar{\tau}) P_{\tau}(\tau) d\tau}{P_{\tau\_tot}}} \,, \qquad (2.6)$$

where τ is delay and P_{τ_tot} is received power [1].

2.4.3 Coherence Bandwidth

Coherence Bandwidth is a function of delay spread and it defines the bandwidth of the multipath channel. Delay spread represents the multipath component on the time domain. The coherence bandwidth represents the multipath component of frequency domain [1]. Separation of different frequencies is a function of delay spread and is given:

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

2.4.4 Signal Fading

The amplitude of radio signal changes over a short interval of time due to multipath environment. These rapid fluctuations in signal strength are influenced by the relative motion between transmitter and receiver. This phenomenon is known as fast fading (also called short-term fading). Fast fading is caused by interference and phase mixing from different multipath components of the transmitted signal. It is affected by the bandwidth used for transmission, motion of mobile and motion of surrounding objects. By averaging the fast fading signal, slow fading (also known as long-term fading) response is obtained. Slow fading is mainly caused by the obstacles such as terrain elevation, buildings and trees in signal propagation path. Slow fading is depends on the propagation environment and the carrier frequency [4, 6]. Figure 2.6 shows the fading effects on multipath signal.

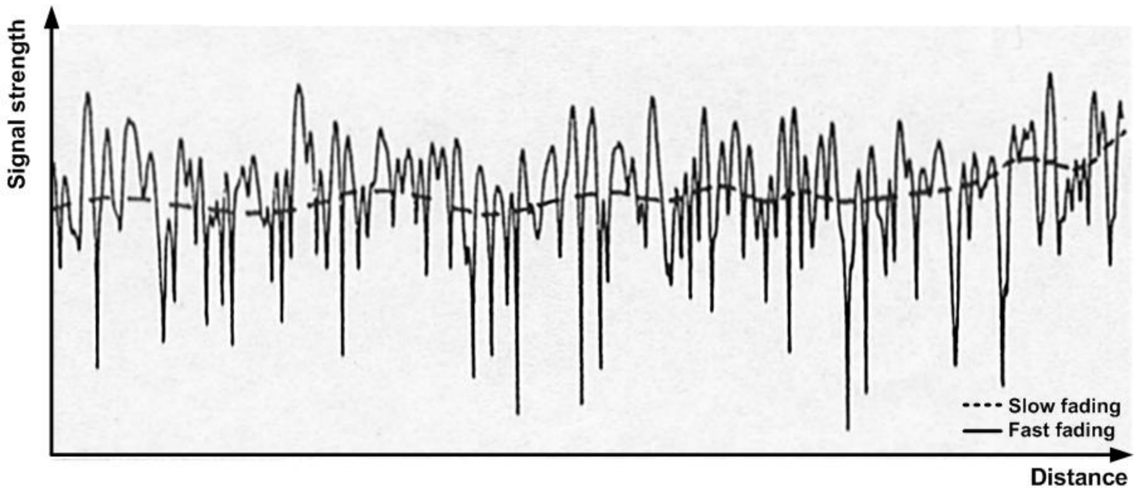


Figure 2.6 *Multipath signal having fading.*

3. UMTS Principles

First generation mobile networks refer to analog cellular systems which include the large number of subscribers over a wide area. This system includes Advance Mobile Phone System (AMPS) and NMT. Later, digital systems such as GSM (2G), CDMAone and WCDMA were used. At the beginning of 90's mobile communication changed extensively due to successful 2G system in Europe and Digital AMPS (D-AMPS) in North America. The high demands of internet applications such as the video call, multimedia services and e-mail brought internet in mobiles. The international Telecommunication Union (ITU) defines a common name for 3G systems known as IMT-2000 and third generation partnership project, 3GPP. The standardization work takes care for entire network family including GSM (2G), EDGE (2.5G) and UMTS (3G). These standards take care of all the mobile network technologies that have evolved till now [1]. Figure 3.1 shows these relationships.

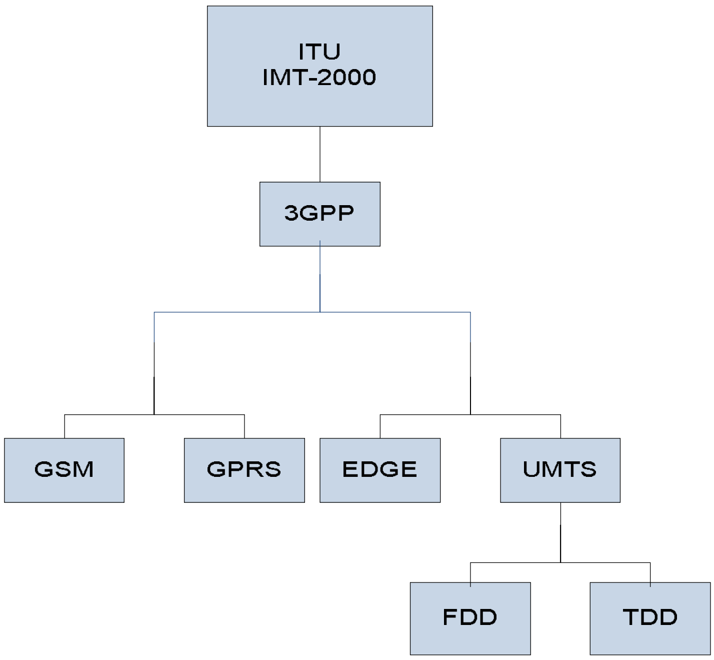


***Figure 3.1** 3GPP families. [1]*

For flexible planning in different environments, UMTS technology is required which has an adjustable capacity mechanism. For different transmission rates, UMTS is considered an evolutionary step for voice and data calls. Voice and data services vary according to need [1] (considering call quality and data throughput). Major upgrades were performed in 3G technology such as HSPA, HSPA+ and Long Term Evolution

(LTE). As HSPA+ is backward compatible and supports both HSPA+ and LTE [9]. A very simple deployment approach from HSPA to LTE is given in Figure 3.2

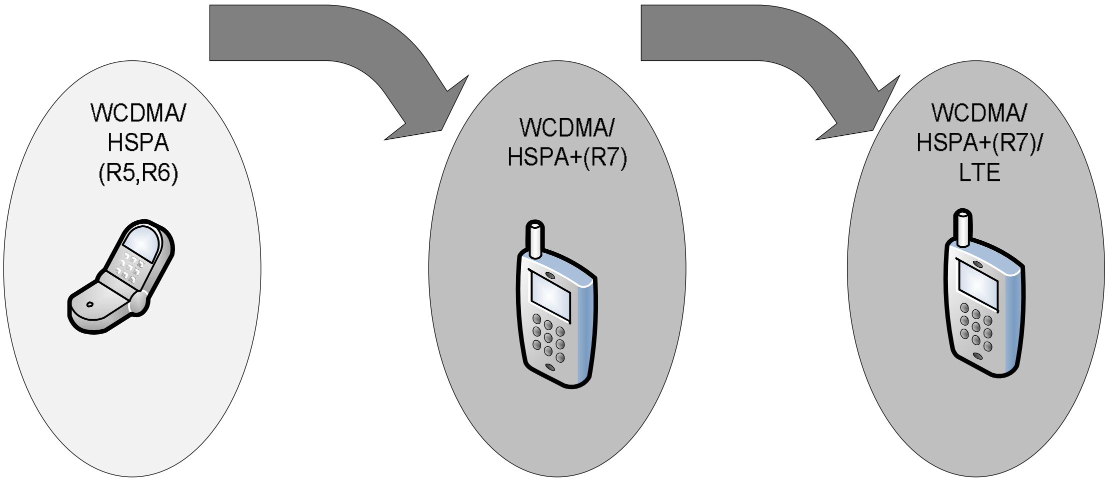


Figure 3.2 *Evolutions from HSPA to LTE. [9]*

3.1 UMTS Architecture

In UMTS high level architecture, three main elements are present which include user equipment (UE), UMTS Terrestrial RAN (UTRAN) and Core Network (CN) [20]. UTRAN handles all radio related functionality. CN is responsible for switching, routing voice calls and data services from other networks [1, 21]. Figure 3.3 shows high level architecture of UMTS system.

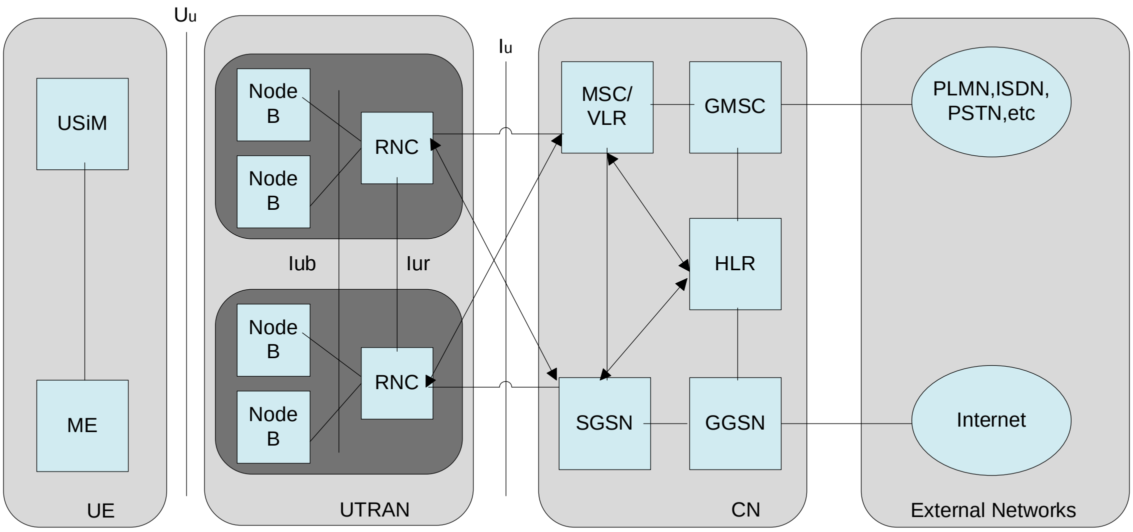


Figure 3.3 *High level architecture of UMTS. [5, 11]*

3.1.1 User Equipment

User equipment (UE) mainly consists of two parts Mobile Equipment (ME) and UMTS Subscriber Identity Module (USIM). Mobile equipment is radio terminal by which radio communication takes place and USIM contains all the information which is required for the identification and authentication of user, including encryption keys and some subscription information. The communication interface from UE to UTRAN is Uu [9].

3.1.2. UMTS Terrestrial RAN

UMTS terrestrial RAN (UTRAN) consists of Node-B (Base Station) and Radio Network Controller (RNC). Node-B is the main radio interface between UE and system. It relates to traffic flow from UE to RNC using U_u and I_{ub} interfaces (and vice versa). Node-B is the termination point for UE towards RNC and it handles the transmission of one or more cells between the users. The RNC is access point and controlling entity between Node-B, packet switch (PS) and circuit Switch (CS) core networks [5, 21].

3.1.3. Core Network

Core network (CN) handles both packet switched and circuit switched data. The main elements used in CN are as follow [5, 21, 22]:

- Home location register (HLR) contains the database for user’s service profile. It consists of information such as roaming areas, allowed services and call forwarding. HLR also stores information of UE location on MSC/VLR on level of serving system.
- Gateway MSC (GMSC) is a point where UMTS PLMN is connected to external CS networks. It is the gateway to all the incoming and outgoing CS calls.
- Serving GPRS support node (SGSN) is used for packet switch (PS) services and these are similar to MSC/VLR. The network part that can be access through SGSN is mostly referred to PS domain.
- Gateway GPRS support node (GGSN) has a functionality of connecting the external PS network with UMTS network.
- Mobile switching center/visitor location register (MSC/VLR) has functionality to serve UE in its current location for circuit switched services. MSC performs the tasks of CS and VLR contains a copy of visiting user’s profile including the precise information of user’s current location.
- An external network uses CS Network for providing circuit-switched connections (e.g. ISDN and PSTN) and PS Network for providing data connections for data services (e.g. internet).

3.2 WCDMA Radio Interface

UMTS Terrestrial RAN defined the WCDMA air interface and is one of the most adopted one for the current 3G systems. Both FDD and TDD can be utilized in WCDMA but this thesis only focuses on the FDD.

3.2.1 Spreading and Despreading of Signal

Signal spreading is done by multiplying each modulated information bit with another bit sequence. Spreading occurs when the bandwidth of the transmitted signal is becomes larger than the bandwidth of information signal. Transmission bandwidth does not depend on the information signal. The spreading method used in UMTS is DS-CDMA. In general view, spreading and despreading can be described by looking into Figure 3.4.

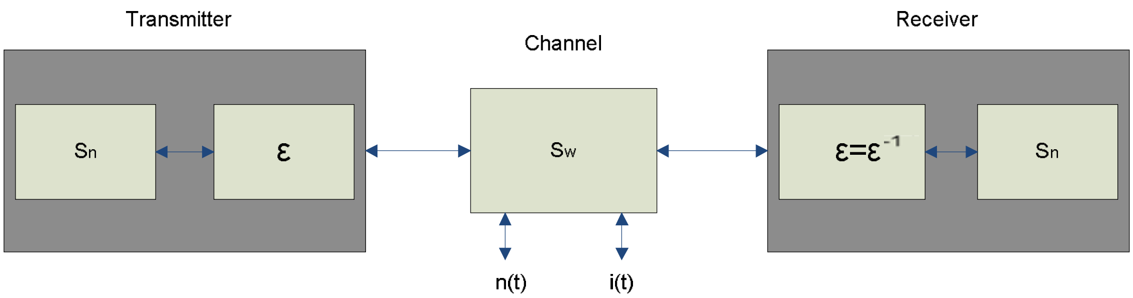


Figure 3.4 *Spreading concepts. [2]*

In above narrow band signal S_n is formed which has a frequency band W_i (information bandwidth). After the modulation process, bit sequences of length n are mapped to different narrow band symbols. The signal spreading is carried out containing narrow band signal, spreading over a large frequency band Wc (system chip rate). S_w denotes the spreading signal and spreading function is denoted by ε( ).

In DS-CDMA, information signal is multiplied with spreading code for calculating spreading factor:

$$SF = \frac{W_c}{R}, \qquad (3.1)$$

where one spreading code period is called chip and R denotes user data rate.

For despreading, the received signal is multiplied by the same user specific spreading code. Receiver spreads the narrow band interference until the actual information can be extracted. Spread spectrum technique puts major benefits over narrow band transmission. As the spreading of narrow band modulated signal into the wide band makes it unaffected from narrow band interference [23]. Interference energy is averaged over a wide bandwidth in despreading whereas the information signal is added into the narrow band signal. By this targeted signal is easily detected and interference is neglected because of very low amplitude. Figure 3.5 illustrates the despreading process and rejection of narrow band interference more conceptually.

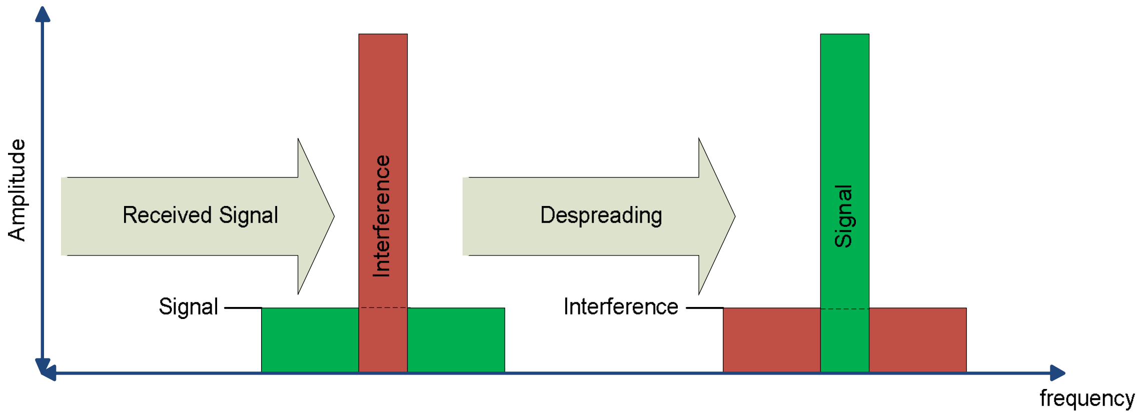


Figure 3.5 *Despreading process.*

In above only small amount of narrow band interfering signal energy passes the filter because of carrier chip rate W_c. The ratio of carrier chip rate W_c and user data rate R is called processing gain (PG) [2]:

$$PG = 10\log_{10}\left(\frac{W_c}{R}\right). \tag{3.2}$$

3.2.2 WCDMA Parameters

The information bits on WCDMA physical layer are spread over the bandwidth. The chip rate of WCDMA is fixed to 3.84 Mcps with a channel bandwidth of 5MHz. The access technology is direct sequence CDMA (DS-CDMA) and modulation technique is QPSK. Frequency band used for UL is 1920-1980 MHz and for DL is 2110-2170 MHz. Each of the transmission frame is a 10 ms containing 15 time slots. Spreading factor for UL is 4-256 and for DL is 4-512.

3.2.3 RAKE Receiver

In multipath propagation, signal energy may arrive at the receiver with some distinguishable time instants. The delayed signal extends from 1 µs to 2 µs in urban and indoor areas [5]. The receiver can separate the multipath component if the time difference of multipath is at least 0.26 µs [5].

RAKE receiver contains several sub-receivers, fingers, which are assigned to receive different multipath components of the signal. Each finger is equipped with a correlator, channel estimator and phase rotator. The channel estimator tunes the amplitude according to certain attenuation factor and phase rotator equalizes the phases of fingers. The amount of fingers depends on the maximum amount of multipath component that can be separated in the receiver. Delay at the receiver can be compensated by the difference in arrival time of symbols in each finger. Components are weighted properly and then combined by maximum ratio combining (MRC) method [2, 5, 9]. The block diagram of CDMA RAKE receiver is shown in Figure 3.6.

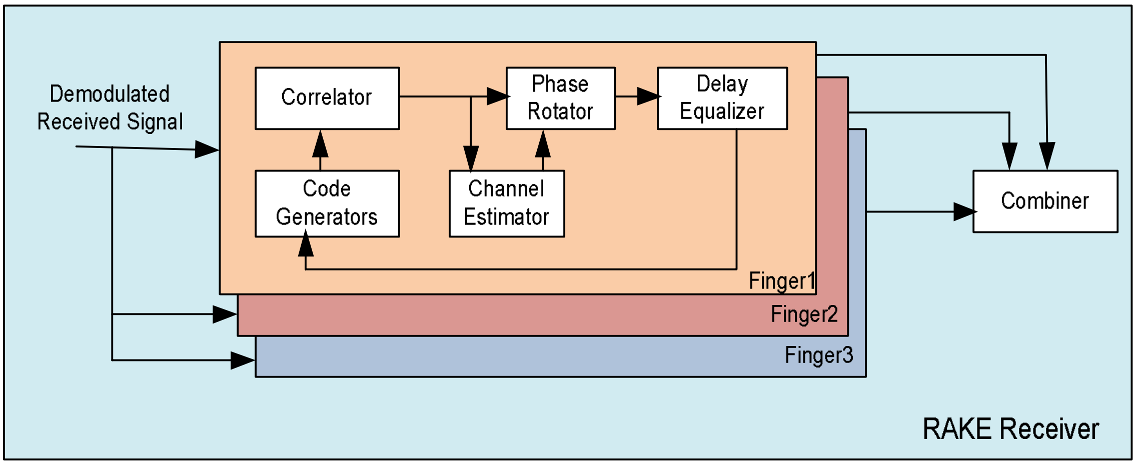


Figure 3.6 *CDMA RAKE receiver block diagram. [5]*

3.3 Radio Resource Management in UMTS

Radio resource management (RRM) mainly covers the functionality for handling the air interface resources of a radio access network. They are responsible for providing optimum coverage, QoS, ensuring best utilization of transport channels and offering maximum planned capacity. RRM consists of power control (PC), handover control (HO), admission control (AC), load control (LC) and packet scheduling (PS).

In UMTS, the main issue is interference as all users are using the same frequency. To ensure good QoS, PC is mainly responsible for adjusting transmit powers in uplink and in downlink. Physical and logical radio resources are controlled by resource manager. Its main task is to coordinate usage of available hardware resources and to manage code tree. HO takes care of user connected to mobile network is handed over to other cell while it is moving without breaking up the connection. AC is used to set up and reconfigure a RAB unless it is not overloaded. If overload situation is encountered by the system, LC functionality returns the system quickly and controllably back to the targeted load. The main functions of RRM are located in the RNC. The distribution of RRM and their locations in UMTS is described in Figure 3.7 [1, 2].

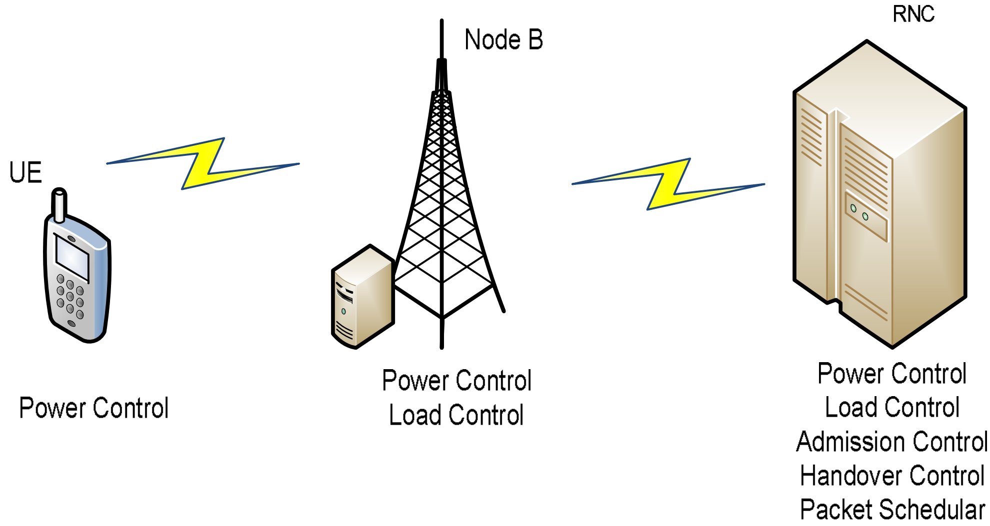


Figure 3.7 *Location and distribution of RRM in UMTS system. [10]*

3.3.1 Handover Control

Handovers are required in radio networks to ensure the continuous connection of moving mobile and good quality of service. There are three main types of handovers in UMTS: soft handover (SHO), softer handover (SfHO) and hard handover (HHO). There are algorithms in RNC which determine when handover is being made and these algorithms require measurements which are sent by Node-B and mobile itself.

In soft handover, UE is always connected with more than one radio link to UTRAN. UE is simultaneously controlled by two or more cells belonging to different Node-B's of the same RNC. In SHO, UE is always controlled by at least two cells under one BTS and also possible with one carrier frequency [5].

In softer handover, UE comes to the overlapping cell coverage area of two adjacent sectors of a base station. UE is controlled by at least two cells under one Node-B in softer handover. There are two air interface channels for the communication between a base station and UE, one for each sector separately. Two separate codes are required by UE in downlink direction. These codes are received due to RAKE receiver processing.

Hard handovers occur due to connection re-establishment by changing a serving cell. In simple words, the old radio links of UE are released before the new radio links are established. In this situation, cells are controlled by different RNC's and SHO is not allowed. Decision is made by RNC and it gets required measurements information from UE [2].

3.3.2 Power Control

As users share the same frequency in UMTS, transmission power control (PC) needs to be controlled. To ensure low interference, good coverage and better capacity of the system, one has to keep transmission power as low as possible. By the near-far effect, mobiles near the base station can easily block the connection for users who are near the cell edge if transmission power is too high. Without controlling transmission power, single mobile can block a whole cell [5].

Closed loop power control is being used in uplink direction to set the power of uplink DPCH and PCPCH. Where DPCH controls data and user data time multiplexed and PCPCH carries common packet channel (CPCH) and used for data transmission but no soft handover allowed. Node-B receives the target SIR from uplink outer-loop PC which is located at RNC and compares it with the estimated SIR on the pilot symbol of uplink DPCCH. DPCCH carries physical layer information and uses a slot structure with 15 slots over the 10 ms radio frame. If the measured SIR is higher than the target SIR, the base station will command the mobile station to lower the power. If it is too low, then it will send command to increase the power. The measuring command cycle is executed at 1500 times per second for each mobile station. Figure 3.8 shows the basic idea of closed loop power control for uplink [2, 5].

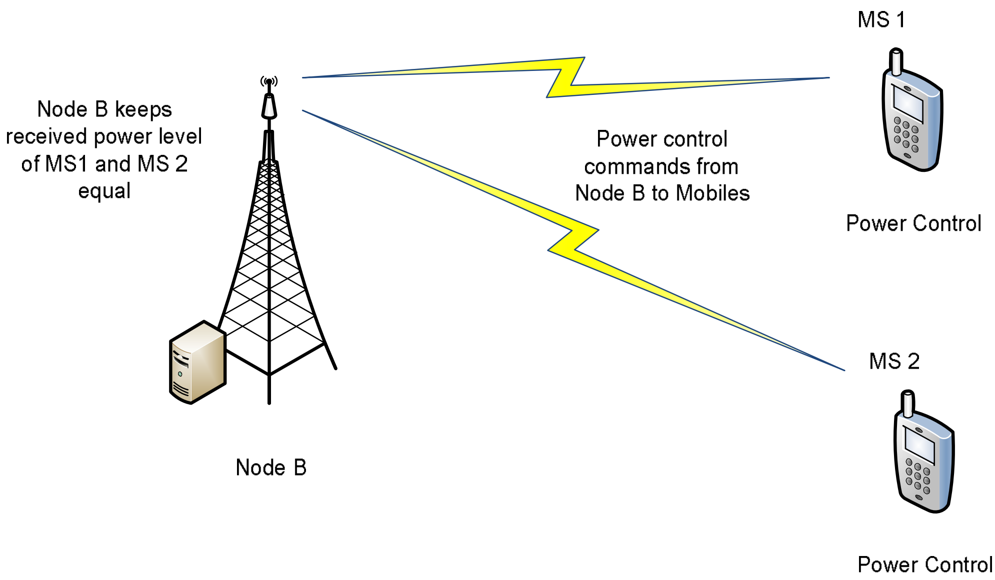


Figure 3.8 *Closed loop power control. [5]*

The same closed loop PC technique is used on the downlink direction. In downlink direction there is no near-far problem as the signal is delivered from one Node-B to many mobiles. But it provides more power for mobile station stations that are at cell edge, as they suffer from increased other-cell interference.

