

HELSINKI UNIVERSITY OF TECHNOLOGY

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Macro Diversity Combining Optimisation in HSPA Flat Architecture

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HELSINKI UNIVERSITY OF TECHNOLOGY	ABSTRACT OF THE MASTER'S THESIS
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<p>This thesis, Macro Diversity Combining Optimization in High Speed Packet Access (HSPA) flat architecture, concentrates on analyzing implementation alternatives of Macro Diversity Combining (MDC) in flat architecture.</p> <p>When centralized elements, like Radio Network Controller (RNC), are removed from the architecture, centralized functionalities need to be implemented differently. One of the most important centralized functionality is Macro Diversity Combining which collects traffic from multiple base stations and improves radio performance like bit rate and coverage area. When this functionality is implemented inside base station traffic needs to be sent between base stations. Traffic between base stations creates new requirements for transport network and potentially also increases operator transport cost. In short, if MDC is fully implemented, traffic between base stations is maximized and opposite, if MDC is left out, radio performance is reduced.</p> <p>The thesis starts with the overview introduction of Universal Mobile Telecommunication System (UMTS) network. Here we discuss the architecture of the UMTS packet switched network, and the main functionalities of the Radio Resource Management (RRM): power control and handover control.</p> <p>A deeper look is taken into evolution of 3GPP packet access namely High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Data Access (HSUPA) plus the relevant HSDPA cell change and HSUPA handovers are covered. A short glance is also taken into the gains introduced by MDC.</p> <p>In this thesis four proposals presented in 3GPP to improve the MDC with regards to utilization of transport network, implementation complexity, radio performance, latency and amount of additions to existing 3GPP specifications are evaluated.</p> <p>Finally, an implementation alternative for MDC optimization in flat architecture is presented based on the proposals in 3GPP.</p>	
Keywords: UMTS, WCDMA, Soft Handover, Macro Diversity Combining	

Preface

This Master of Science Thesis, Macro Diversity Combining Optimization in HSPA flat architecture, was carried out at I-HSPA program at Nokia Siemens Networks.

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Contents

1.	Introduction	1
1.1	Background and motivation for the work	1
1.2	Objectives and methods	1
1.3	Scope and contribution	1
1.4	Organisation of the thesis	1
2.	UMTS overview	2
2.1	3GPP background	2
2.2	3GPP high level UMTS architecture	2
2.3	UMTS packet data network architecture in 3GPP Rel06	4
2.3.1	UE – ME, USIM.....	4
2.3.2	UTRAN – NodeB, RNC.....	4
2.3.3	Core – SGSN, GGSN, HLR	5
2.4	Overview of UTRAN packet access protocols.....	6
2.4.1	UTRAN packet domain control plane.....	7
2.4.2	UTRAN packet switched domain user plane and Radio Interface Protocols.....	9
2.5	WCDMA logical, transport and physical channels	12
2.5.1	Logical and transport channels.....	12
2.5.2	From transport to physical channels.....	12
2.5.3	UMTS packet access data rates until Rel05	15
2.6	Radio resource management in WCDMA.....	17
2.6.1	Power control	17
2.6.2	Soft handovers	22
2.6.3	Power control in soft handover	25
2.6.4	Soft handover gains – Uplink	26
2.6.5	Delay budget in SHO's – Uplink	28
3.	High speed downlink packet access and high speed uplink packet access – HSDPA and HSUPA.....	29
3.1	HSDPA	29
3.1.1	HSDPA channels and operation	29
3.1.2	UE categories for HSDPA support.....	30
3.1.3	Radio resource management fundamentals for HSDPA support	30
3.1.4	HSDPA channelisation codes and modulation.....	32
3.1.5	HSDPA power control	33
3.2	HSUPA	33
3.2.1	HSUPA channels and operation	33
3.2.2	UE categories for HSUPA support.....	34
3.2.3	Radio resource management fundamentals for HSUPA support	35
3.2.4	HSUPA channelisation codes and modulation.....	37
3.2.5	HSUPA power control	37
3.3	HSPA cell change and handovers	38
3.3.1	HSDPA cell change.....	38
3.3.2	HSUPA handovers and cell change.....	42
3.3.3	Macro diversity combining and delay budget in HSUPA	44
3.3.4	HARQ and MDC gain while using E-DCH	44
4.	UMTS high speed packet access evolution	46
4.1	Way towards Evolved HSPA, system description and architecture.....	46
4.1.1	Evolved HSPA architecture.....	46
4.1.2	Flat architecture benefits and LTE/SAE	48

4.1.3	Circuit switched services in evolved HSPA	49
4.2	Handovers in flat architecture.....	49
4.3	Handover without Iur.....	50
4.4	Handover with Iur.....	51
4.5	Uplink macro diversity combining, key issue in flat architecture	52
4.6	Proposals for enhanced MDC in flat architecture by 3GPP	54
4.6.1	Improvement of UL macro diversity combining in serving NodeB	54
4.6.2	MDC & Cell interference control in eHSPA architecture.....	56
4.6.3	Proposal of interference control and MDC in eHSPA architecture	58
4.6.4	Service differentiated uplink macro diversity combining in flat evolved HSPA architecture 60	
4.7	Summary of the proposals for enhanced MDC in flat architecture made by 3GPP	61
5.	Enhanced MDC proposal comparison in flat architecture	62
5.1	Complexity of the implementation	62
5.1.1	Improvement of UL macro diversity combining in serving NodeB	62
5.1.2	MDC & Cell interference control in eHSPA architecture.....	62
5.1.3	Proposal of interference control and MDC in eHSPA architecture	63
5.1.4	Service differentiated uplink macro diversity combining in flat evolved HSPA architecture 63	
5.2	Transport resource need.....	64
5.2.1	Improvement of UL macro diversity combining in serving NodeB	64
5.2.2	MDC & Cell interference control in eHSPA architecture.....	64
5.2.3	Proposal of interference control and MDC in eHSPA architecture	64
5.2.4	Service differentiated uplink macro diversity combining in flat evolved HSPA architecture 64	
5.3	Radio performance in inter eNodeB soft handover	64
5.4	Latency	65
5.4.1	Improvement of UL macro diversity combining in serving NodeB	65
5.4.2	MDC & Cell interference control in eHSPA architecture.....	65
5.4.3	Proposal of interference control and MDC in eHSPA architecture	65
5.4.4	Service differentiated uplink macro diversity combining in flat evolved HSPA architecture 65	
5.5	Needs for additions to existing 3GPP specifications	65
5.5.1	Improvement of UL macro diversity combining in serving NodeB	65
5.5.2	MDC & Cell interference control in eHSPA architecture.....	66
5.5.3	Proposal of interference control and MDC in eHSPA architecture	66
5.5.4	Service differentiated uplink macro diversity combining in flat evolved HSPA architecture 66	
5.5.5	Summary	67
6.	Conclusions and considerations	68
6.1	Results and contribution	68
6.2	Future consideration for MDC in flat architecture	68
7.	References	70

LIST OF SYMBOLS AND ABBREVIATIONS

3GPP	3 rd Generation Partnership Project
AAL2	ATM Adaptation Layer 2
AAL5	ATM Adaptation Layer 5
ALCAP	Access Link Control Application Protocol
AMC	Adaptive Modulation & Coding
AS	Access Stratum
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
BLER	Block Error Rate
BPSK	Binary Phase Shift Keying
BTS	Base Station 2G
CAPEX	Capital Expenditures
CC	Call Control
CFN	Connection Frame Number
CN	Core Network
CIR	Carrier to Interference Ratio
CP	Control Plane
CPICH	Common Pilot Channel
CRC	Cyclic Redundancy Check
CS	Circuit Switched
DCH	Dedicated Channel
DPCCH	Dedicated Physical Control Channel
DPDCH	Dedicated Physical Data Channel
E-DCH	Enhanced Dedicated Channel
E-TFCI	Enhanced Transport Format Combination Indicator
eNodeB	Evolved NodeB
FACH	Forward Access Channel
FDD	Frequency Division Duplex
FP	Frame Protocol
GGSN	Gateway GPRS Support Node
GMM	(GPRS) Mobility Management
GSM	Global System for Mobile communications
GPRS	General Packet Radio Service
GTP-C	GPRS Tunneling Protocol-Control
HARQ	Hybrid Automatic Repeat Request
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
LTE	Long Term Evolution
M3UA	MTP-3 User Adaptation Layer
MAC	Medium Access Control
MDC	Macro Diversity Combining
ME	Mobile Equipment
MGW	Media Gateway
MM	Mobility Management
MRC	Maximal Ratio Combining

MSC	Mobile Switching Center
MT	Mobile Termination
MTP	Message Transfer Part
NAS	Non-Access Stratum
NBAP	NodeB Application Part
NodeB	Base Station 3G
OPEX	Operational Expense
OVSF	Orthogonal Variable Spreading Factor
PC	Power Control
PDH	Plesiochronous Digital Hierarchy
PDP	Packet Data Protocol (context)
PDU	Protocol Data Unit
PS	Packet Switched
QE	Quality Estimate
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAB	Radio Access Bearer
RACH	Random Access Channel
RANAP	Radio Access Network Application Part
RIP	Radio Interface Protocol
RLC	Radio Link Control
RNC	Radio Network Controller
RNS	Radio Network Subsystem
RNSAP	Radio Network Subsystem Application Part
RRC	Radio Resource Control
SAE	System Architecture Evolution
RRM	Radio Resource Management
SCCP	Signaling Connection and Control Part
SCTP	Stream Control Transmission Protocol
SDH	Synchronous Digital Hierarchy
SGSN	Serving GPRS Support Node
SHO	Soft Handover
SIR	Signal to Interference Ratio
SM	Session Management
SRB	Signaling Radio Bearer
SSCOP	Service Specific Connection Oriented Protocol
TE	Terminal Equipment
TFCI	Transport Format Combination Indicator
TPC	Transmission Power Control
TTI	Transmission Time Interval
UBR	Unspecified Bit Rate
UDP	User Datagram Protocol
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
UP	User Plane
UPDT	User Plane Data Transfer indicator
USIM	Universal Subscriber Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access

1. INTRODUCTION

1.1 Backgound and motivation for the work

The study item for Macro Diversity Combining Optimisation in High Speed Packet Access Flat Architecture was initiated at Nokia Siemens Networks. Flat architecture is a network architecture where MDC would be performed at base station level instead of Radio Network Controller level.

In the original 3rd Generation Partnership Project network architecture where two base stations are in a soft handover situation MDC is done in the RNC. The Iub interface between RNC and the base stations should be dimensioned to handle soft handover traffic. In case the base stations are connected to different RNC's, an Iur interface between RNC's would be needed to carry the SHO traffic between RNC's and also here the Iur interface capacity should be enough to carry the SHO traffic.

In a flat architecture where MDC would be performed at base station level the Iur type links between base stations would be required, thus generating a larger need for Iur type transmission capacity than Iur links between RNC's.

1.2 Objectives and methods

The objective of this thesis is to elarobate a solution for MDC done at base station level, where the references are the implementation complexity, increase in transport capacity, and interference control (radio performance).

1.3 Scope and contribution

3GPP has contributed four proposals how the link capacity and interference control could be handled in flat architecture. These proposals are evaluated and compared resulting in a proposal for minimum transmission capacity increase, simple implementation and keeping the radio performance like in original 3GPP architecture.

1.4 Organisation of the thesis

Chapter 2 gives an overview of Universal Mobile Telecommunication System packet data network architecture, protocols and the two fundamental parts of the Radio Resource Management: power control and soft handovers.

Chapter 3 covers the packet access enhancements, High Speed Downlink Packet Access and High Speed Uplink Packet Access and the related handovers, before the era of flat architecture.

Chapter 4 describes the UMTS HSPA evolution in flat architecture, handovers and the proposals presented in 3GPP for improving the uplink MDC and interference control in flat architecture SHO situation.

Chapter 5 compares the proposals presented in 3GPP based on implementation complexity, transport capacity increase, radio performance, possible latency increase and specification modifications needed in current 3GPP specification set and finally a solution is presented with enhancements to the 3GPP proposals.

2. UMTS OVERVIEW

In the second chapter of this thesis, the basis of the UMTS network principles are presented from standardization work to the architecture of UMTS packet networks including a detailed look at the packet access protocols and data rates achieved. This is followed by the logical, transport and physical channels presentations and the essentials of radio resource management: power control and handover control. In handover control, also the gains achieved in Wideband Code Division Multiple Access (WCDMA) are examined and compared to a GSM type of solution.

2.1 3GPP background

The 3rd Generation Partnership Project (3GPP) is the forum where standardization for the third generation (3G) Universal Mobile Telecommunication System (UMTS) is handled. The 3GPP publishes sets of specifications, called releases. These releases are recommendations for the new functionalities and enhancements, showing also the continuous work done in 3GPP. Below, in table 1, is a summary of the 3GPP releases and their main new functionalities regarding packet data access.

Table 1 3GPP releases.

3GPP Releases	Notation in this thesis	Date	Description
Release 99	Rel99	End of 1999	First 3GPP UMTS specification set. Uplink and downlink 384 Kbit/s
Release 5	Rel05	2002	Specification for High Speed Downlink Packet Access (HSDPA)
Release 6	Rel06	End of 2004	Specification for High Speed Uplink Packet Access (HSUPA). A.k.a E-DCH
Release 7	Rel07	End of 2008	Specification for Flat Packet Network Architecture
Release 8	Rel08	In progress	Long Term Evolution (LTE)

2.2 3GPP high level UMTS architecture

In this chapter the high level 3GPP UMTS architecture is presented followed by a more detailed architecture and short description of the network elements in UTRAN Packet data access network that are valid in until Rel07.

In 3GPP the UMTS architecture is described in terms of its entities [1]:

- UE, User Equipment
- UTRAN, UMTS Terrestrial Radio Access Network
- CN, Core Network

The radio interface Uu and the UTRAN-CN interface Iu are the reference points of the entities.

The functional grouping into Access Stratum (AS) and Non-Access Stratum (NAS) is shown in figure 1. The Access stratum is specific for access technique; it includes protocols for supporting transfer of radio related control information and supporting access to the resources provided by the access network.

The Non-Access Stratum functionality is aimed at Call Control (CC), for Circuit Switched (CS) voice and data; Session Management (SM) for Packet Switched data (PS); (GPRS) Mobility Management (GMM, MM) for PS and CS domains.

The Access Stratum provides a service called the Radio Access Bearer (RAB) to the Non-Access Stratum for user data transfer between the UE and the CN, and the RAB is used to transfer user data between UE and CN, the RAB is described by a Quality of Service (QoS) profile, containing a set of traffic parameters suitable for different applications.

The signaling provided by Access Stratum consists of two parts: Radio Resource Control (RRC) connection (UE <-> UTRAN) and the Iu connection, which expands the RRC signaling towards CN.

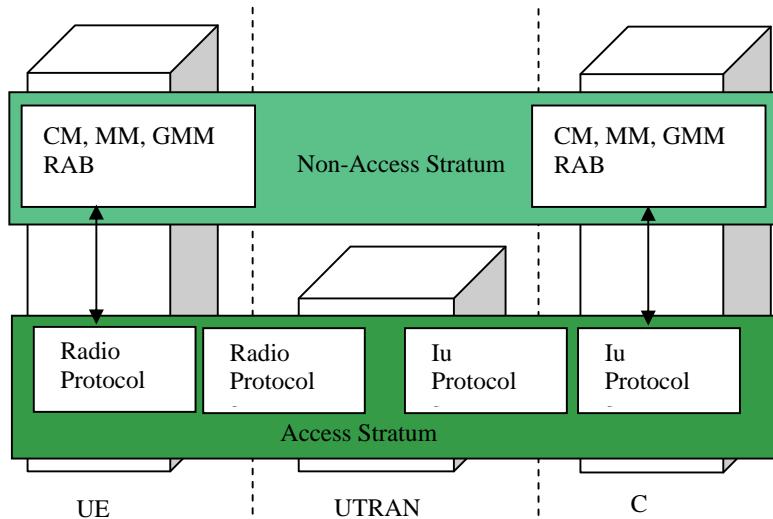


Figure 1 High level UMTS Architecture.

2.3 UMTS packet data network architecture in 3GPP Rel06

The UMTS packet data network as specified in 3GPP [2] until Rel07 is presented in figure 2 and the UE is in an inter NodeB inter RNC soft handover situation.

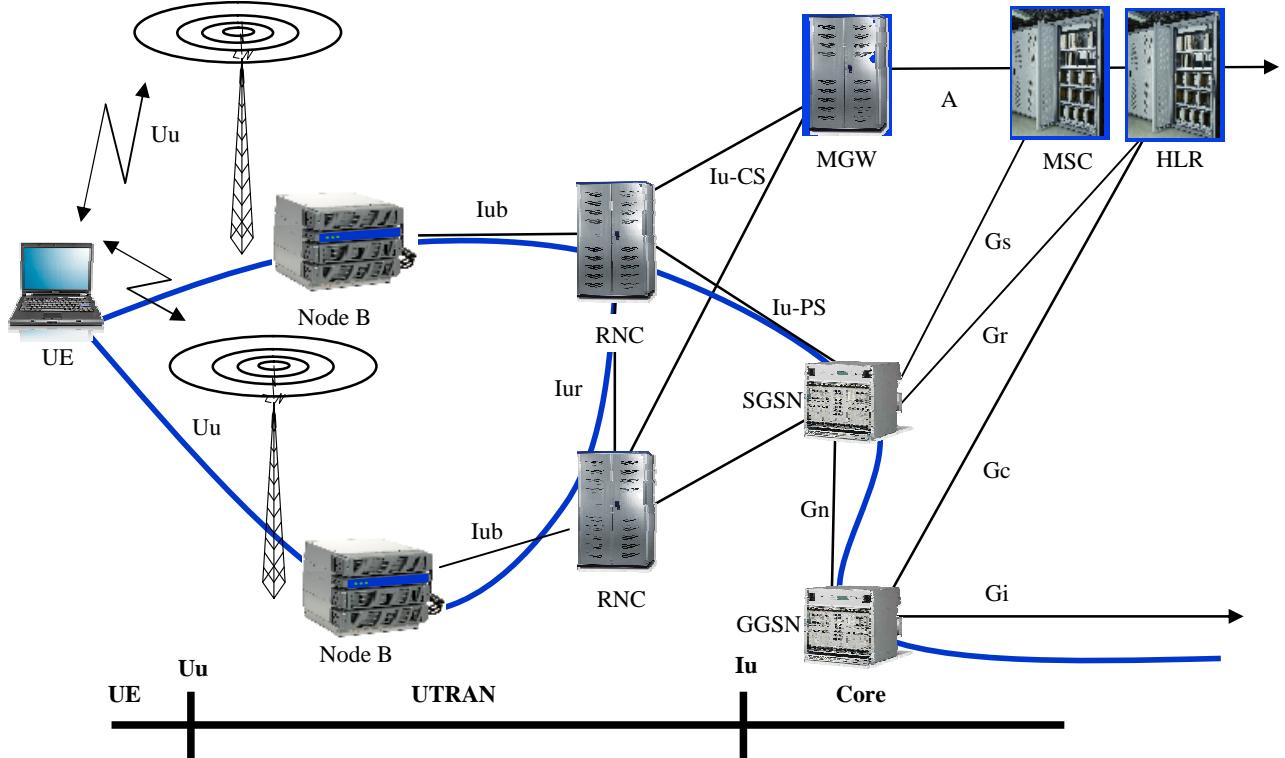


Figure 2 UMTS packet data network architecture in 3GPP Rel06.

The network elements in short:

2.3.1 UE – ME, USIM

In 3GPP terms the User Equipment (UE) is a device that allows the user access to the network services. The UE can be subdivided into two domains, Mobile Equipment (ME) and Universal Subscriber Identity Module (USIM) [3].

2.3.2 UTRAN – NodeB, RNC

NodeB provides the gateway interface between the UE and the Radio Network Controller (RNC) via the Iub interface.

RNC is responsible for centralized operation and maintenance of the entire Radio Network Subsystem (RNS – RNC and NodeB's). Circuit switched data streams from RNC towards core go via the Iu-CS interface and packet switched data streams towards the Iu-PS interfaces. RNS's are connected together via the Iur interface [1].

2.3.3 Core – SGSN, GGSN, HLR

Serving GPRS Support Node (SGSN) network element handles PS domain call control, data transfer and mobility management.

Gateway GPRS Support Node (GGSN) contains routing information for PS attached users and provides interworking with external PS networks.

Home Location Register (HLR) contains PS domain user profiles and PDP context data [2].

2.4 Overview of UTRAN packet access protocols

The general protocol model for UTRAN interfaces is depicted in figure 3. The structure is based on the principle that the layers and planes are logically independent of each other [1] and [4].

The protocol structure consists of two main layers, Radio Network Layer (RNL), and Transport Network Layer (TNL). All UTRAN related issues are visible only in the Radio Network Layer, and the Transport Network Layer represents standard transport technology that is selected to be used for UTRAN, but without any UTRAN specific requirements.

The Control Plane (in RNL) includes the Application Protocol, i.e. Radio Access Network Application Part (RANAP on Iu), Radio Network Subsystem Application Part (RNSAP on Iur) or NodeB Application Part (NBAP on Iub), and the Signalling Bearer for transporting the Application Protocol messages.

The User Plane (in RNL) includes the Data Stream(s), and the Data Bearer(s) for the Data Stream(s). The Data Stream(s) is/are characterised by one or more frame protocols specified for that interface.

The Transport Network Control Plane (in TNL) does not include any Radio Network Layer information, and is completely in the Transport Layer. It includes the Access Link Control Application Protocol(s) (ALCAP) that is/are needed to set up the transport bearers (Data Bearer's) for the user plane. It also includes the appropriate Signaling Bearer(s) needed for the ALCAP protocol(s). The Transport Network Control Plane is a plane that acts between the Control Plane and the user plane.

Transport Network User Plane (in TNL), the Data Bearer(s) in the user plane and the signaling bearer(s) for Application Protocol belongs to the Transport Network User Plane.