3.3.3 Congestion Control

In UMTS, air interface load has to be kept under the predefined threshold because excessive loading will not give required performance from the network. The main things which should be taken into account are capacity lower than required, planned coverage area and bad quality of service. Mainly three different functions are used and they are summarized here:

- Admission control: takes care of all new incoming traffic in the network. It checks the possibility that new packet or circuit switched user can be admitted in the system or not. Also it produces parameters for newly admitted user in the network.
- Packet scheduling: handles all non-real time traffic such as packet data users. As the non-real time traffic is not vulnerable to delay or bit rate variation it has loose requirements for packet timing. It defines when a packet transmission is initiated and bit rate used with the best effort basis.
- Load control: prevents the overloading of a system and run counter measures if system load has exceeded a certain threshold. If system gets overloaded, then load control functionality returns the system quickly to target load, defined by the radio network planner. [5, 11]

3.4 Channel Structure of UMTS

In UMTS, many channels are required for the establishment of the connection between UE and network. This means a lot of information exchange between both entities. These channels contain both logical and physical path flow during the establishment. As third generation systems are the wideband so they require more flexibility in services such as speech and data. There are three different types of communication channels in WCDMA system: logical channels, transport channels and physical channels. These channels exist in both uplink and downlink directions.

3.4.1 Physical Channels

In UMTS different types of channels are required to facilitate all communication links between the UE and network. The data carried by logical channels is carried over the air interface using transport channels mapped onto different physical channels [2, 23]. Some of the main Physical channels for UL and DL are described below:

- Physical random access channel (PRACH) for UL: it carries random access channel (RACH) and used for small amount of data transmission.
- Physical common packet channel (PCPCH) for UL: it carries common packet channel (CPCH) and used for data transmission but no soft handover allowed.
- Dedicated physical channel (DPCH) for DL: controls data and user data time multiplexed. It is a combination of DL DPDCH and DPCCH but both channels have the same power. The bit rate can vary for DPDCH frame-by-frame i.e. 10ms.
- Primary common pilot channel (P-CPICH) for DL: It is phase reference for other common channels, has fixed power and scrambled with primary scrambling code.
- Primary common control physical channel (P-CCPCH) in DL: it carries BCH channel with no transmission power control (TPC).
- Secondary common control physical channel (S-CCPCH) in DL: carries FACH and PCH with no transport control protocol (TCP).

- Synchronization channel (SCH) in DL: mainly used for search procedures.

  Primary SCH (P-SCH) carries primary synchronization code (PSC) and similarly secondary synchronization code is carried by secondary SCH (S-SCH).

3.4.2 Logical Channels

The logical channels provide a path for data transfer services. It depends on the type of data transferred that includes control channels and traffic channels. The control channels are used to carry the control plane information whereas the traffic channels are used to carry the user plane information. The main logical channels are described below with their functionality [2, 5].

- Broadcast control channel (BCCH): provide system information for mobiles in a cell in downlink.
- Paging control channel (PCCH): gives the paging information in downlink.
- Dedicated control channel (DCCH): controls information in UL and DL when there is no radio resource control.
- Dedicated traffic channel (DTCH): provides user data in UL and DL direction.
- Common traffic channel (CTCH): delivers data from one point to multipoint mobiles.

3.4.3 Transport Channels

It contains data that has been generated on higher layers and carried to the air interface. They are mapped in the physical layer to different physical channels. Transport channels have two main divisions: common transport channels, which can be used by any user and dedicated transport channels, which are reserved for a single user [2, 5]. Some main transport channels are given below:

- Random access channel (RACH): used for initial access and small data transfers in UL.
- Common packet channel (CPCH): shares packet data channel in UL.
- Forward access channel (FACH): used for small data transfer in DL.
- Broadcast channel (BCH): gives system information in a cell.
- Downlink shared channel (DSCH): is a common channel used for dedicated control and user data.
- Dedicated channel (DCH): used for dedicated control and user data in UL and DL.

4. HSPA Evolution (HSPA+)

With the growth of users and higher data rates in the network 3GPP has brought two new techniques, HSPA and LTE. LTE is now known to be the technology of future and HSPA is cost reducing solution for UMTS network. The main difference between HSPA and HSPA evolution (HSPA+) is that prior uses Release 5 and Release 6 with 16-QAM modulation technique and the later one uses Release 7 with 64-QAM modulation technique [11]. 64-QAM feature increases the peak interference bit rate to 21.6 Mbps with category 14 terminals [15]. Whereas category 10 terminals in Release 6 only supports the air interface bit rate of 14.4 Mbps [15]. The bit rate for LTE in Release 8 is 100 Mbps in downlink and 50 Mbps in uplink. The 3GPP Release 5, Release 6 and Release 7 are summarized in this chapter.

4.1 HSDPA Concept

HSDPA can be deployed on existing WCDMA network architecture and it is defined in Release 5 specification [11]. HSDPA is based on downlink shared channel and allows data rates up to 14.4 Mbps. It is also known as reverse link as it is designed to support services that require instantaneous high rates in downlink and lower rates in uplink [12]. This will enhance the UMTS downlink packet data performance that will provide users with higher data rates, increased capacity and less redundancy. The two important features in UMTS are variable spreading factor (SF) and fast power control which has been replaced in HSDPA with adaptive modulation and coding (AMC) [14]. In HSDPA, resources such as codes and transmission power are shared among all users. The transport channel which is carrying user data is known as HS-DSCH. Some of the main features of this channel is to support channel dependent scheduling, AMC and HARQ with soft combining.

4.1.1 Channel Sharing Concept

In HSDPA code and transmission power are dynamically distributed among users in the time domain. HS-DSCH is a transport channel which uses spreading factor of 16. The maximum number of codes used for transmission is 16 and from these 16 codes, one code is dedicated to mandatory channels. To support the signaling of HS-DSCH some new channels were introduced: high speed shared control channel (HS-SCCH) in downlink and high speed dedicated physical control channel (HS-DPCCH) in uplink [11].

HS-SCCH contains the main information for HS-DSCH demodulation. If there is no data on HS-DSCH, then there is no need to transmit HS-SCCH. There will be maximum four HS-SCCH at a given time which can be divided into two parts: first part contains time-critical information such as the transport format and allocated codes before the utilization of HS-DSCH channel use and second part contains information related to retransmission [11].

The main feature of HS-DPCCH is ACK/NACK transmission to ensure correct decoding of packet data. To determine channel quality, HS-DPCCH uses the channel quality indicator (CQI) for estimation of transport block size, the number of parallel codes and modulation technique. Figure 4.1 shows the flow of user data and associated control signaling involved in HSDPA transmission

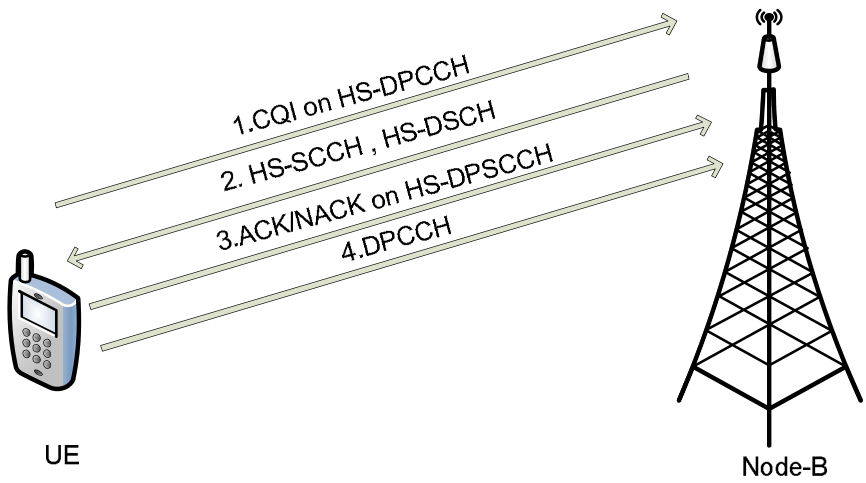


Figure 4.1 *Transmission scheme of HSDPA.*

4.1.2 Packet Switched Data on DCH, FACH and HSDPA

Transmission of packet switched data in Release 99 typically uses DCH and FACH. As DCH is suited for high traffic volumes, setup time is slow, making DCH unsuitable for bursty data such as a web browsing. Whereas FACH is a common channel without power control and has a low setup time. This makes it unsuitable for larger traffic volumes and makes highly suitable for bursty traffic. By contrast, HSDPA is well suited for bursty traffic and it provides much higher data rates than system operating on DCH or FACH. A simple comparison is given below in Table 4.1:

Table 4.1 *Comparison of fundamental properties of DCH, FACH and HSDPA. [11]*

Mode	DCH	FACH	HSDPA (HS-DSCH)
Channel Type	Dedicated	Common	Common
Power Control	Closed Inner Loop	Open Loop	Fixed Loop
Suitability for Bursty	Poor	Good	Good
Data Rate	Medium	Low	High
Soft Handover	Yes Support	No Support	No Support

4.1.3 Modulation Scheme

Modulation scheme used in HSDPA consists of quadrature amplitude modulation with 16 constellation points (16-QAM) and quadrature phase shift keying (QPSK) that is used in UMTS R99. QPSK contains four symbols with 2 bits/symbol whereas 16-QAM contains 4 bits/symbol. By this 16-QAM doubles the peak data rate compared with QPSK and allows till 14.4 Mbps peak data rate with 15 codes of SF 16. But there are some issues as higher amount of symbols requires more accurate estimation and more accurate phase information. Since constellation points have smaller differences in the phase domain compared with QPSK [5,11]. Figure 4.2 shows the constellation of QPSK and 16-QAM.

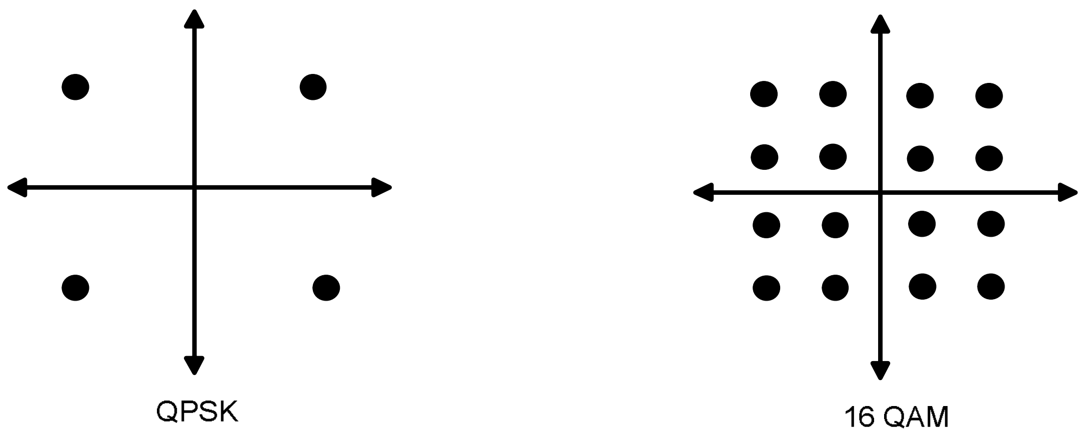


Figure 4.2: *QPSK and 16-QAM Modulation scheme. [11]*

4.1.4 Scheduling

Scheduling controls allocation for shared resources among users at each time instant. In HSDPA resource allocation has been moved to Node-B. Due to this, MAC layer enables the rapid reallocations of resources and faster adaptation to radio channel variation. Total available transmit power of the cell is shared when transmission to multiple users occurs in parallel. Scheduling decisions are made on the packet scheduler based on the reception capability of UE and returned CQI value [9, 11].

If link adaptation is based on power control, then the lowest power can be used for a given data rate which minimizes the interference to transmission in other cells for a given link. But if link adaptation is based on rate control then the highest data rate for given transmit power can be achieved [9]. As link conditions vary for every user, the scheduling decision is made is made on bases of schedule users with the instantaneous best channel conditions. This method of scheduling is referred as maximum C/I scheduling. This principle of maximum C/I scheduling is shown in Figure 4.3 where each user has different scheduling according to link conditions.

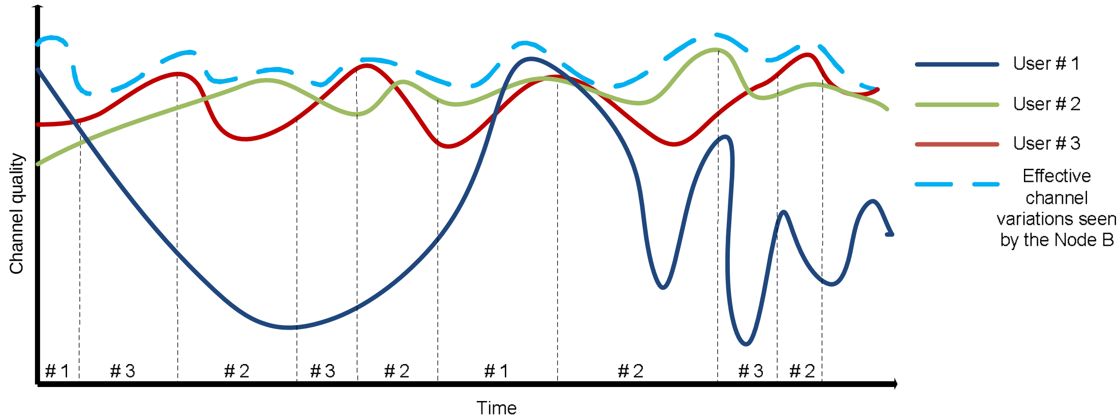


Figure 4.3 *Channel dependent scheduling in HSDPA. [9]*

4.1.5 HSDPA Mobility

Data transmission in HSDPA is done by one shared channel, HS-DSCH so soft handover is not possible. When changing best cell, measurement report from UE is sent to RNC which makes the decision and initiates the hard handover. If the handover is between the cells of same Node-B, the MAC-hs layer can forward the data flow from the source cell to target cell, maintaining HARQ process. Whereas if the handover is between different Node-B’s than handover procedure resets MAC-hs buffers in the source cell and at the same time target cell starts to send data to the user.

Hysteresis margin is used to avoid the fast and random changes of the serving cell. After UE changes the cell, data transmission is terminated from previous cell and all MAC functions of UE are reset. All packet losses during handover are controlled by RLC before a new HARQ process is activated.

4.1.6 Hybrid Automatic Repeat Request (HARQ)

HARQ basic operation is to request for retransmission of corrupted or discarded received packets. HARQ rely on error detection to detect uncorrectable errors and uses forward error correcting codes to correct a subset of errors. Short comings in transmission are completed by HARQ with soft combining. Retransmission has the same number of bits and information set as the original transmission but set of coded bits transmitted may be selected differently. HARQ is layer 2 process where UE sends ACK/NACK reports to Node-B for a successful transport block received. Retransmission is needed only if NACK messages are returned. From the networks point of view then transmission is successful if one transmission succeeded [5, 9].

In soft combining, soft information from the previous transmission attempts is used to increase the probability of successful decoding. There are two main methods used for soft combining namely: chase combining and incremental redundancy (IR).In chase combining retransmission contains the same set of coded bits as the original transmission. But in the incremental redundancy multiple sets of coded bits are generated that represent the same set of information. In IR, each transmission does not have identical information as the original transmission. HSDPA utilizes IR for the combining process as it increases the amount of higher coding rate for retransmitted packets. There are maximum three retransmission requests and if still HARQ fails to retransmit then this process is moved to an upper layer [9, 11].

4.2 HSUPA Concept

Release 6 of 3GPP specification shows the study for enhanced uplink UTRA FDD which focuses on performance enhancements for uplink dedicated transport channels. The key idea is to increase uplink data throughput by using the similar concepts of HSDPA such as fast physical layer and base station scheduling. On the basis on device feedback, Node-B estimates the data rate on which transmission has to take place. Similarly retransmission takes place on the basis of Node-B feedback. A simple comparison of the basic properties of HSDPA and HSUPA are given in Table 4.2.

Table 4.2 *Comparison of HSUPA and HSDPA [11].*

Feature	HSUPA	HSDPA
Variable spreading factor	Yes	No
Fast power control	Yes	No
Scheduling	Multipoint to point	Point to multipoint
Fast L1 HARQ	Yes	Yes
Soft handover	Yes	No
Non scheduled transmission	Yes	No

In HSUPA, Node-B calculates the data rate required for each active user based on device feedback. The scheduler in Node-B then gives instruction to devices on the uplink data rate to be used at fast pace depending on the feedback received and scheduling algorithm. Also retransmissions are initiated from Node-B feedback. Fast scheduling allows dynamic sharing on interference and on network resources [11]. As the control of scheduling is now on receiver side of radio link, there is added delay in the operation. Thus tracking the fast fading of the user for scheduling the uplink is not necessarily that beneficial. Fast scheduling allows dynamic sharing not only of the interference budget but also of the network resources such as baseband processing capacity.

4.2.1 HSUPA Channels

Performance has been upgraded in HSUPA by including a new transport channel called enhanced dedicated channel (E-DCH). E-DCH is a dedicated channel which requires fast power control to avoid uplink interference. E-DCH supports fast physical layer HARQ with incremental redundancy, fast Node-B based scheduling and optionally a shorter 2-ms TTI. HSUPA does not support adaptive modulation because it does not support any higher order modulation schemes. [16]

4.2.2 Fast HARQ

The main purpose of fast HARQ is to allow Node-B to ask UE to retransmit the uplink packet if a received packet is corrupted. The ratio E_c/N_0 can be reduced by using different methods of combining at Node-B. With fast HARQ, BLER of the first transmission is high due to the reduction of delay experienced from retransmission. A higher BLER reduces the UE transmission power required for a given data rate. Considering a fixed data rate, capacity increases and lower energy per bit contributes to range improvement as well. A simple comparison between fast HARQ and Release 99 is shown in Figure 4.4.

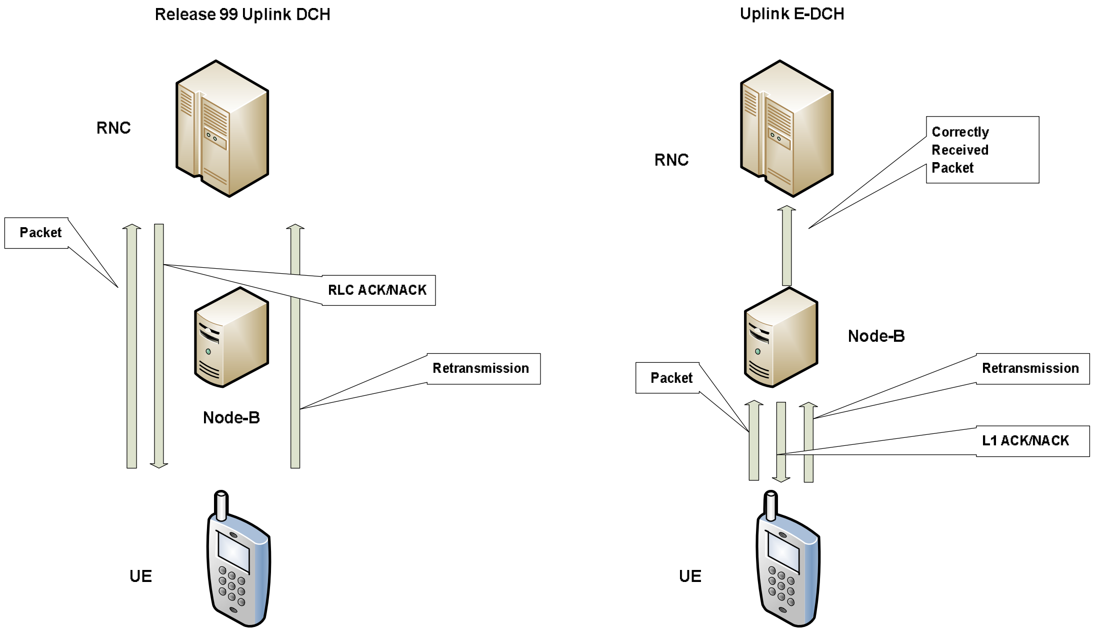


Figure 4.4 *Release 99 and enhanced uplink retransmission control. [5]*

4.2.3 Power Control

Power control does not vary while comparing E-DCH and DCH. The transmission power of DPCCH is controlled by an inner power control loop. As DPDCH transmission power is controlled by transport format combination (TFC) selection, similarly E-DPDCH transmission power is set by E-TFC selection. The inner loop of Node-B makes decision on SIR set by the outer loop power control in RNC. If random transmission takes place at DCH, then information E-DCH will also get affected. Whereas due to the introduction of hybrid ARQ for E-DCH, BLER is not an adequate input for the outer loop power control. Therefore to control outer loop power, retransmission request are being sent from Node-B to RNC. [9]

4.2.4 Multi Code Transmission

A spreading factor of minimum 4 is used in UMTS 99 for dedicated physical channel in uplink whereas HSUPA utilizes a spreading factor of 2. But due to I/Q-modulation restrictions, SF4 is used simultaneously with SF2 in HSUPA. As far as signaling is concerned, HSUPA transmission requires two codes with SF4 and UE is able to get two codes with SF4 and two with SF2 for multi code transmission. Modulation scheme for UMTS 99 is binary phase shift keying (BPSK) which remains the same for HSUPA transmission [5].

4.3 HSPA Evolution (HSPA+) Concept

HSPA+ is a 3GPP Release 7 with 64-QAM modulation technique. Its data rate in Release 7 is 5.76 Mbps in uplink and 21.1 Mbps in downlink. Using 2x2 MIMO in Release 7, peak data rate will increased to 28 Mbps. If 2x2 MIMO and 64-QAM modulation are combined then peak data rate will be more than 40 Mbps, but this combination is not included in Release 7. In Release 8, LTE data rate is improved to 50 Mbps in uplink and 100 Mbps in downlink. Some of the main features include the best CS and PS combined radio network; higher data rates, lower latency and spectrum can be shared with current 3G network. HSPA+ is working in parallel with LTE development and some properties of LTE work are also reflected on HSPA+. HSPA+ has continuous packet connectivity, high speed FACH and utilizing 64-QAM HSDPA [14]. As HSPA+ includes interworking with LTE, providing both packet handovers and voice handovers from LTE VoIP to HSPA+ circuit switched voice.

4.3.1 Higher Order Modulation

In Release 6, modulation scheme for HSUPA is QPSK with multi-code transmission, providing 5.76 Mbps. Release 7 introduces 64-QAM transmission for downlink and 16-QAM for uplink. 64-QAM can increase the peak bit rate by 50% compared with 16-QAM and can transmits 6 bits with a single symbol. In 64-QAM, one can transfer more bits/symbol but the constellation is closer together, hence the probability of error is higher. As constellation points are closer to each other, SIR will be increased. There is approximately 6 dB difference of SIR between 16-QAM and QPSK, similar difference is present between 16-QAM and 64-QAM [13]. Figure 4.5 shows the constellation between 16-QAM and 64-QAM.

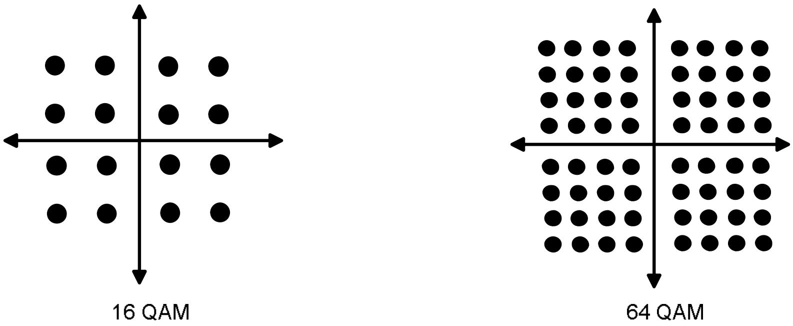


Figure 4.5 *16-QAM and 64-QAM constellation. [13]*

Maximum HS-DSCH data rate can be calculated for HSPA+ with some assumptions such as link adaptation mode with 64-QAM (6 bits/symbol), UE capable of using all 15 OVSF, empty cell and 1/1 coding (no redundancy). Chip rate of system is 3.84 Mcps and TTI is 2 ms. Table 4.3 shows the maximum theoretical physical layer downlink bit rate for HSPA+. According to calculations, system symbols rate was 480 symbols/TTI and user bits per code is 2880 bits/TTI. After some simple calculation, max HSDPA throughput for HSPA+ is 21.6 Mbps.

Table 4.3 *Calculation for maximum physical throughput for HS-DSCH in HSPA+.*

Equations and calculations	Description
$R_{chip} = 3.84Mcps * 2ms = 7680\ chips/TTI$	System chip rate times TTI.
$R_{symbol} = \frac{R_{chip}}{16SF} = 480\ symbols/TTI$	Chips per TTI divided by fixed spreading factor.
$R_{bit} = \frac{R_{symbol}}{6\frac{bits}{symbol}} = 2880\ \ bits/TTI$	Maximum number of user buts per code, utilizing the 64-QAM modulation.
$R_{HSDPA\_max} = \frac{R_{bits} * 15codes}{2ms} = 21.1Mbps$	Maximum theoretical physical layer throughput by 15 codes with 2880 bits every TTI.

4.3.2 MIMO Transmission

Theoretically, improvements can be made in the peak data rate by using larger bandwidths, higher order modulation or multiple input multiple output (MIMO) using multi-antenna transmission. Release 7 includes MIMO and higher order modulation, 64-QAM for downlink and 16-QAM for uplink. Whereas dual carrier HSDPA was introduced in Release 8. MIMO transceivers are used for diversity and multistream MIMO is used for having a high quality channel indicator (good CQI). In general 3GPP uses closed loop feedback from terminal to adjust antenna weighting. MIMO concept uses two transmit antennas at Node-B and two receiver antennas at terminal [11, 13]. A brief diagram of 2x2 MIMO transmission concept is shown in Figure 4.6. By using 64-QAM and MIMO concepts, data rate is improved by 200 % providing data rate from 14 Mbps to 42 Mbps, but in practical cell capacity was improved by 20 % [13].

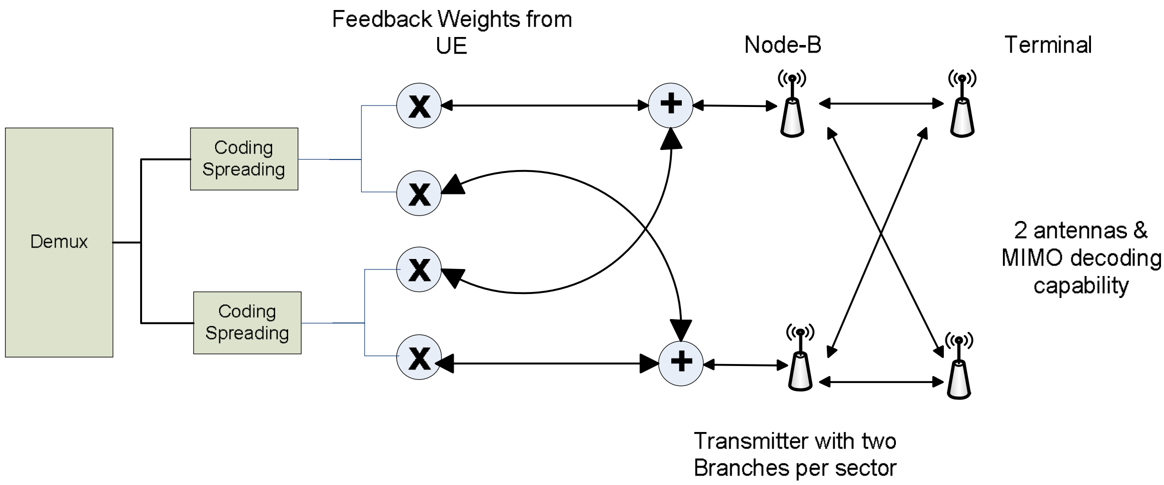


Figure 4.6 *2x 2 MIMO concepts. [11, 13]*

4.3.3 Dual Carrier

Data rates are improved in LTE as its bandwidth is up to 20 MHz compared with 3.84 MHz in HSPA+. Release 8 includes dual carrier for HSDPA providing two adjacent carriers. These carriers are used in transmission to single terminal using 10 MHz downlink bandwidth. This doubles the user data rate at low loading since user can access the capacity of two carriers instead of one.

Dual carrier HSDPA and MIMO can increase HSDPA data rates. Both can provide sam data rate of 42 Mbps with 64-QAM MIMO. Similarly spectral efficiency can be improved by MIMO as it uses two antenna transmissions. If comparing both, then dual carriers HSDPA is easily upgraded in a network as it only requires single 10 MHz power amplifier whereas MIMO requires two separate power amplifiers [13]. Comparison of dual carrier HSDPA and MIMO is given in Table 4.4.

***Table 4.4** Comparison between Dual carrier HSDPA and MIMO. [13]*

Properties	Dual carrier	MIMO
Peak bit rate	42 Mbps	42 Mbps
Spectral efficiency improvement	20% due to frequency domain scheduling and larger trunk gain	10% due to two antenna transmission
Data rate gain	Similar gain over the whole area	Largest gain close to Node-B where dual
Node-B RF requirements	Single power amplifier per sector	Two power amplifier per sector
UE RF requirements	Possible with 1 antenna terminal	2 antennas required

4.3.4 HSPA+ Uplink

Release 6 HSUPA uses QPSK modulation providing 5.76 Mbps. In Release 7, 16-QAM modulation was adopted as HSUPA, doubling the peak data rate to 11.5 Mbps. But utilizing higher modulation improves the downlink spectral efficiency because in downlink there is limited number of orthogonal resources which is not the same in uplink. HSUPA uplink is not orthogonal and practically unlimited number of codes is available in uplink so the highest spectral efficiency can be achieved by QPSK modulation. In simple words, HSUPA 16-QAM is a peak data rate feature but it is not valid for a capacity feature. [13, 14]

4.3.5 Discontinuous Transmission & Reception (DTX/DRX)

Improvement in technology includes decreasing the mobile terminal power consumption. HSPA+ improved power consumptions for CS voice calls and for all packet services. In Release 6, UE always sends control channels even if there is no data transmission. This has been changed in Release 7 where UE can cut off the control channel transmission as if there is no data transmission. This solution is known as discontinuous uplink transmission and brings clear savings in transmitter power consumptions. [14]

Similar is the case with downlink where UE checks after some time if downlink data transmission has been started again or not. If there is no data frame to be received, then UE uses a power safe mode. This concept is known as discontinuous reception. The idea of discontinuous transmission is illustrated in Figure 4.7 where as an example user is downloading a web page. When user starts reading it then the connection enters the discontinuous transmission and reception mode [13, 14].

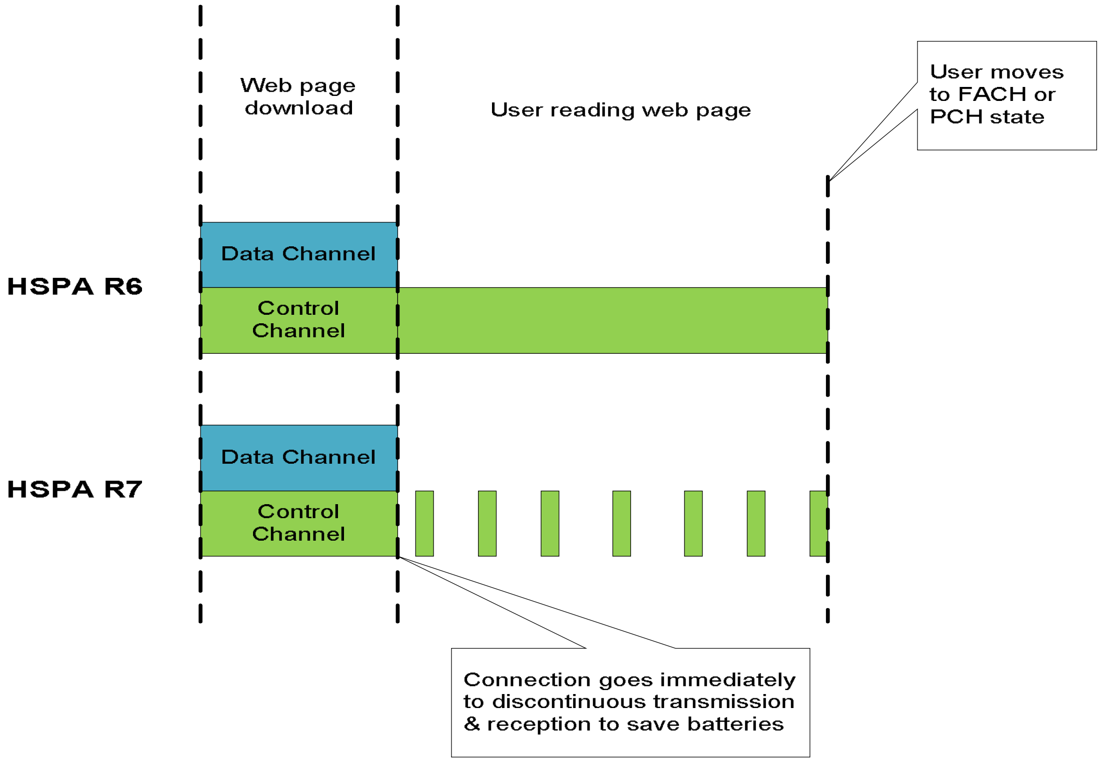


Figure 4.7 *DTX and DRX with continuous packet connectivity. [13]*

4.3.6 Circuit Switched Voice on HSPA+

Two main benefits of CS voice on HSPA+ are improvement in spectral efficiency and reduction in UE power consumption because of DTX/DRX. IP header is not required for compression of a CS voice. Talk time is improved to 50 % and core signaling runs faster on HSPA+. There is advantage of CS voice on HSPA+ for IP protocol and packet transmission considering all interfaces such as I_u-CS over IP, air interface carried by HSPA+ and backbone between media gateways (MGW) using IP. There are no changes required for charging, roaming and emergency calls. These interfaces are shown in Figure 4.8.

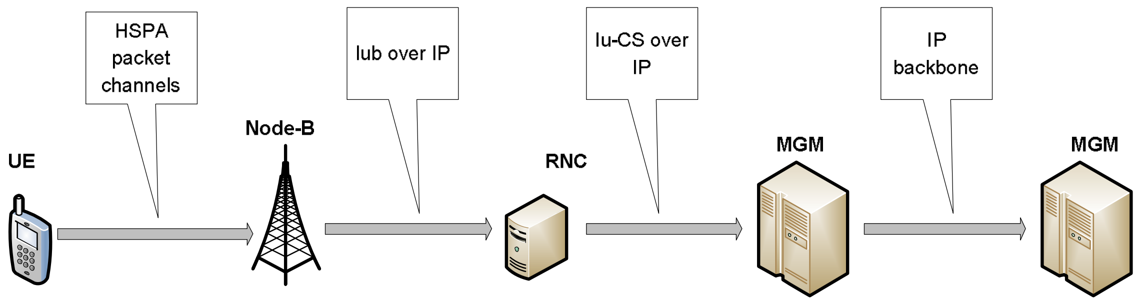


Figure 4.8 *Different modes of CS voice call. [13]*

4.3.7 Flat Architecture in HSPA+

By introducing flat architecture, overall performance of both user and control-plane efficiency is improved. It also improves the IP based services and competence of last mile transport in a network. Protocols such as RLC protocols are completed in Node-B only and they are not passed to RNC. In Release 5 and Release 6 more functionality were distributed and transferred from RNC to Node-B. Therefore a flat HSPA+ architecture is designed which includes all RNC functionalities in Node-B. In Release 6, a maximum number of 4096 RNC's can be connected to each SGSN. But address space is increased in Release 7 by connecting SGSN directly to each base station [11].

Release 7 includes flat architecture improvements both in radio network and the packet core. Such a solution is called direct tunnel solution which allows a user- plane to bypass SGSN [11]. There is no RNC element required so RNC dimensioning is not affected by the traffic. Evolution toward flat architecture is shown in Figure 4.9.

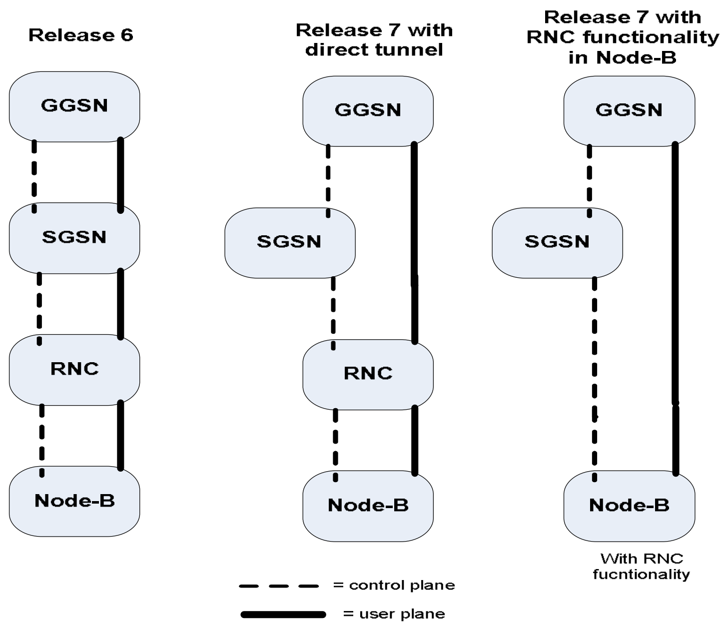


Figure 4.9 *HSPA Evolution Flat architecture. [13]*

4.3.8 Properties HSDPA/HSUPA and HSPA+

Different properties of all these three technologies according to their releases are given in Table 4.5. Major properties include data channels, modulation techniques (with their Releases), physical throughputs and channelization codes. Transmission time interval is same for HSUPA, HSDPA and HSPA+. Soft handover is present in HSPA+ and HSUPA.

Table 4.5 *Properties of HSDPA/HSUPA and HSPA+*.

Different Properties of HSUPA/HSDPA/HSPA+			
	HSUPA	**HSDPA**	**HSPA+**
Data Channel	E-DCH (UL)	DL: HS-DSCH & HS-SCCH, UL: HS-DPCCH	HS-DSCH, E-DPDCH (UL), E-HICH (DL)
Modulation	QPSK (R6)	QPSK, 16-QAM (R5)	HSUPA QPSK, 16-QAM HSDPA QPSK, 16-QAM,64-QAM
Transmission time interval	10ms	2ms	2ms
MIMO	No	No	Yes
Physical Throughput	5.76 Mbps	14.4 Mbps	HSUPA 11.5Mbps, HSDPA 21.1Mbps, HSDPA 42.2Mbps (R8 with 64-QAM &2x2 MIMO)
Channelization codes per user	2SF2+2SF4	15 SF16	UL: 2SF2+2SF4 DL: 15 SF16
Soft Handover	Yes	No	Yes

5. Radio Network Planning

Radio network planning (RNP) is used to ensure that a telecommunication network successfully operates with peak performance. For operators, RNP is the main tool for achieving high QoS and cost effective network. The key achievement in good RNP is to meet current and future demands of the market considering coverage, capacity and quality. In WCDMA network single frequency used making it highly vulnerable to interference as compared to GSM system. WCDMA network uses the same old philosophy of planning used in GSM, “coverage first a, capacity later” but UMTS network requires constant feedback from the network for optimization process. [1]

5.1 Channel Concept

The fundamental aspect in radio network planning is the amount of information that can be transmitted over the communication channel with good QoS and GoS. As the number of user grows, demands for more resources available from the allocated spectrum grow as well. In order to minimize the problems of blocked and dropped calls, intense use of channels reuse between cells begins [6]. Reasonable bandwidth, higher order modulation, interference suppression and spatial multiplexing are required to get effective data rates in WCDMA systems. Shannon capacity theorem gives better understanding of channel capacity. Also channel sharing concept is important aspect that gives better perceptive of sharing the channels among the resources.

5.1.1 Capacity Planning in UMTS

The capacity of UMTS network is known to be interference limited and is directly related to the link budget. As UMTS is interference sensitive system so rise in interference causes decrease in capacity of the network. In interference limited system call blocking is caused by the rise in interference of cell. [6] The load equation approach is commonly used to compute the capacity of UMTS network in DL and UL. The factors in loading equations include activity factor in speech and data services, required E_c/N_0, number of handovers in DL direction and other to own cell interference.

In DL direction, two main aspects are considered, interference from other cells and BS power. Whenever a UE is in soft handover condition with two BS, then at that time UE is communicating with two base station at the same time and sue to this downlink capacity decreases. DL pole capacity can be interpreted as the maximum capacity with infinite BTS power and formula for calculating pole capacity in DL direction is given as: [1]

$$N_{pole\_DL} = \frac{\frac{W}{R_b}}{\frac{E_b}{N_0} * v * [1-\delta] + i}, \qquad (5.1)$$

where (N_{pole_DL}) is the pole capacity in downlink direction, (W) is the spreading bandwidth of the system (3.84 MHz), (R_b) is the bit rate of offered service, (E_b/N_0) is quality requirement, (v) is the activity factor, (i) is the interference factor defined as the ratio between other cell to own cell interference and (δ) is orthogonality defined as the measure of how much code into the same cell do not interfere with each other.

5.1.2 Shannon Capacity Theorem

Capacity theorem is used to determine the total information that can be transmitted over a communication channel. According to Shannon theorem, maximum rate of information C for a given communication system is known as channel capacity in bits per second and given as:

$$C = B \log_2(1 + S / N), \qquad (5.2)$$

where B is the bandwidth of channel in hertz and S/N is the signal to noise ratio. If information rate $R \le C$ then transmission may be accomplished without any error in presence of noise.

5.2 Cellular Radio Network Planning Process

The planning process contains three main phases which include pre-planning (i.e. dimensioning), detailed planning and post planning (optimization and monitoring) [1]. The dimensioning phase of HSPA+ is similar to 2G network planning as both consider coverage and capacity. After pre-planning, detailed planning starts with configuration planning, coverage planning, frequency planning, capacity planning and parameter planning. WCDMA planning process is illustrated in Figure 5.1.

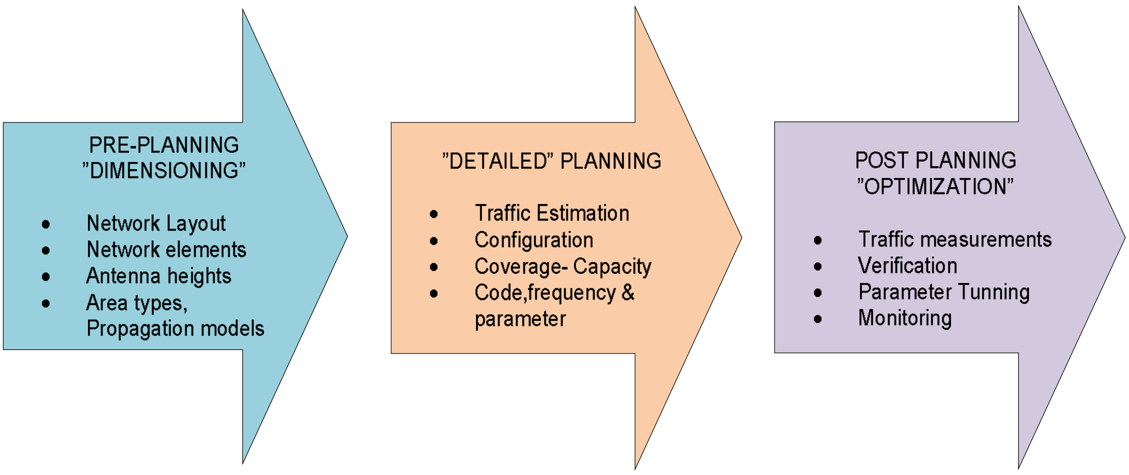


Figure 5.1 *WCDMA planning process. [1]*

5.2.1. Pre-Planning

This phase includes a rough estimate for network requirements such as the number of base stations to cover a certain area and to serve a certain capacity. Input data for the pre-planning phase are traffic load (demand), maximum number of users and network coverage area. The estimation is based on the radio propagation environment in the area and requirements set by the operator. One of the important parameter that is required for dimensioning is Node-B antenna height. The antenna height is needed in preliminary cell range estimations and considering the maximum allowable path loss. It is a result of subsequently introduced link budget calculation. Initial planning phase cannot be ignored as coverage and capacity demands of the radio network may vary with the passage of time.

5.2.2. Detailed Planning

Detailed planning consists of configuration planning, topology planning and parameter fine tuning using actual network data. Network parameters of initial planning phase are moved to planning tool or simulator. This tool provides capacity estimations and coverage predictions when base station sites are used. For better coverage and capacity, site configuration has to be modified and sector orientation has to be optimized for different locations and antenna configurations (antenna heights, beam widths). Second phase has much more practical approach than assumptions and requirements defined in the pre-planning phase [1].

5.2.2.1. Configuration Planning

Intention of configuration planning is to define the network base stations and antenna line equipment. For the configuration planning, first thing to calculate is radio power budget which determines the maximum allowable path loss in radio environment. Power budget calculations vary for different service profiles. Cell breathing phenomenon must be taken into account in coverage threshold and cell range calculations. Path losses are calculated separately for downlink and uplink direction for different loads and services in order to detect limiting factors [1]. UMTS power budget is uplink limited due to maximum coverage and low targeted load in the network. As a result of configuration planning, list of antenna line elements for different phases and detailed base station configuration are known [1].

5.2.2.2. Topology Planning

In topology planning, coverage and capacity calculations are estimated. The main parameters include site location, coverage area, site density and cell direction. To ensure good coverage, adjustments are made in antenna-element elevation, the antenna down tilting and radiation beam width. The main things that are required in topology planning are coverage predictions, simulations and network performance analysis. WCDMA topology planning process is shown in Figure 5.2.

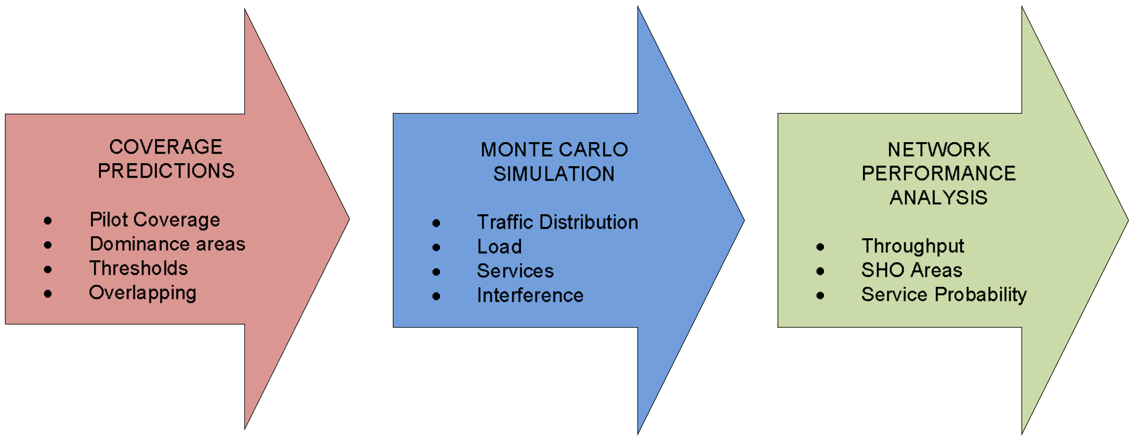


Figure 5.2 *WCDMA topology planning. [1]*

The outcome of the initial phase is the estimation of the pilot signal coverage areas, cell dominance areas and cell overlapping areas. System level simulations help in predicting the impact on coverage and maximum traffic load of the network in different cells. Simulations contain distribution of the certain number of mobile terminals that are located over the area. From these results, the total capacity of network and correct locations of base stations are known.

Link budget is used to calculate the maximum uplink and downlink path loss. In UMTS, link budget is affected by the system load. As an example, a simple UMTS outdoor link budget calculation is given in Table 5.1 for speech and data services. Maximum allowable propagation loss for speech service is with 50% load in UL and DL. For data services, 75% load is used for 64 kbps UL and 384 kbps DL service.

Table 5.1 *Link budget UMTS 2100 MHz. [1]*

Link Budget UMTS 2100 MHz					
		Speech/12.2 kbps		Data/384 kbps	
Service profile	**Unit**	**Uplink**	**Downlink**	**Uplink**	**Downlink**
Load	%	50	50	75	75
Bit rate	kbps	12.2	12.2	64	384
Chip rate	cps	3.84E+06			
Temperature	K	293			
Boltzman's constant	J/K	1.38E-23			
Receiving end		**Node-B**	**Mobile**	**Node-B**	**Mobile**
Thermal noise level	dBm	-108.09	-108.09	-108.09	-108.09
Noise figure	dB	4	8	4	8
Noise power	dBm	-104.09	-100.09	-104.09	-100.09
Interference margin	dB	3.01	3.01	6.02	6.02
Total interference level	**dBm**	**-101.08**	**-97.08**	**-98.07**	**-94.07**
Required Eb/No	dB	5	7	2.50	1.50
Processing Gain	dB	24.98	24.98	17.78	10.00
SHO diversity gain	dB	2	3	2	3
Required C/I	**dB**	**-21.98**	**-20.98**	**-17.28**	**-11.50**
Receiver sensitivity	dBm	-123.06	-118.06	-115.35	-105.57
RX antenna gain	dBi	18	0	18	0
Cable loss	dB	5	2	5	2
Required signal power	**dBm**	**-136.06**	**-116.06**	**-128.35**	**-103.57**
Transmitting end		**Mobile**	**Node-B**	**Mobile**	**Node-B**
TX Power	dBm	20.00	43.98	20.00	43.98
TX Power / connection	dBm	20.00	33.98	20.00	33.98
Antenna gain	dB	0	18	0	18
Cable loss	dB	2	5	2	5
Peak EIRP	dBm	18.00	46.98	18.00	46.98
Maximum allowable path loss	**dB**	**154.06**	**163.04**	**146.35**	**150.55**

The link budget in Table 5.1 is unbalanced, as there is clear difference in path loss in both UL and DL direction. However unbalance power budget can be balance by using techniques such as reception diversity in UL and using LNA's. In practical UMTS network, high indoor coverage probabilities are required as outdoor cell coverage area overlap excessively. In order to summarize, the results from configuration planning provide details about the link losses in UL and DL for coverage prediction and configuration of Node-B. [1]

5.2.2.3 Code and Parameter Planning

Before the launch of the network, code and parameter planning are needed in CDMA systems. In code planning, unique orthogonal codes are allocated to different cells to differentiate among users and physical channels. There are altogether 512 scrambling codes according to 3GPP specifications thus code limitation is not a problem. Parameter planning includes objects like signaling, RRM, measurement tasks, cell selection and handover control groups (both in idle and connected modes). Values of parameters can be changed after the network is launched according to the need of radio propagation environment, low capacity, coverage holes and customer feedback.

5.2.2.4 Optimization Parameters

When the network has been launched, then performance evaluation is performed by the network KPI's, customer feedback and field measurements. Performance evaluation results give idea about the network deficiencies that can be rectified and helps to resolve future bottlenecks. This is known as the optimization of the network which is an ever going process as it involves the continuous monitoring and verification of parameters in the network. Optimization requires extension in the network that can be hardware, software, expansion for removing the coverage holes and implementation of new technology

5.2.3 Post planning

Last phase of radio network planning includes the verification and monitoring of current radio network plan. The call establishment, soft handovers, inter-system handovers are tested to ensure the correct definition of network parameters. Verification of coverage area is also important as coverage holes might be there where subscribers are present. Optimization of the network is also a part of post-planning that can improve network coverage and capacity by simple changes including the antenna tilting, changing antenna bearing and the correct antenna scenario which reduces interference. It is important that each serving cell have clear, not scattered dominance areas [2].

5.3 Indoor Planning

Most of the cellular traffic is generated in the indoor network as in the past it was provided by outdoor cells. There is a direct relation of downlink power with capacity if considering power load per user (PLPU) [3]. To ensure good indoor coverage for users, the network planner has to take into account the building penetration loss margin which varies from 15 to 20 dB [3]. It is important to cover high traffic generating areas in the building. Placement of the antenna is one of the important factors considered in indoor planning as losses to undesired area are minimized and coverage to desired area is maximized.

The maximum performance and highest data rates from HSPA+ are typically needed in hot spot areas of building. These areas include cafes, business lounges, shopping malls and many other crowded areas. In indoor, data rate is directly related to SNR and for good radio link, SNR should be high. The best way of planning HSPA+ network is to plan from the inside out, not from outside in [3]. The isolation of indoor signal and radio link quality affects HSPA+ performance. DAS is a good choice for indoor coverage of HSPA+. This will provide less noise figure and highest downlink radiated power. Users can easily roam from outdoor network to indoor DAS with full mobile data service. [3]

5.3.1. Wall and Floor Factor Model

One of the successful approach used by Keenan in 90's [6] is to characterize indoor path loss by a fixed path loss exponent of 2 as in free space, additional loss factors relating to the number floors n_f and number of walls n_w. A straight line intersects the terminals having distance r. Therefore pathloss will be:

$$L = L_1 + 20\log_{10} r + n_f a_f + n_w a_w, \tag{5.3}$$

where a_f and a_w denotes the attenuation factor (dB) for per floor and per wall and L_1 denotes loss at a distance of one meter (r=1). In ITU-R model [27], a comparable approach is used except that only floor loss is accounted explicitly and losses between points on same floor is included implicitly by changing the path loss exponent. This path loss model is given as :

$$L_T = 20\log_{10} f_c + 10n\log_{10} r + L_f(n_f) - 28, \tag{5.4}$$

where $L_f(n_f)$ is floor penetration loss as a function of n_f which is number of penetrated floors. Here n is the path loss exponent and defined as the power loss involved in transmission between base and the mobile. Different values according to environment are given in Tables 5.2 and 5.3.