The transport bearers for the Data Bearer in the user plane are set up in the following fashion:

First there is a signaling transaction by the Application Protocol in the control plane, which triggers the set up of the data bearer by the ALCAP [1].

For clarity, in the next chapter we only show the control plane and user plane protocol stacks and leave the Transport Network Control Plane, since it's not required on the packet switched domain and its visibility is hidden in the evolved flat architecture Iub [5].

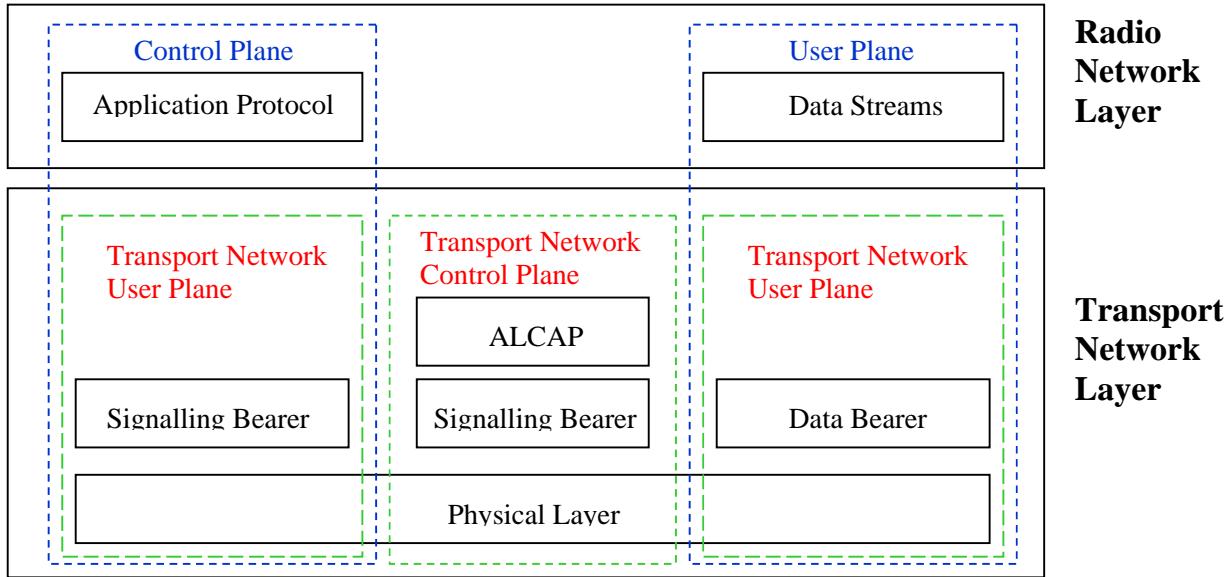


Figure 3 Protocol model for UTRAN interfaces, Iub, Iur and Iu.

2.4.1 UTRAN packet domain control plane

In UMTS, the logical architecture comprises of a control plane and a user plane. The control plane performs all the signaling functions and the user plane performs all the data transfer functions. Through the control plane functions, data bearer connections are setup, terminated and maintained. The control plane and its protocol stack are shown in figure 4 [2].

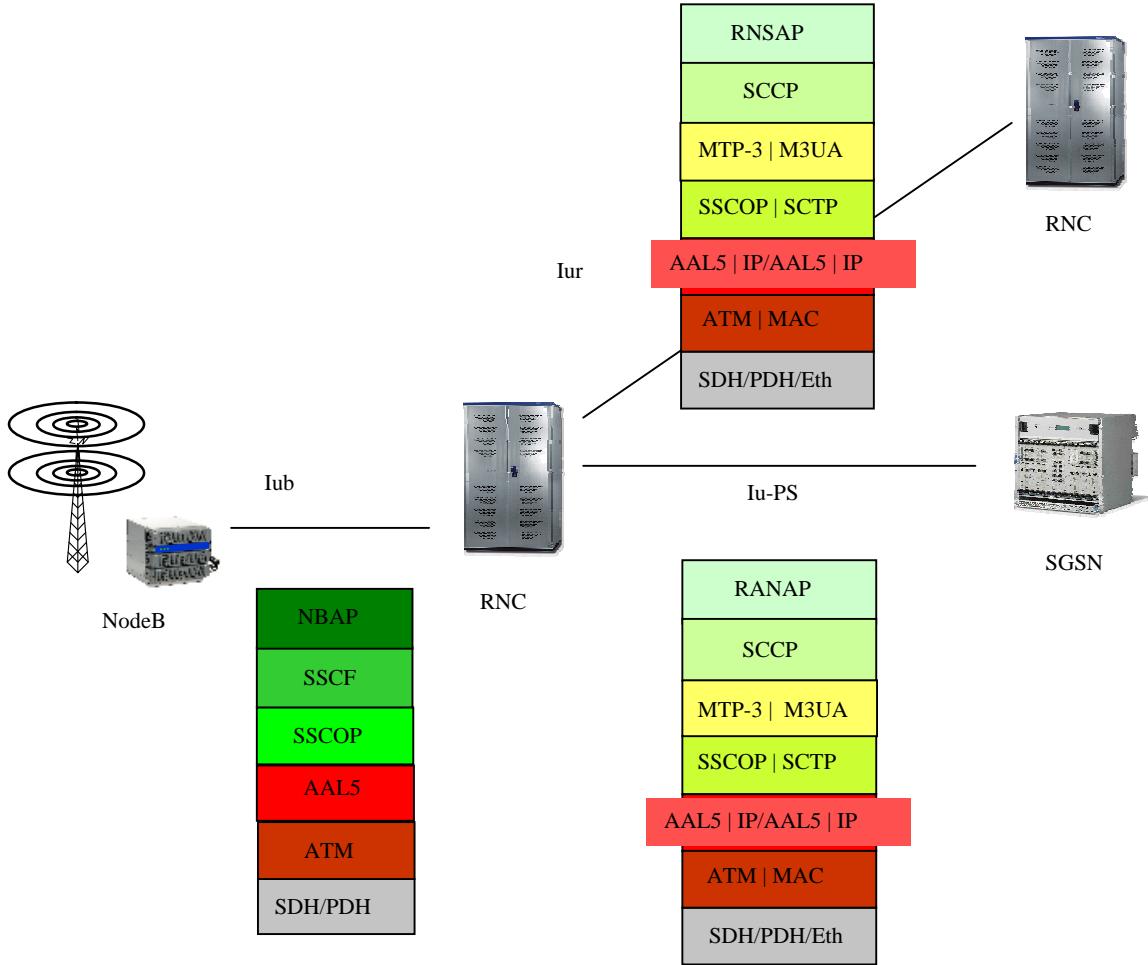


Figure 4 UTRAN PS domain control plane.

UTRAN Iub side control plane functions

- *NodeB Application Part (NBAP)* is responsible for the control of the NodeB by the RNC. NBAP is subdivided into Common and Dedicated NBAP (C-NBAP and D-NBAP), where Common NBAP controls overall NodeB functionality, and Dedicated NBAP controls radio links to specific user equipment. [6]
- The *Service Specific Coordination Function (SSCF)* receives layer 3 signaling and maps it to the SSCOP, and visa versa. [7]
- The *Service Specific Connection Oriented Protocol (SSCOP)* provides mechanisms for the establishment and release of connections and the reliable exchange of signaling information between signaling entities. [8]
- *Atm Adaptation Layer 5 (AAL5)* [9], *Asynchronous Transfer Mode (ATM)* [10] and *Synchronous Digital Hierarchcy/Plesiochronous Digital Hierarchy (SDH/PDH)* [11] and [12] are considered as the link level and physical layer transmission media.

UTRAN core side control plane functions

In the PS core side there are three options to carry RANAP (Iu-PS) [13] and RNSAP (Iur) [14] signaling messages over Signaling Connection and Control Part (SCCP). Two ATM based options and one Internet Protocol (IP) [15] based transport option. Detailed description of these options can be found in 3GPP 25.412 [16]. Here we shortly describe the ATM option 1 (Rel99), ATM option 2 (Rel99) and the IP transport option (Rel05 onwards) as shown in figure 4.

Iu-PS/Iur Interface - ATM based Option 1

- *Message Transfer Part 3 (MTP-3)* provides message routing, discrimination and distribution. [17]
- *Service Specific Connection Oriented Protocol (SSCOP)* provides mechanisms for the establishment and release of connections and the reliable exchange of signaling information between signaling entities. [7]
- *AAL5 and ATM* are the Data Link and *SDH/PDH* the physical transmission media in the ATM based option. [9-12]

Iu-PS/Iur Interface - ATM based Option 2

- *MTP-3 User Adaptation Layer (M3UA)* is a protocol for supporting the transport of any MTP3-User signaling over the IP Network. [18]
- *Stream Control Transmission Protocol (SCTP)* has been developed for the purpose of transporting various signaling protocols over IP networks. [19]
- *IP* is used for routing [15]
- *AAL5 and ATM* are the Data Link and *SDH/PDH* the physical transmission media in the ATM based option. [9-12]

Iu-PS/Iur Interface – IP transport Option

- *MTP-3 User Adaptation Layer (M3UA)* is a protocol for supporting the transport of any MTP3-User signaling over the IP Network. [18]
- *Stream Control Transmission Protocol (SCTP)* has been developed for the purpose of transporting various signaling protocols over IP networks. [19]
- *IP* is used for routing and Ethernet as the physical medium. [15] and [20]

2.4.2 UTRAN packet switched domain user plane and Radio Interface Protocols

On the presentation of the PS user plane we shall broaden the vision from the UTRAN interfaces as shown in figure 2 of the UMTS high level architecture to include the Radio Interface Protocols.

On the Uu interface a three layered protocol stack called the Radio Interface Protocol (RIP) is specified by 3GPP 25.301 [21], RIP includes the physical layer, MAC, RLC and PDCP on layer 2 (Radio Bearer), and its main task being multiplexing of traffic flows of different kinds and different origins. Layer 3 consists of one protocol, called the Radio Resource Protocol (RR) that belongs to the control plane (Signaling Radio Bearer); RR handles the control plane signaling between UE and UTRAN.

The user plane data application carried over IP is processed through Packet Data Convergence Protocol (PDCP) that provides IP header compression, and through RLC/MAC that is used for logical link control over the Uu and Iub interfaces. The GPRS Tunneling (GTP-U) protocol encapsulates and carries all user data between RNC, SGSN and GGSN. In figure 5 below the PS and RIP protocol stacks are presented, included with the Iur interface.

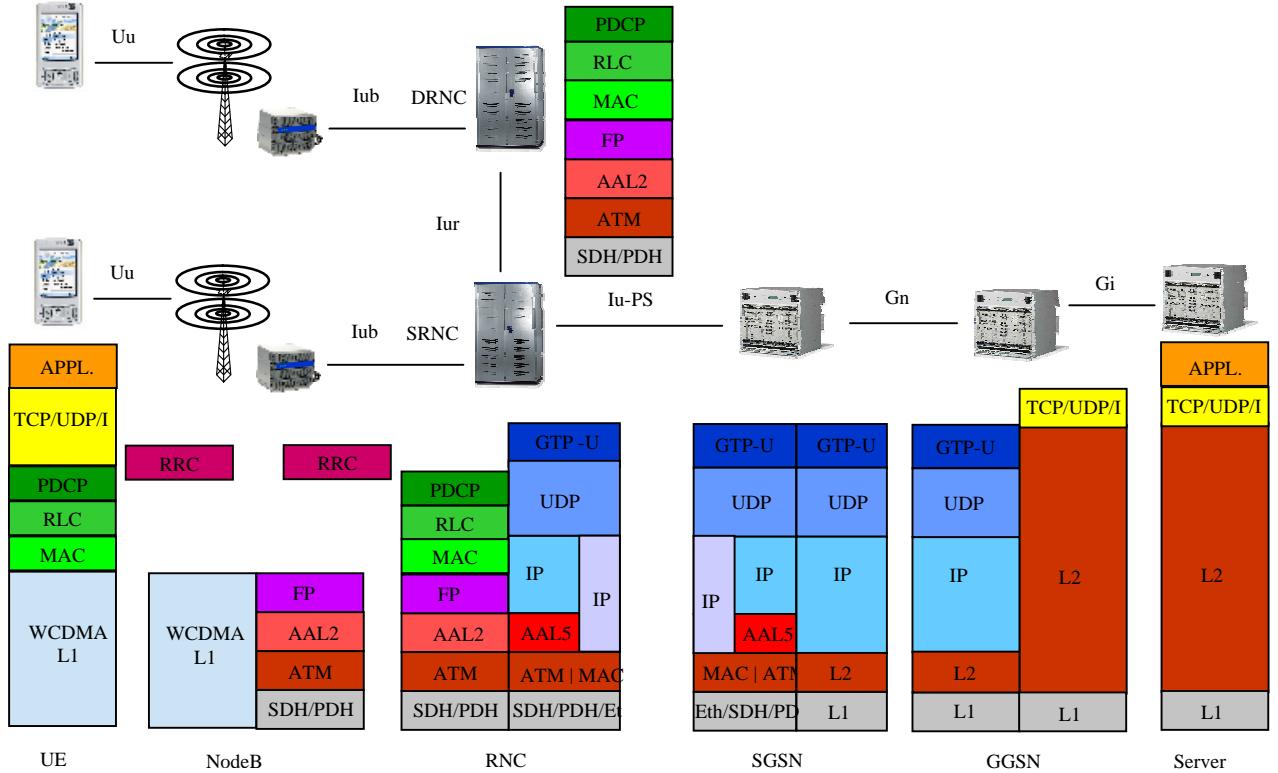


Figure 5 PS domain user plane and radio interface protocols.

Uu / Iub interface layer 1 – 3 protocols are:

- *Uu: L1: WCDMA on Uu interface*
- *Iub L1- L2: AAL2 and ATM are considered as the Data Link and SDH/PDH as the physical transmission media.*
- *L2: MAC – dedicated, maps the logical channels to transport channels.*
- *L2: RLC is configured by RRC and the service is called the Radio Bearer (RB). In PS domain user plane RLC operates in acknowledged mode.*
- *L2: PDCP is for IP header compression*

Iub: FP provides services for transport of user data, transport channel synchronization and timing adjustment. FP is the UTRAN user plane protocol. [22]

- L3 consist of one protocol, denoted Radio Resource Control (RRC), which belongs to the control plane of the radio interface protocols and service is called the Signaling Radio Bearer (SRB) [31].

Core side user plane functions

On Iu-PS there are two options to carry user data in the transport layer [23]

- 1) ATM based Transport (ATM transport option, Rel99)
- 2) IP based Transport (IP transport option, Rel05 onwards)

The figure 5 shows the protocol stacks of these two options.

Gn interface interface protocols are:

- *GTP-U* encapsulates and tunnels user data, between RNC, SGSN and GGSN.
- *UDP* is the transport protocol for tunneled user data. [24]
- *IP* is used for routing GTP-U/UDP packets.

2.5 WCDMA logical, transport and physical channels

2.5.1 Logical and transport channels

The channel organization in WCDMA uses a 3 layer structure, there are logical, transport and physical channels. From these, the logical channels describe certain tasks to be performed, transport channels information sequences to transmitted/received and physical channels are the transmission media providing the platform through which the information is actually transferred [25].

Concerning the logical channels, the UE and the network have different tasks to do. Thus, the logical channel structure is a bit different in either direction.

Here are the main network side functions and logical channels in downlink:

- Network information delivery (BCCH)
- Paging (PCH)
- Common control (CCCH)
- Dedicated control (DCCH)
- Dedicated traffic (DTCH)

As discussed in chapter 2.4 the functionality of the MAC layer is to map logical channels onto appropriate transport channel. The transport channels carrying the above logical channel information flows in downlink direction are:

- Broadcast channel (BCH) carrying the logical BCCH
- Paging (PCH), carrying the logical paging (PCH)
- Forward access channel (FACH) carrying the common and dedicated control channels, CCCH and DCCH
- Dedicated Channel (DCH) carries information from DTCH and DCCH

In uplink the need for logical channels is much less, only three logical channels being CCCH, DTCH and DCCH. The transport channels in uplink are:

- Random access channel (RACH), that carries the initial access information
- Dedicated channel (DCH), carries the user and control data

2.5.2 From transport to physical channels

Before transmitting, the transport channels are mapped to physical channels. In addition, there exist physical channels to carry only information related to physical layer procedures. The synchronization channel (SCH), Common Pilot channel (CPICH), and the Acquisition indication channel (AICH) are not directly visible to the higher layers, but are mandatory for the system operation point of view. Downlink and uplink channel mapping is presented in figure 6.

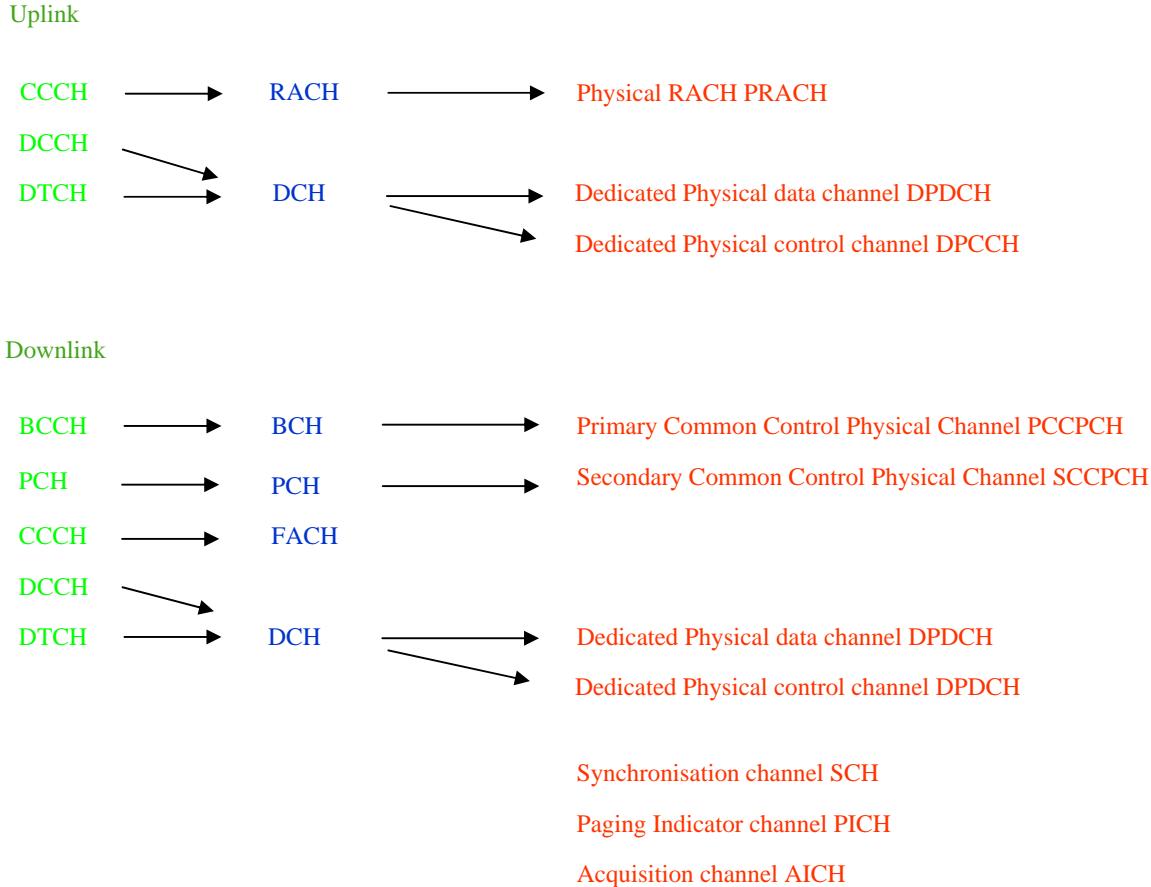


Figure 6 WCDMA logical, transport and physical channels [24].

Channelisation, scrambling and modulation

Here we shortly present the channelisation (spreading), scrambling and modulation used in WCDMA. The purpose is to present the usage of Orthogonal Variable Spreading Factor (OVSF) channelisation codes in differencing users in downlink and services of one user in uplink. Secondly the usage of scrambling codes and also the differences in mapping the modulating data stream into the carrier signal using QPSK modulation in uplink and downlink is presented. 3GPP 25.213 [26] covers in detail the channelisation and spreading of physical channels.

Channelisation and scrambling

In WCDMA, before modulation, two operations are applied to the data. The first one is the channelisation, which transforms every data bit into a number of chips, thus increasing the bandwidth of the signal to a wideband signal (spreading), and providing the requested data rate. The number of chips per data bit is called the spreading factor (SF). The second operation is the scrambling, scrambling codes are used to make the signal from different sources separable from each other.

In channelisation, the channelisation codes are picked from the OVSF code tree according to the requested user data rate. The number of codes at each level is equal to the value of the SF.

In an ideal environment, channelisation codes can be picked from an OVSF tree so that they do not interfere with each other, this is called orthogonality.

However orthogonality requires that they are transmitted in synchrony. Therefore, OVSF codes can be used in downlink to separate users within one cell, but in uplink as different UE transmissions can't be in synchrony, different services by one user are separated by channelisation codes and users are separated by scrambling codes. It should be noted that multipath propagation destroys the perfect orthogonality and thus some interference is will be present.

There is one code tree per NodeB, thus making it a limited resource in downlink, in uplink there is one code tree per UE, hence no resource allocation limitations in uplink exists.

Scrambling is used on top of channelisation, here the signal (physical channels) that are already channelised (spread) and summed together are further combined with a scrambling code. In uplink scrambling codes are used to identify the UE's in the NodeB. In downlink each cell has its own scrambling code as identification purposes [4].

WCDMA modulation

The modulation method in WCDMA uplink and downlink is the Quadrature Phase Shift Keying (QPSK). In QPSK modulation process the scrambled signal is converted from serial stream into two parallel data streams called the I (in phase) and Q (quadrature) branch. These two branches are sent to separate oscillators with the same carrier frequency, I branch directly and Q branch with a 90 degree phase shift in the carrier. These two modulated carriers are then summed to build the QPSK signal.