Table 5.2 *Path loss exponent n for the ITU-R model. [6]*

Frequency [GHz]	Environment		
	Residential	Office	Commercial
0.9	-	3.3	2.0
1.2-1.3	-	3.2	2.2
1.8-2.0	2.8	3.0	2.2
4.0	-	2.8	2.2

Table 5.3 *Floor penetration factors, Lf(nf)[dB] for ITU-R model. [6]*

Frequency [GHz]	Environment		
	Residential	Office	Commercial
0.9	-	9 (1 floor) 19 (2 floors) 24 (3 floors)	-
1.8-2.0	$4n_f$	$15+4(n_f-1)$	$6+3(n_f-1)$

5.3.1. Full 3D model (Ray Tracing)

Full 3D model has no restriction on object shape and includes transmission through surfaces. For this reason, full 3D is the only ray based model that is applied on indoor environments. The ray tracing has two main methods used with full 3D model. First method is based on SBR that traces the ray paths through the two dimensional. Ray paths are traced without any regard for the location of specific field points. The rays that hit walls would be reflected secularly and would continue to be traced up to maximum number of reflections. This method can construct ray paths with up to 30 total reflections and transmissions having maximum number of diffractions equal to three.

Second ray tracing method is known as eigenray method. The approach used in this method involves an explicit construction of the ray paths between the each transmitter and receiver. The eigenray method is limited to ray paths with up to three reflections and diffractions. As the computational time does not increase significantly with number of transmissions, the eigenray method will be a good choice for applications that require large number of transmissions.

5.3.2 Indoor System Configuration

Repeaters can provide good indoor coverage for the enhancement of signal from outdoor base station to indoor base station. It includes a donor antenna directed towards the donor Node-B and service antenna designed for the building to provide service. The indoor environment performance is improved when indoor traffic volume is considered high. The main configurations used for indoor antenna systems are [1]:

1. Picocell
2. Distributed antenna system (DAS)
3. Radiating cable system
4. Optical solution

5.3.2.1 Picocell

Picocell is formed from a Node-B with small power located inside a building. Picocell is used to provide high quality indoor building coverage. It requires good planning, expert installation and optimization so that more and more users can be served. For high traffic areas in cellular telephony, picocell is extensively used. Picocells have very limited area to serve within their coverage zone. Picocell propagation is important in determining signal propagation in buildings because both macrocellular and microcellular systems can act as source of interference. [6] The behavior of picocell could be analogous to WiFi or hotspots.

5.3.2.2 Distributed Antenna System (DAS)

Mostly a DAS system contains one base station and multiple antenna lines. Power is equally distributed among the antenna lines. Here a trunk cable is divided into branch cables connected to indoor antennas. Target is to achieve evenly distributed coverage with the EIRP values in the range of 5-8 dBm measured at the antenna where typical EIRP value is 20-25 dBm [1]. Quantity of antennas in a DAS system is ranging from a few to up to 30 antennas. If DAS system is large enough, then there might be a need to use an amplifier in downlink direction due to antenna line losses whereas in uplink direction there is no need to use any LNA [1].

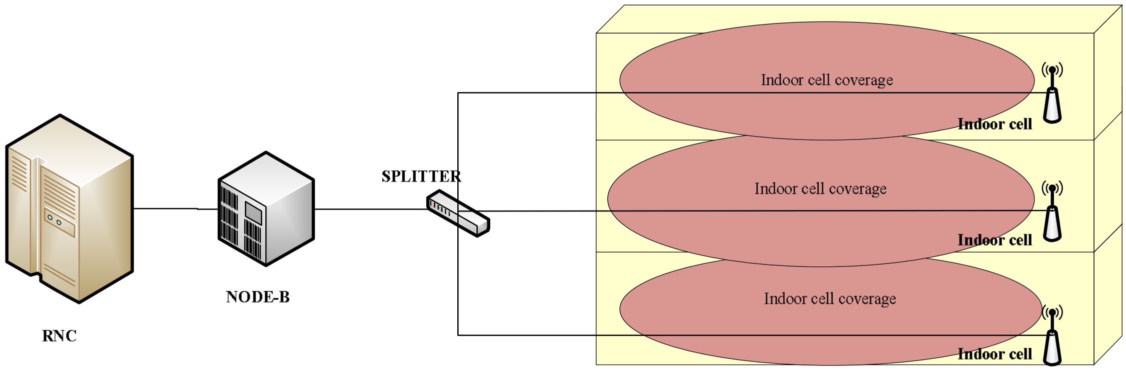


Figure 5.3 *Three antenna DAS configuration.*

5.3.2.3 Radiating Cable System

It is a special type of cable which is installed throughout the building to be served by a base station. It consists of coaxial cable with an inner conductor, a dielectric, outer shield, tuned slots in outer shield and the jacket [3]. The cable acts as an antenna by radiating signal through small holes. The cable has to be run through the whole building area where service has to be provided. Cable is usually being more flexible due to system invisibility and coverage provided is even more than DAS [1]. These applications are usually designed for a limited number of users requiring a lot of capacity in a small area.

5.3.2.4 Indoor Coverage and Capacity Strategies

To provide coverage in medium size building where amount of traffic is low, single cell strategy works fine. In Figure 4.4 one base station is connected with different antenna configuration providing coverage. Such type of planning will be affected when amount of traffic is increased. It is important to remember that amount of antennas cannot be increased because of antenna line losses such as splitter, cable and connector losses to overcome the problem of capacity.

For resolving the issue of capacity, the concept of multi-cell strategy is used given in Figure (5.5). Where planning should be in such a way that there is good overlapping of cells and successful handovers present without losing any coverage. It is important to consider interference while doing multi-cell planning. The main thing is initial antenna placement for the evolution of indoor networks as exact numbers of users are not known. Therefore an old method of coverage first , capacity later is adopted [3].

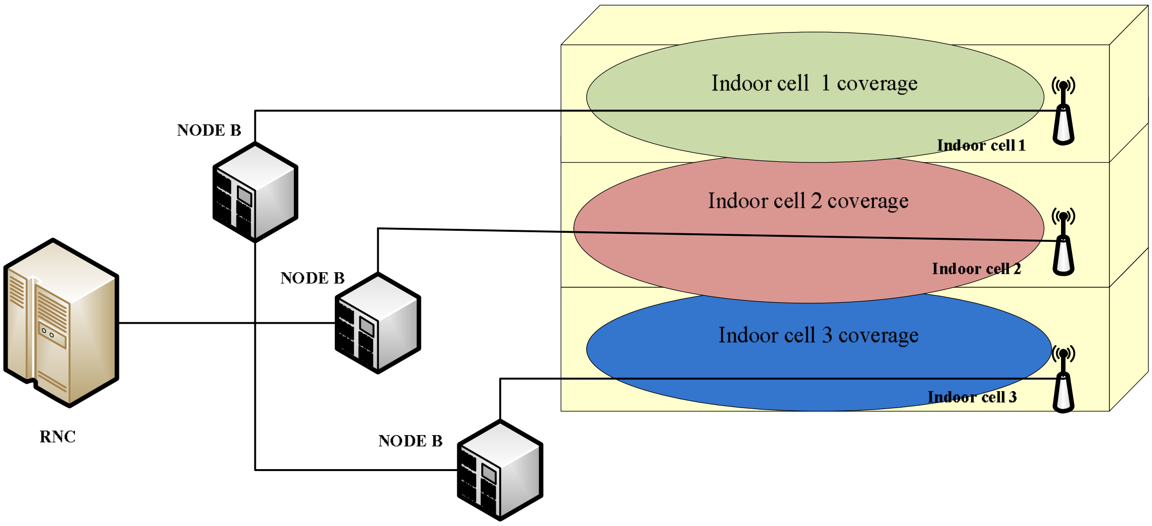


Figure 5.4 *Indoor coverage using multi-cell strategy.*

5.4 HSPA+ Parameters and Metrics

The fundamental parameters of radio interface such as chip rate and operating frequencies (900 MHz and 2100 MHz) are same for every configuration. In order to verify the functionality and the performance of implemented radio network, some parameters can be obtained from field measurements. Important parameters for the measurement of HSPA+ are:

- Received signal strength indicator (RSSI) which contains the downlink power received from wideband channel bandwidth.
- P-CPICH RSPC (Received signal code power) is the decoded power received of Node-B measured by MS. Coverage and path loss from base station is measured from RSCP as the transmit power of P-CPICH can be read from the system information.
- Energy per chip to noise ratio (E_c/N_0) is evaluated from primary common pilot channel P-CPICH. E_c/N_0 is the ratio of RSCP and RSSI. E_c/N_0 is a common parameter when quality of radio signal is measured and the relation is shown: [2]

$$\frac{E_c}{N_0} = \frac{RSCP}{RSSI} \qquad (5.7)$$

- Signal to interference ratio (SIR) is one of the parameters that greatly affect the performance of radio communication system. SIR starts to degrade as receiver starts to move away from the Node-B towards the cell edge. Assuming that each base station is transmitting at the sam power and the path loss exponent is same throughout the cell coverage area, then the approximate SIR for a receiver at any given point, within the cell is given as:

$$SIR = \frac{R^{-n}}{\sum_{i=1}^{i_o}(D_i)^{-n}}, \tag{5.8}$$

where D_i is the distance of i^{th} interferer for receiver, n is the path loss exponent and R is the radius of serving cell. [4]

- Interference margin (IM) is calculated at the receiving end and can be easily derived from:

$$IM = -10\log_{10}\left(\frac{100-\eta}{100\%}\right), \tag{5.9}$$

where η represents the load factor. [11]

5.4.1 Transport Channel Performance in HSPA+

Important parameters for HSPA+ with respect to transport are data rate and service delays. Two main types of transport channels exist, dedicated channels and common channels. In common channel resource is divided between all users or group of users in a cell, whereas dedicated channel is reserved for a single user [2]. Some of the important performance indicators are given below for better understanding:

- Block error rate (BLER) is the percentage of incorrect received packets in physical layer of downlink and uplink. Too high BLER is a result of too large transport block sizes and too low BLER indicates that resources are not fully utilized.
- Channel quality indicator (CQI) is the feedback returned by the UE which indicate the instantaneous DL channel quality.
- Physical layer in the transport channel list gives throughput of bits transmitted per second. It includes all the signaling traffic and overhead required by upper layers.
- MAC layer throughput is responsible for performance degradation due to retransmission. It is more appropriate data rate indicator than throughput in the physical layer.

HSPA+ has performance degradation due to SIR and it is reasonable to measure SIR to get the relevant information about affecting conditions.

5.4.2 HSPA+ Indoor Network Link Budget

Link budget is required for any network to calculate the maximum uplink and downlink path loss. In HSPA+ indoor network, link budget is affected by parameters such as spreading factor, system load and interference margin. Link budget is also affected by the unstable link balance for the system load. A simple HSPA+ indoor link budget example has been given in Table 5.4.

Table 5.4 *Link budget HSPA+. [11, 17, 18]*

	HSPA+ Indoor Link Budget				
	General info	**Unit**	**Value**		
	Frequency	Mhz	2100.00		
A	Chip rate	cps	3.84E+06		
B	Temperature	K	293		
C	Boltzman's constant	J/K	1.38E-23		
	Service profile	**Unit**	**Uplink**	**Downlink**	
D	Load	%	50	50	
E	Bit rate	kbps	11500	21000	
F	Spreading Factor		16	16	
	Receiving end		**NodeB**	**Mobile**	
G	Thermal noise level	dBm	**-108.09**	**-108.09**	=10log10(ABC/0.001)
H	Noise figure	dB	6	8	=10log10(ABC/0.001)+H
I	Noise power	dBm	-102.09	-100.09	=10log10(100/(100-D))
J	Interference margin	dB	**3.01**	**3.01**	
K	**Total interference level**	**dBm**	**-99.08**	**-97.08**	I+J
L	Required Eb/No	dB	6	6	[17,18]
M	Processing Gain	dB	**12.04**	**12.04**	=10log10(F)
N	SHO diversity gain	dB	0	0	
O	Loss Power control headroom indoor	dB	0	0	
P	**Required C/I**	**dB**	**-6.04**	**-6.04**	L-M-N+O
Q	**Receiver sensitivity**	**dBm**	**-105.12**	**-103.12**	K-P
R	RX antenna gain	dBi	2	0	
S	LNA improvement	dB	0	0	
T	DAS antenna line losses	dB	10	0	
U	**Required signal power**	**dBm**	**-97.12**	**-103.12**	Q-R-S+T
	Transmitting end		**Mobile**	**NodeB**	
V	E-DCH/HS-DSCH Power	W	0.13	0.8	=10log10(W/0.001)
W	E-DCH/HS-DSCH Power	dBm	**21.14**	**29.03**	=10log10(V/0.001)
X	Antenna gain	dB	0	2	
Y	DAS Antenna line losses	dB	0	10	
Z	**Peak EIRP**	**dBm**	**21.14**	**21.03**	W+X-Y
	Isotropic path loss (w/o tresholds)	**dB**	**118.26**	**124.151**	Z-U

6. Analytical Comparison of Picocell and DAS

This chapter provides an overview of the analytical study that compares the performance of picocell and DAS configurations. A 3D ray tracing tool was used to predict the radio propagation of electromagnetic waves in different outdoor and indoor environment [26]. This tool has ability to construct virtual buildings, floor places and terrain environment for simulating specific indoor/outdoor scenarios. Moreover, the software provides accurate results for a frequency range of 50 MHz to 40 GHz [26]. Calculations were made on the basis of shooting rays from transmitters and propagating these rays within the defined environment.

6.1. Overview of Analysis Method

Interference analysis was made by considering the interfering signals from adjacent cells. Two main performance indicators were considered in the simulation study: signal to interference ratio (SIR) and received signal strength indicator (RSSI). In the first scenario, antenna coverage was simulated for single, double and four antennas cases. In second scenario antennas were placed in two adjacent rooms in the form of picocell and DAS configuration. Layout for single, double and 4 picocells is shown in Figure 6.1 (a-c).

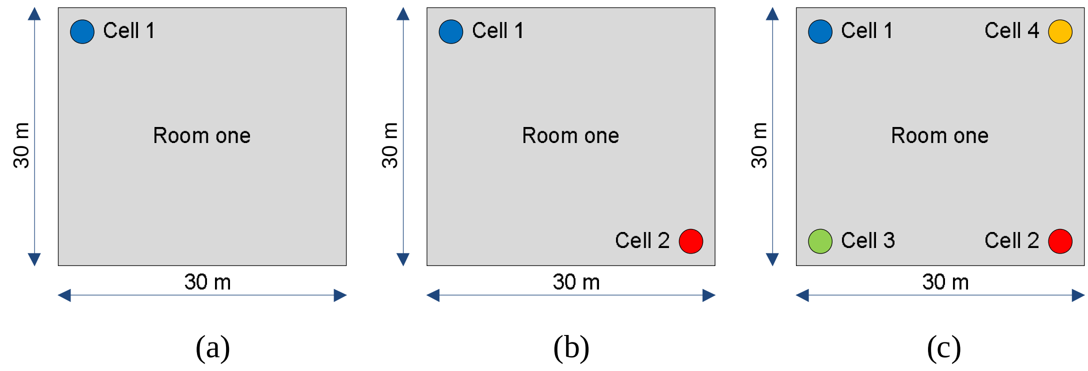


Figure 6.1 *Layout for a) single, b) double and c) 4 picocells in one room.*

In a traditional cellular concept, where one transmit antenna provides coverage to a certain area, the SIR starts to degrade as the receiver moves away from transmitter. This factor is due to the drop in signal strength as a power law of the distance of separation between the transmitter and receiver. Analytically, SIR is calculated by the free space path loss difference. In terms of HSPA+ performance, SIR can be evaluated by dividing spreading factor (SF) and HS-DSCH power with power signal from other cells P_{other}, own P_{own} and received noise power P_{noise}. Equation 6.1 shows this relation and here α denotes the orthogonality factor in downlink direction [5]:

$$SIR = SF \frac{P_{HS-DSCH}}{((1-\alpha)P_{own} + P_{other} + P_{noise})} \quad . \tag{6.1}$$

6.2. Coverage Comparison Scenarios

In this section of chapter, studies were made to understand the coverage .of each transmitting picocell. The studied scenarios were based on two different propagation models. In the first scenario, free space path loss model (FSL) was used to calculate SIR and RSSI. In second scenario, 3D ray tracing based on “Shooting and Bouncing Ray Method (SBR)” was used for calculating SIR and channel capacity on per user for picocells and DAS.

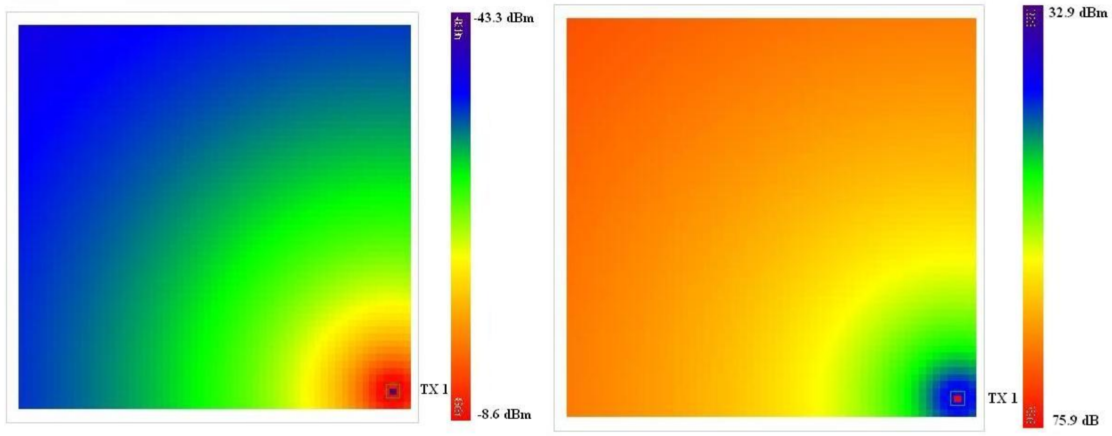
A virtual room was created to simulate an indoor environment with dimensions 30m x 30m with wall height of 3.65m. Antennas were placed at the corner to analyze the SIR and RSSI over the whole room pixel by pixel. Free space path loss model gives us a general idea of measured parameters. Table 6.1 gives all the parameters used in simulations.

Table 6.1 *Simulation Parameters.*

Parameters	Type / Values
Frequency	2100 MHz
Bandwidth	5 MHz
Antenna Type	Omni-directional
Height of Wall	3.65 m
Transmission Power	29 dBm
Transmitter Antenna Height	2 m
Receiver Antenna Height	1.8 m
Pixel Size	0.5 m

6.2.1 Single Antenna Coverage

Figure 6.2(a-b) shows RSSI and FSL plots of single antenna transmission. Results showed that RSSI was between -43.3 dBm to -8.6 dBm and FSL lies between 32.9 dB to 75.9 dB. Pixels that were close to transmitting antenna were having good RSSI values and pixels that were far from the antenna were having worse RSSI.

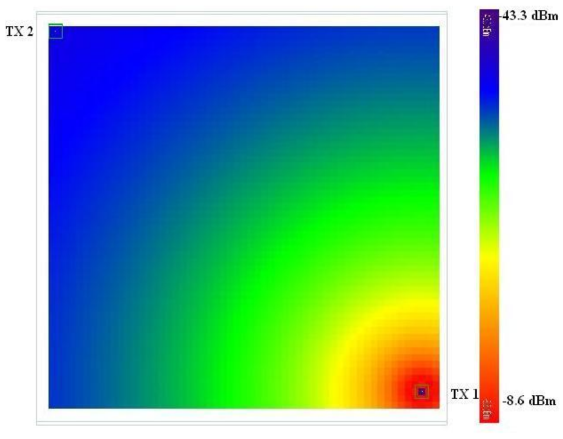


(a) (b)

Figure 6.2 *Plots for a) RSSI and b) FSL Single antenna coverage.*

6.2.2 Two Antenna Coverage

For two antenna case, one of the antennas was placed at lower right corner and other was placed on upper left corner of simulation area. The RSSI of transmitter one was between -43.3 dBm to -8.6 dBm shown in Figure 6.3 (a) and for transmitter two it was between -38.2 dBm and 8.7 dBm shown in Figure 6.3 (b).



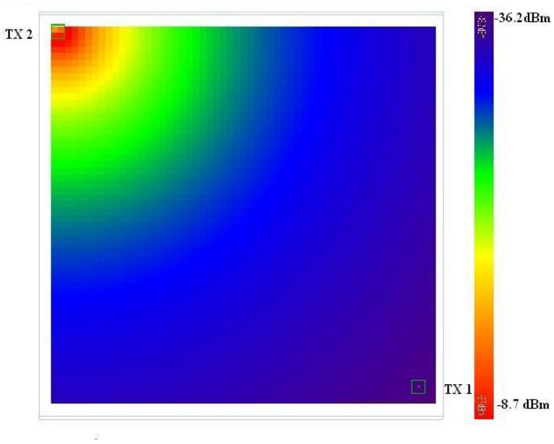


Figure 6.3 (a) *RSSI of Transmitter one.* ***Figure 6.3 (b)*** *RSSI of Transmitter two.*

The average value of SIR was 6.50 dB for two antenna configuration. As both antennas were facing each other, interference level was high and due to this interference the SIR value decreased. Also transmitter one and two had same transmitting power and antenna heights.

6.2.3 Four Antennas Coverage

In four antenna case, each antenna was placed at either corners of the room. Now four antennas were interfering with each other, thus SIR will be affected a lot and this results in decrease in Shannon channel capacity of the system. The antenna configuration with respect to SIR is given in Figure 6.4. The simulation showed that SIR was very poor in the middle of simulation room. As all 4 picocells were having high interference at middle of room.

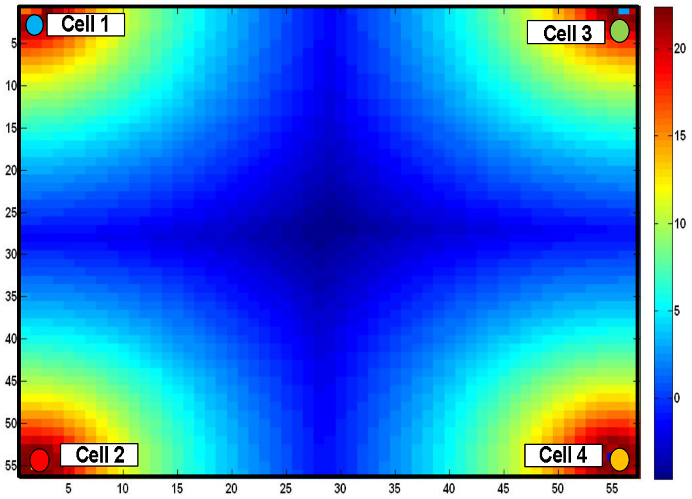


Figure 6.4 *SIR (dB) of 4 picocells in single room.*

In Figure 6.5, comparison of SIR between 2 antenna and four antenna cases is given. SIR plot for 2 picocells shows that most of the changes in SIR occurred between 4.4 dB and 15 dB. In 4 picocells, major changes in SIR value occurred between 6.38 dB and 3.3 dB. Results show that by increasing the number of interfering antennas, SIR starts to decrease.

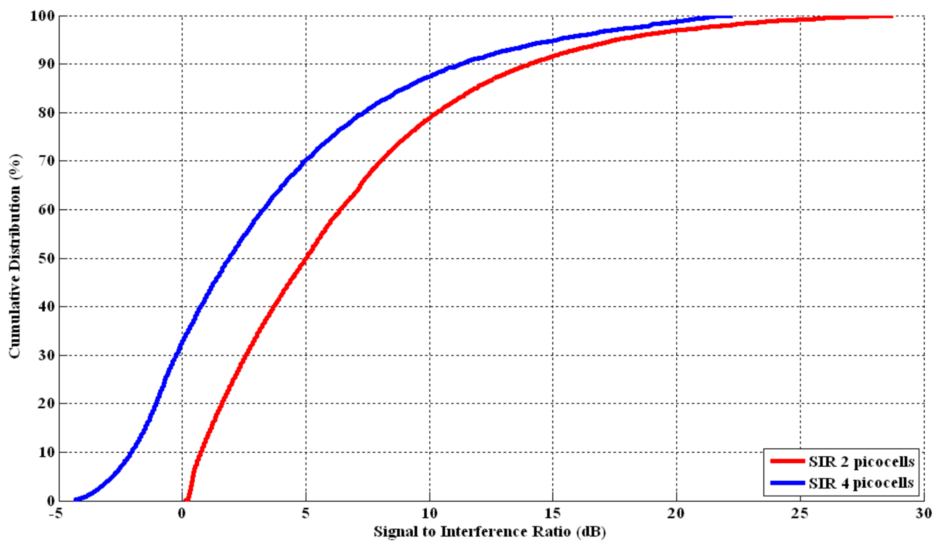


Figure 6.5 *Comparison of 2 and 4 picocells SIR.*

6.3. Comparison of Picocells and DAS

Picocells have been used as a cost effective means for providing indoor coverage for a long time now and they still continue to exist. Depending on the service requirements, picocells have an average range of about 20-40m distance. As coverage area of picocell was increasing without increase in capacity, so picocells were combined in the form of DAS to extend the footprint of a single picocell.

First scenario for comparison study includes four antennas. At first, two antennas were placed in each of the rooms, connected in the form of 4 picocells and 2x2 DAS configuration. Simulations were set according to parameters given in Table 6.2. The Propagation model used for this scenario was 3D Ray Tracing based on SBR [26].

Table 6.2 *Simulation Parameters.*

Parameters	Type / Values
Frequency	2100 MHz
Bandwidth	5 MHz
Antenna Type	Omni-directional
Transmission Power	29 dBm
Transmitter Antenna Height	2.5 m
Receiver Antenna Height	1.8 m
Receiver spacing	0.5 m

6.3.1 Four Antennas Coverage

Comparison has been made on the basis of SIR and channel capacity between four picocells and 2x2 DAS configurations. A simulation environment was created having two adjacent rooms of dimensions 30 m x 30 m each with 3.65 m wall height. Receiver spacing throughout the room was 0.5 m. Two antennas were placed at opposite corners of each room. Figure 6.6 shows the calculated SIR value per pixel for 4 picocells configuration with an average SIR value of 1.13 dB. The SIR value for 4 picocells was very low as high interference was present in both rooms.

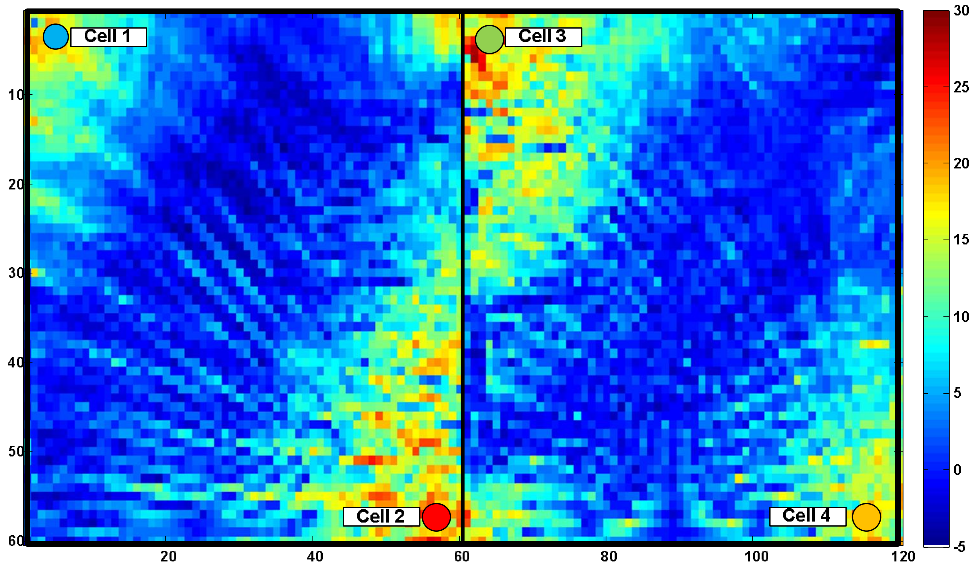


Figure 6.6 *SIR (dB) for 4 picocells antennas.*

Now considering the same simulations scenario, the antennas in the same room are connected to a single base station forming 2x2 DAS configuration. Figure 6.7 shows SIR value per pixel for 2x2 DAS with average SIR value of 9.39 dB. CDF plot of SIR for 4 picocells and 2x2 DAS is given in Figure 6.8.

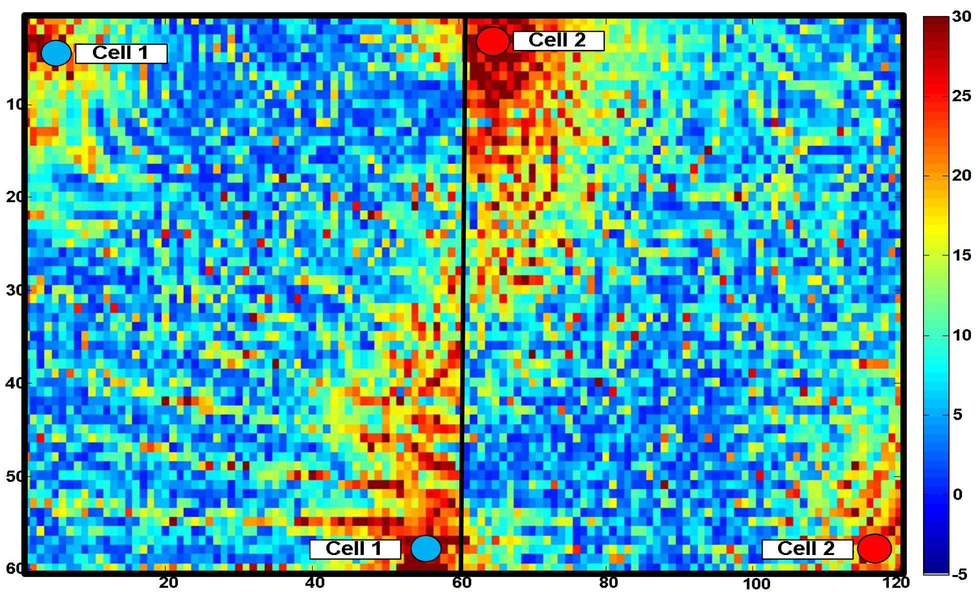


Figure 6.7 *SIR (dB) for 2x2 DAS configuration.*

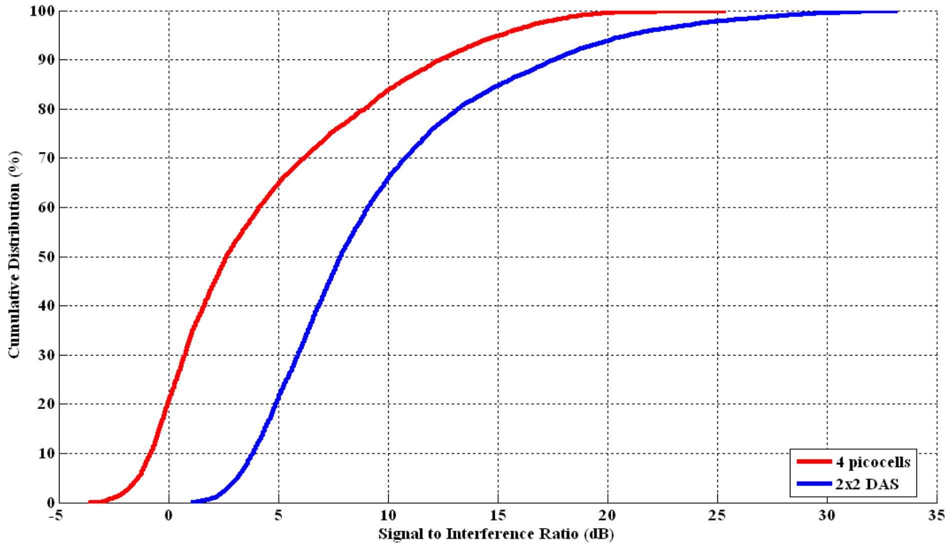


Figure 6.8 *SIR CDF plot for 4 picocells and 2x2 DAS configuration.*

Shannon channel capacity results for 4 picocells is shown in Figure 6.9 and average capacity per pixel was 10.48 Mbps. Considering the same area for 2x2 DAS configuration, average Shannon channel capacity per pixel is shown in Figure 6.10. The average value of Shannon capacity for 2x2 DAS was 17.11 Mbps. Conclusion can be made on the basis of results shown above that when the SIR increase, average channel capacity decreases.

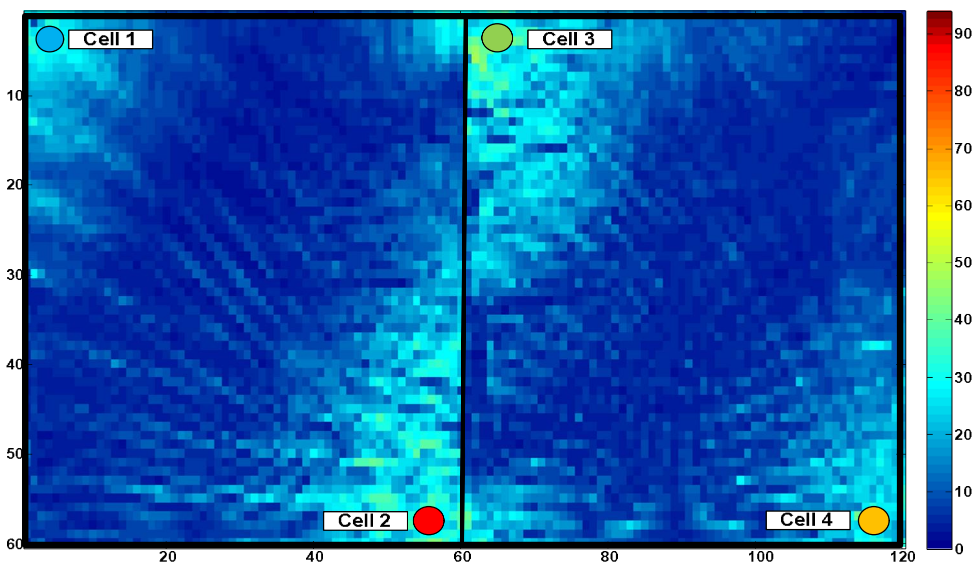


Figure 6.9 *Channel capacity (Mbps) for 4 picocells antennas.*

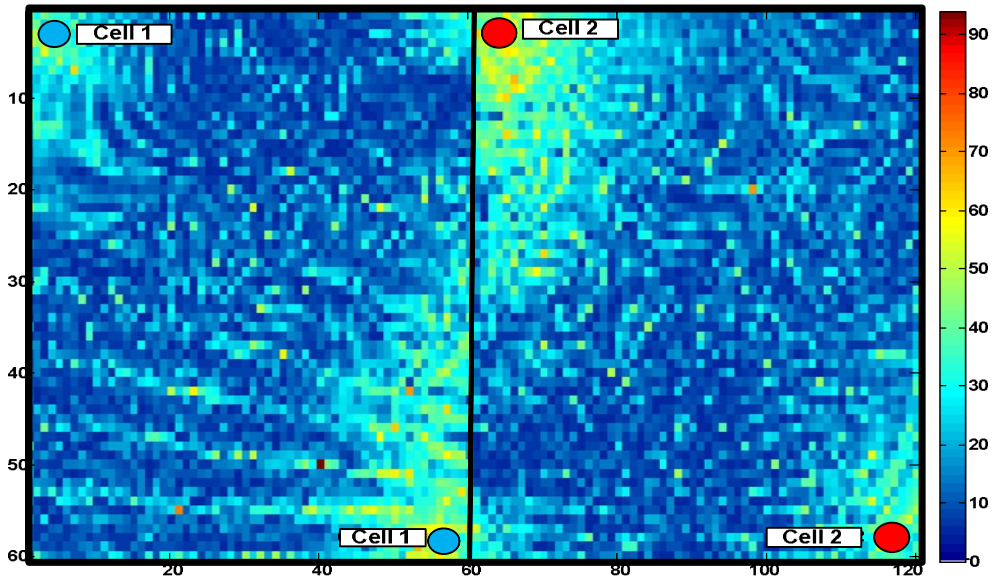


Figure 6.10 *Channel capacity (Mbps) for 2x2 DAS configuration.*

For further analysis, all four antennas were connected to one serving cell thus performing a 4x1 DAS. Figure 6.11shows SIR value per pixel with an average SIR value of 82 dB. One thing to remember is that all these results are simulated for ideal conditions. The average Shannon channel capacity per pixel is given in Figure 6.12 with an average channel capacity of 136 Mbps.

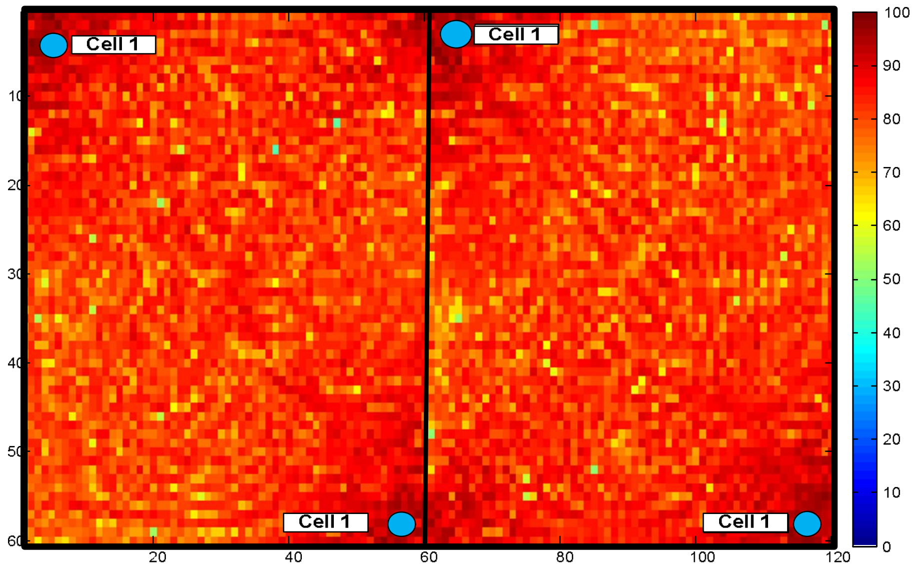


Figure 6.11 *SIR (dB) for 4x1 DAS configuration.*

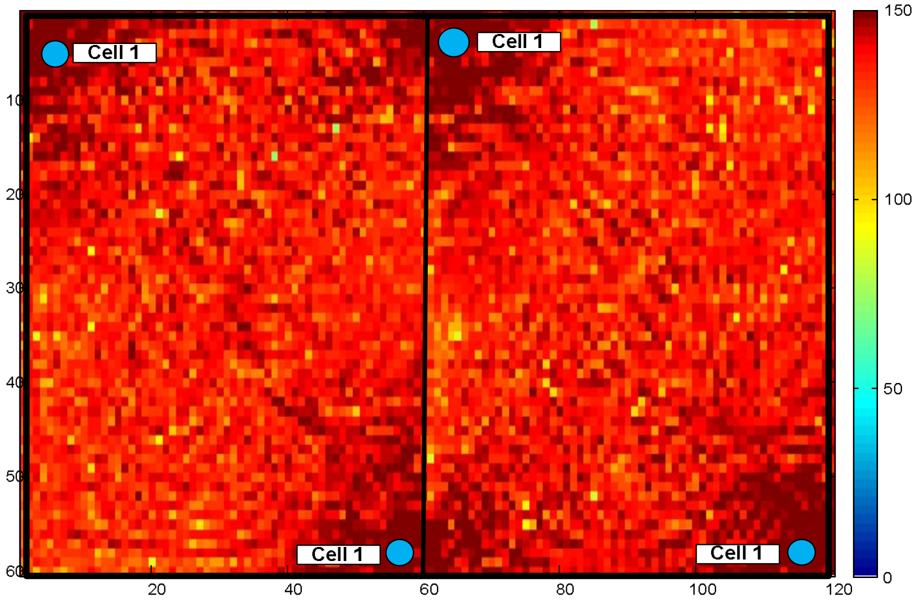


Figure 6.12 *Channel capacity (Mbps) for 4x1 DAS configuration.*

6.3.2 Eight Antennas Coverage

In eight antenna case, four antennas were used in each room. First simulations were performed for 8 picocells. For DAS case, each room was having four antennas connected to one cell and thus performing a 4x2 DAS. So by increasing number of antennas from four to eight, average SIR value had degraded too much for picocells as compared to 4x2 DAS configuration. Figure 6.13 shows the SIR for 8 picocells with an average SIR value of 0.58 dB. Similarly, Figure 6.14 shows the average SIR value per pixel for 4x2 DAS with an average SIR value of 8.26 dB. It is clear that when numbers of picocell antennas are increased then average SIR value decrease and affects many parameters of system.

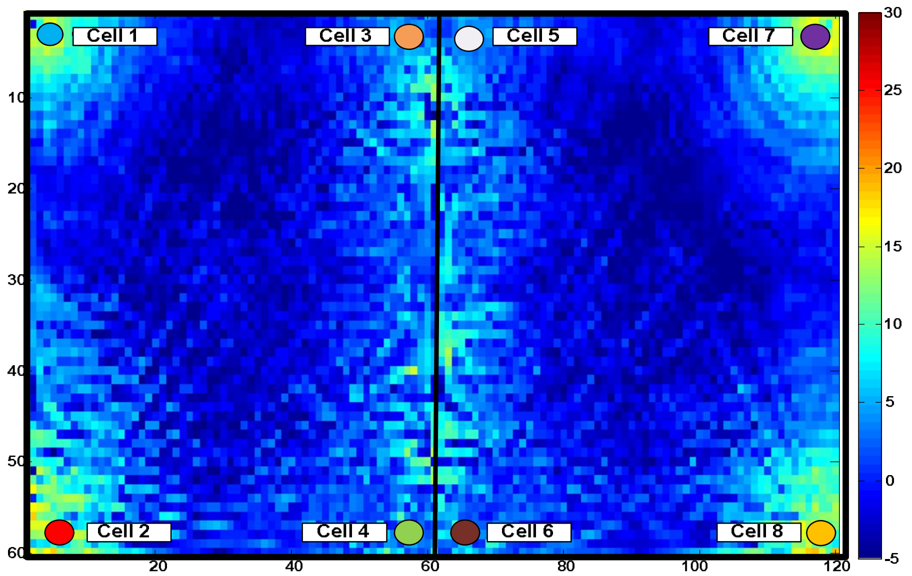


Figure 6.13 *SIR (dB) for 8 picocells.*

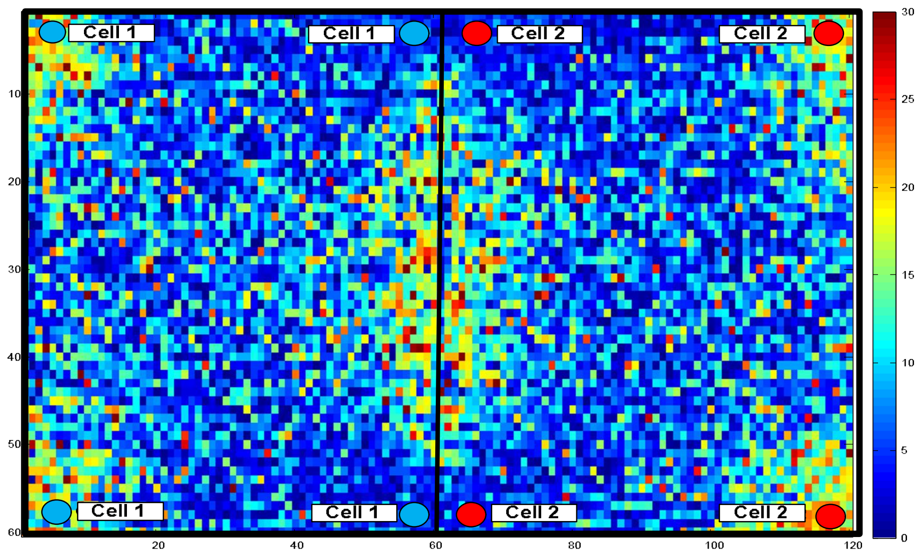


***Figure 6.14** SIR (dB) for 4x2 DAS.*

Average Shannon channel capacity per pixel for 8 picocells is given in Figure 6.15 with an average capacity of 6.2 Mbps. Whereas Figure 6.16 shows the average Shannon channel capacity of 15.41 Mbps. So there is difference of 9.21 Mbps in capacity between 8 picocells and 4x2 DAS.

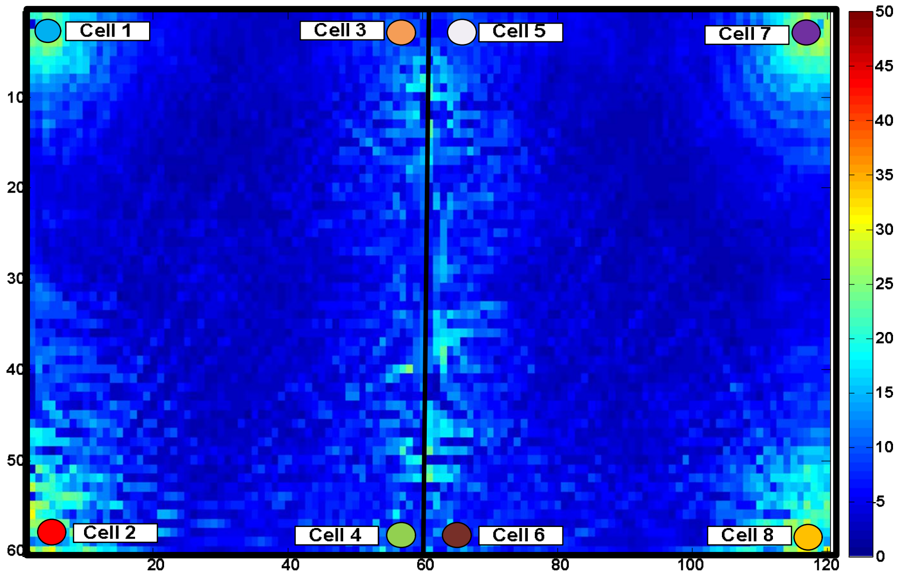


***Figure 6.15** Channel capacity (Mbps) for 8 picocells.*

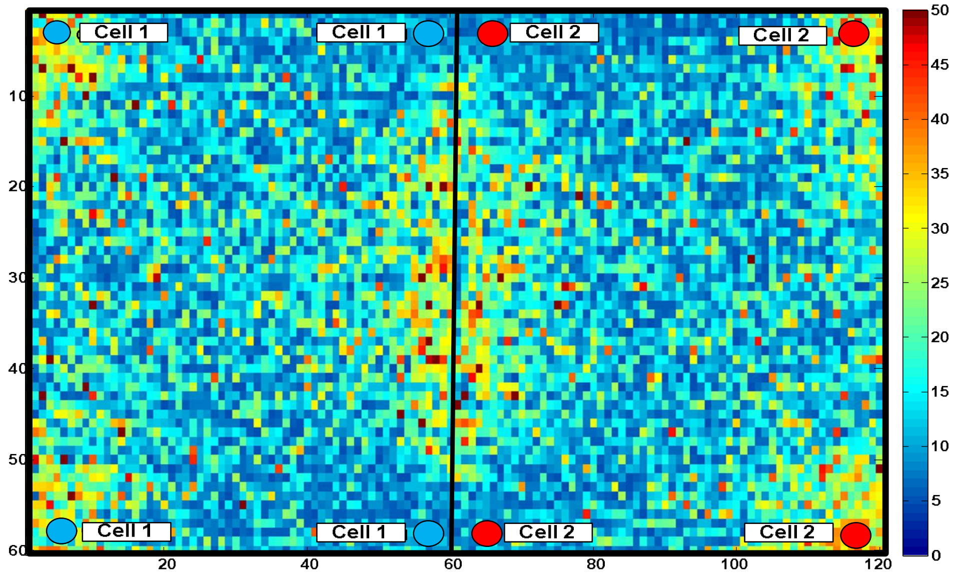


Figure 6.16 *Channel capacity (Mbps) for 4x2 DAS.*

Based on the results shown above, DAS configuration provides better SIR and high throughput than picocells. As eight antennas provides better average SIR than four antennas due to interference management. It can be concluded as the number of antennas increases per cell then SIR performance also improves for DAS. Figure 6.17 shows the CDF plot of 8 picocells and 4x2 DAS.

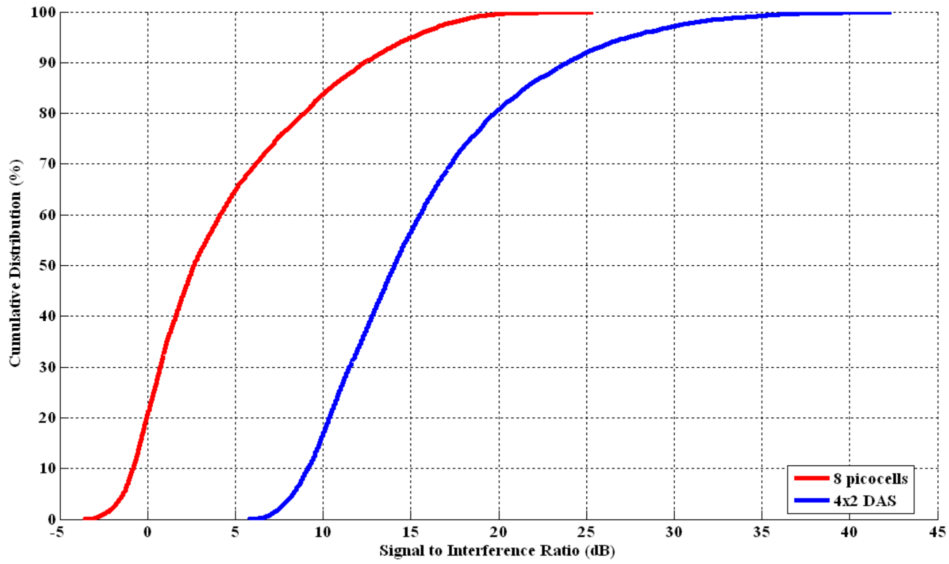


Figure 6.17 *SIR CDF plot for 8 picocells and 4x2 DAS.*

Table 6.3 summarizes the average SIR and Shannon channel capacity for four and eight antennas connected in picocells and DAS configuration. The result shows that four picocells can achieve total capacity of 41.92 Mbps but due to interference, an average Shannon channel capacity of 10.48 Mbps was achieved. Whereas, by using DAS configuration for same scenario, the total channel capacity achieved was 34.22 Mbps with average channel capacity of 17.11 Mbps.

Similarly, 8 picocells achieved a total capacity of 49.6 Mbps but the average channel capacity was approximately 6.2 Mbps which was very low due to high interference from other cells. 4x2 DAS achieved a channel capacity of 30.84 Mbps but simulations showed that 15.41 Mbps was achieved. The above scenario analysis shows that the total channel capacity for picocell was higher than DAS configuration; however simulation results showed that average channel capacity achieved was better for DAS than picocell.

Table 6.3 *Simulation result summary.*

Configuration	Average SIR (dB)	Shannon cell capacity (Mbps)	System capacity (Mbps)
4 picocells	1.13	10.48	41.92
2x2 DAS	9.39	17.11	34.22
4x1 DAS	82.00	136.00	136.00
8 picocells	0.580	6.20	49.60
4x2-DAS	8.26	15.41	30.82

7. Measurement Campaign and Results

One of the important confronts of UMTS and HSPA+ is to provide indoor coverage and capacity. In earlier studies [24, 25], HSDPA (R7) multilayer concept, difference between picocells and DAS indoor configuration were described. This chapter includes thesis measurement campaign on multiple picocells and DAS indoor configuration. Measurement campaign will also provide verification to earlier analytical studies described in Chapter 6. By using 64-QAM, network spectral efficiency was increased thus providing better user experience. 64-QAM also provides higher throughput values in areas having strong radio reception levels and rich scattering environment.

7.1. Measurement Setup

7.1.1. Measurement Environment

Measurements were performed in modern building of Tampere University of Technology (Department of Communication Engineering). Most of the measurements were taken during weekends and evening time to avoid system load generated by other users on testing network. Measurements were taken in two similar rooms of Tietotalo building as shown in Figure 7.1. Omni directional antennas were placed in both rooms with 9 meter separation and measurement route was selected.

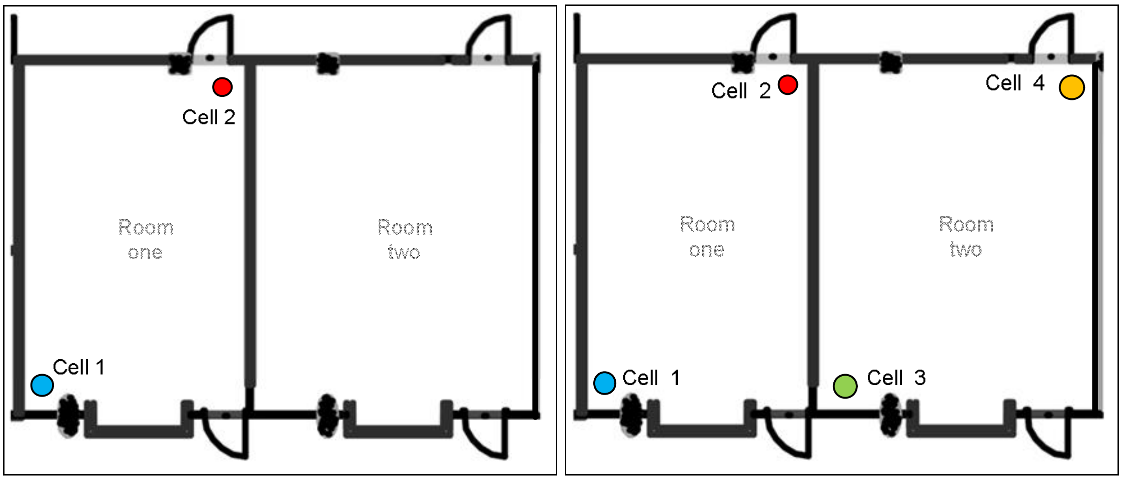


Figure 7.1 *Layout of rooms with antenna placement.*

Measurements were taken inside each room, following the same route for all scenarios. Idea of these measurements was to check different network parameters in picocells configuration and DAS configuration. Some of these parameters include utilization of 64-QAM in DL, cell TP, system TP, signal-to-interference ratio and RSCP values for high and low loaded cells. The performance bench mark was outcome of field measurement made between picocells and DAS configuration. Cell TP was calculated by taking average value of all combined measured TP values of DC's. For system TP, calculated cell TP was multiplied by number of antennas present at scenario.