In BPSK only one bit at a time modulates the carrier phase, resulting in one bit / one modulated symbol in I plane (symbol rate = channel bit rate), where as in QPSK there are two bits per modulated symbol in I/Q plane, thus channel bit rate is twice the symbol rate [25].

Uplink modulation

In the uplink I/Q code multiplexing is applied. Here the DPDCH is transmitted on the I branch and DPCCH on the Q branch. This is also called the dual BPSK, where DPDCH and DPCCH are modulated using BPSK and then summed resulting in QPSK. Hence the channel symbol rate and channel bit rate are the same on both branches. The reason for this selection is that time multiplexed DPDCH and DPCCH transmission can cause discontinuous moments in transmission (DTX) that can cause audible interference to audio equipment that are very close to the terminal [4].

Downlink modulation

In the downlink, QPSK is used with time multiplexed DPCCH and DPDCH streams. The principle of uplink and downlink modulation is shown in figure 7.

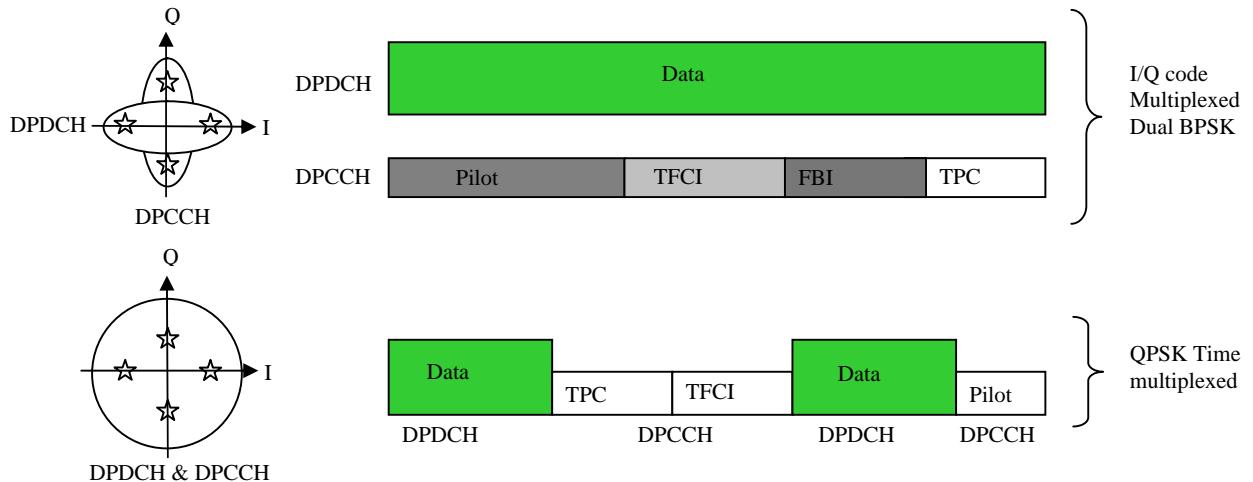


Figure 7 Uplink and downlink DPDCH & DPCCH constellation and transmission.

2.5.3 UMTS packet access data rates until Rel05

WCDMA technology provides a flexible platform for a wide range of bit rates to be used for packet data services. In Rel99 the highest available bit rate is in practice 384 Kbit/s with a wide range of intermediate bit rates down to 8 Kbit/s. Rel99 includes three different channels for downlink data transmission: Dedicated channel (DCH), FACH (Forward Access Channel) and the Downlink Shared Channel (DSCH).

The DCH is the primary data channel and can be used for any traffic class. In the downlink, the DCH is allocated a certain spreading factor (SF) 4 – 512 according to the connection peak data rate (pls. refer to 2.5.1 for channels, spreading factor and channelisation codes). In the table 2 below the achievable data rates with different spreading factors are presented for DCH.

The FACH is a common channel offering low data rate in downlink. However, it's not efficient since it does not support fast closed loop power control – therefore it is limited to carry small amounts of data.

The DSCH has been removed from Rel05 onwards, simply due to lack of interest for actual implementation and has been overridden by HS-DSCH.

Table 2 Downlink maximum user data rate [4].

Max. user data rate with ½ rate coding ~ (kbps) / Actual rate (kbps)	Channel Bit rate (kbps)	Channel Symbol rate (kbps)	Spreading factor
1-3	15	7.5	512
6-12 / 8	30	15	256
20-24 / 16	60	30	128
45 / 32	120	60	64
105 / 64	240	120	32
215 / 128	480	240	16
456 / 384	960	480	8
936	1920	960	4

In the uplink direction the possible spreading factors for the DCH are from 4 to 256.

As FACH in the downlink, RACH can be used in uplink for low data rates for non-continuous transmission purposes. In the table 3 below the achievable data rates with different spreading factors are presented.

Table 3 Uplink maximum user data rate [4].

Max. user data rate with ½ rate coding ~ (kbps) / Actual rate (kbps)	channel / bit rate (kbps)	channel symbol/ bit rate (kbps)	spreading factor
7.5	15	15	256
15 / 8	30	30	128
30 / 16	60	60	64
60 / 32	120	120	32
120 / 64	240	240	16
240 / 128	480	480	8
480 / 384	960	960	4

The difference in data rates in tables 2 and 3 vs. SF are from modulation. The uplink DPDCH consists of BPSK and the downlink DPDCH consists of QPSK symbols. Although downlink DPDCH is time multiplexed with DPCCH, the bit rate accommodated in a single code in the downlink DPDCH is almost double that in the uplink DPDCH with the same spreading factor.

As mentioned, the highest available uplink (SF 4) and downlink (SF 8) bit rates are 384 Kbit/s, the downlink the bit rate could be double, but the 384 Kbit/s limitation comes from UE's not supporting higher rates.

2.6 Radio resource management in WCDMA

Radio Resource Management (RRM) algorithms are responsible for efficient use of the air interface resources. RRM is also needed to guarantee Quality of service (QoS) to maintain the planned coverage area and capacity. The RRM functions can be divided in to power control, handover control, admission control, load control and packet scheduling functionalities. Taking into account the objective of this study, power control and handover control are picked from the RRM family for a closer look. Several sources cover the whole RRM functionality in detail, such as [4].

2.6.1 Power control

In this section power control essentials in WCDMA [27] system is described briefly from the system capacity point of view and also the mechanisms that are used in the WCDMA power control, the power control of HSPA channels are described in chapters 3.1 and 3.2.

As already mentioned one of the most important features in WCDMA system is a fast and exact power control mechanism over the air interface between UE's and NodeB since the WCDMA system capacity is based on received interference on the receivers in the UE and NodeB. In WCDMA context interference is used as term of channelisation code signals that are not ment to be despread.

2.6.1.1 Wideband interference and power control

In case of WCDMA, the receiver is able to despread the desired code signal as long as the power of the despread signal is few decibels higher than the interference power; carrier to inference power, as shown in figure 8. In case the interfering power of users comes larger then the wanted despread code signal carrier power, the wanted code signal cant be recovered, as shown in figure 9 [28].

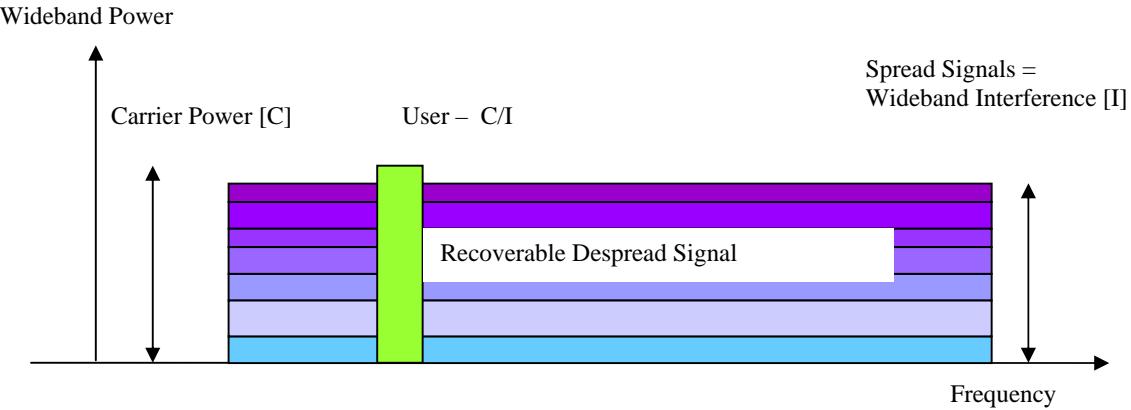


Figure 8 Recoverable despread signal.

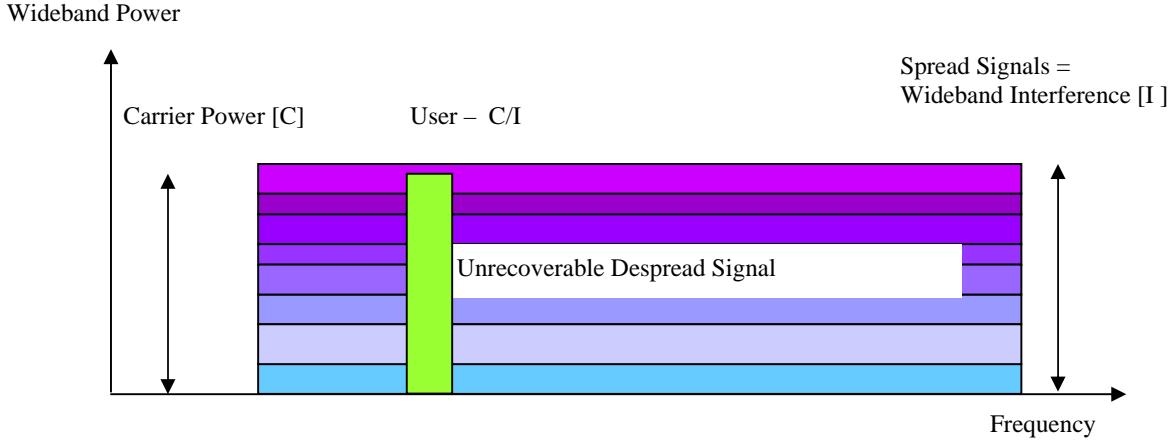


Figure 9 Unrecoverable despread signal.

The essentiality of the power control in WCDMA is to adjust the transmitter power to a minimum level so that the receiving end signal to interference (SIR) level can receive the signal at a sufficient quality. This is most important in the uplink direction, since the total bandwidth is shared simultaneously among all users and different users are experienced as noise interference for each other. Downlink power control is not as essential as uplink power control in WCDMA and it's mainly for minimizing the interference to other cells and also to provide marginal amount of additional power for UE's at the cell edge [28].

In the uplink, the main task of the power control is to adjust the transmitted power levels of the UE's, regardless of their distance and changing variations of the radio channel, to the NodeB to a level that the received signals of all UE's, under the specific cell, are at acceptable quality level (SIR) and equal compared to each other in the NodeB receiver¹. In case UE transmission power would not be tightly controlled a UE close to NodeB, transmitting with similar power as an UE far from the NodeB, would block a significant part of the cell, due to interference. This is known as the near-far problem in WCDMA [29].

To manage the required power control properly the following mechanisms are adopted in WCDMA

- Open Loop power control
- Closed loop power control (Inner Loop)
- Outer Loop power control

2.6.1.2 Open Loop Power Control

Open-Loop Power Control is responsible for setting the initial uplink and downlink transmission powers when a UE is accessing the network. Open Loop PC can be done according to the path loss calculations in the downlink direction, since the uplink and downlink frequencies of WCDMA are within the same frequency band.

¹ SIR is derived from Block Error Rate (BLER) or Bit Error Rate (BER) in the pilot bits of the uplink DPCCH.

2.6.1.3 Closed loop power control

The closed loop power control (inner loop PC) helps the UE/NodeB to adjust its transmitted power based on the received SIR level at the UE/NodeB for compensating the fading of the radio channel. It is taken into function based on the feedback information at Layer 1 from the opposite end of the radio link. The inner-loop PC function in UMTS is implemented for the dedicated channels in both the uplink and downlink directions. The frequency of fast closed-loop PC is 1.5 kHz in WCDMA.

The uplink closed loop power control is used to set the power of the uplink DPCH. The base station receives the target SIR from the uplink outer-loop PC located in the RNC and compares it with the estimated SIR on the pilot symbol of the uplink DPCCH one every slot. If the received SIR is greater than the target, the base station transmits a TPC command ‘down’ to the UE on the downlink DPCCH and asks the UE to lower the transmitted power. If the received SIR is below the target, a TPC command ‘up’ is sent, as shown in figure 10 [29].

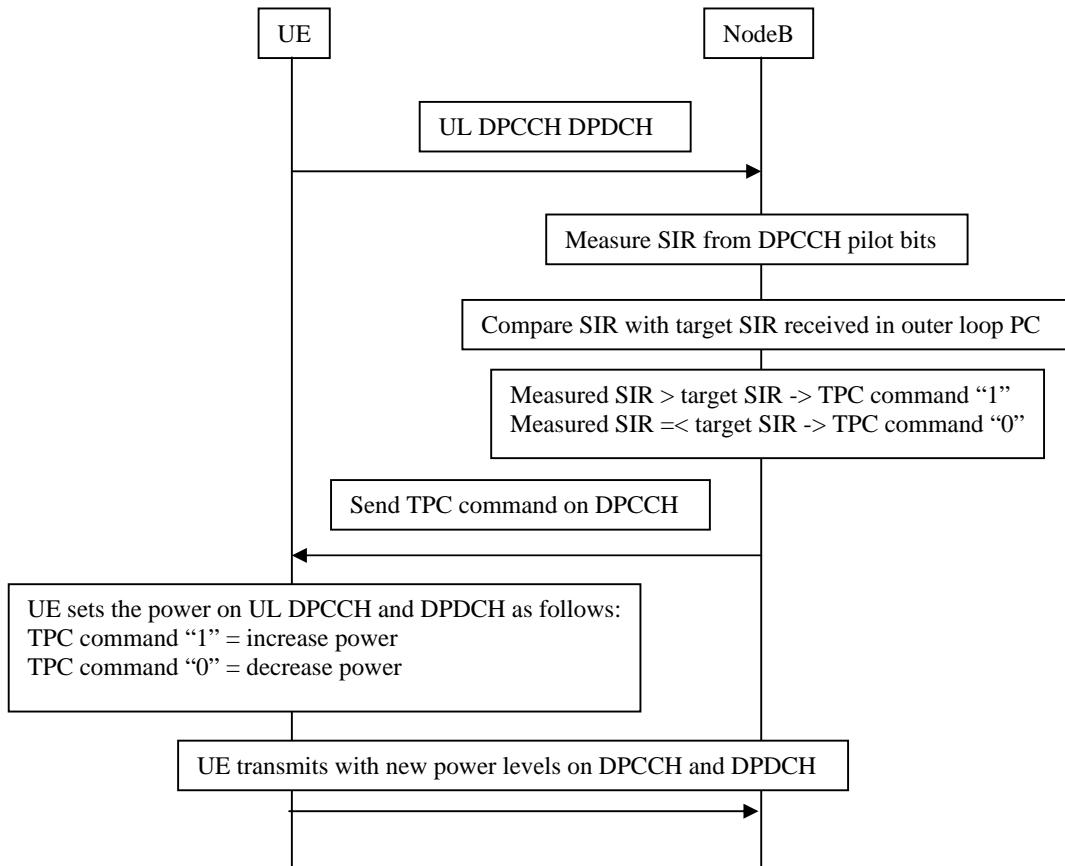


Figure 10 UL fast closed loop power control procedure (one radio link case).

The downlink closed loop power control sets the power of the downlink DPCH. The UE receives the BLER target set by the RNC for the downlink outer-loop PC together with other control parameters and the estimation value measured from DL DPCCH is compared with a target SIR. If the estimated SIR is greater than the target, the UE transmits the TPC command ‘down’ to the base station. If the estimated SIR is below target and “up” is sent. The TPC commands are sent on the UL DPCCH and simultaneously control the power differences between the DL DPCCH and its corresponding DL DPDCHs by the same amount [25].

2.6.1.4 Outer loop power control

The outer loop power control is needed to keep the quality of communication at the required level by setting the SIR target for the closed loop power control. The outer loop aims at providing the required quality: no worse, no better. Too high quality would waste capacity. The outer loop is needed in both uplink and downlink because there is fast power control in both uplink and downlink.

The outer loop power control is done for each DCH belonging to the same RRC connection. The SIR target needs to be adjusted when the mobile speed or the multipath propagation environment change. The higher variation in the received power, the higher the SIR target needs to be. If a fixed SIR target was selected, the resulting quality of the communication would be too low or too high, causing an unnecessary power rise in most situations. The frequency of outer-loop PC ranges typically from 10 to 100 Hz [4].

The uplink outer-loop PC operates within the serving RNC (SRNC) and is responsible for setting the target SIR in the NodeB for each individual uplink closed loop PC. This target SIR is updated for each UE according to the estimated uplink quality for a particular RRC connection. The logical structure of the SIR calculation is shown in the figure 11 below. A drift RNC (DRNC) with a inter RNC handover branch is also included in the figure, as can be seen the DRNC is transparent for the SIR calculation. The initial value of the SIR target for a radio link is sent from SRNC in RNSAP/NBAP radio link Setup messages [29].

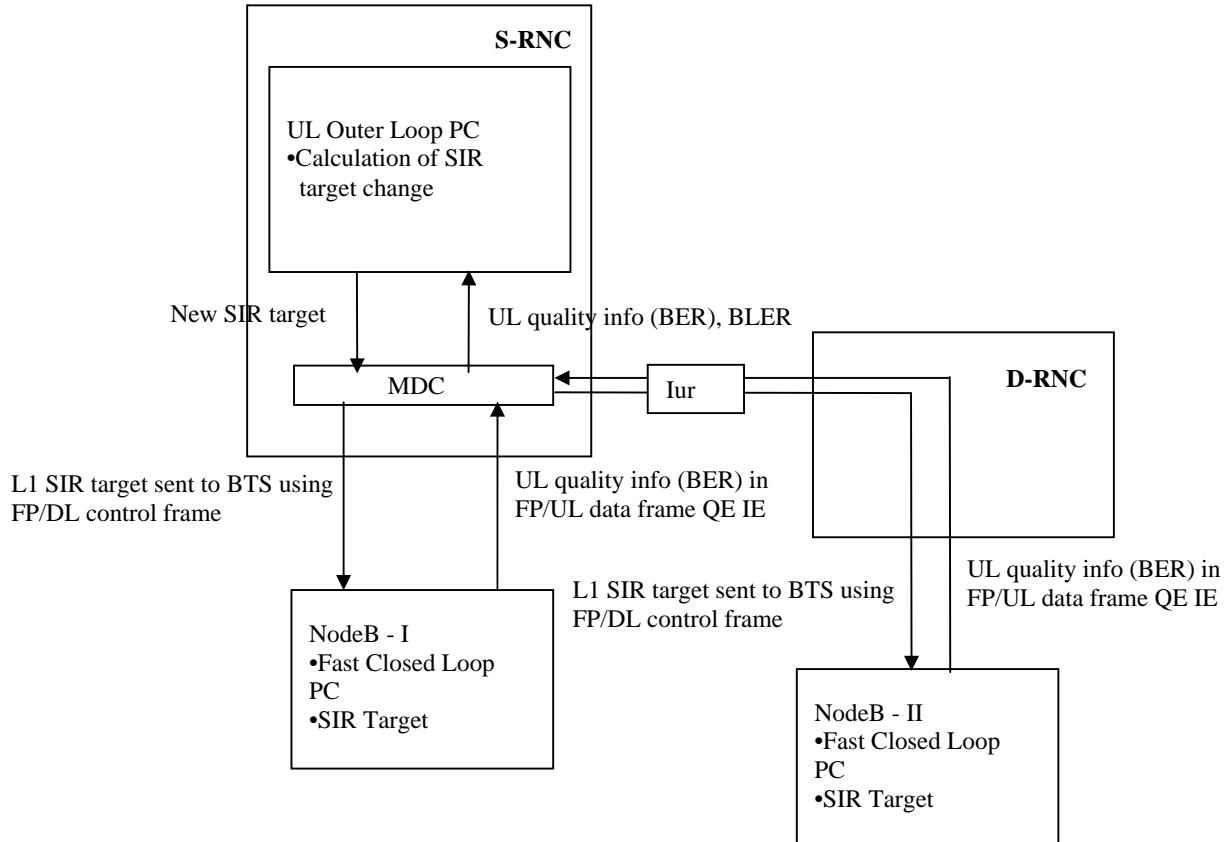


Figure 11 Outer loop power control with an inter RNC handover branch.

Since the DPCCH BER used in closed loop PC is not considered suitable for estimating the quality of the connection and thus to be used in SIR target estimation, the outer loop power control (OLPC) adjusts the SIR target based on ‘Quality Estimate’ (QE) derived by NodeB from transport channel BER, physical channel BER or by ‘BLER Estimate’ based on Cyclic Redundancy Check (CRC) indications (inserted by NodeB) for transport blocks in a FP frame (FP-PDU based CRC check). The MDC entity’s function before OLPC is to report the quality of the (best) radio links Quality Estimate (BER) or BLER for SIR target calculation to OLPC. Once OLPC has calculated the new SIR target, this value is sent via FP/DL OLPC control frame to all NodeB’s that the UE in SHO is having a radio link with [29].

In summary, the outer loop power control adjusts the SIR target used by closed loop PC. The SIR target is independently adjusted for each connection based on the estimated quality of the connection. The SIR target value is to be set so that the usage of radio resources is most effective still ensuring that the quality of the connection is good enough.

In estimating the quality of the connection OLPC can use two options, Quality Estimate (BER) or BLER based method [22] and [29].

- Quality Estimate (BER)
 - Based on transport channel BER measured by NodeB and inserted in the Quality Estimate Information Element (IE) in FP frames.
 - Based on physical channel BER measured by NodeB and inserted in the Quality Estimate IE in FP frames.
- BLER Estimate
 - Based on transport block CRC indicators calculated and inserted by NodeB in FP frames. MDC entity derives the quality estimate for OLPC from the correct CRC indicators vs. incorrect CRC indicators of the transport blocks in a FP frame.