7.1.2. Measurement System

HSPA+ network used for measurements consists of 4 cells Node-B connected to RNC through optic fiber. Node-B supports Release 7 HSDPA and HSUPA. The antenna line configuration includes Node-B connected to antennas with ½" feeder cables, 2-way splitters and connectors. Omni directional antennas with 2 dBi gain were used during measurements. To achieve comparable measurements results, antenna line losses between picocell and DAS configurations have only difference of 3 dB from 2-way splitter.

The measurement equipment consists of four HSPA+ data cards and three laptops. One laptop will be having two DC's and other two laptops were having one DC each. Field measurement software (Nemo Outdoor) for collecting measurement data was installed in each measurement laptop. The general details of measurement equipment are given in Table 7.1.

Table 7.1 *Measurement equipment details.*

Equipment	Type / Version
Laptop	IBM T61
Operating system	Windows XP
Data cards	Sierra Wireless Aircard HSPA+ USB 308/309
Data card category	HSDPA Category 14 (Max physical 21.1 Mbps) HSUPA Category 6 (Max physical 5.76 Mbps)
Measurement softwares	Nemo Outdoor Version 5.0 Nemo Analyzer Version 5.0

The block diagram of antenna line configuration for single antenna, 2 picocells and 2x1 DAS are given in Figure 7.2 (a-c). One 2-way splitter was used in 2x1 DAS to connect 2 antennas to one single cell of Node-B.

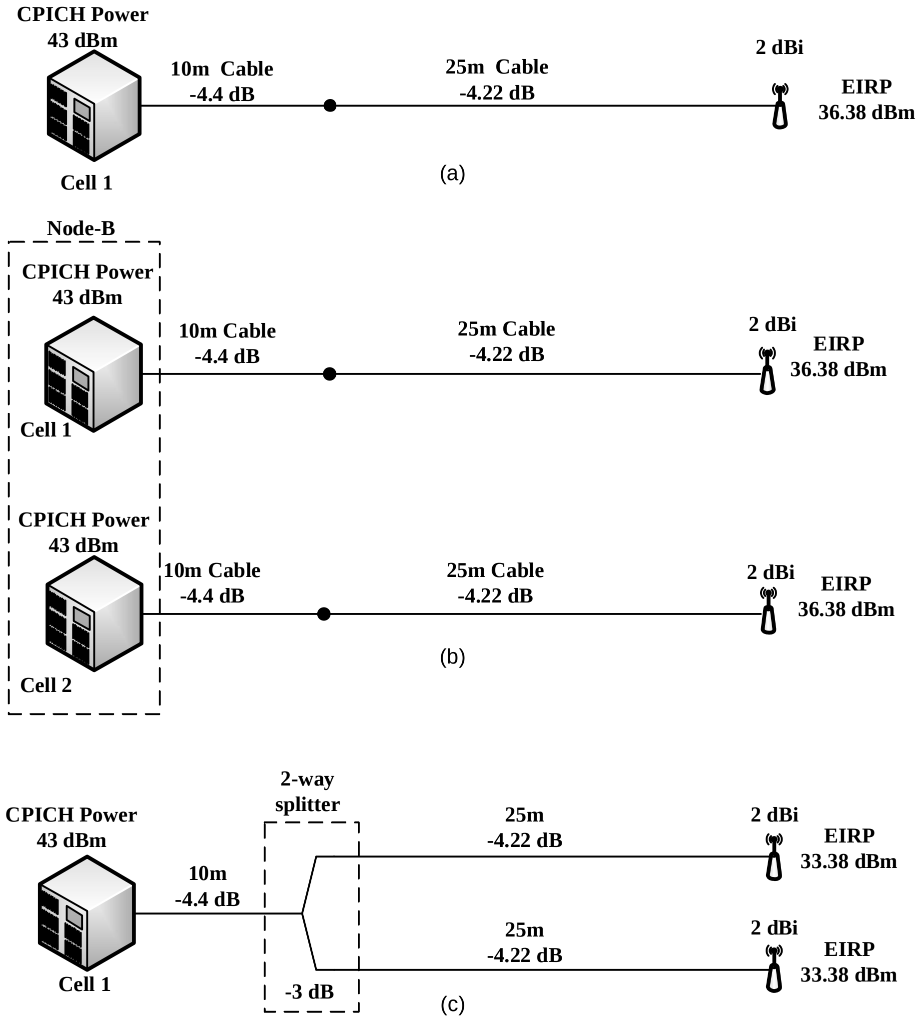


***Figure 7.2** Antenna line configurations for a) single antenna b) 2 picocells and c) 2x1 DAS HSPA+ in single room.*

Theoretical downlink data rate for HSPA+ is around 21.1 Mbps but due to some limitations from network side, maximum amount of data rate achieved was 10.1 Mbps. Therefore all scenarios became throughput limited. Measurement equipment consists of three category 14/6 (HSDPA / HSUPA) data cards with maximum physical throughput of 21.1/5.76 Mbps. The block diagram of antenna line configuration for 4 picocells, 2x2 DAS and 4x1 DAS is given in Figure 7.3 (a-c).

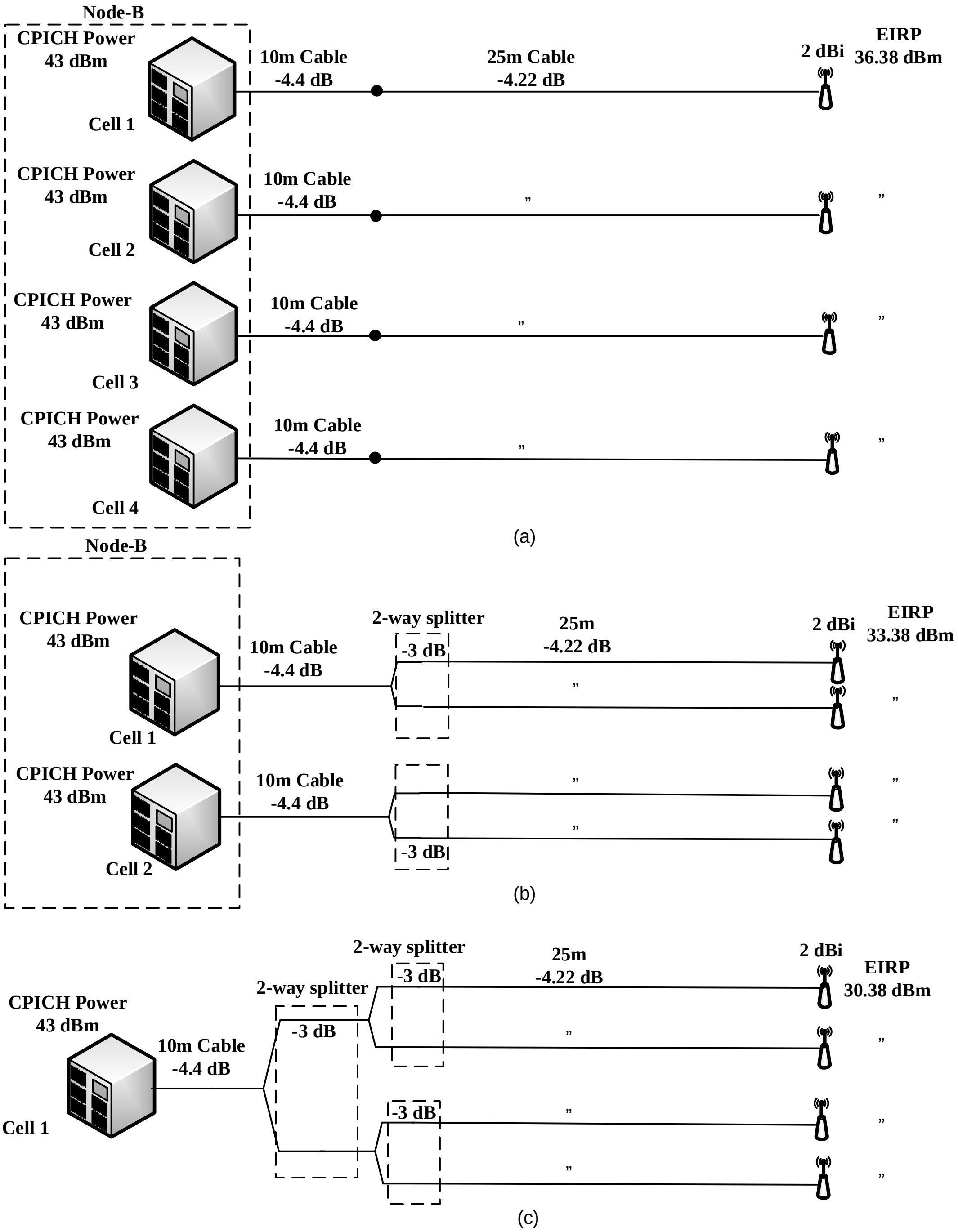


Figure 7.3 *Antenna line configurations for a) 4 picocells b) 2x2 DAS and c) 4x1 DAS HSPA+ configuration in two rooms.*

Table 7.2 contains calculated EIRP values for different measurement scenarios.

Table 7.2 *EIRP values for different measurement scenarios.*

Measurement Configuration	EIRP (dBm)
Single antenna	36.38
2 picocells	36.38
2x1 DAS	33.38
4 picocells	36.38
2x2 DAS	33.38
4x1 DAS	30.38

7.1.3 Arrangements

Single antenna scenario required one data card for measurement. For two/four antenna scenarios, two/four data cards were used simultaneously for achieving balanced scheduling between different measurements. In total three different scenarios were present namely:

- Single antenna scenario
- 2 antennas scenario
- 4 antennas scenario

Measurements were taken for both low and high load. In low load, one DC was downloading and uploading data during the measurement. For high load, one DC was downloading and uploading for each antenna present in measurement configuration. Single and two antenna cases consists of both low load and high load configurations but four antenna cases consists only high load configuration. Stationary and moving data cards generated traffic by downloading 100 Mb test file for HSDPA and uploading 100 Mb test file for HSUPA. Application layer protocol for HSDPA was HTTP and HSUPA used FTP. Average walking speed was around 5 km/h and measurement equipment was placed at a height of 1.5 meters.

7.1.4 Idle Mode Measurements

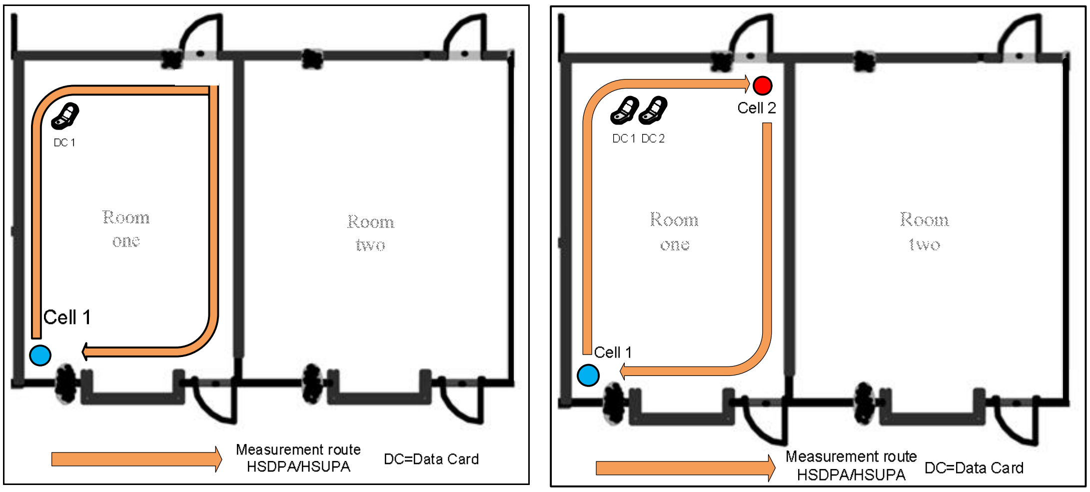
The purpose of idle measurement was to determine the coverage level of single antenna based on RSCP, signal quality parameter E_c/N_0 and estimating other-to-own-cell interference level.

7.1.5 Measurement Process and Results

Measurement process contains different measurement scenarios divided in terms of environment and radio technology. Analysis was done according to environment and measurement configuration. Main parameters analyzed were RSCP, SIR, TP and modulation schemes. To perform the analysis, data from moving and stationary data cards were gathered and summed up. Cell TP was calculated by taking the average value of summed TP values from all DC's. For calculating system TP, calculated cell TP was multiplied by number of antennas present in measurement configuration.

7.2 Single and 2 Antenna Scenarios

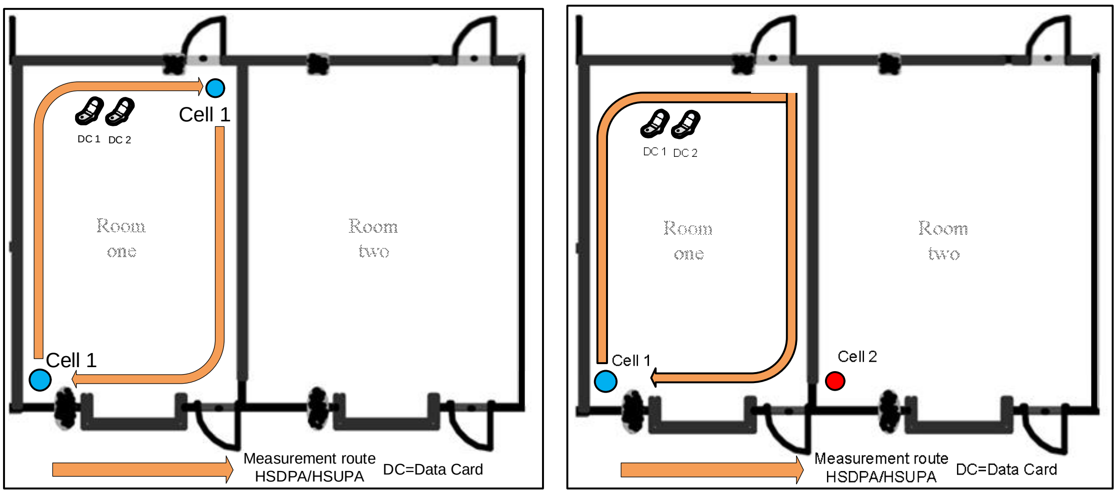
In the first scenario, single antenna was used at the corner of one room. Measurements were carried out for idle, HSDPA and HSUPA with low/high load. Single antenna was placed to check the RSCP and throughput value of single transmitter without any interferer. In the next phase of measurement the target was to find performance degradation of HSPA+ indoor user due to interference. For 2 antenna scenario, another picocell was placed inside the same room. Second picocell was connected to same Node-B with same parameters as the first picocell making the whole configuration as 2 picocells. Figure 7.4(a-b) shows the single antenna and two antenna placements with measurement routes in the room.



(a) *(b)*

Figure 7.4 *Measurement configurations for a) single antenna b) 2 picocells in same room.*

First measurements were taken for 2 picocells placed in same room. Then configuration was changed to 2x1 DAS by attaching the two antennas with same serving cell as shown in Figure 7.5 (a). To verify the results for 2 picocells, measurement were taken by placing 1 picocell in each of the two rooms, making a 2 picocells configuration as shown in Figure 7.5 (b).



(c) *(d)*

Figure 7.5 *Measurement configurations for a) 2x1 DAS is same room and b) 2 picocells in different rooms.*

7.2.1 Idle Results

The idle results for single antenna, 2 picocells and 2x1 DAS based on RSCP and E_c/N_0 are given in Table 7.3.

Table 7.3 *Idle measurements for single antenna, 2 picocells and 2x1 DAS.*

Parameters	Single Antenna transmission	2 picocells in single room	2x1 DAS in single room
RSCP (dBm)	-36.33	-35.69	-34.88
E_c/N_0 (dB)	-2.93	-7.33	-2.38

Results show that average RSCP value for 2x1 DAS was around 1 dB better than 2 picocells. Both antennas were transmitting the same signal in single room, so signal strength was better in 2x1 DAS. 2x1 DAS contains losses from 2-way splitter (3 dB) but still providing better RSCP values as coverage area was very small and CPICH power was high. E_c/N_0 is the ratio of RSCP over RSSI, and in 2 picocells RSSI becomes higher due to the presence of other cell interference. 2x1 DAS helps in reducing the interference from other cells and hence reduce the RSSI which in turns improves the E_c/N_0 value. The difference of 4.95 dB in E_c/N_0 was observed, which shows that signal quality of 2 picocells was inferior compared to 2x1 DAS.

7.2.2 HSDPA

The results of single antenna, 2 picocells and 2x1 DAS coverage for HSDPA are shown in Table 7.4. Measurements were performed for both low load and high load. In HSDPA measurements, RSCP value of 2 picocells was better than 2x1 DAS. This was because ideally DAS uses maximum ratio combining if two channels were perfectly orthogonal but in here channels were not orthogonal, so 2x1 DAS was not providing better RSCP values. Averaged SIR and E_c/N_0 were better in DAS configuration. Difference of 3 dB in E_c/N_0 was noticed in high load between 2 picocells and 2x1 DAS in single room. This high showed that, interference was affecting the transmitting signal in 2 picocells.

Considering low load case, SIR value was 4 dB better in 2x1 DAS compared to both 2 picocells configurations. This improvement in SIR provides better Shannon cell capacity and system capacity. The measured cell TP for low load was almost same for all of the three measurement scenarios. As discussed earlier that system was TP limited from network side, so higher TP values were not achieved during measurement. But considering the Shannon system capacity, then 2x1 picocells was providing higher system capacity values, 32 Mbps compared to 21 Mbps in 2x1 DAS.

Table 7.4 *Averaged results from moving data cards in single room.*

HSDPA	Load	Single antenna transmission	2 picocells in single room	2x1 DAS in single room	2 picocells in different room
RSCP (dBm)	Low		-34.06	-36.76	-38.54
	High	-39.00	-35.18	-36.90	-37.76
E_c/N_0 (dB)	Low		-5.83	-5.05	-7.39
	High	-4.93	-9.15	-6.36	-7.85
SIR (dB)	Low		12.08	16.14	12.12
	High	17.28	11.08	17.43	11.69
Measured cell TP (Mbps)	Low		3.50	3.00	3.00
	High	3.00	2.67	5.28	2.55
Measured system TP (Mbps)	Low		6.10	3.00	6.00
	High	3.00	5.20	5.28	5.10
Shannon cell capacity (Mbps)	Low		16.00	21.00	16.00
	High	22.14	14.50	22.50	15.20
Shannon system capacity (Mbps)	Low		32.00	21.00	32.00
	High	22.14	29.00	22.50	30.40

Considering the high load scenario, measured cell TP and Shannon cell capacity was higher in 2x1 DAS compared to 2 picocells. Measured cell TP in 2x1 DAS was 5.28 Mbps which was higher than 2.67 Mbps measured in 2 picocells. But picocells got higher measured system and Shannon system capacity values compared to 2x1 DAS.

Figure 7.6 shows high loaded CDF of SIR for 2x1 DAS and 2 picocells in one room and two different rooms. For 2 picocells, average SIR value for high load case is 11.08 dB with measured cell TP of 2.67 Mbps, whereas 2x1 DAS was providing SIR value of 17.43 dB with measured cell TP of 5.28 Mbps. 2x1 DAS was providing higher measured cell TP with better SIR compared to 2 picocells.

Comparing measured system TP for high load, 2 picocells and 2x1 DAS was providing the same TP values. But considering the Shannon capacity calculation based on measured SIR value, 2 picocells was providing better system capacity than 2x1 DAS.

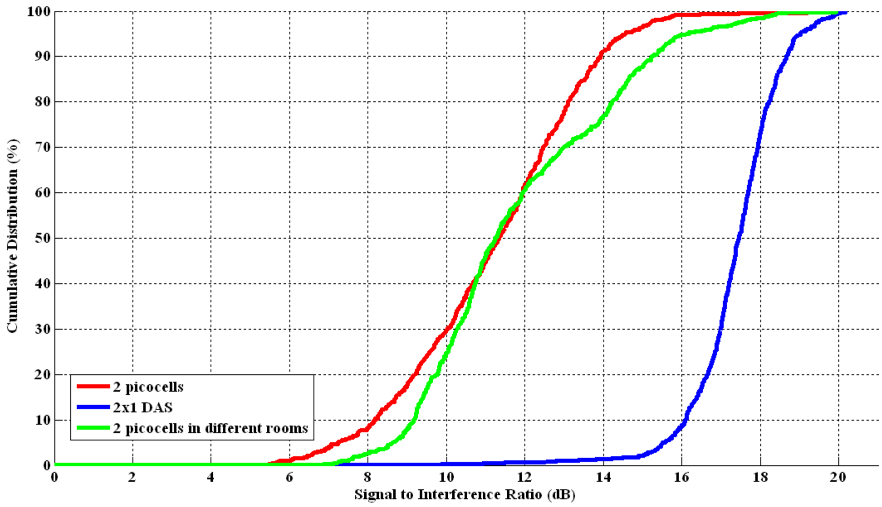


Figure 7.6 *Cumulative distribution of SIR in DAS and picocell configurations with high loaded system.*

As shown in Figure 7.5 the SIR distribution in 2x1 DAS configuration was 5 dB better and smoother compared 2 picocells in same room and 2 picocells in different rooms. This indicates that DAS provides better SIR quality in indoor area due to less interference from other cells.

Low and high loaded results presented in Table 7.4 shows that in low load, 2 picocells performs better than 2x1 DAS with very little margin of 0.5 Mbps in terms of measured cell TP. But considering E_c/N_0 and SIR values, DAS configuration was better and this gives some small pull for DAS performance. According to [11], TP should be directly related to SIR, TP value of 5.28 Mbps with 17.43 dB SIR clearly indicates that 2x1 DAS could achieve much better measured cell TP values without having TP limitation from network side. Figure 7.7 shows the high loaded TP CDF of 2x1 DAS and 2 picocells for both configurations. The results showed that 2x1 DAS was performing better in terms of cell TP compared to 2 picocells.

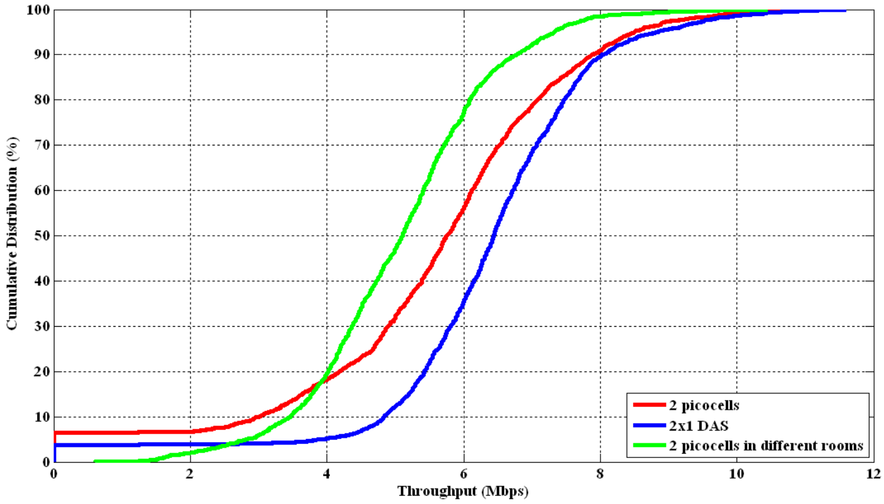


Figure 7.7 *CDF of cell TP for DAS and picocell configurations with high loaded system.*

7.2.3 HSUPA

Table 7.5 presents the averaged HSUPA results of single antenna, 2 picocells in same room, 2x1 DAS and 2 picocells different rooms. RSCP values provide difference of 2.93 dB in 2 picocells and 2x1 DAS because of 2-way splitter loss (3 dB). Due to more number of cells, 2 picocells were providing better values of RSCP. Measured system TP was high in 2 picocells (in same room) but measured cell TP was less compared to 2x1 DAS. Lower cell TP in 2 picocells was due to the presence of high UL interference. Measured system TP of 2 picocells was 3.03 Mbps and cell TP was 1.5 Mbps. Whereas 2x1 DAS has measured system TP of 2.95 Mbps providing cell TP of 2.95 Mbps. This concludes that DAS provides better uplink cell TP but smaller system TP.

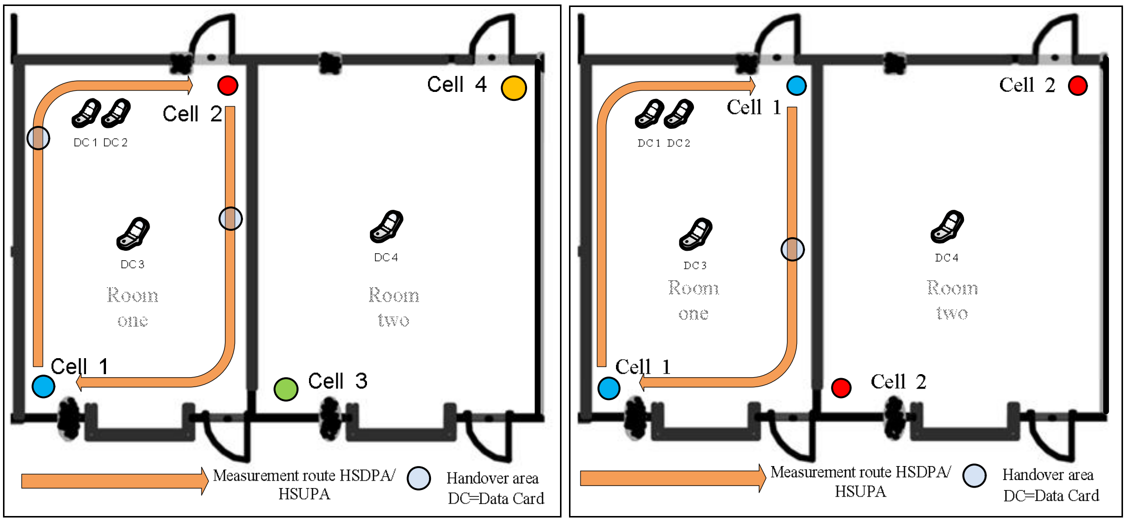
Table 7.5 *Average results of HSUPA moving data cards.*

HSUPA	Single antenna transmission	2 picocells in single room	2x1DAS in single room	2 picocells in different room
RSCP (dBm)	-40.90	-33.89	-36.82	-37.82
Tx Power (dBm)	-42.90	-48.52	-44.62	-45.55
Measured cell TP (Mbps)	1.70	1.50	2.95	1.57
Measured system TP (Mbps)	1.70	3.03	2.95	3.15

7.3 Four Antennas, Measurement Configuration One

Measurement plan was expanded to 4 antennas to get clear comparison of picocell and DAS configuration. For this, 4 antennas were placed such that 2 antennas were placed in each room. Measurement route was different for some of the configurations to ensure reliable results. Therefore, measurements were performed with three different scenarios.