For services using turbo coding and with a BLER target lower than 1% is proposed to use the algorithm, which uses the Quality Estimate and services with a BLER requirement of 1% or higher the algorithm to be used should be based on the BLER estimation [29].

There is well justifiable reason for having the MDC entity before the OLPC, since during handover (intra or inter NodeB/RNC) MDC will in practice select the least erroneous radio links data stream for OLPC SIR calculation and thus OPLC adjusts the SIR target for all radio links according to the best radio link. Closed loop PC will keep the UE transmission power according to level set by the OLPC for the best radio link and thus the more errored radio links will not generate any increase in the UE’s transmit power [29].

The downlink outer-loop PC is located in the UE. The network (RNC) sets the quality target to the UE that can be updated during the connection for each downlink connection. UE autonomously adjusts the SIR target to achieve the target set by the network [25].

2.6.2 Soft handovers

The second functionality of the RRM that is discussed here is the handover control. First we look the principle and algorithms that are used in UMTS handovers and later the gains that are achieved by using soft handovers. Soft handover gains in UMTS can be classified on link level into Macro Diversity Combining Gain and Micro diversity Gain, these gains also reflect to system level for example in factors like coverage, capacity, outage probability and call blocking probability.

HSDPA serving cell change and HSUPA active sets and cell change mechanisms are covered in more detail in the following chapter.

2.6.2.1 Principle and terminology of soft handover

The UMTS handover procedure differs from GSM type handover in a crucial way. As in GSM, Hard Handover (HHO) is used, where only one BTS communicates with one UE at a time. In UMTS, UE can be connected simultaneously to several NodeB's, this procedure is called the soft handover, as shown in figure 12 [30].

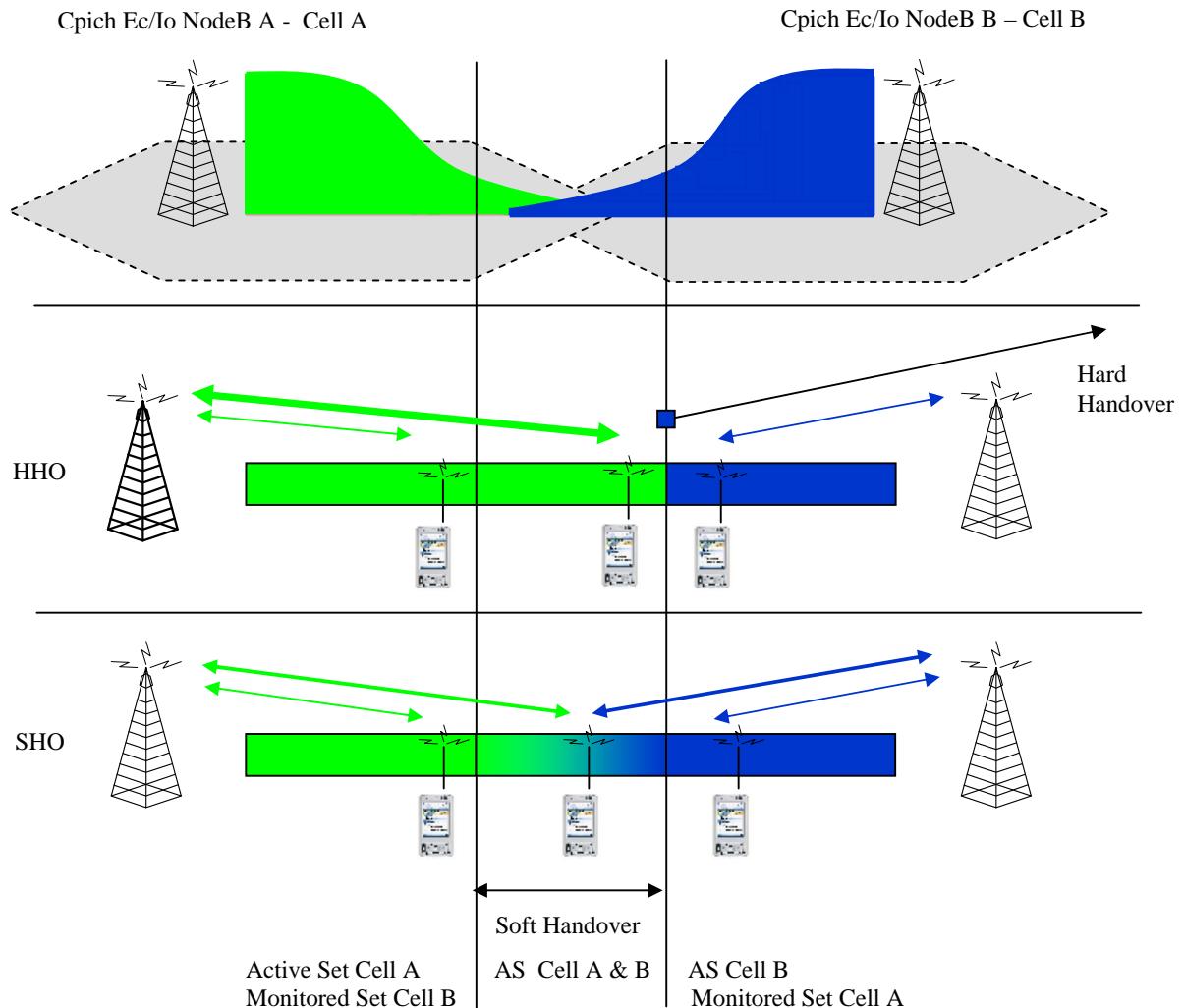


Figure 12 Hard handover and soft handover.

Soft handovers are classified as intra NodeB or inter NodeB handovers, the former is known as softer handover and the latter as soft handover.

The following terminology is used in handover description:

- Active set: the cells in the active set form a soft/softer handover connection to the UE and vice versa (max. 3)
- Monitored set/Neighbor set: list of cells that UE continuously measures, but whose Ec/Io (energy per chip over the noise) are not strong enough to be added to the active set.

In the uplink softer and soft HO differ quite much. In softer HO the code channel received by NodeB's different cells is handled by the same Rake receiver, where maximal ratio combining (MRC) is done and only one data stream is sent to RNC. In soft HO the UE's code channel is received in different NodeB's Rakes, despread and routed towards RNC via frame protocol as shown in figure 13.

In RNC Macro Diversity Combining (MDC) is applied to the incoming frames from different NodeB's, RNC does the selection of frames based on CRC in Frame Protocol for each individual transport block [22].

In the downlink direction SHO the UE needs to decode maximum three different radio links with different channelisation codes. The different radio links are received in the UE by means of Rake processing, this includes despreading operation for each channelisation code as a function of fingers in the Rake receiver. From UE point of view there are very few differences in softer or soft handover.

However, to support soft handover in the downlink, at least one extra radio link (2-way SHO) is needed. This extra downlink radio link acts to other users like additional interference in the air interface. Thus, to support soft handover in the downlink, more resource is required. As a result, in the downlink direction, the performance of the soft handover depends on the trade-off between the macro diversity gain and the extra interference caused by SHO radio links in downlink [30]. The principle of softer and soft handovers are shown in figure 13.

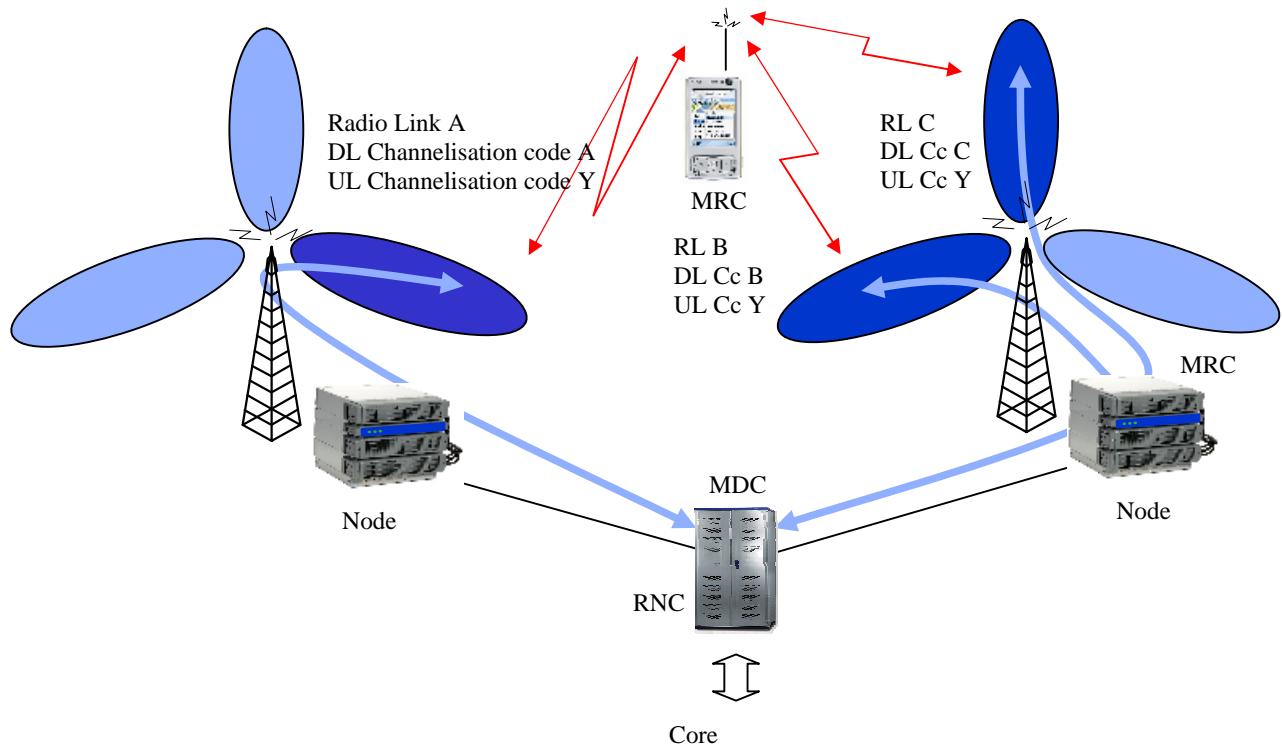


Figure 13 Softer, soft handover, macro diversity combining and maximal ratio combining.

2.6.2.2 Functionality of SHO in UMTS

The soft handover uses the cells CPICH Ec/Io as the handover measurement quantity, measured by the UE. Once the addition threshold to the active set is reached, this is signaled to the RNC, where the decision algorithm is located, by the means of RRC: Measurement Report event 1A. RNC establishes a new radio link and UE adds the cell to the active set. Once the level of the CPICH Ec/Io fades over the removal threshold, the cell removal from the active set is signaled to the RNC, RRC: Measurement Report event 1B and RNC releases the resources of this radio link [31].

Radio link addition of the handover procedure is shown in figure 14.

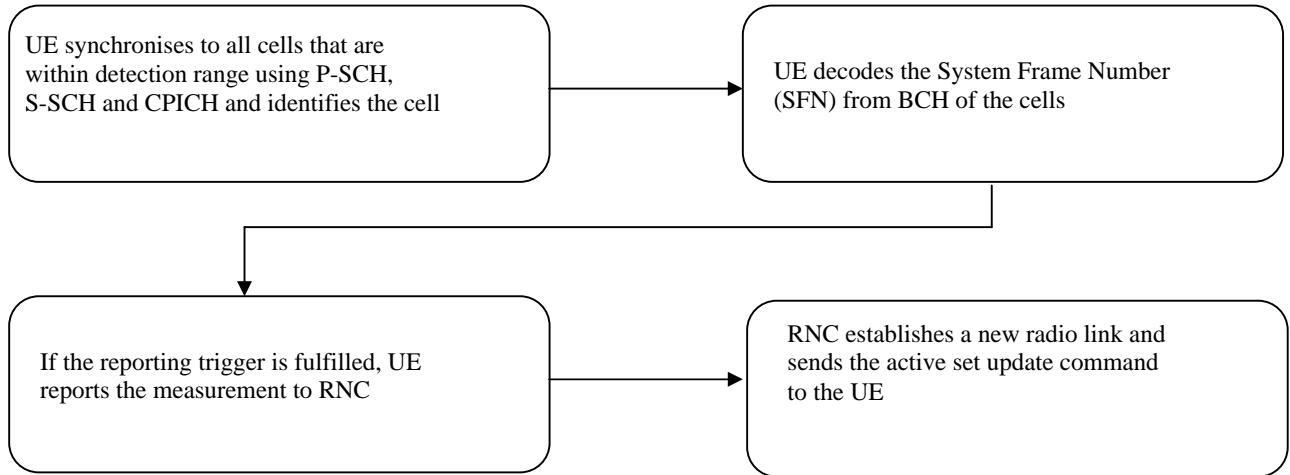


Figure 14 Radio link addition procedure.

The following intra frequency Measurement Reports are specified in [31]

- Reporting event 1A: A Primary CPICH enters the reporting range
- Reporting event 1B: A primary CPICH leaves the reporting range
- Reporting event 1C: A non-active primary CPICH becomes better than an active primary CPICH
- Reporting event 1D: Change of best cell
- Reporting event 1E: A Primary CPICH becomes better than an absolute threshold
- Reporting event 1F: A Primary CPICH becomes worse than an absolute threshold
- Reporting event 1J: A non-active E-DCH but active DCH primary CPICH becomes better than an active E-DCH primary CPICH

2.6.3 Power control in soft handover

As fast power control is a main feature also for radio links in soft HO well take a look of two important issues that need to be taken into consideration in SHO: reliable detection of the uplink power control commands in the UE and power drifting in the NodeB's powers in the downlink.

2.6.3.1 Reliable detection of uplink power control commands

All the NodeB's in the active set send an independent power control command to the UEs to control the uplink transmission power. It is enough if one of the NodeB's in the active set receives the uplink signal correctly. Therefore, the UE can lower its transmission power if one of the NodeBs sends a power-down command. Maximal ratio combining can be applied to the data bits in soft handover in the UE, because the same data is sent from all soft handover NodeB's, but not to the power control bits because they contain different information from each of the NodeB's. Therefore, the reliability of the

power control bits is not as good as for the data bits, and a threshold in the UE is used to check the reliability of the power control commands.

The power control signaling quality can be improved by setting a higher power for the dedicated physical control channel (DPCCH) than for the dedicated physical data channel (DPDCH) in the downlink if the UE is in soft handover. This power offset between DPCCH and DPDCH can be different for different DPCCH fields: power control bits, pilot bits and TFCI [29].

2.6.3.2 Downlink Power drifting (a.k.a power balancing)

The UE sends a single command to control the downlink transmission powers; this is received by all NodeB's in the active set. The NodeB's detect the command independently, since the power control commands cannot be combined in RNC because it would cause too much delay and signaling in the network. Due to signaling errors in the air interface, the NodeB's may detect this power control command in a different way. It is possible that one of the NodeBs lowers its transmission power to that UE while the other NodeB increases its transmission power. This behavior leads to a situation where the downlink powers start drifting apart; this is referred as power drifting. As this is off course not desirable following alternatives are to tackle the power drifting [29]:

- NodeB downlink power control dynamics is limited by RNC
- RNC can average the downlink power and send an reference value to the NodeB's to reduce their power drifting

2.6.4 Soft handover gains – Uplink

One of the fundamental issues for this thesis are the gains provided by SHO, there are two major gain contributors in uplink SHO on link level: Macro Diversity Combining Gain and Micro Diversity Gain (We use MDC for Macro Diversity Combining Gain and Micro Diversity Gain terms).

Macro diversity combining gain is a diversity gain against slow fading, where in SHO RNC has the choice to select the least erroneous data stream coming in uplink over different Iub interfaces.

Micro diversity is a gain against fast fading, where SHO on uplink Uu interface can reduce the TX Eb/No (UE Tx power).

2.6.4.1 Macro diversity combining gain

The main gain provided by SHO is the Macro Diversity Combining Gain, here the RNC has the possibility to select the less erroneous packets received from several radio links over the Iub interface. RNC does the selection based on CRC check in Transport Blocks on Frame Protocol layer. In the figure 15 below, two radio links with different BLER's are forwarded to RNC's MDC entity.

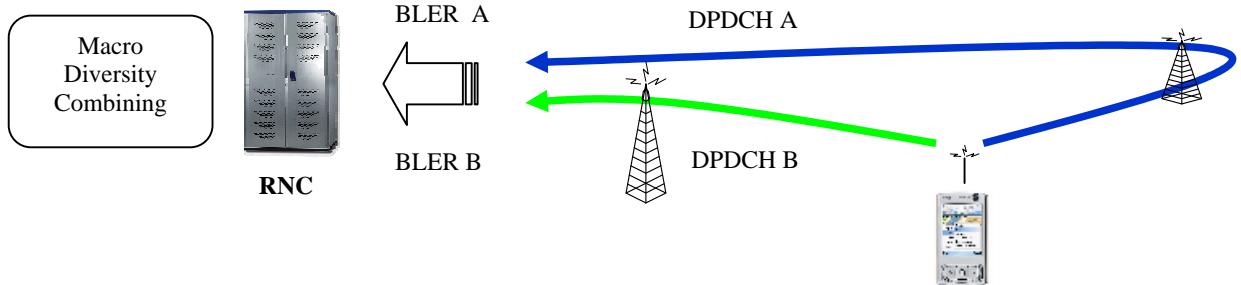


Figure 15 Uplink macro diversity combining.

A short example of the macro diversity combining gain is shown: In the example, we have two radio links with following fictive BLER's [32]:

- BLER of radio link A is 50 %
- BLER of radio link B is 20 %

The effective BLER seen at the RNC is 10.0 %. A block error will happen at the probability:

$$\text{Block Error Propability} = \text{BLER A} \cdot \text{BLER B}$$

That is, both radio links fail. In this SHO example, the radio links A and B are equal to one radio link with a BLER of 10 %.

The MDC gain in the uplink should be applied to Eb/Io (the uncoded bit energy to interference density ratio) when estimating the interference reduction achieved by MDC [32].

In other words, the MDC gain is equal to the reduction in the Eb/Io of the strongest radio links in the active set to achieve the target BLER, thus the MDC gain reflects to the cell capacity.

2.6.4.2 Micro diversity gain

In micro diversity gain, the reduction of the UE transmit power in SHO vs. HHO case is analyzed. A very clear presentation of Micro Diversity gain is presented in [4] and [33] by link level simulations and the following is an excerpt of those. The micro diversity gains are presented relative to the ideal hard handover case, where the UE would be connected to the NodeB with the highest pilot Ec/Io only.

Figure 16 show the simulation results of 8 kbps speech in an ITU Pedestrian A channel, at 3 km/h, assuming that the UE is in soft handover with two NodeB's. The relative path loss from the UE to NodeB #1 compared to NodeB #2 is 0, -3, -6 or -10 dB.

The maximum gain in uplink TX Eb/No (reduction in UE Tx power) due to soft handover is observed to be 1.8 dB if the path loss is the same to both NodeBs. Also from the figure 16 can be concluded, that the NodeB should not be in the active set of the UE if the path loss were 3 – 6 dB larger than the path loss to the strongest NodeB in the UE's active set.

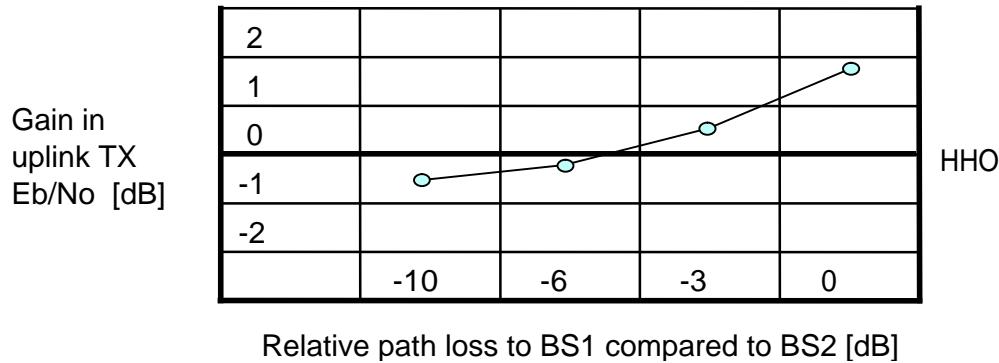


Figure 16 Micro diversity gain in uplink TX Eb/No [4].

In summary micro diversity gain is achieved due to degradation in Eb/No per radio link in Uu interface and hence reflects to the cell coverage. The total soft handover gain is assumed to be between 2.0 and 3.0 dB, including the macro and micro diversity gains.

2.6.5 Delay budget in SHO's – Uplink

In a SHO scenario RNC can have maximum of three radio links from different NodeB's, hence some buffering is needed in the RNC to compensate delay differences caused by transmission and NodeB processing.

Each FP frame may carry several transport blocks (i.e. transport block set) and selection is carried out on transport block basis between received transport block sets. In MDC the transport block that has passed the FP CRC check successfully is selected.

The CFN is common for all the Iub and Iur DCH radio links of the same connection. It is monitored by the MDC in order to be able to determine the corresponding FP frames; the macro diversity combining is performed on the transport blocks that were received in the FP frames having the same CFN number.

The maximum allowable delay difference between DCH radio links in SHO is vendor specific, and is typically around 50 ms. the maximum allowable delay difference between DCH data streams is set during the DCH activation.

If several transport blocks have passed the CRC check successfully, anyone of the transport blocks can be used and the others can be discarded [22].

3. HIGH SPEED DOWNLINK PACKET ACCESS AND HIGH SPEED UPLINK PACKET ACCESS – HSDPA AND HSUPA

HSDPA is the first step in the evolution of WCDMA packet access networks, presented in 3GPP Rel05. The second step is the HSUPA (or enhanced dedicated channel, E-DCH in 3GPP terms) in Rel06. The main target is to increase the user peak data rates and QoS, and in general improve the spectral efficiency for downlink/uplink asymmetrical and bursty packet data services. The evolution of packet access enhancements, HSDPA and HSUPA, and the associated handovers are described in detail in this third chapter of the thesis.

3.1 HSDPA

In this chapter will go through the new channels introduced by HSDPA, new UE categories needed to support the HSDPA and the fundamental features added in Radio Resource Management in a new entity called the MAC-hs, such as Adaptive Modulation and Coding, Hybrid ARQ and fast scheduling. Last the power control of HSDPA channels is covered.

3.1.1 HSDPA channels and operation

A new transport channel called High Speed Downlink Shared Channel (HS-DSCH) has been introduced as a new radio bearer and a corresponding physical channel called High Speed Physical Downlink Shared Channel (HS-PDSCH). The HS-DSCH multiplexing per user occurs in the time domain, where Transmission Time Interval (TTI) is reduced to 2 ms. The TTI has been significantly reduced from the 10, 20, 40 or 80 ms TTI intervals supported in Rel99 in order to achieve better round trip delays between UE and the NodeB [34].

Within each 2 ms TTI, a constant spreading factor (SF) of 16 is used for data transmission, with a maximum of 15 parallel codes allocated to the HS-PDSCH. These codes may all be assigned to a single user during one TTI, or split between two or three users (code multiplexing). The number of parallel codes allocated to each user depends on cell loading, QoS requirements and the UE capabilities (multicode transmission).

In order to support the HS-DSCH operation, two control channels have been added: the High-Speed Shared Control Channel (HS-SCCH) in downlink and the High-Speed Dedicated Physical Control Channel (HS-DPCCH) in uplink [34].

The HS-SCCH is a fixed rate (SF=128) channel used for carrying downlink signaling between the NodeB and the UE just before the beginning of each scheduled TTI. This includes the UE identity, Hybrid Automatic Repeat Request (HARQ) related information and the parameters of the HS-DSCH transport format selected by the link adaptation mechanism [34].

The HS-DPCCH (SF=256) in uplink carries ACK/NACK indicating whether the corresponding downlink transmission was successfully decoded as well as Channel Quality Indicator (CQI) used for link adaptation purposes. The CQI is based on Primary Common Pilot Channel (P-CPICH) and is used to estimate the transport block size, modulation type and the number of codes that can be supported at a given reliability level for the downlink transmission [34].

The HS-DSCH is always associated with a downlink DCH. In HS-DSCH use, the DPDCH of the associated DCH is used for layer 3 signaling (typically 3.4 Kbit/s) and the DPCCH for fast power control [55].

Whilst HSDPA is used for downlink transmission, uplink transmission can either be Rel99 DCH or E-DCH (Enhanced DCH, HSUPA)

3.1.2 UE categories for HSDPA support

Naturally, also HS-DSCH support in the UE's is needed. Twelve categories are specified in 3GPP 25.306 Rel05 for HS-DSCH UE's according to following parameters as shown in table 4.

- Maximum number of multicode UE can receive, 5, 10 or 15
- Minimum inter TTI interval UE is able to receive transmission
- Maximum number of transport block bits
- Maximum number of soft channel bits in HARQ
- Modulation 16 QAM, QPSK

Table 4 HS-DSCH UE categories [35].

HS-DSCH category	Maximum number of HS-DSCH codes received	Minimum inter-TTI interval	Maximum number of bits of an HS-DSCH transport block received within a TTI	Total number of soft channel bits	Modulation	Data rate at L1 in Mbits
Cat 1	5	3	7298	19200	QPSK/QAM	1.2
Cat 2	5	3	7298	28800	QPSK/QAM	1.2
Cat 3	5	2	7298	28800	QPSK/QAM	1.8
Cat 4	5	2	7298	38400	QPSK/QAM	1.8
Cat 5	5	1	7298	57600	QPSK/QAM	3.6
Cat 6	5	1	7298	67200	QPSK/QAM	3.6
Cat 7	10	1	14411	115200	QPSK/QAM	7.2
Cat 8	10	1	14411	134400	QPSK/QAM	7.2
Cat 9	15	1	20251	172800	QPSK/QAM	10.1
Cat 10	15	1	27952	172800	QPSK/QAM	14.4
Cat 11	5	2	3630	14400	QPSK	0.9
Cat 12	5	1	3630	28800	QPSK	1.8

However, it should be emphasized that the peak data rates are temporary rates at the physical layer L1 and neglect protocol overhead at the different layer.

3.1.3 Radio resource management fundamentals for HSDPA support

Three fundamental RRM features have been added to support HS-DSCH. These functionalities are located in the NodeB, MAC-hs entity [34].

- Adaptive Multirate (or Modulation) and Coding (AMC)
- Hybrid ARQ
- Fast Scheduling

In adaptive multirate and coding, different modulation QPSK or 16QAM together with channel coding rates, based on rate matching, are used to form a suitable Transport Format Combination (TFC)

to achieve the best possible peak data rate for the existing air interface conditions. This functionality replaces the two fundamental mechanisms in WCDMA, variable SF and fast power control.

The Hybrid Automatic Repeat Request (HARQ) with Stop and Wait, employs a “stop and wait hybrid automatic repeat request” (SAW HARQ) retransmission protocol between the NodeB and the UE. With HARQ, UE checks the integrity of its received data in each relevant HS-DSCH TTI. If the data is correct, the UE returns an “ACK” (acknowledging receipt of correct data) signal, in which case the base-station can move on to the next set of data.

If the data is not successfully received, the UE transmits an “NACK” (negative acknowledgement) and the base-station retransmits the corresponding data. With “soft combining” at the user device, the earlier set(s) of corrupted data can be combined with subsequently retransmitted data to increase the likelihood of correctly decoding valid data [45].

In soft combining each received packet is placed into a reserved buffer and in case a retransmission is required combined with the retransmitted packet in an attempt to recover the original transmission. In case retransmission is not required packet is directly forwarded to the decoder. Two soft combining methods are available for HSPA: Chase Combining (CC) and Incremental Redundancy (IR)

In CC the retransmission is identical to the first transmission as in IR the retransmission contains different redundancy information compared with the channel encoder output that was received during the first/previous transmission. IR can result in fewer retransmissions than CC, however UE memory requirements will be higher [4].

The fast scheduling determines the system overall behavior and performance. For each 2 ms TTI it determines to which UE the HS-DSCH should be transmitted and in conjunction with AMC at which data rate. Together with 2 ms TTI and the CQI feedback, the scheduler can quickly estimate the channel condition and adapt the data rate accordingly.

The most popular algorithms for the fast scheduler are: Round Robin (RR), Maximum Carrier to Interference (C/I) and Proportional Fair (PF).

- Round Robin algorithm provides a high degree of fairness among users, but uneven data rates since some users are served even in weak signal conditions.
- The Maximum C/I algorithm schedules users with the highest C/I during the current TTI. Here there is no fairness among users since its serving the users with highest C/I.
- The Proportional Fair algorithm offers a good trade off between RR and maximum C/I. The PF schedules users according to the ratio between their instantaneous achievable data rate and their average served data rate. This results in all users having equal probability of being served even in different channel quality conditions [45].

The new protocol entity MAC-HS in the PS domain user plane protocol stack is show in figure 17. To recall the PS domain user plane protocol stack please refer to chapter 2.4.2

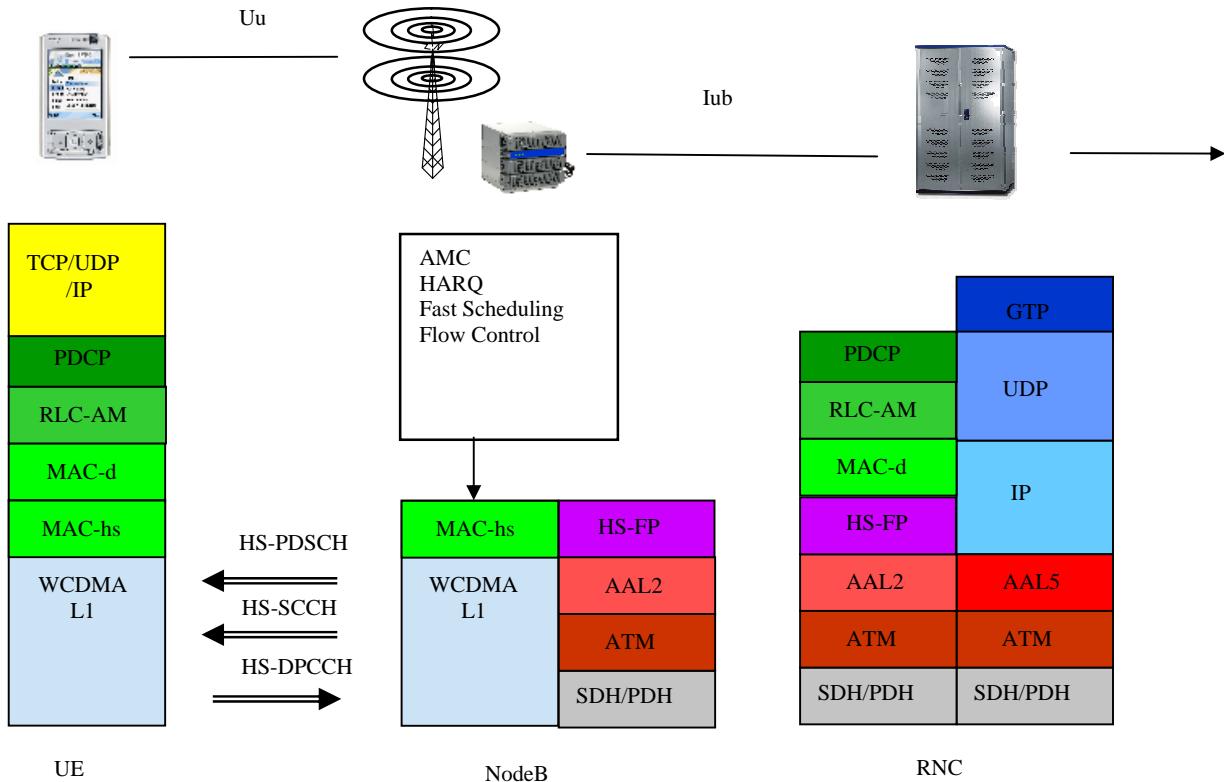


Figure 17 HSDPA enhancements.

3.1.4 HSDPA channelisation codes and modulation

HSDPA uses fixed SF 16 and *multicode* transmission (1 - 15 codes in one 2 ms TTI can be designated to one user) and possibly with *code multiplexing* between different users during the same 2 ms TTI (example 5 codes to user 1 and 5 codes to user 2) as in figure 18. The usage of code multiplexing requires one HS-SCCH channel per code multiplexed user [51].

Two modulation schemes can be applied depending on the channel conditions, QPSK and 16QAM. The symbol rate is fixed for SF 16 (240 ksymbols/s) but the channel bit rate varies, in QPSK 480 kbps and in 16QAM 960 kbps.

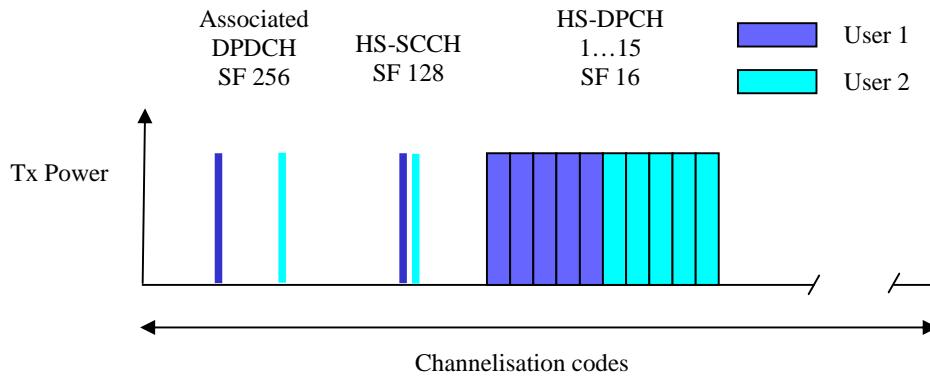


Figure 18 HSDPA multicode and code multiplexing transmission.

3.1.5 HSDPA power control

In HSDPA, the fast power control for HS-PDSCH has been deactivated and replaced with AMC, multicode operation and fast layer 1 HARQ [36]. The power allocated to HS-PDSCH in vendor implementation is typically as follows:

$$\text{Power [HS-PDSCH]} = \text{Power [Carrier]} - \text{Power [Common Channels]} - \text{Power [Planned maximum for RT services]} - \text{Power [Planned maximum for NRT services]}$$

The HS-SCCH power control is under the control of the NodeB. It may follow the power control commands sent by the UE to the NodeB or any other power control procedure applied by the NodeB [27].

The HS-DPCCH power is set relative to the uplink DPCCH. Slight difference exists in adjusting the power level in case HS-DPCCH transports the CQI or ACK/NACK info [27].

3.2 HSUPA

HSUPA is the next evolution step in WCDMA packet data technology after HSDPA. This technology is known as FDD enhanced dedicated channel (E-DCH) in 3GPP Rel06. Target in HSUPA is to enhance the uplink data transmission rates up to 5.76 Mbps and reduce the latency, together with HSDPA it will optimize the packet transfer in uplink and downlink.

In this chapter will go through the new channels introduced by HSUPA, new UE categories needed to support the HSUPA and the fundamental features added in Radio Resource Management, in a new entity called the MAC-e, such as E-DCH scheduling, Hybrid ARQ and 2 ms TTI. Finally yet importantly, the power control of HSUPA channels is covered.

3.2.1 HSUPA channels and operation

In HSUPA, the E-DCH is introduced as the new transport channel for carrying user data in the uplink. On physical layer, the E-DCH translates into two new uplink channels [37]:

- E-DCH – Dedicated Physical Data Channel (E-DPDCH)
- E-DCH – Dedicated Physical Control Channel (E-DPCCH)

The user data in E-DCH is mapped to the E-DPDCH either in 2 ms TTI or 10 ms TTI. Higher data rates are achieved (up to 5.76 Mbps) with numerous spreading factor combinations, as described in chapter 3.2.4. The E-DPCCH is used to carry following information (outband) associated to the E-DPDCH.

- Retransmission sequence number (RSN) used in HARQ (2 bits)
- An E-DPDCH Transport format indicator (E-TFCI) indicator, identifying the transport block size on E-DPDCH. (7 bits)
- The Happy bit (1 bit)

In the downlink, three new channels are introduced:

- E-AGCH – E-DCH Absolute Grant Channel
- E-RGCH – E-DCH Relative Grant Channel
- E-HICH – E-DCH Hybrid ARQ Indicator Channel

The E-AGCH is a fixed rate (SF=256) downlink channel carrying the absolute grant (power ratio) to be used by the UE, thus determining the maximum power and data rate the UE can use.

The E-RGCH is a fixed rate (SF=128) downlink channel carrying the relative grant, used for incrementally fine tune the UE transmit power.

The E-DCH Hybrid ARQ indication channel (E-HICH) is a fixed rate (SF=128) dedicated downlink physical channel carrying hybrid ARQ acknowledgement indicator for the uplink E-DPCH.

3.2.2 UE categories for HSUPA support

As for HSDPA, there are different UE categories defined for HSUPA, these categories are specified according the following parameters and shown in table 5 [35]:

- Maximum number of E-DCH codes
- Minimum spreading factor
- TTI
- Maximum transport block size

Table 5 HSUPA UE categories [35].

E-DCH category	Maximum number of E-DCH codes transmitted	Minimum spreading factor	Support for 10 and 2 ms TTI EDCH	Maximum number of bits of an E-DCH transport block transmitted within a 10 ms E-DCH TTI	Maximum number of bits of an E-DCH transport block transmitted within a 2 ms E-DCH TTI	Data Rate at L1 in Mbps	Data Rate at L2/User. 320 byte PDU and coding overhead included in Mbps.
Cat 1	1	SF4	10 ms TTI only	7110	-	0.71	0.672
Cat 2	2	SF4	10 ms and 2 ms TTI	14484	2798 1.4	1.45 1.4	1.37
Cat 3	2	SF4	10 ms TTI only	14484	-	1.45	1.37
Cat 4	2	SF2	10 ms and 2 ms TTI	20000	5772 2.89	2 2.89	1.88 2.72
Cat 5	2	SF2	10 ms TTI only	20000	-	2	1.88
Cat 6	4	SF2	10 ms and 2 ms TTI	20000	11484	2 5.76	1.88 5.44

3.2.3 Radio resource management fundamentals for HSUPA support

As in HSDPA three fundamental RRM enhancements are taken in to use to support HSUPA, these are also located in the NodeB, in MAC-e entity, and shown in figure 19 [37]:

- E-DCH scheduling
- Hybrid ARQ
- Short 2 ms TTI

E-DCH scheduling has the task to control the uplink resources the UE's in the cell range are using. The scheduler therefore grants maximum allowed transmit power ratios to each UE relative to UL CCPCH. This effectively controls the E-TFCI the UE can use and thus the uplink data rate. The scheduling mechanism is based on absolute and relative grants. The absolute grant is used to initialize the scheduling process and provide absolute transmit power ratios to the UE, where as the relative grants are used for incremental up or down variations of the allowed transmit power.

As a basic principle of the uplink scheduling mechanism, the UE maintains a serving grant, which represents the maximum E-DPDCH to DPCCH power ratio the UE may use in the next transmission. This serving grant is updated at every TTI boundary.

The hybrid ARQ has the same principle as in HSDPA, in opposite directions naturally.

Short 2 ms TTI is allowed in the HSUPA to speed up packet scheduling and reduce latency. Unlike HSDPA, this is not a mandatory feature and is dependent of the UE capability.

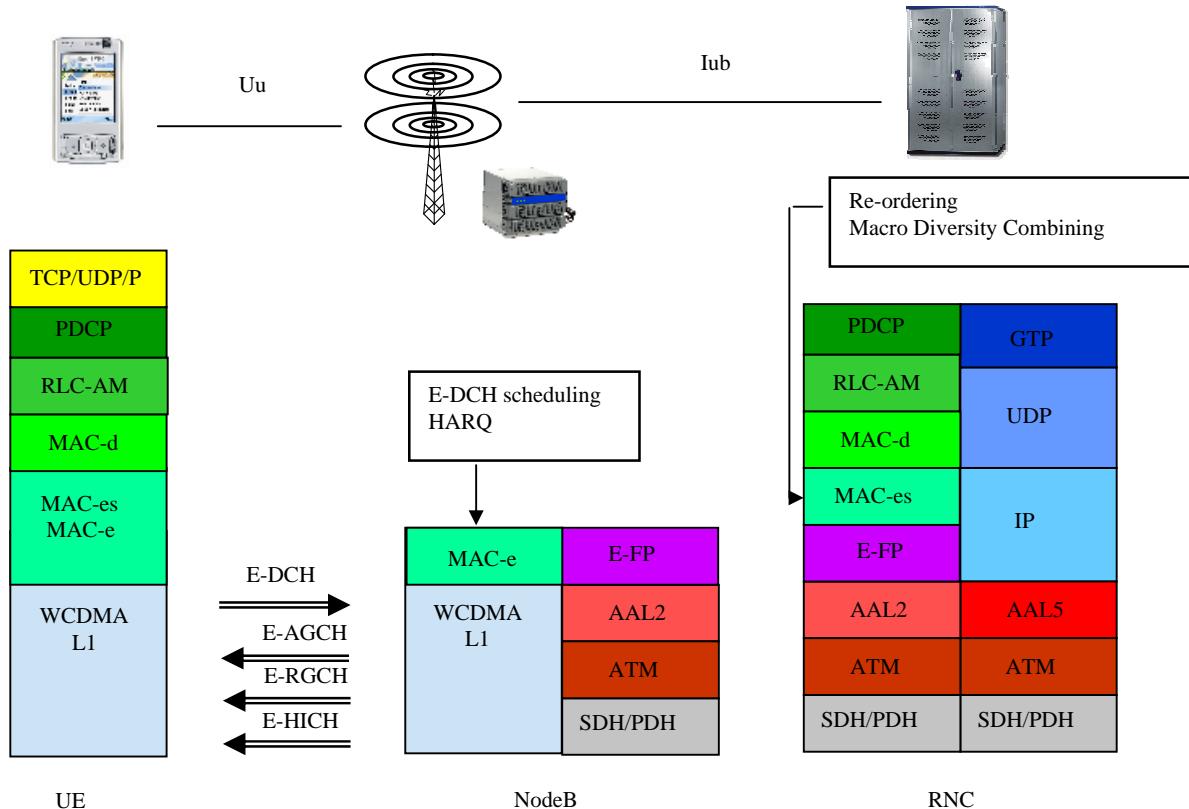


Figure 19 HSUPA enhancements.

E-DCH Frame Protocol entity of the NodeB shall compose a FP frame by packaging MAC-es PDUs of the same MAC-d flow into one frame [22].

E-DCH FP entity in RNC performs the ‘pre’ macro diversity combining by checking the payload CRC of each E-DCH FP frame. If the CRC check is passed successfully, then E-DCH FP entity transmits the E-DCH FP frame to MAC-es [38].

The MAC-es entity (RNC) handles E-DCH specific functionality, which are not covered in the MAC-e entity in NodeB. For each UE, there is one MAC-es entity in the SRNC. The functionalities of MAC-es are:

- reordering queue distribution (The reordering queue distribution function routes the data coming from different SHO branches / MAC-d flows (MAC-es PDUs) to the correct reordering queues),
- reordering (Reordering of PDU's that might have lost their original sequence during transmission),
- macro diversity combining.

3.2.4 HSUPA channelisation codes and modulation

HSUPA introduces the usage of SF2 with the bit rate of 1920 kbps. BPSK modulation is used for E-DPDCH and DPCCH and a technique called multicode transmission is applied. The figure 20 below clarifies the term multicode transmission on I and Q branches and the channelisation code usage.

In the example $2 \cdot \text{SF } 2$ and $2 \cdot \text{SF } 4$ are used for E-DPDCH with HSDPA in downlink. E-DPDCH1 (I branch) and E-DPDCH2 (Q branch) use the same channelization code (1st code of SF2), and E-DPDCH3 (I branch) and E-DPDCH4 (Q branch) use the same channelization code (1st code of SF4) [37].