In first measurement configuration, antennas were connected in 4 picocells configuration shown in Figure 7.8 (a). One static data card was present in middle of each room and two data cards were moving in room one. Data was simultaneously downloaded and uploaded on each of the data cards attached to laptop. Same measurements were repeated for 2x2 DAS for moving mobile in room one. Figure 7.8 (a-b) shows the 4 picocells configuration in two rooms and 2x2 DAS with position of DC's. In 2x2 DAS, 2 antennas were placed in one room and connected to one cell.



(a) (b)

Figure 7.8 *Measurement configurations for a) 4 picocells b) 2x2 DAS with two data card moving in room one.*

Furthermore same measurement route and data cards configuration were taken to compare with the performance of 4x1 DAS. In this situation, all four antennas were connected to one serving cell on Node-B as shown in Figure 7.9. Same measurement route was followed for 4x1 DAS with two DC's moving in room one.

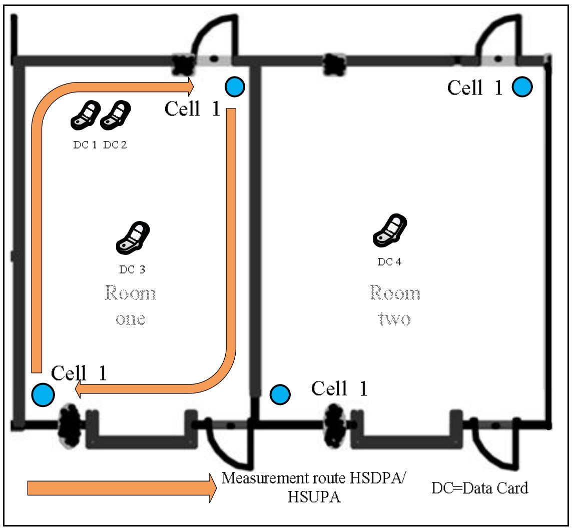


Figure 7.9 *Measurement configurations for 4x1 DAS with two data card moving in room one.*

7.3.1. Idle Results

Table 7.6 shows the average idle mode results of the measurements performed. According to these results the RSCP value of 4 picocells was better than 2x2 DAS due to higher EIRP values for each antenna as given in Table 7.2. But margin was only 1.40 dB which was very less as 2x2 DAS was also having two 2-way splitters losses and antennas were very close to each other in the room.

Table 7.6 *Idle measurements for 4 picocells, 2x2 DAS and 4x1 DAS.*

Idle Mode	4 picocells	2x2 DAS	4x1 DAS
RSCP (dBm)	-34.07	-35.47	-37.42
E_c/N_0 (dB)	-6.9	-4.65	-2.56

The average E_c/N_0 of signal was poor in 4 picocells compared to 2x2 DAS and 4x1 DAS. This was due to the presence of high interference in 4 picocells configuration E_c/N_0 was 2.25 dB higher in 4 picocells than 2x2 DAS. As DAS helps in reducing the interference level from other cells, but here small interference was also present in 2x2 DAS. In 4 picocells, DC's were facing high cell reselections which increases the physical layer channels load.

7.3.2 HSDPA

Measurement results for moving data cards in room one in four antennas case is presented in Table 7.7. Measurement results were in high load thus all data cards were downloading or uploading simultaneously. In idle mode, 4 picocells were providing better RSCP values but in HSDPA almost same RSCP was present for 4 picocells and 2x2 DAS.

Table 7.7 *HSDPA measurements for 4 picocells, 2x2 DAS and 4x1 DAS in room one.*

HSDPA	Load / Modulation	4 picocells (Moving 2MS in room one)	2x2 DAS (Moving 2MS in room one)	4x1 DAS in two rooms
RSCP (dBm)	High	-36.57	-36.45	-42.08
E_c/N_0 (dB)	High	-9.71	-9.22	-9.65
SIR (dB)	High	6.67	10.48	15.49
Measured cell TP (Mbps)	High	2.45	5.05	8.90
Measured system TP (Mbps)	High	9.80	10.10	8.90
Shannon cell capacity (Mbps)	High	9.50	13.80	20.00
Shannon system capacity (Mbps)	High	38.00	27.60	20.00
Modulation percentage	QPSK	25.21%	16.95%	16.20%
	16-QAM	61.04%	38.97%	12.39%
	64-QAM	13.76%	44.09%	71.42%

In 2x2 DAS, measured SIR was 10.48 dB that was 3.81 dB higher compared to 4 picocells. High interference was present in 4 picocells because 4 different channels were interfering with each other. Whereas in case of 2x2 DAS only two channels were interfering with each other, producing less interference.

Figure 7.10 shows the CDF plot of SIR comparison of 4 picocells, 2x2 DAS configuration and 4x1 DAS. Results show that average SIR value for 4 picocells was 6.67 dB and this value was 3.81 dB less than the SIR value measured for 2x2 DAS. This degradation was due to high interference from neighboring cells. Many performance parameters were also affected because of interference. The highest value of SIR was 15.49 dB achieved in 4x1 DAS as no direct interference was present in the system. In terms of systems capacity, picocell was having the highest value of 38 Mbps (calculated from Shannon capacity) but due to high interference level the performance got degraded and averaged measured cell TP of 2.45 Mbps can be achieved. One thing to remember here is that TP was limited from the network side for all configurations as discussed before in section 7.1.2. Figure 1 and Figure 2 in Appendix A shows the average SIR for 4 picocells and 2x2 DAS in low and high load system.

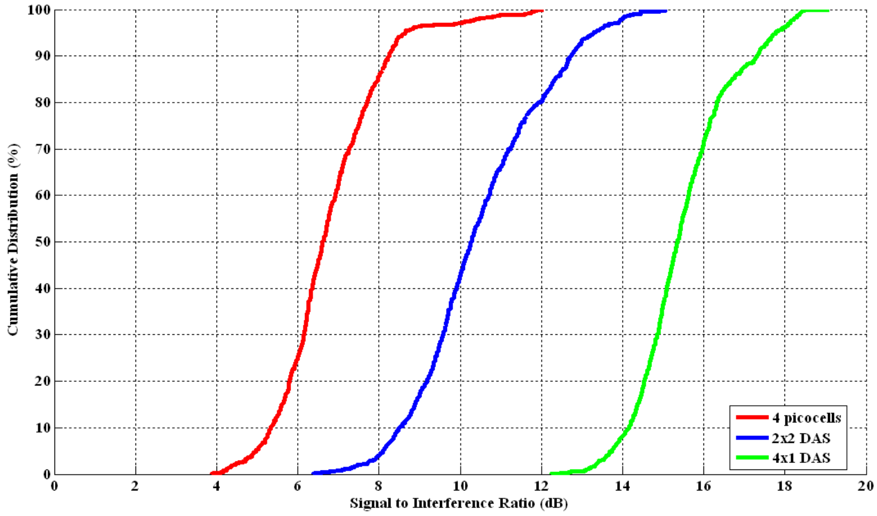


Figure 7.10 *SIR CDF for 4 picocells, 2x2 DAS and 4x1 DAS configurations.*

2x2 DAS was providing 5.05 Mbps as measured cell TP, 4 picocells was providing 2.45 Mbps cell TP and 4x1 DAS was providing 8.90 Mbps as measured cell TP. Shannon cell capacity calculated for 4 picocells was 9.5 Mbps, 2x2 DAS was 13.8 Mbps and 4x1 DAS was 20 Mbps. Comparing both measured and Shannon results, the cell TP of 4x1 DAS was better compared to 2x2 DAS and 4 picocells as there was no interfere present. But comparing interference case, 2x2 DAS was providing much better cell TP than 4 picocells. Figure 7.11 provides CDF plot of measured cell TP for 4 picocells, 2x2 DAS and 4x1 DAS. Here measured cell TP of 4x1 DAS decreased because all of the DC's were sharing the same channel and producing high cell load.

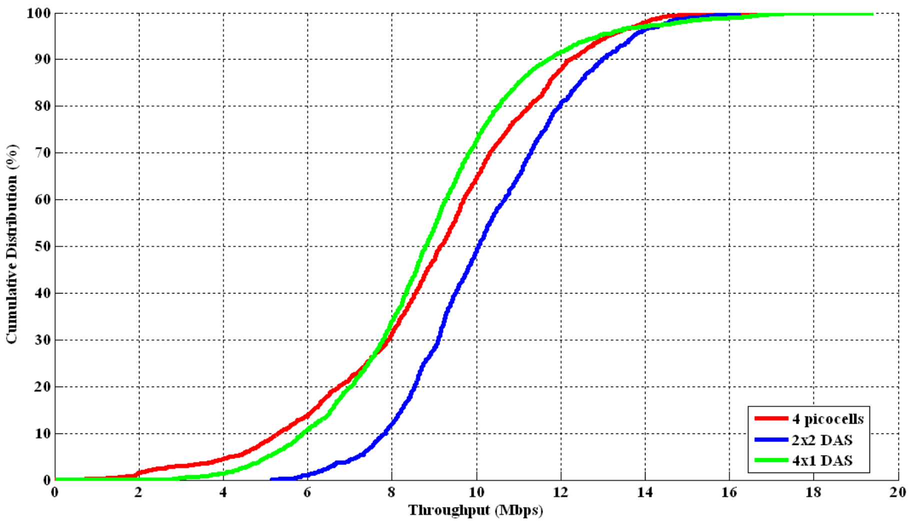


Figure 7.11 *TP CDF for 4 picocells, 2x2 DAS and 4x1 DAS configurations.*

In terms of measured system TP, 2x2 DAS was still providing better results compared to 4 picocells. But system capacity calculated from Shannon capacity theorem shows that 4 picocells was better and was providing 10.4 Mbps more system TP compared to 2x2 DAS due to more channel resources.

To get more reliable results for the comparison, cell TP graphs of DC 1 and DC 2 for 4 picocells and 2x2 DAS are shown in Figure 7.12 and Figure 7.13. These graphs show that average measured cell TP achieved in 4 picocells was around 3.9 Mbps whereas in case of 2x2 DAS, average measured cell TP was 4.5 Mbps. Here 4 picocells was providing lower cell TP due to lower SIR value. Due to high interference, more handovers were performed in the 4 picocells increasing load on physical layer. High TP value for DC 2 can be seen from time period 50s to 60s and this was due to some measurement error. Figure 7.11 also shows the handover areas during the measurement and due to these handovers TP became zero at some time instant. In case of 2x2 DAS average TP was consistent and no loss in data TP was observed.

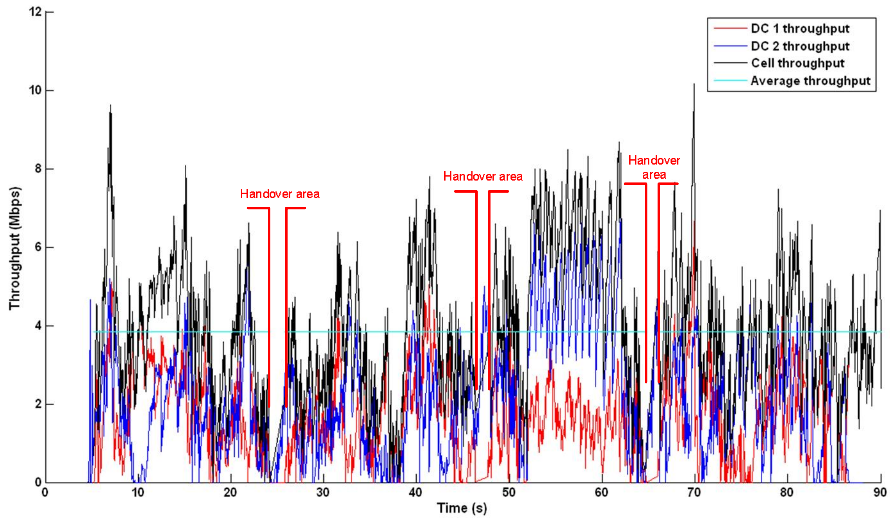


***Figure 7.12** 4 picocells cell TP of DC 1 and DC 2.*

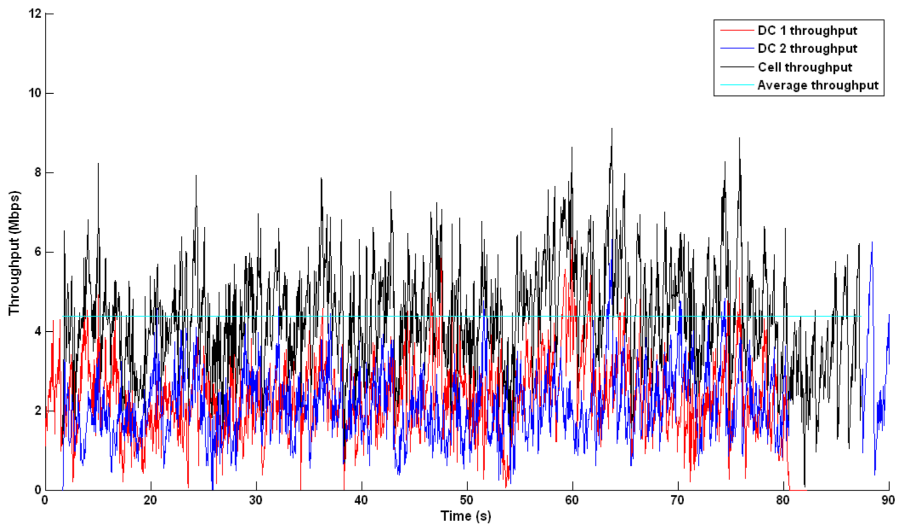


Figure 7.13 2x2 *DAS cell TP of DC 1 and DC 2.*

Modulation scheme usage percentage is presented in Table 7.7. Analysis showed that 64-QAM usage percentage was decreased a lot in case of 4 picocells compared to 2x2 DAS. 2x2 DAS was using 30% more samples from 64-QAM than used in 4 picocells. 4 picocells was using more samples from 16-QAM and less sample from 64-QAM due to high interference in the network. 4x1 DAS was downloading 71.42 % of the data samples using 64-QAM as there was no interfere present which confirm that interference affects higher order modulation.

To verify results, same measurement setup used in section 7.2.2 was again used. But now DC 1 and DC 2 were moving in room two. Appendix A, Figure 3 (a-b) provides measurement configuration for room two with CDF graphs of SIR and TP in Figure 4 and Figure 5. HSDPA measurement results are tabulated in Table A in Appendix A. Results show that SIR was 3.06 dB better in 2x2 DAS compared to 4 picocells. In terms of cell TP and system, 2x2 DAS was providing better TP values compared to 4 picocells. Cell TP was 3.13 Mbps and system TP was 3 Mbps better in 2x2 DAS compared to 4 picocells.

7.3.3 HSUPA

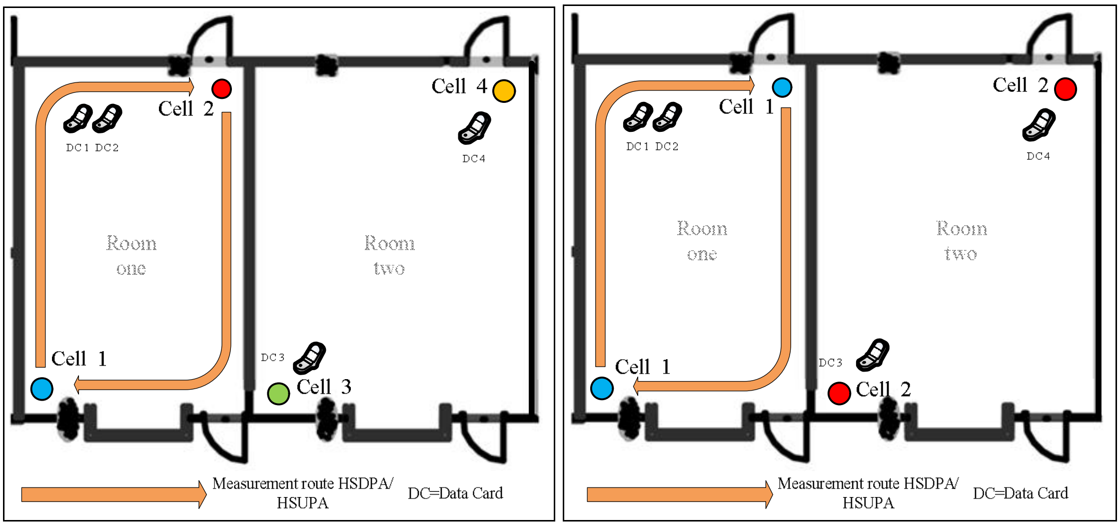
Average HSUPA results for 4 picocells, 2x2 DAS and 4x1 DAS are presented in Table 7.8. RSCP value of 4 picocells was 1 dB higher than 2x2 DAS as expected due to 2-way splitter loss in 2x2 DAS. Almost all the time LOS was present between DC and antennas. Average TX power was almost same in 4 picocells and 2x2 DAS. But TX power decreased in case of 4x1 DAS as four antennas were connected to same cell and four data cards were simultaneously uploading data. Measured system TP was 6 Mbps for 4 picocells and 3.85 Mbps for 2x2 DAS. 4 picocells was providing better system TP but cell TP was not better than 2x2 DAS. Measured cell TP for 2x2 DAS was 1.9 Mbps whereas in 4 picocells measured cell TP was 1.5 Mbps. The uplink interference was measured in empty network and it was -106 dBm, which is almost same for all three scenarios.

Table 7.8 *HSUPA measurements for 4 picocells, 2x2 DAS and 4x1 DAS in room one.*

HSUPA	4 picocells (Moving 2 MS in room one)	2x2DAS (Moving 2 MS in room one)	4x1 DAS
RSCP (dBm)	-35.2	-36.8	-40.4
Tx Power (dBm)	-44.9	-44.6	-37.0
Measured cell TP (Mbps)	1.51	1.92	2.27
Measured system TP (Mbps)	6.07	3.85	2.27

7.4 Four Antennas, Measurement Configuration Two

Measurement configuration was changed in order to make a fair comparison between 4 picocells and 2x2 DAS. For this measurement configuration, two data cards were moving in room one having two antennas. One data card attached to laptop was placed static in front of each antenna in room two. The distance of static data cards from antennas was 1.5 m. Measurement route and EIRP values were same as described in section 7.2.2. Figure 7.14 (a-b) shows the 4 picocells in two rooms and 2x2 DAS.



(a) (b)

Figure 7.14 *Measurement configurations for a) 4 picocells b) 2x2 DAS with two data cards moving in room one and one static data card in front of each antenna in room two.*

7.4.1 HSDPA

Table 7.9 shows HSDPA results for measurement configuration two. In case of 4 picocells, average RSCP value was better because DC 3 and DC 4 were downloading just in front of the antennas with good radio conditions. As RSCP value was calculated by taking average from all DC's, so due to good values from DC 3 and DC 4 averaged values was also better. Average E_c/N_0 value was poor in case of 2x2 DAS with very little margin due to average values of DC 3 and DC 4. As in 4 picocells, DC 3 and DC 4 were served by the one cell providing good RSCP value. But in case of 2x2 DAS, DC 3 and DC 4 were served by the same cell having some interference with other cell serving in room one. Figure 7.15 shows CDF plot of average SIR of 4 picocells and 2x2 DAS. Averaged SIR was 1.4 dB better for 2x2 DAS as compared to 4 picocells. 2x2 DAS was having higher value of SIR due to less interference from other cells. Whereas 4 picocells was having 4 active cells and they were causing interference with each other. Comparing the measured cell TP, 2x2 DAS was performing better than 4 picocells and similarly 2x2 DAS was also performing well in terms of system TP. As mentioned earlier that system TP was calculated by multiplying the number of cells with average cell TP. So if cell TP was decreased for one DC, than whole average cell TP will be affected. And this happened over here, DC 3 was placed at the cell border which caused high interference and random handovers, decreasing cell TP. Due to this cell TP (DC 3) decrease, overall average cell TP was decreased. Figure 7.16 shows CDF of cell TP graph and shows that 2x2 DAS was performing better than 4 picocells by 2.1 Mbps (39%).

Table 7.9 *HSDPA measurements for 4 picocells and 2x2 DAS.*

HSDPA	Load / Modulation	4 picocells	2x2 DAS
RSCP (dBm)	High	-33.57	-38.56
E_c/N_0 (dB)	High	-6.97	-7.27
SIR (dB)	High	9.87	11.27
Measured cell TP (Mbps)	High	1.40	3.58
Measured system TP (Mbps)	High	5.61	7.16
Shannon cell capacity (Mbps)	High	13.13	15.00
Shannon system capacity (Mbps)	High	52.50	30.00
Modulation percentage	QPSK	35.20 %	26.67 %
	16-QAM	50.82 %	34.88 %
	64-QAM	13.98 %	38.46 %

Due to better SIR values, most of the CQI values used in DAS were in between 25 to 27 and this concludes that DAS was performing better in terms of modulation. Picocell was using only 13.98% of 64-QAM samples for downloading whereas DAS was using 38.46% of 64-QAM. So average measured cell TP and Shannon cell capacity shows that 2x2 DAS was performing better than 4 picocells. Whereas in terms of measured system TP and Shannon system capacity, 4 picocells was outperforming the 2x2 DAS.

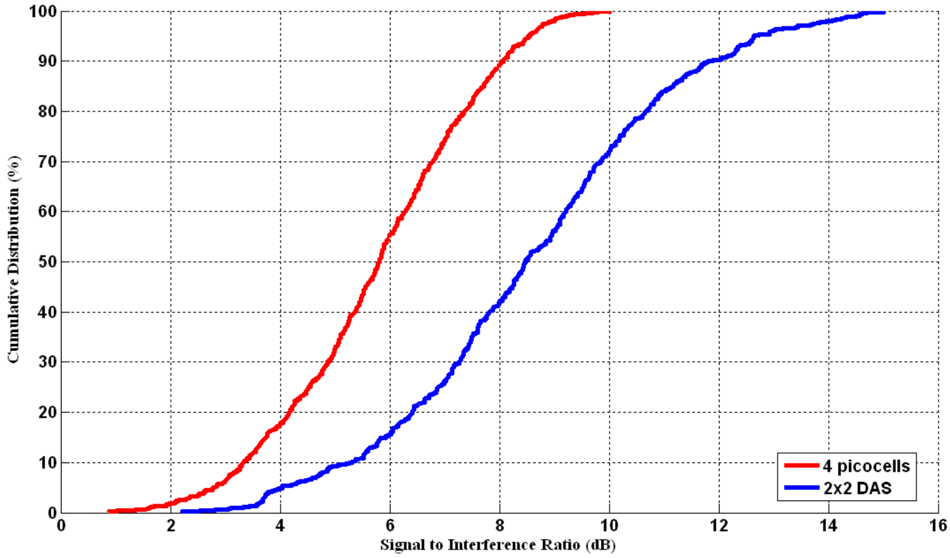


Figure 7.15 *CDF plot of SIR for four picocell and 2x2 DAS.*

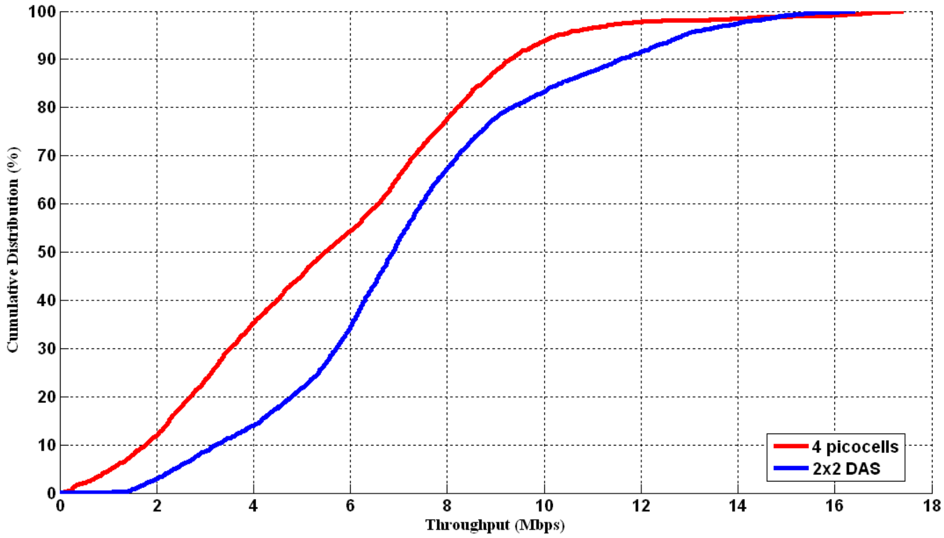


Figure 7.16 *CDF plot of cell TP for four picocell and 2x2 DAS.*

7.4.2 HSUPA

Averaged HSUPA measurement results for second case scenario are depicted in Table 7.10. Average results showed that picocell was providing better RSCP values due to high EIRP from serving cells. The total uplink TX power for 4 picocells was -2.89 dBm lower compared to DAS. Thus, Node-B commands the mobiles in 4 picocells to increase their transmission power in order to maintain the TPs at the optimal level. Results presented were taken as combined average of all the data cards. As discussed before, DC 3 and DC 4 present in room two were static and just placed in front of serving cells, so average RSCP value was better in 4 picocells. Measured system TP was 4.78 Mbps and it was less compared to 2x2 DAS system TP. But cell TP of 2x2 DAS was 2.47 Mbps and that was better compared to 4 picocells.

Table 7.10 *HSUPA measurements for 4 picocells and 2x2 DAS.*

HSUPA	4 picocells	2x2DAS
RSCP (dBm)	-32.89	-36.45
Tx Power (dBm)	-47.15	-44.26
Measured cell TP (Mbps)	1.19	2.47
Measured system TP (Mbps)	4.78	4.94

7.5 Four Antennas, Measurement Configuration Three

The measurement configuration for this scenario was same as described in section 7.4, only difference was that data cards placed in room two were now moving. Mobility was in the sense that each data card was moving front and back in its cell coverage area. All DC's were in motion, so mobility affects different measurement parameters. Figure 7.17(a-b) shows the layout of measurement configuration.