Hence the maximum HSUPA bit rate on layer 1 is 5.76 Mbps, $2 \cdot 1920 \text{ kbps} + 2 \cdot 960 \text{ kbps}$. Please refer also to HSUPA UE categories in table 5.

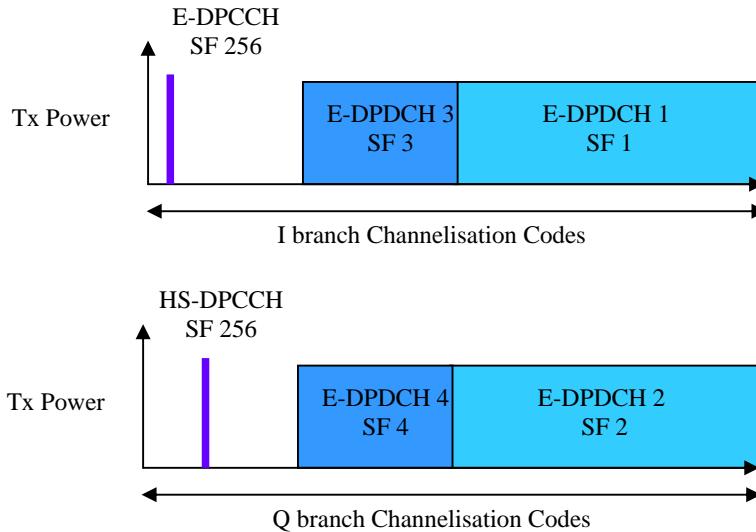


Figure 20 E-DPDCH multicode transmission.

3.2.5 HSUPA power control

3.2.5.1 Power control for E-DCH

As notified, the scheduling function in NodeB controls the transmit powers of the E-DCH channels of the Ue's. The power of the E-DPCCH and the E-DPDCH in UE are set in relation to the UL DPCCH, for this purpose *gain factors* are used for scaling the uplink E-DCH channels relative to the UL DPCCH. These gain factors are typically configurable network element parameters.

Due to the nature of the data that the E-DPCCH is carrying (RSN, E-TFCI) it is much more important that this channel is decoded correctly at the NodeB side. Especially well performing HARQ requires correct RSN and E-TFCI for soft combining, thus its gain factor is typically slightly higher than the E-DPDCH's factor.

3.2.5.2 Power control for E- AGCH, E-RGCH and E-HICH

Two alternatives are available depending on vendor implementation policy.

- Power offsets are relative to the pilot bits on the DL DPCCH.
- The Power offsets are relative to the primary CPICH

3.2.5.3 HSUPA outer loop power control

Compared to UL DCH case where SIR target is adjusted from BER/BLER from DPDCH, the situation is different in E-DCH case. The HARQ retransmission functionality should ensure that RNC will receive only correct CRC E-FP frames, thus it is impossible for NodeB or RNC MDC entity to calculate the BER/BLER of the E-DPDCH. To overcome this, a HARQ retransmission count is inserted in every E-FP frame by NodeB. E-DCH UL outer loop PC Entity receives the number of HARQ Retransmissions and HARQ failure indicators from MAC-es. From this information OLPC entity is able to estimate the E-DCH BLER (measured E-DCH BLER). Measured BLER is calculated based on number of HARQ retransmissions and HARQ failure indicators. Once E-DCH UL OLPC needs to change the SIR target of UL DPCCH, based on HARQ info on L1 E-DPDCH, it is signaled to the NodeB in DL/FP OLPC control frame [39].

3.2.5.4 HSUPA outer loop power control over Iur:

Soft handover functionality for HSUPA between RNC's over Iur has been specified by 3GPP. For outer loop power control to control the UE Tx power and ensure the desired BER/BLER on the radio link over Iur on drift RNC, the same mechanism as in radio links on serving RNC can be applied

As the content of the Iur E-DCH data frame include [58]:

- Mac-es PDUs
- Number of HARQ retransmissions
- CFN and Sub frame number.

From the number of HARQ retransmissions the serving RNC OLPC entity is able to adjust the SIR target of the radio link over Iur interface.

3.3 HSPA cell change and handovers

First in this chapter, the mechanism of HSDPA Cell Change is studied, for intra NodeB, Inter NodeB and inter RNC cases. Followed by HSUPA handovers, cell change, MDC implementation and ending in presenting the benefits in terms of gains of implementing SHO for HSUPA compared to a non-SHO implementation.

3.3.1 HSDPA cell change

HSDPA does not use the described soft handover mechanism in chapter 1.7.3. Instead a serving cell change approach is used.

A serving HS-DSCH cell change facilitates the transfer of the role of serving HS-DSCH radio link from one radio link belonging to the source HS-DSCH cell to a radio link belonging to the target HS-DSCH cell. Hence this is called the serving cell change and it is not a handover with MDC nor MRC [40].

In network-controlled serving HS-DSCH cell change (most implemented) the network makes the decision of the target HS-DSCH cell, and the decision is based on UE measurement reports and other information available in the network. A network controlled HS-DSCH cell change is performed as a RRC layer signaling procedure and is based on the existing handover procedures in CELL_DCH state. The uplink DCH is handled like in Rel99 soft handover and MDC.

3.3.1.1 Intra NodeB synchronized HS-DSCH serving cell change

UE reports periodically the CPICH Ec/No of the cells that are in the reporting range in RRC: ‘MEASUREMENT REPORT’ towards the RNC.

When the serving RNC has made the cell change decision, the NodeB in an intra NodeB cell change is prepared for the serving HS-DSCH cell change with an activation time. The SRNC then sends a RRC: ‘PHYSICAL CHANNEL RECONFIGURATION’ message, which indicates the target HS-DSCH cell and the activation time to the UE.

When the UE has completed the serving HS-DSCH cell change it transmits a RRC: ‘PHYSICAL CHANNEL RECONFIGURATION COMPLETE’ message to the network. Intra NodeB synchronized HS-DSCH serving cell change signalling scenario shown in figure 21.

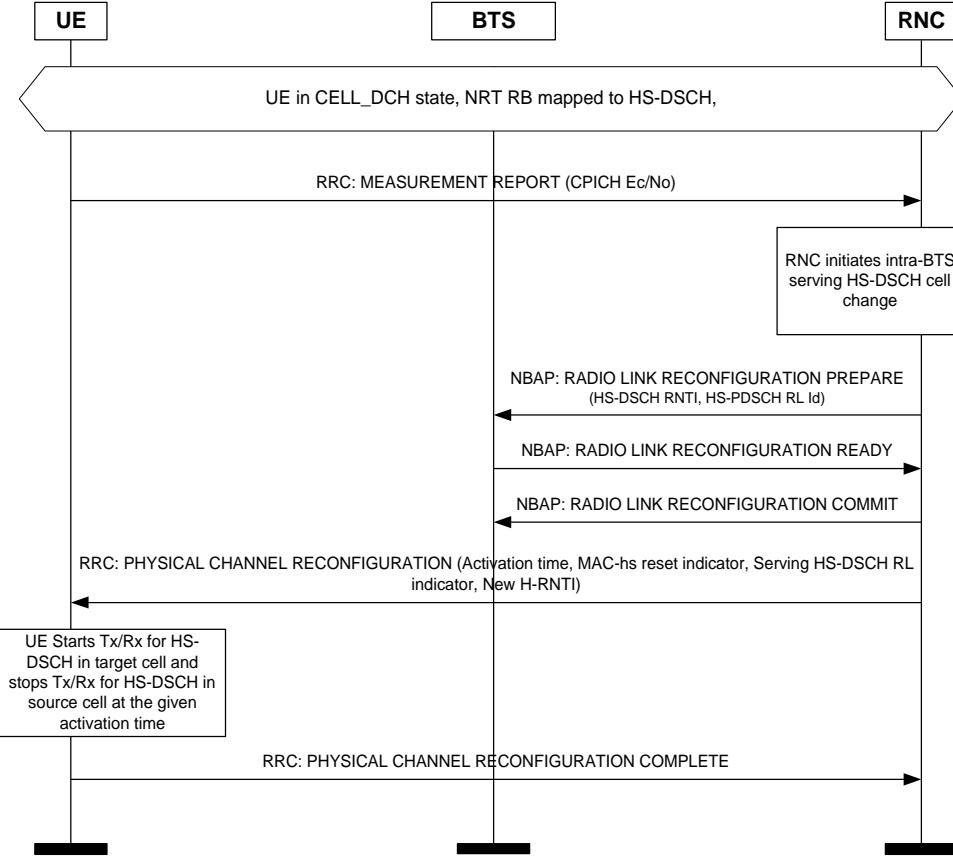


Figure 21 Intra NodeB synchronized HS-DSCH serving cell change [57].

3.3.1.2 Inter NodeB synchronized HS-DSCH serving cell change

The reporting mechanism here is the same, Ue reports periodically the CPICH Ec/No of the cells that are in the reporting range in RRC: Measurement Report towards the RNC.

Once RNC has made the cell change decision, in the first step, the SRNC establishes a new radio link in the target NodeB. In the second step this newly created radio link is prepared for a synchronized reconfiguration to be executed at a given activation time. After the first step, the target NodeB starts transmission and reception on dedicated channels. At the indicated activation time, transmission of HS-DSCH is started in the target HS-DSCH NodeB and stopped in the source HS-DSCH NodeB.

The SRNC then sends a RRC: ‘RADIO BEARER RECONFIGURATION’ message on the old configuration. This message indicates the configuration after handover, both for DCH and HS-DSCH. The RADIO BEARER RECONFIGURATION message includes a flag indicating that the MAC-hs or the MAC-ehs entity in the UE shall be reset. The message also includes an update of transport channel related parameters for the HS-DSCH in the target HS-DSCH cell.

The UE terminates transmission and reception on the old radio link at the activation time indicated in the RADIO BEARER RECONFIGURATION message, and configures its physical layer to begin reception on the new radio link. After L1 synchronization has been established, the UE sends a RRC: ‘RADIO BEARER RECONFIGURATION COMPLETE’ message. The SRNC then terminates reception and

transmission on the old radio link for dedicated channels and releases all resources allocated to the considered UE. Inter NodeB synchronized HS-DSCH serving cell change signaling scenario shown in figure 22.

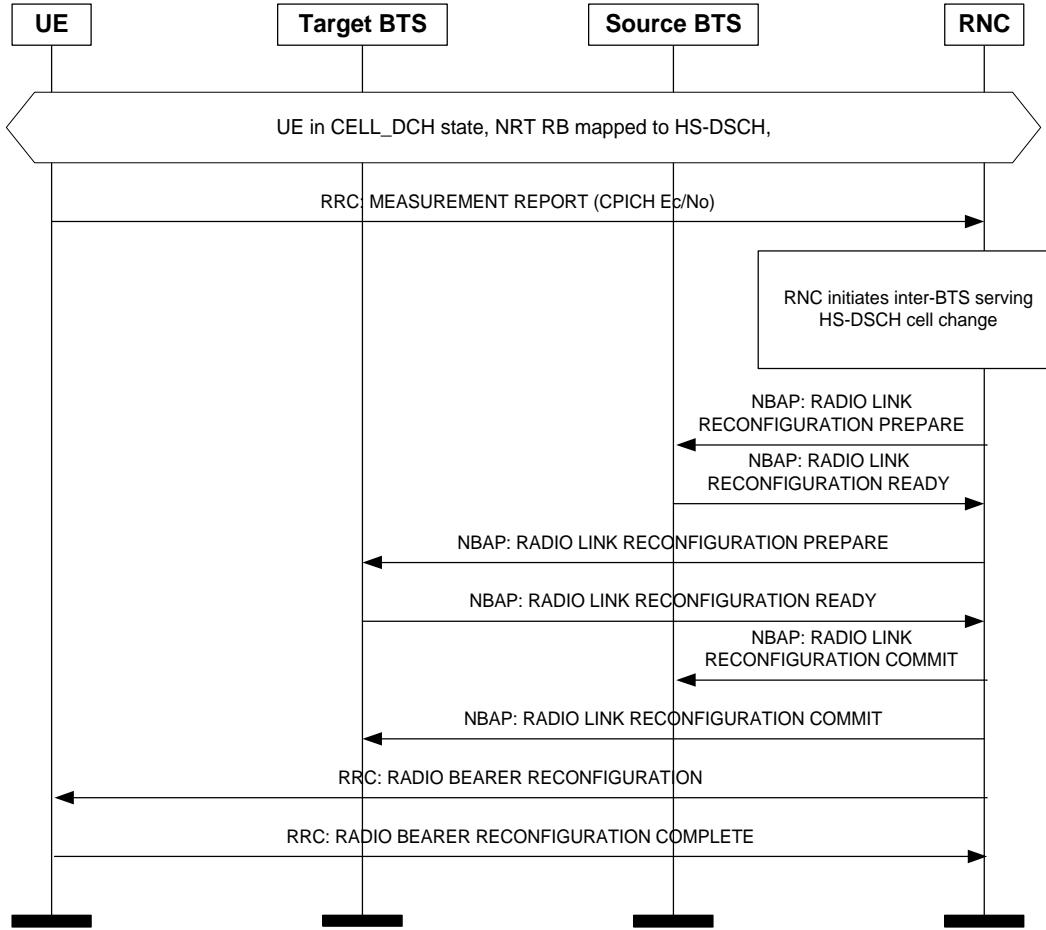


Figure 22 Inter NodeB synchronized HS-DSCH serving cell change [57].

3.3.1.3 Inter RNC HS-DSCH serving cell change

When intra-frequency measurements indicate that the strongest cell in the active set is located under the DRNC, HSDPA intra-frequency inter-RNC cell change is executed. Triggering point for inter-RNC cell change can specifically be defined by the operator by means of the management parameters.

HSDPA intra-frequency inter-RNC cell change utilizes serving RNS relocation with UE involvement, i.e. UE is reconfigured according to the target RNC resources during SRNS relocation. Target RNC allocates resources on best effort basis, that is, even though HSDPA is primarily allocated, also DCH/DCH can be allocated when HSDPA is not available in the DRNC.

HSDPA data flow is not established over Iur-interface but HSDPA resources are reserved and allocated under DRNC in conjunction of the SRNS relocation. Associated DCH (signaling link) and uplink DCH return channel can be set up over Iur-interface, whereas HS-DSCH is not allowed over Iur-interface. HSDPA Inter-RNC Cell Change is supported also when Iur-interface is disabled,

congested or not existing [41]. Figure 23 shows the Inter RNC HS-DSCH serving cell change signalling when Iur is enabled.

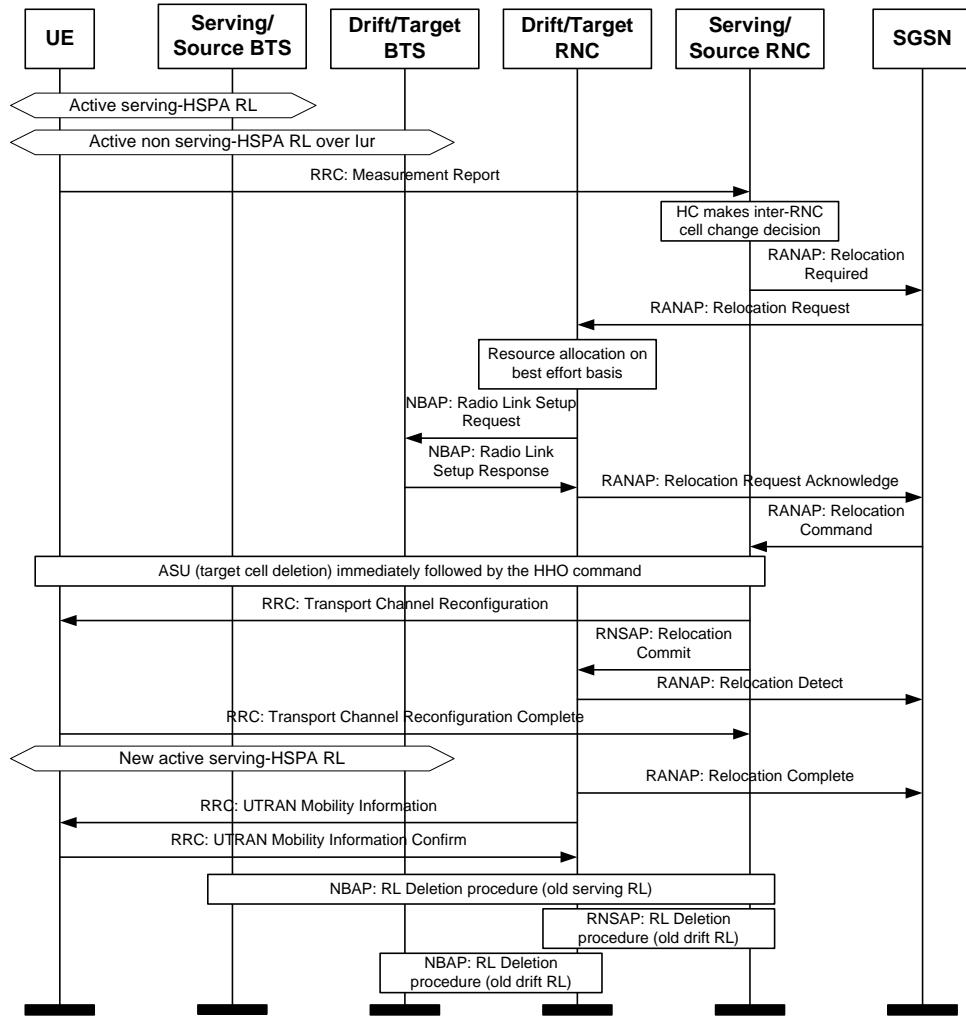


Figure 23 Inter RNC HS-DSCH serving cell change [41].

3.3.2 HSUPA handovers and cell change

In HSUPA conventional WCDMA soft/softer handovers mechanisms are applied.

3.3.2.1 Intra NodeB synchronized HSUPA active set update

In case the UE has established E-DCH channel, the soft and softer handover mechanisms apply. Once a cell enters the reporting range the UE sends a RRC: 'MEASUREMENT REPORT' with event 1A. RNC sends a RRC: 'Active Set Update' message to the UE containing the new cell E-HICH and E-RGCH parameters. Once the UE has replied with a RRC: Active Set Update complete, SRNC then sends a RRC: 'PHYSICAL CHANNEL RECONFIGURATION' message, which indicates the

activation time to the UE. When the UE has completed the radio link addition it transmits a RRC: ‘PHYSICAL CHANNEL RECONFIGURATION COMPLETE’ message to the network [39].

3.3.2.2 Inter NodeB synchronized HSUPA active set update

The signaling sequence is the same in Inter NodeB synchronized HSUPA radio link addition, except with the addition of the radio link in the second NodeB RRC:Active Set Update/Complete and RRC: ‘PHYSICAL CHANNEL RECONFIGURATION’/Complete [39].

When UE is in soft handover and it has several E-DCH channels allocated, one of the cells is the serving cell from scheduling point of view. The serving cell shall give absolute grants and relative grants (Up/Down/Hold) for the UE. The other cells in E-DCH active set are non-serving cells and can send only relative grants. The idea is that serving cell should be the best cell in active set to guarantee good scheduling and best possible performance for the UE [39].

The figure 24 below shows HSUPA SHO in a case where UE’s transmission has been decoded correctly in the serving cell but not in the two non-serving cells in the active set. One received ACK from the cells in the active set is enough for the UE to continue transmission without retransmissions.

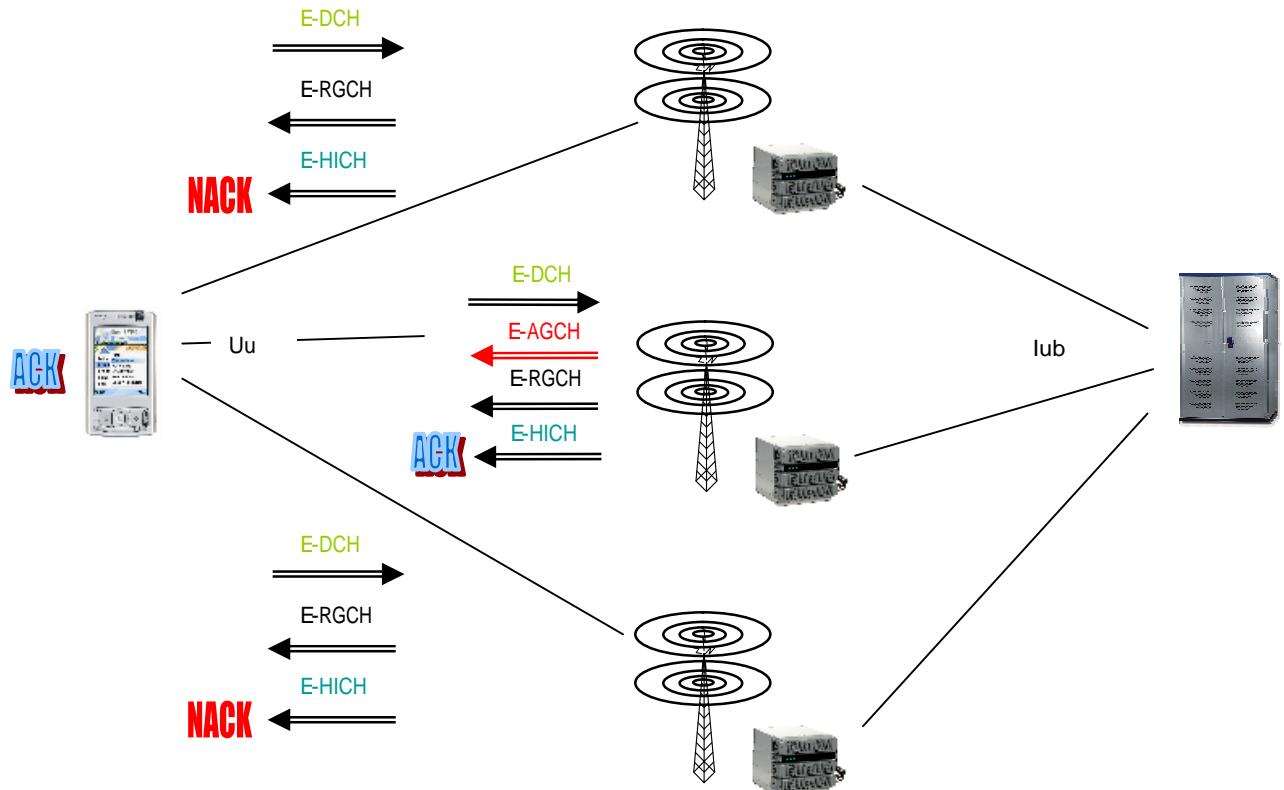


Figure 24 HSUPA soft handover.