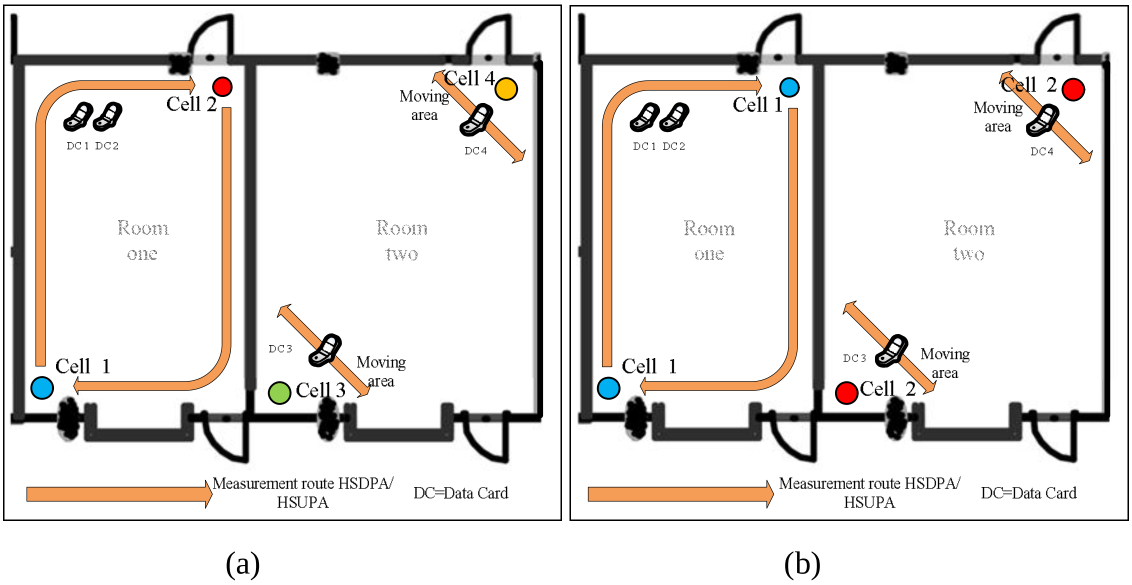


Figure 7.17 *Measurement configurations for a) 4 picocells b) 2x2 DAS with two data card moving front and back around their serving cell in room two.*

7.5.1. HSDPA

Measurement results shown in Table 7.11 are for high load case. All data cards were downloading and uploading at the same time. E_c/N_0 difference between 4 picocells and 2x2 DAS was not big as DC 3 and DC 4 were now in motion and they come near to the cell border where high interference was present in both 4 picocells and 2x2 DAS. 2x2 DAS was having high SIR values due to less interference from other cell and value of SIR was 11.9 dB. But in case of 4 picocells, SIR value was 9.3 dB and that was 2.6 dB less than 2x2 DAS due to presence of more interferer. Figure 7.18 shows the SIR CDF plot for measurements and results shows that smoothness of 2x2 DAS and 4 picocells was almost the same. Whereas in terms of average SIR values, 2x2 DAS was providing better SIR compared to 4 picocells.

Table 7.11 *HSDPA measurements for 4 picocells and 2x2 DAS.*

HSDPA	Load / Modulation	4 picocells	2x2 DAS
RSCP (dBm)	High	-38.86	-39.29
Ec/No (dB)	High	-8.05	-7.59
SIR (dB)	High	9.35	11.91
Measured cell TP (Mbps)	High	1.51	3.71
Measured system TP (Mbps)	High	6.04	7.42
Shannon cell capacity (Mbps)	High	12.50	15.50
Shannon system capacity (Mbps)	High	50.00	31.00
Modulation percentage	QPSK	40.53%	31.19%
	16-QAM	45.15%	36.59%
	64-QAM	14.32%	32.23%

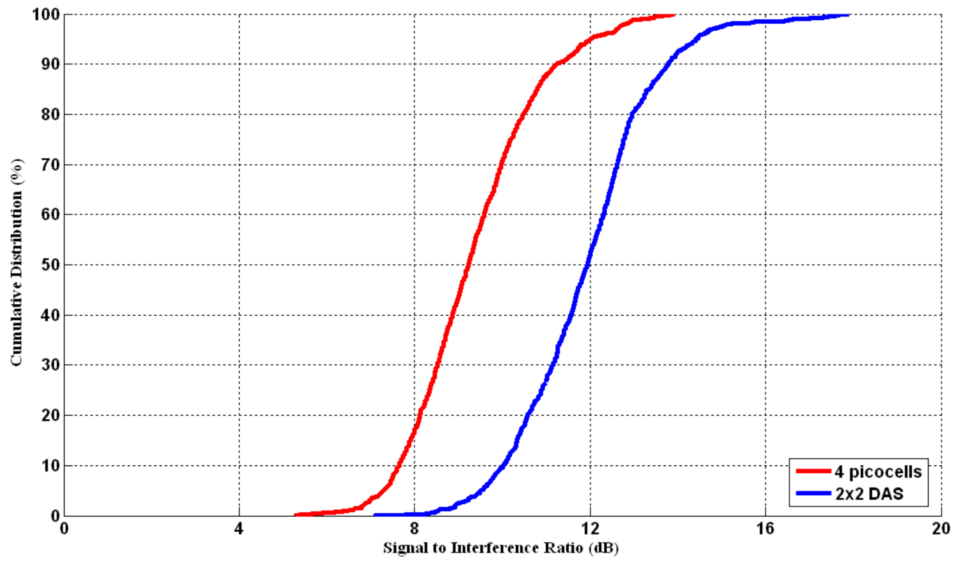


Figure 7.18 *CDF plot of SIR for 4 picocells and 2x2 DAS with moving data cards in room two.*

The results showed that 2x2 DAS was providing better cell TP compared to 4 picocells, measured cell TP was 2.2 Mbps higher in 2x2 DAS. Now comparing the measured system TP, 2x2 DAS was still providing higher value compared to 4 picocells. Measured system TP was 1.4 Mbps higher in 2x2 DAS compared to 4 picocells. Results showed that 4 picocells was providing better Shannon system capacity. Shannon system capacity was 19 Mbps higher in 4 picocells compared to 2x2 DAS. Figure 7.19 shows the CDF TP plot and analysis showed that 2x2 DAS was performing better than 4 picocells.

Modulation scheme results confirm that the usage of 64-QAM benefits users in good radio conditions corresponding to use 32.23% samples. In bad radio conditions like high interference, performance of 64-QAM usage drops and thus TP decreases. The CDF plot of TP shown in Figure 7.18 confirms that due to high interference level performance of picocell was dropped and TP was decreased.

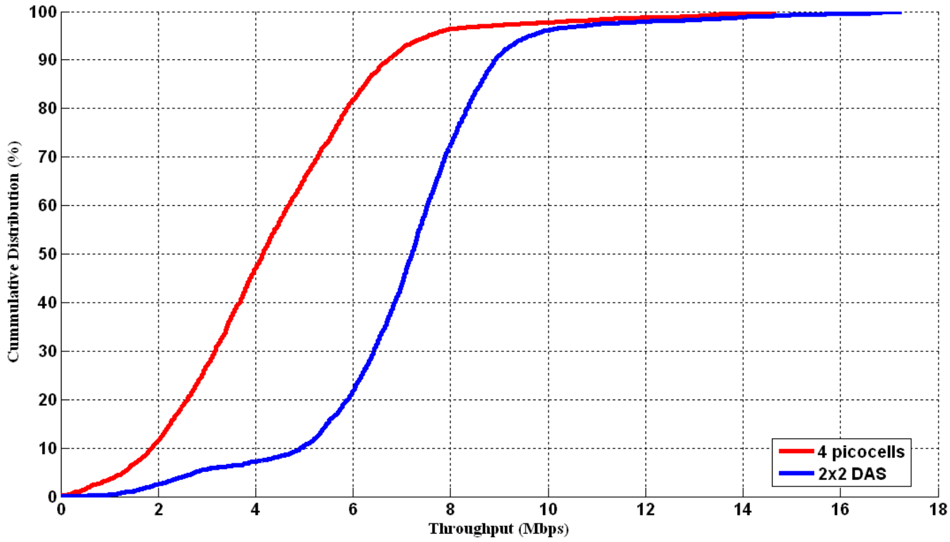
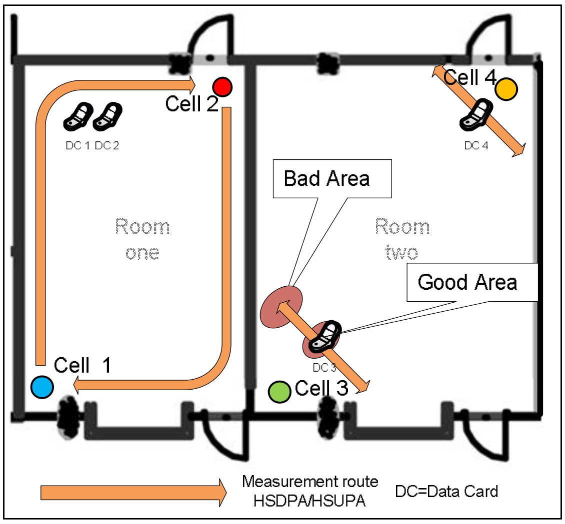
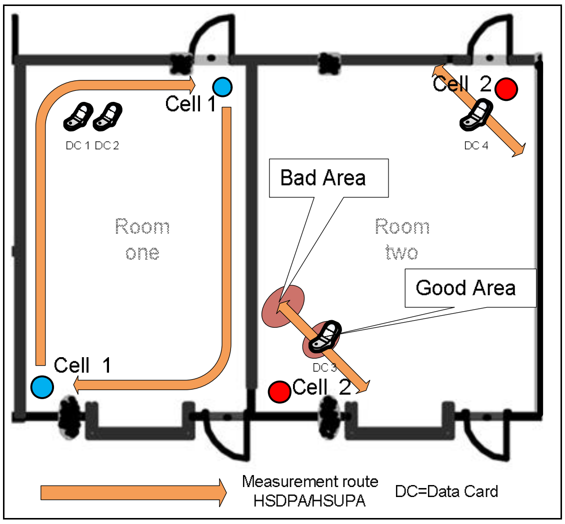


Figure 7.19 *CDF plot of cell TP for 4 picocells and 2x2 DAS with moving data cards in room two.*

In measurement scenario three, one more analysis was performed to check the performance of moving data card in good and bad area of cell. For this, measurement data collected from data card three was analyzed as it was more near to cells located in room one. Figure 7.20(a-b) shows the good and bad areas for data card three in 4 picocells and 2x2 DAS configuration.





(a) **(b)**

Figure 7.20 *Good and bad area analysis in a) 4 picocells and b) 2x2 DAS.*

Table 7.12 summarizes the results of good and bad area for 4 picocells and 2x2 DAS configurations. Good and bad areas were judged by RSCP values of data card measurement as there was no GPS or pinpoint method used. Analysis was performed by taking five samples from the bad and good RSCP values to make results more authenticated. Results show that in bad area like at cell edge where interference was high, 2x2 DAS was still performing better in terms of SIR and E_c/N_0 in bad area but TP was affected in 2x2 DAS due to cell edge. SIR value of 4 picocells was 2.3 dB and in 2x2 DAS SIR was 3.3 dB. This shows that SIR was still better in bad area for 2x2 DAS. Whereas in good area of cell SIR was 3.6 dB better in 2x2 DAS than in picocell. Shannon cell capacity for 2x2 DAS was 0.8 Mbps better in bad area and 4.6 Mbps better in good area.

Table 7.12 *HSDPA measurements of data card three for good and bad areas.*

HSDPA	Load	Bad area		Good area	
		4 picocells	2x2 DAS	4 picocells	2x2 DAS
RSCP (dBm)	High	-50.00	-40.7	-26.80	-30.40
E_c/N_0 (dB)	High	-15.8	-13.00	-4.80	-7.50
SIR (dB)	High	2.30	3.30	16.60	20.20
Measured cell TP (Mbps)	High	0.40	0.20	3.70	3.80
Shannon cell capacity (Mbps)	High	5.50	6.30	21.20	25.80
Shannon system capacity (Mbps)	High	22.00	12.60	84.80	51.70

2x2 DAS was providing Shannon cell capacity value of 6.3 Mbps and 4 picocells was providing 5.5 Mbps in bad area. This shows that 2x2 DAS was still serving better in bad area in terms of cell TP. Whereas the comparing the system TP, 4 picocells was providing better TP both in bad and good area.

7.5.2 HSUPA

Results of HSUPA measurements are listed in Table 7.13. Sum of TP values from data cards showed that system capacity of 4 picocells was 5 Mbps and system capacity of 2x2 DAS was 4.7 Mbps. But the difference comes in the cell TP values of 4 picocells and 2x2 DAS. 4 picocells was providing low cell TP of 1.2 Mbps while 2.3 Mbps was achieved in 2x2 DAS as cell TP. Average results showed that RSCP value of 2x2 DAS was much better than 4 picocells. TX power of 2x2 DAS was higher than 4 picocells. From these results, conclusion can be made that 4 picocells was better in terms of system TP compared to 2x2 DAS. But 2x2 DAS outperforms 4 picocells in terms of RSCP, Tx power and cell TP.

Table 7.13 *HSUPA measurements in case of moving data cards in both rooms.*

HSUPA	4 picocells	2x2DAS
RSCP (dBm)	-38.21	-36.90
Tx Power (dBm)	-45.51	-43.25
Measured cell TP (Mbps)	1.25	2.35
Measured system TP (Mbps)	5.00	4.70

7.6 Error Analysis

Thesis results provide approximation to the real HSPA+ network in indoor environment. Results also contain some errors from simulation, measurement and analysis parts. Simulation part includes 3D ray tracing model which consists of number of transmissions, number of reflections and number of diffractions. Simulation software supports maximum of 30 transmissions, 30 reflections and 3 diffractions. So higher the value, more accurate is the results but it is pertinent to mention that as values are increased to maximum limit, the computation complexity starts to increase. This results in high computation time and demands very high system resources. Therefore there is a tradeoff between computational complexity and prediction accuracy.

Measurements are done by walking the same measurement route so it can never be exactly same and walking speed was also varying. Therefore sometimes data cards are spending more time in bad coverage area than in good coverage area. As antennas are placed in lecture rooms so white board, chair and other stuff are also attenuating the signal. Time synchronization between multiple data cards is one of the important things. The length of TTI in HSDPA is 2ms and in HSUPA TTI is 10 ms. Whereas the measurement software has sampling interval of 200 ms. So provided results are averages of actual values with in 200 ms.

Data is combined and summed up after every measurement. Network TP is a sum of 200 ms window from every measurement. As HSPA+ measurement were having TP limitations from network side so throughout measurement campaign, per cell TP was not more than 10.1 Mbps. Possibility of error is present in the post –processing analysis as results were calculated by rounding in the script that calculates the average cell TP. The synchronization of data cards may be incorrect so the samples may have been gathered at different time instants. Therefore averaged samples were partially overlapping.

8. CONCLUSIONS AND DISCUSSION

In this Master of Science thesis, the purpose was to study different parameters using indoor DAS and multiple picocells. The study provides deployment strategies for indoor network to enhance and optimize HSDPA performance in terms of capacity. Furthermore, research provides better options and guidelines for network planners to choose between DAS or picocells. The studies were based on two parts: analytical part and measurement part. Analytical part consists of simulations performed on propagation tool using WCDMA parameters, and measurement part consists of measurements taken from HSPA+ network.

Analytical studies show that average SIR was better in DAS compared to picocells in all configurations. Considering the 4 antennas, average SIR value for 4 picocells was 1.13 dB whereas 2x2 DAS was providing SIR of 9.39 dB. Shannon cell capacity was calculated from SIR values and results showed that Shannon cell capacity of 2x2 DAS was 63.26% (6.63 Mbps) better compared to 4 picocells. From deployment point of view, system capacity is more significant, and the results show that 4 picocells is providing 22.50% (7.7 Mbps) better system capacity than 2x2 DAS. This is due to ability of reusing resources in picocell configuration. Similarly in 8 antennas, 8 picocells were providing low SIR value of 0.58 dB and 4x2 DAS was providing a SIR value of 8.26 dB. Shannon cell capacity of 4x2 DAS was 15.41 Mbps and 8 picocells was having Shannon cell capacity of 6.2 Mbps. Thus 4x2 DAS was providing 67.50% (9.21 Mbps) more Shannon cell capacity compared to 8 picocells. But in terms of system capacity, 8 picocells was having a system capacity of 49.60 Mbps and that was 60.93% higher compared to 4x2 DAS system capacity providing 30.82 Mbps.

In the second part of this thesis, measurements were performed to verify the simulation results using HSPA+ network. These measurements were conducted in two rooms of modern office building at TUT. For comparison study, measurements were performed for single antenna, 2 picocells, 2x1 DAS, 4 picocells, 2x2 DAS and 4x1 DAS. HSDPA results showed that measured cell throughput for low load was almost the same for 2 picocells and 2x1 DAS. But 2x1 DAS was providing 4.06 dB better SIR compared to 2 picocells. In high load, measurement showed that 2x1 DAS was providing 6.35 dB better SIR with 97.7% (2.61 Mbps) better cell throughput. But from operator point of view, system throughput is much more important compared to other parameters. Measured system throughput in low load for 2 picocells was 50.81% (3.10 Mbps) more compared to 2x1 DAS. Whereas system throughput for 2 antennas scenarios in high load was almost same for 2 picocells in same room, 2x1 DAS and 2 picocells in different rooms. In 4 antennas scenario, 4x1 DAS was having highest SIR value compared to other measurement configuration. SIR value for 4x1 DAS was 15.49 dB, 2x2 DAS was 10.48 dB and 4 picocells got SIR value of 6.67 dB. Cell throughput of 2x2 DAS was 106% (2.6 Mbps) higher compared to 4 picocells. In terms of measured system throughput, 4x1 DAS was having lowest system throughput compared to 4 picocells and 2x2 DAS. But considering the interference scenarios, results show that measured system throughput of 4 picocells was low compared to 2x2 DAS whereas according to Shannon system capacity calculations, 4 picocells provide 37.68% (10.4 Mbps) better capacity compared to 2x2 DAS. Modulation results for 2x2 DAS show that most of the DL samples were using 64-QAM due to less interference. But in case of 4 picocells, most of the DL samples were 16-QAM. This concludes that DAS provides higher order modulation compared to picocell.

Based on the results provided in this thesis, conclusion can be made that DAS performs better in terms of SIR, cell throughput and modulation schemes due to less interference. Whereas picocell provides better system capacity compared to DAS configuration. As cost matters a lot for operators, so DAS is better option in low traffic areas like small or medium sized buildings. Picocell is better for high loaded cases and capacity can be increased by increasing number of base stations. But deployment cost of picocell is higher as more Node-B’s are required compared to DAS. Picocell performance is also degraded by handovers and inter-cell interference. So picocell configuration fits better in building having high capacity requirement.

One of the key things for better indoor coverage and capacity is radio network planning. If good planning is done then it is easier to change from picocell to DAS configuration by doing simple equipment up gradation and minor changes in antenna line configuration. But this changeover from picocell to DAS depends on the traffic requirement.

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APPENDIX A

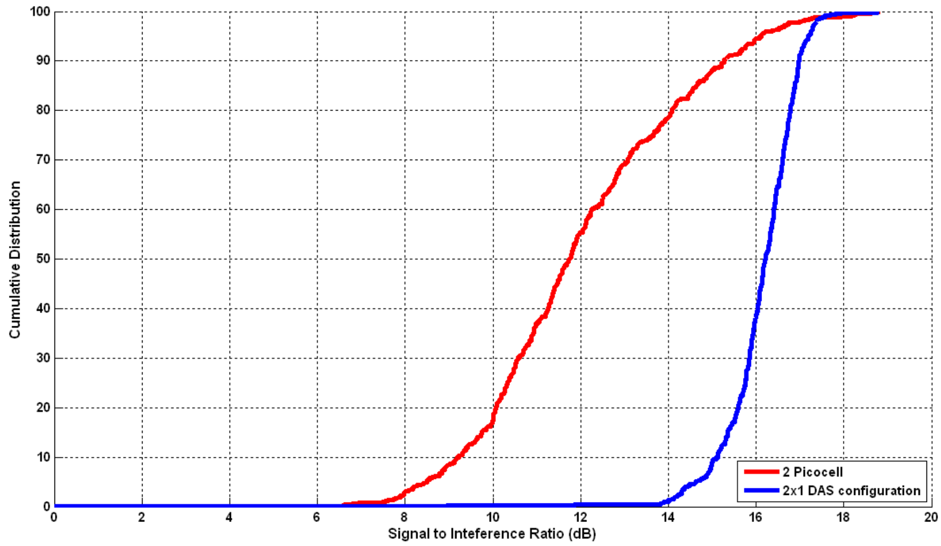


Figure 1 *Cumulative distributive function of SIR for low loaded data cards in two picocells and 2 antenna DAS configuration.*

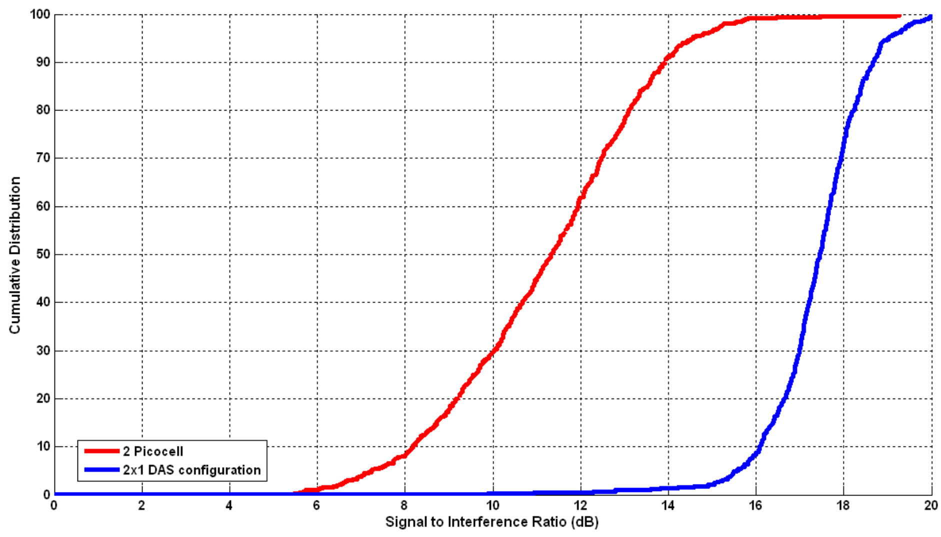
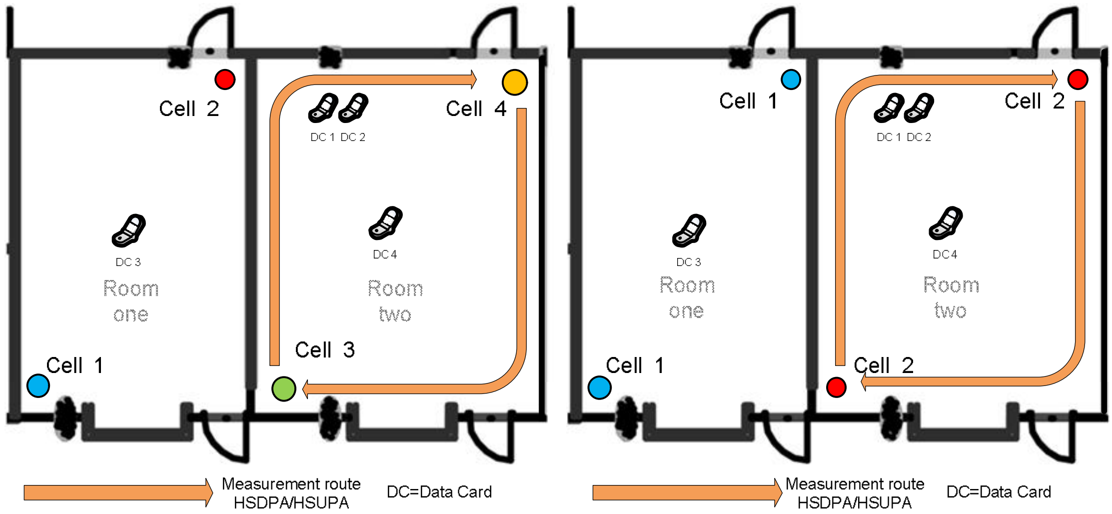


Figure 2 *Cumulative distributive function of SIR for high loaded data cards in two picocells and 2 antenna DAS configuration.*



(a) (b)

Figure 3 *Measurement configurations for a) 4 picocells b) 2x2 DAS with two data card moving in room two.*

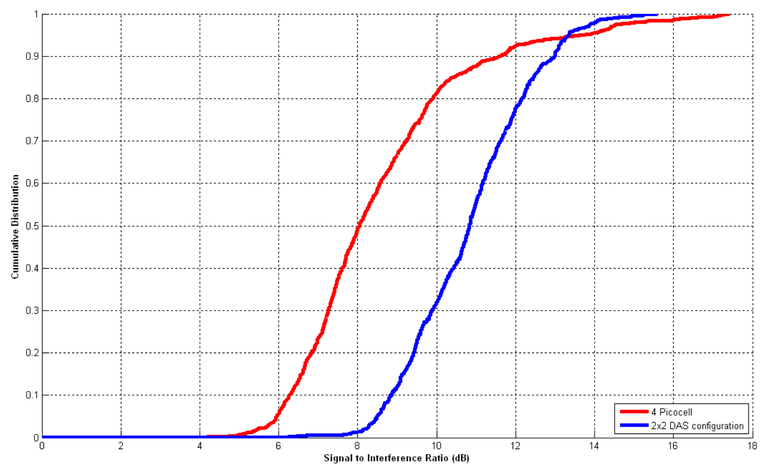


Figure 4 *SIR CDF for four picocell and 2x2 DAS in room two.*

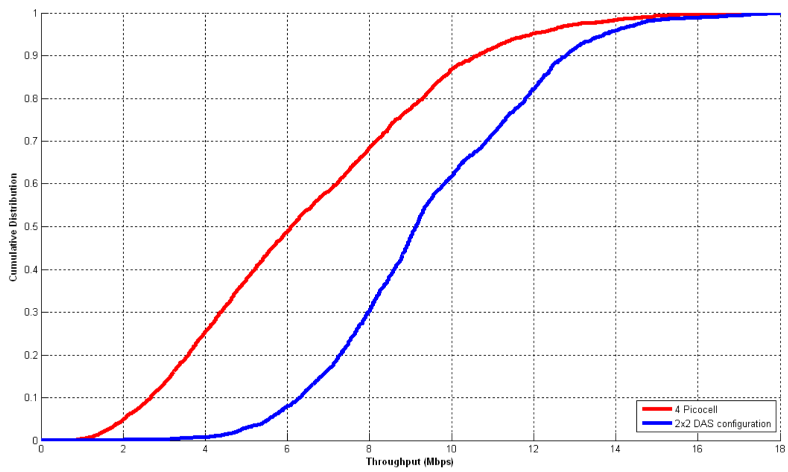


Figure 5 *TP CDF for four picocell and 2x2 DAS in room two.*

Table.A *HSDPA measurements for four picocells, 2x2 DAS and 4x1 DAS in room two.*

HSDPA	Load / Modulation	4 picocells (Moving 2MS in Room2)	2x2DAS (Moving 2MS in Room2)
RSCP (dBm)	High	-39.39	-38.15
Ec/No (dB)	High	-9.81	-9.47
SIR (dB)	High	7.80	10.86
Measured cell TP (Mbps)	High	1.62	4.75
Measured system TP (Mbps)	High	6.50	9.50
Shannon cell capacity (Mbps)	High	10.80	14.20
Shannon system capacity	High	43.20	28.50
Modulation percentage	QPSK	30.92 %	16.24 %
	16 QAM	49.97 %	31.32 %
	64 QAM	19.12 %	36.37 %