Serving E-DCH cell shall be the same as serving HS-DSCH cell when HS-DSCH and E-DCH are used simultaneously. Thus the serving E-DCH cell changes at the same time as the HSDPA serving cell, with only the E-AGCH changing.

3.3.2.3 Inter RNC HSUPA handover

3GPP has specified the NBAP 25.433, RNSAP 25.423 and Frame Protocol 25.427 in Rel06 for E-DCH Iub and Iur interfaces. Meaning, that an inter-RNC handover for E-DCH over Iur is possible, but the typical implementations in an inter RNC handover are

- Serving RNC Relocation together with Inter RNC HS-DSCH serving cell change – where only associated UL data is transported over Iur via DRNC and E-DCH is only under SRNC
- Downgrade of E-DCH to DCH and transporting UL DCH over Iur via DRNC

3.3.3 Macro diversity combining and delay budget in HSUPA

MDC in HSUPA can be divided in to two phases:

1. E-DCH FP entity in RNC performs the ‘pre’ macro diversity combining by checking the payload CRC of each E-DCH FP frame. If the CRC check is passed successfully, then E-DCH FP entity transmits the E-DCH FP frame to MAC-es.
2. The macro diversity combining is in practise collecting the MAC-es PDUs from different SHO branches and removing the duplicates in MAC-es entity in RNC.
The duplicate detection is based on the TSN of the MAC-es PDU. TSN is included in the MAC-es PDU header. When a duplicate TSN is detected for the MAC-es PDU in the reordering buffer the first received MAC-es PDU is selected for reordering. The other (duplicate) MAC-es PDUs are flushed.

As in DCH case, the delay that the system can tolerate between different radio links is vendor specific. Generally, longer absolute delays for E-DCH radio links compared to DCH can be allowed, especially when HSUPA is intended to carry Unspecified Bit Rate (UBR) type of traffic.

As an example of radio link delay tolerance: H-ARQ re-transmissions over air interface (max. 3), may cause in worst case 120 ms delay ($4 \text{ H-ARQ processes} \cdot 10 \text{ ms TTI} \cdot \text{Maximum number of re-transmissions}$) and an additional delay from transmission 200 ms, adding up to 320 ms.

3.3.4 HARQ and MDC gain while using E-DCH

Next we shall have a short motivation of implementing the SHO also in the case where E-DCH is allocated in the uplink.

As discussed in chapter 3.2.5 the method used in E-DCH for MDC compared to Rel99 MDC in chapter 2.6.4 the MDC gains can not be compared with the same strategy. The reason being, that the HARQ functionality in NodeB should ensure that RNC shall receive only correct CRC’s in E-DCH FP frames.

In [42] HARQ performance and MDC gain in RNC were simulated with respect to data throughput with the following prerequisites:

- The UE is connected to two NodeB’s with a 3 dB link imbalance
- The UE and NodeB operation when the macro diversity is enabled or not, is as follows:

- Macro diversity “ON”: All active set NodeBs decodes the E-DCH packet and generate ACK/NACK. The UE performs the retransmission only if there is no ACK.
- Macro diversity “OFF”: Only a single active set NodeB decodes the E-DCH packet and generates ACK/NACK. The UE performs the retransmission in case of NACK.

In figure 25 we can see the simulation results with a 3dB link imbalance. The macro diversity gain is more emphasized compared to the case that only the weaker cell decodes the E-DCH packet. The macro diversity gain can still be seen with respect to E-DCH decoding at the stronger cell, although the gain is reduced.

The MDC functionality in the RNC here is the selection of receiving correct E-DCH FP frames on different NodeB’s.

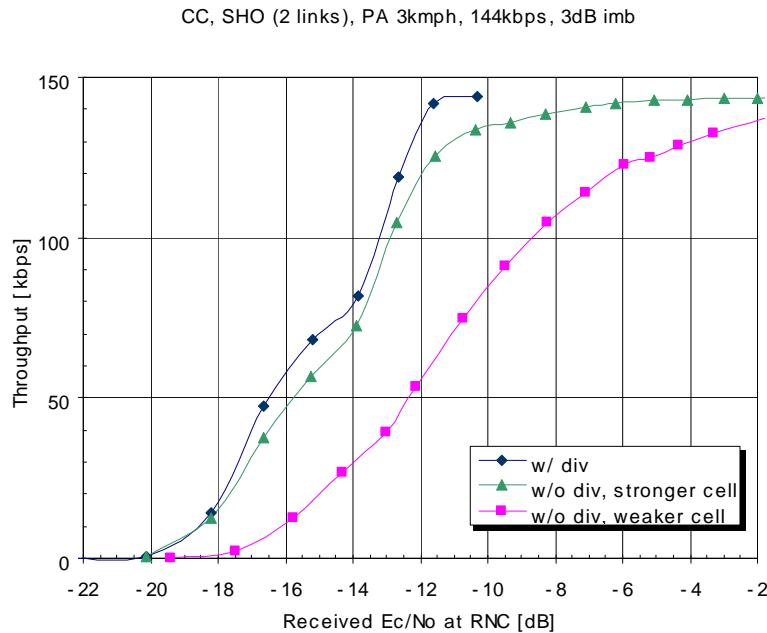


Figure 25 Throughput in soft handover with 3dB link imbalance in ITU-T PA channel at 3 kmph [43].

4. UMTS HIGH SPEED PACKET ACCESS EVOLUTION

3GPP release 7 in June 2007 completed a number additional and substantial enhancements to the high speed data access regarding end user performance, cell throughput and network architecture. Here we shortly look the end user performance and cell throughput issues and concentrate in more detail in the new proposed network architecture, the evolved HSPA (eHSPA) [43].

End user performance and cell throughput evolution in Rel07

- Continuous Connectivity for Packet Data Users (CPC)
CPC is intended to maintain users in DCH state to avoid the delays associated with UE state transitions.
- Multiple Input / Multiple Output (MIMO)
The MIMO concept in Rel07, employs two transmit antennas in the NodeB and two receive antennas in the UE.
- Downlink higher order modulation
64 QAM – usage requires very favorable channel conditions, enabling top rate at 28 Mbps with MIMO and 21 Mbps without MIMO
- Uplink higher order modulation
16 QAM – usage requires very favorable channel conditions, can double the 5.76 Mbps top rate to 11.5 Mbps
- Improved Layer 2 support for high data rates
Flexible and larger RLC PDU sizes and segmentation on MAC layer
- Enhanced Cell FACH
In enhanced FACH state the UE uses HS-PDSCH instead of S-CCPCH as in Rel99

4.1 Way towards Evolved HSPA, system description and architecture

The exponential growth of data traffic carried by wireless networks has made the mobile service providers and standardization organizations to search new alternatives to accelerate the ever growing data volumes. In 3GPP this challenge is known as the Long Term Evolution (LTE), LTE uses Orthogonal Frequency Division Multiplexing (OFDM) as its radio access technology, together with advanced antenna technologies. In addition to LTE, 3GPP is also defining IP-based, flat network architecture. This architecture is defined as part of the System Architecture Evolution (SAE) effort. This new architecture is designed to optimize network performance, improve cost-efficiency and facilitate the uptake of mass market IP based services [44].

4.1.1 Evolved HSPA architecture

The current UTRAN architecture, inherited from GPRS, is not optimized for very pervasive broadband packet services. In fact in this architecture the presence of an RNC in the user plane path plays as a bottleneck for the traffic throughput. This is due to two different but linked factors [43]:

- limitations given by switching and routing capacity of an RNC
- limitations given by RLC/MAC and Iub Framing Protocol overhead for transmission

Rel07 [43] proposes a solution (Alt-3 in [43]) to those limitations by allowing user plane and control plane to scale separately and terminate the user plane protocols in the NodeBs. This is the introduction of the ‘flat’ architecture for the UP part.

As a consequence, the NodeB will have a direct IP broadband connection to the Packet Core.

Moreover latency and delay on the user plane will improve since radio protocols and retransmission will be terminated in the NodeB, similar to what has been decided for SAE.

Evolved HSPA architecture (Alt-4 in [43]) – stand-alone deployment scenario – is a solution for a flat radio access architecture of UTRAN network. In this architecture the RNC functions are integrated in the NodeB, which we will call as evolved NodeB (eNodeB). Evolved HSPA system enables to use 3GPP Release 5 and later Releases of air interface with no modifications for HSPA traffic. The intended use scenario for HSPA capable terminals is to utilize HSPA both in uplink (E-DCH) and in downlink (HS-DSCH).

The eNodeB has Iu-PS interface towards packet switched CN. Iu-PS user plane is terminated either in SGSN or in case of one direct tunnel approach (Rel07) in GGSN. Evolved stand-alone HSPA is designed with full mobility support, including handovers within the system. Intra-system handover in evolved HSPA is executed between cells, which belong to different eNodeBs (inter-eNodeB handover). Handover towards other 3G networks are standard serving RNC relocations. The communication between eNodeBs takes place over Iur interface [43].

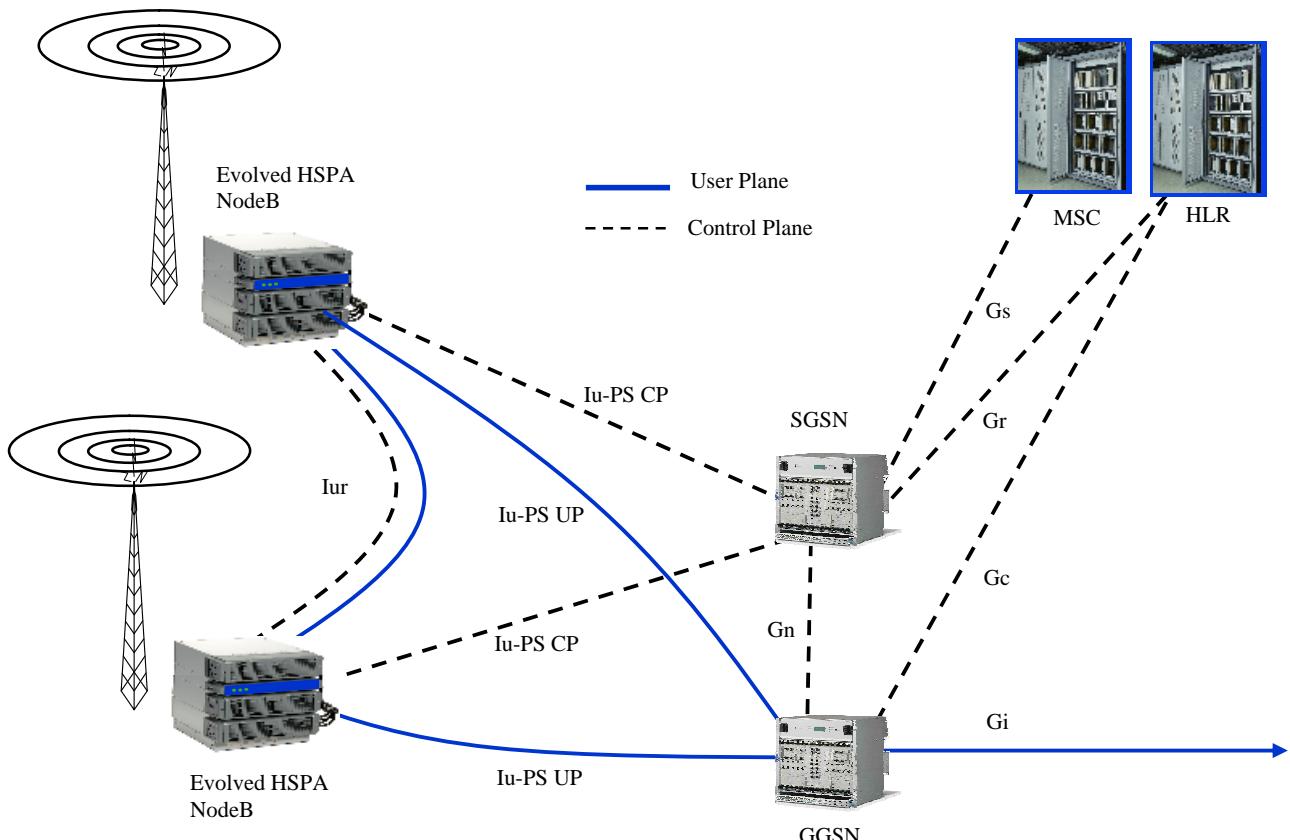


Figure 26 Evolved HSPA architecture – a solution for a flat radio access in UTRAN.

As can be observed from the figure 26, the evolved HSPA architecture, the amount of transmission capacity on Iur interfaces will have an impact to the network capacity compared to the Rel06 architecture where Iur's are used connecting RNC's.

Internet HSPA (I-HSPA) is the Nokia Siemens Networks term for the 3GPP standardized evolved HSPA architecture. I-HSPA is a lean architecture in which the RNC functions are implemented in the base station. User traffic by-passes the RNC. And with the optional Direct Tunneling the user traffic can also by-pass the SGSN making the solution fully 3GPP compliant.

4.1.2 Flat architecture benefits and LTE/SAE

With flat architecture, some of the benefits include lower latency for data applications, lower operational costs (OPEX) due to fewer nodes to maintain and manage, augmented data capacity through a data network overlay, and good preparation for LTE/SAE (System Architecture Evolution), which uses a similar functional architecture, as shown in figure 27. Also, costs won't grow in line with data traffic growth, because operators won't have to deploy extra RNC and SGSN capacity as traffic increases (CAPEX).

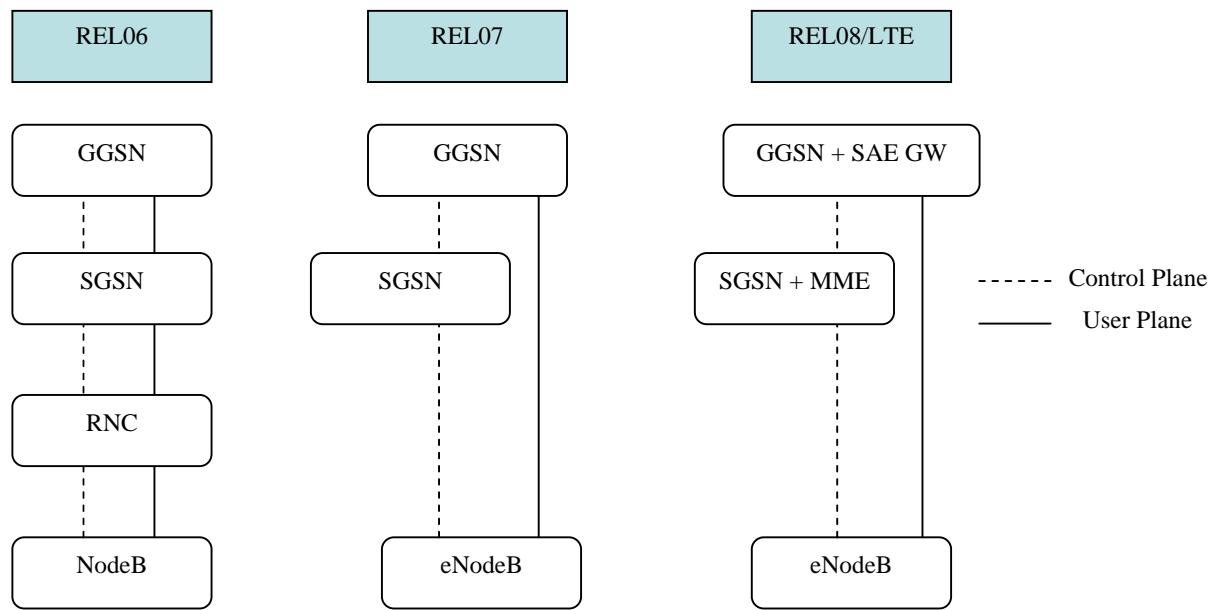


Figure 27 UMTS architecture and node evolution.

In the SAE architecture, the SAE Gateway (GW) can be based on a platform optimized for high bandwidth packet processing, whereas the SAE Mobility Management Entity (MME) is based on a platform optimized for signaling transactions. This enables selection of more cost-effective platforms for, as well as independent scaling of, each of these two elements. Service providers can also choose optimized topological locations of SAE GWs within the network independent of the locations of MMEs in order to optimize bandwidth and reduce latencies.

4.1.3 Circuit switched services in evolved HSPA

In the following we present the solutions how the circuit switched services are enabled in an evolved HSPA environment. As the evolved HSPA is designed for packet services there still has to be support for legacy circuit switched services like voice and video calls. Two network topologies can be identified once building the evolved HSPA network.

- CS services and evolved HSPA operate on a different carrier frequency in the same geographical area. (Stand alone operation)
- CS services and evolved HSPA share the same carrier frequency (carrier sharing).

In the case where CS services and evolved HSPA are using dedicated carrier frequencies the network architecture is slightly lighter than in carrier sharing case.

In carrier sharing topology there has to be an Iur link between eNodeB and a RNC, that the CS services use once they are routed into 3G RNC and CS core.

This Iur link is not needed when CS services use a dedicated carrier frequency, since UE's that initiate CS services under HSPA carrier frequency can be redirected to the CS frequency by means of SRNC relocation. The figure 28 shows the interfaces needed in stand alone and carrier sharing operation modes.

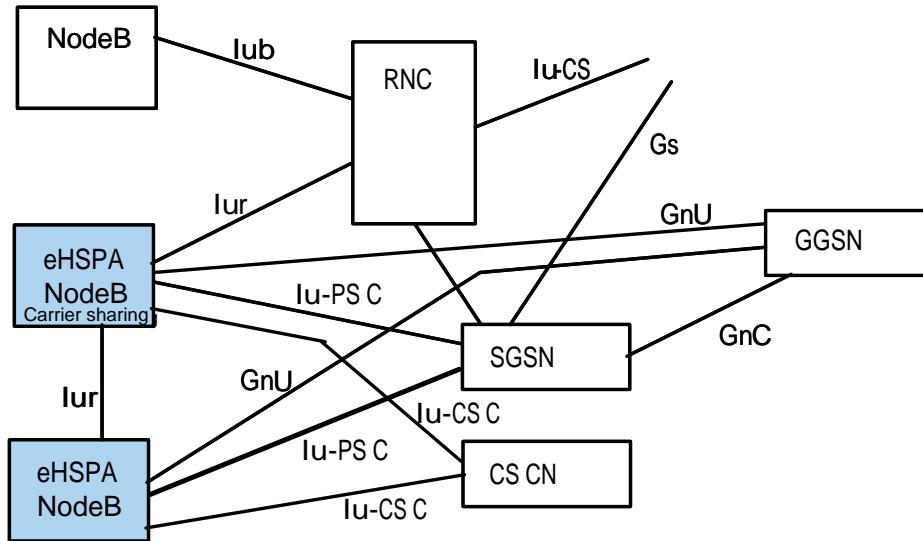


Figure 28 Stand alone operation and carrier sharing in the same network [43].

4.2 Handovers in flat architecture

Flat evolved UTRAN architecture is able to support handovers like in Rel06 architecture, this is due to locating the UL Macro Diversity Combining in the eNodeB's RNC functionality.

There are two options for implementing the inter eNodeB handover

- Handover without Iur connectivity between adjacent eNodeB's – no UL MDC possibility

- Handover with Iur connectivity between adjacent eNodeB's – UL MDC possible

In the alternatives of SHO in uplink discussed here, we assume that the uplink can either be DCH or E-DCH and let the implementation support of E-DCH over Iur be vendor specific.

4.3 Handover without Iur

When the HS-DSCH serving cell change is triggered, the UE related context is transferred from one eNodeB to the adjacent eNodeB, via SGSN, by using the serving RNC relocation procedure. Since there is no connectivity over the Iur, there is a short brake in the PS data transfer during the relocation procedure, the signaling scenario is presented in figure 29. The procedure is similar as GSM type hard handover [41].

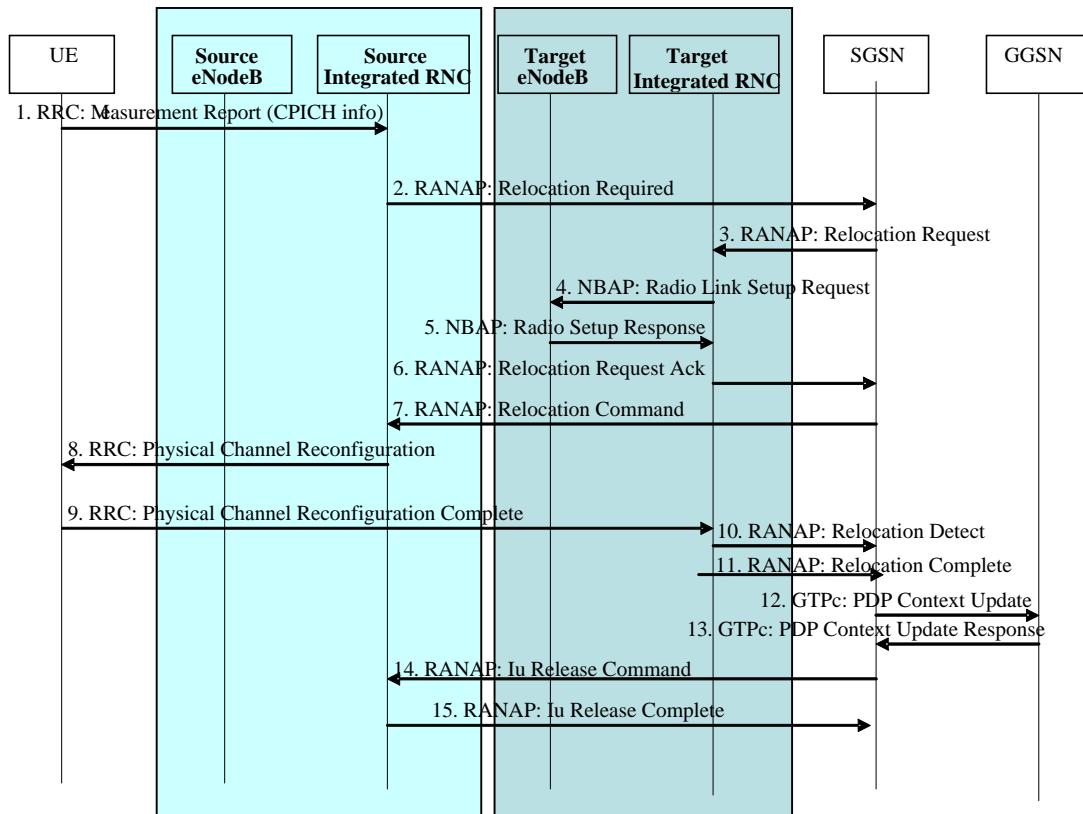


Figure 29 Evolved HSPA handover without Iur connectivity signaling flow, SRNC relocation [56].

4.4 Handover with Iur

From air interface point of view, handover with Iur, is a standard 3GPP HSDPA Serving Cell Change where UL DCH/E-DCH and SRBs apply macro diversity (soft handover). Figure 30 shows the signalling of serving RNC relocation when Iur interface is in use [56].

- PHASE 1: New radio links are added for SRBs and also for UL DCH/E-DCH to operate in soft handover mode once the CPICH of the drift eNodeB exceeds the predefined threshold. Control and macro diversity combining point stays still in the serving eNodeB. HSDPA traffic is not carried over the Iur link (cell change procedure for HSDPA)
- PHASE 2: When the HS-DSCH Serving Cell Change is triggered, whole UE related context is transferred between two involved Adapters via SGSN by using SRNS relocation procedure. One of the specifics of evolved HSPA SHO's is that after serving eNodeB is relocated to new eNodeB, soft handover state for SRBs and UL DCH/E-DCH are still maintained for all cells, which were in active set at the start of SRNS relocation procedure. This means that SRNS relocation is triggered when serving eNodeB still has active radio links unlike legacy 3GPP SRNS relocation
- PHASE 3: Other radio links are released when they go below the predefined value of the drift eNodeB CPICH threshold.

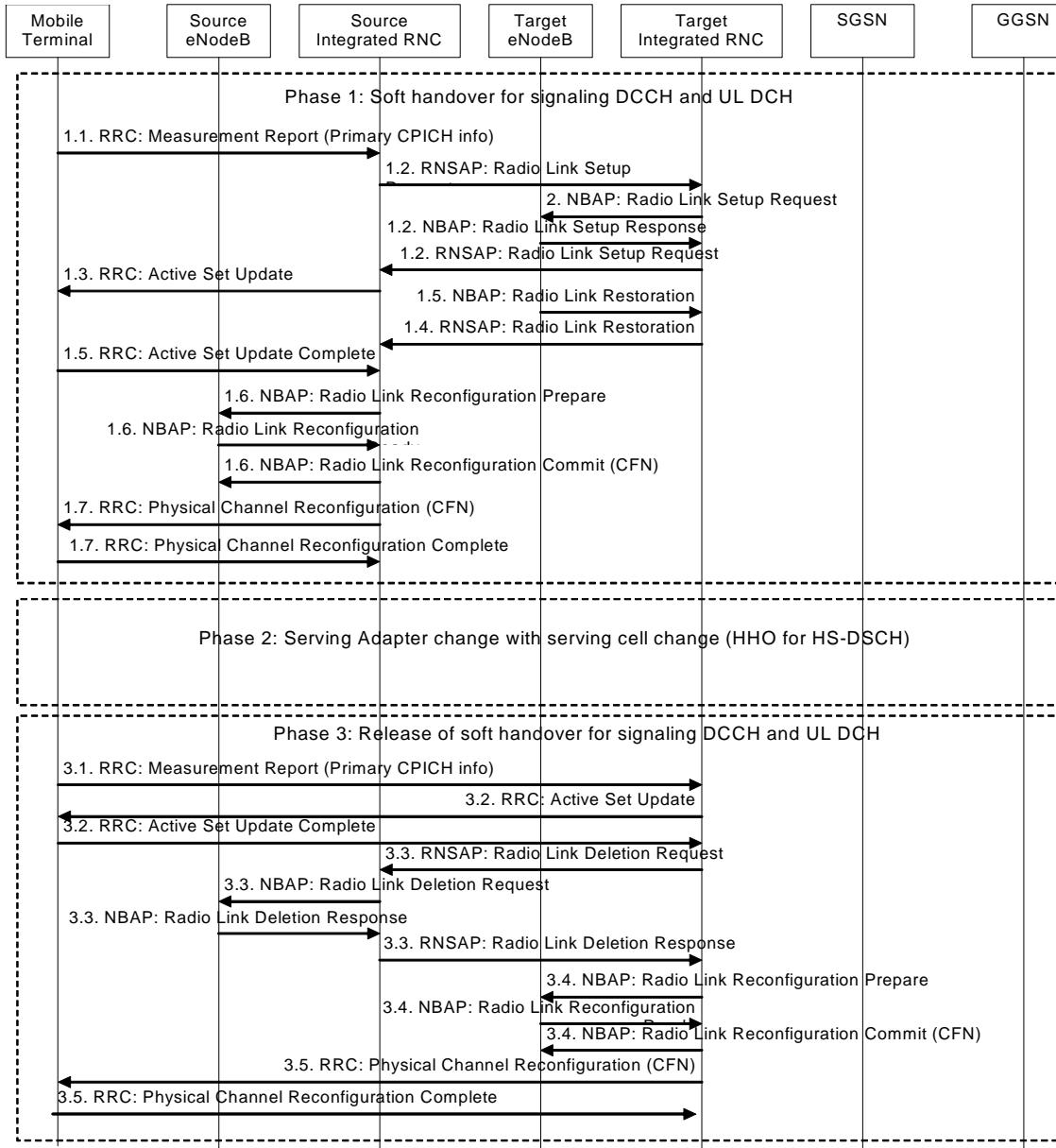


Figure 30 Evolved HSPA handover with Iur connectivity signaling flow [56].

4.5 Uplink macro diversity combining, key issue in flat architecture

A fundamental feature of WCDMA deployments has been the implementation of soft handover and the involvement of a data session being connected to more than one cell. The benefits and gains of MDC were presented in chapters 2.6.4 for UL DCH and 3.3.4 for E-DCH.

In the eHSPA collapsed architecture, the utilization of MDC will become a key implementation point and will become a question of radio savings versus transmission savings i.e. in all instances of inter-eNodeB SHO taking place, additional transmission to ensure that the UL/DL packets are transported to the location of the MDC function will be required as shown in figure 31.

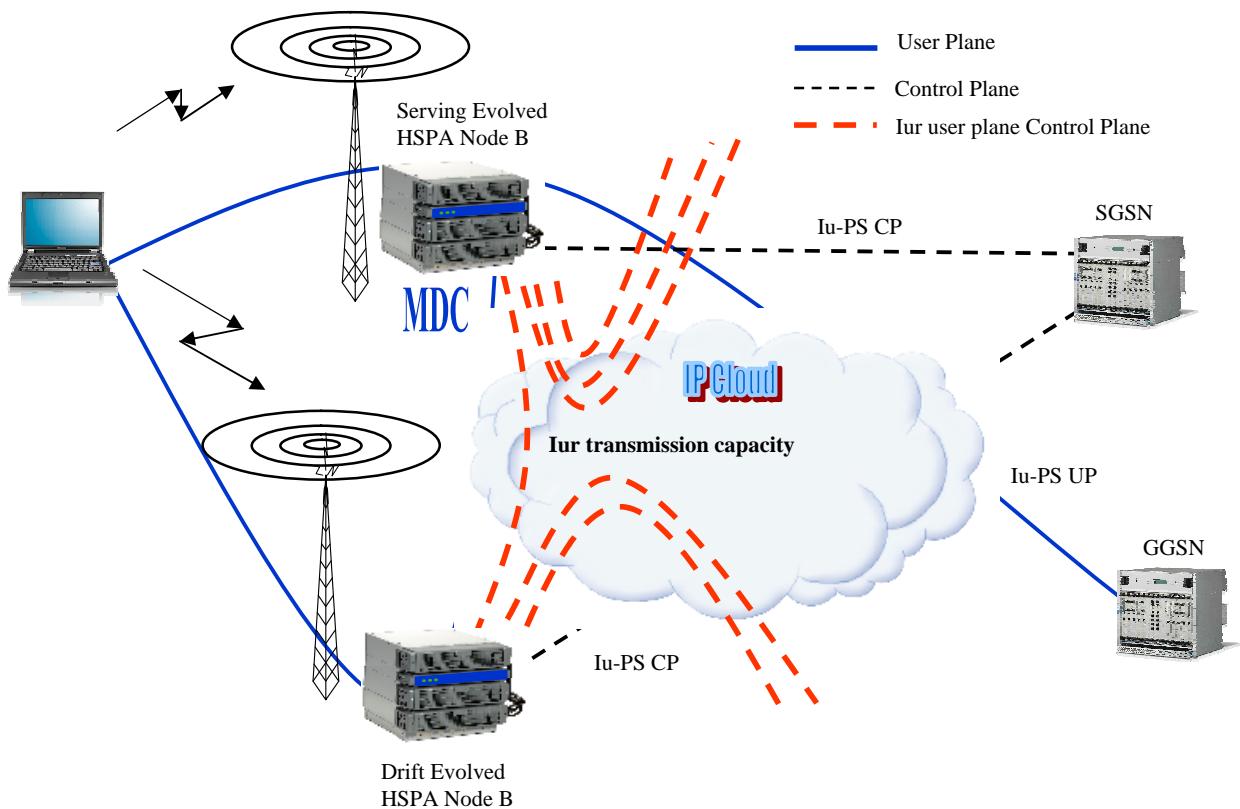


Figure 31 Evolved HSPA inter NodeB soft handover, uplink MDC and Iur's.

However it should be noted that transmission costs will vary from territory to territory and thus it cannot be stated that an eHSPA deployment cannot or should not implement SHO on transmission cost savings – this depends upon that local market.

Fundamentally the benefits of any “turning off of SHO/MDC” function will only arise when the transmission savings outweigh the “radio” savings in the deployment of this architecture in the WCDMA environment [46].

As a consequence, a discussion started in 3GPP with the intention to somehow restrict the use of evolved HSPA uplink MDC so that the dimensioning of the transport network can be done for lower expected capacity. Main focus is the reduction of the *user data* (in contrast to signaling data), since this is expected to be by far the largest contribution to the overall traffic.

It is clear from the outset that a restriction of MDC will lead to degradation on the radio interface, which is the price to be paid for improvement on the transport network side (measured in “cost reduction”). Key question is whether it is possible to keep the quality of service (measured in terms of capacity, throughput, latency, jitter) at acceptable levels, such that a noteworthy total benefit remains.

4.6 Proposals for enhanced MDC in flat architecture by 3GPP

Next, the proposals for enhanced MDC in 3GPP are introduced and in chapter 5 these proposal are compared based on three factors. In chapter 6, a solution is proposed with slight enhancements to the proposals made in 3GPP.

The proposed enhancements for MDC in 3GPP are presented in the following order:

- Improvement of UL Macro Diversity Combining in Serving NodeB [43]
- MDC & Cell Interference control in eHSPA architecture [46]
- Proposal of interference control and MDC in eHSPA architecture [47]
- Selective MDC according to Service/QoS [48]

4.6.1 Improvement of UL macro diversity combining in serving NodeB

The following procedure introduced in [49] and [50] and later included in 3GPP TR 25.999 [43] proposes an improvement to reduce the traffic load on Iur during SHO and a partly improve MDC.

The idea behind this proposal is that, drift eNodeB's only send packets over Iur if requested. The serving eNodeB requests packets only from drift eNodeB's in case when the serving eNodeB detects incorrect CRC's in the received packets. Drift eNodeB's in the active set that have the packet correctly received will forward the packet only upon request to the serving eNodeB.

The description of the scenario:

- If CRC check is correct in the serving eNodeB, the serving eNodeB sends its packets directly to xGSN and MDC procedures end, Figure 32 a.
- If CRC check is wrong, the serving eNodeB sends a notification to the drift eNodeBs in the active set and MDC procedures continue, Figure 32 b.
- After receiving the notification, those drift eNodeBs, which have the right CRC check, send their packets to the serving eNodeB, Figure 32 b.
- The serving eNodeB selects one of the correctly received packets and sends it to xGSN, Figure 32 b.

Figure 32 illustrates the above procedures in the scenario with one serving NodeB and one drift NodeB with Iur.

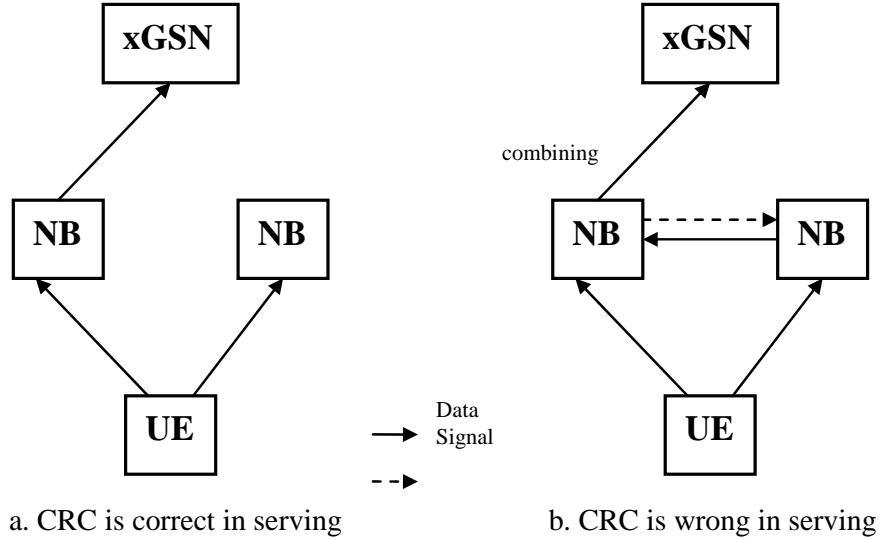


Figure 32 UL MDC in Evolved HSPA architecture with one serving and one drift eNodeB [43].

Considering that for most of the time the serving NodeB has the best channel quality, it is highly possible that the serving eNodeB gets the correct CRC check and no further action is needed for MDC. Even in the occasional case that the serving eNodeB receives the wrong packets, the traffic load between eNodeBs would be much less than in traditional way (full MDC), but a slight increase in latency would be introduced due to notification message and drift eNodeB sending the correct CRC packet.

4.6.1.1 Implementation aspects

In this solution the CRC check for MDC might not be optimum for the Rel06 UE's with an E-DCH uplink due to the fact that HARQ in uplink does the CRC check and passes only the correct CRC FP frames towards the MDC entity. One option could be to replace the CRC check with the indication of HARQ failure [54].

This proposal is more feasible for UE's with a DCH uplink, where CRC check is done from the DCH FP frames in the serving eNodeB.

- *Notification message addition needed*

Notification message should be implemented in Iur/Iub frame protocol. Using RNSAP for these messages is not feasible due to additional specification and its nature of being outband signaling (control plane).

- Iub/Iur FP, notification message to fetch packets from drift eNodeB
- Iur RNSAP / Iub NBAP option activation information element
- *Very Large latency*

In case the notification message is sent after residual HARQ failure (the maximum number of retransmissions has been reached without correct reception) the introduced latency will make this solution only feasible for non real time applications.

- *Limited interference control*

Limited interference control under drift eNodeB's is available based on initial SIR, as shown in the next proposal.

4.6.2 MDC & Cell interference control in eHSPA architecture

The following proposal [46] first clarifies the limitations that will follow if MDC is completely removed and makes several proposals of the possibilities that an operator could have in configuring the MDC usage. The most interesting here is the “*only control plane over iur*” proposal that is examined in more detail.

Firstly, totally removing the possibility for a UE to have cells from a non-serving NodeB e.g. as part of its DCH/E-DCH active set – i.e. removing BOTH the ability to perform CP signaling and UP across the Iur - would be useful in that it would prevent the establishment of the user plane and hence minimal additional narrowband transport resources would be needed, but it may have drawbacks in the sense that it will prevent the establishment of radio resource configuration in the non-serving NodeB for these non-serving cells not under the control of the serving NodeB.

This latter aspect will have the following impact:

- Prevent the non-serving NodeB from being able to control the amount of uplink resource that the UE is taking from its cells.
- The lack of knowledge the non-serving NodeB has about the UE would mean that the non-serving NodeB would not be able to cancel out the interference from this UE.

Thus depending upon the local scenario, a mechanism is proposed to permit the Operator to:

1. Selection of full MDC or no MDC

SRNC decides to perform SHO and perform MDC – or not – and in doing so establishes BOTH the control and user plane across the Iur from any non-serving eHSPA NodeB.

2. Only control plane over Iur

Permit only the establishment of CP context across the Iur, and thus allowing the non-serving NodeB to perform some kind of interference control towards the nearby UE, in this solution the drift eNodeB functionality would remain, with the exception that it flushes the uplink user plane data internally.

3. Selective user plane over Iur

Permit the establishment of a user plane on a per UE channel basis depending upon the service or traffic load on Iur at that point in time.

4.6.2.1 Implementation aspects

Thoughts about proposal “only CP over Iur” established – loophole and SIR target in drift eNodeB

In case, where only CP would be established between serving eNodeB and drift eNodeB without user plane, but the functionality of the eNodeBs in E-DCH case would remain as such – a loophole pops up:

In order to avoid problems when the serving eNodeB did not receive a packet correctly, but the drift eNodeB signals to the UE it did – which causes the UE to start transmission of the next packet, the packet is simply completely lost.

Solution could be that the drift eNodeB always signals to the UEs that packets were *not* received correctly, by sending NACK.

In this “fix” a new message or Information Element to existing signaling would be needed to indicate the drift eNodeB to NACK all uplink data, this indication should happen during the radio link setup phase over Iur.

A partly improved interference control, based on initial SIR, is available for the radio links under the drift eNodeB. The reason being that the serving eNodeB can not get HARQ nor BER/BLER info over Iur Frame Protocol, but the initial SIR target can be utilized together with uplink closed loop power control as can be seen from figure 33 (example of Rel99 uplink).

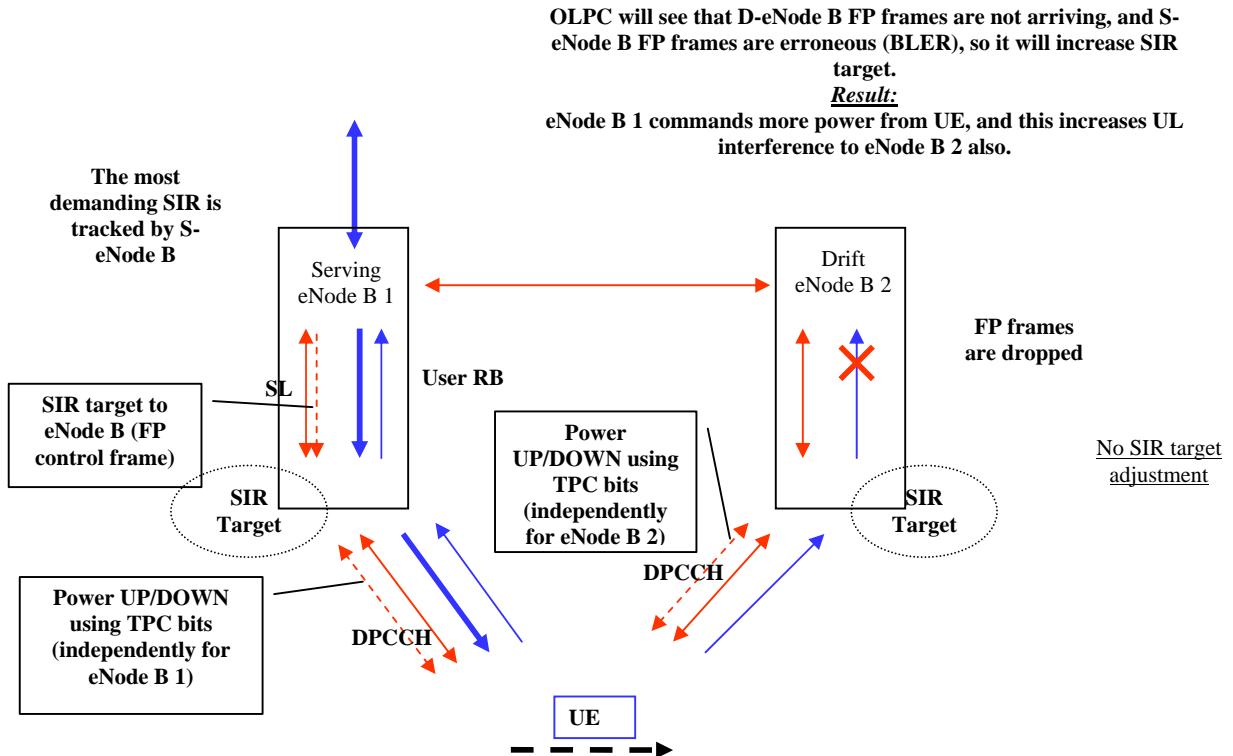


Figure 33 SIR target adjustment when only control plane over Iur is setup (Rel99).

Just turning the Iur user plane data transfer off and thus saving the transport of carrying user data over Iur, but still having a limited interference control, makes the implementation of this proposal quite lucrative and simple.

- *Notification message additions needed*

Indicator should be added as a new information element in existing RNSAP and NBAP protocols [52, 53]. In case “*only CP over Iur*” is selected the drift eNodeB should also NACK all uplink data.

- Iur RNSAP / Iub NBAP option activation information element

4.6.3 Proposal of interference control and MDC in eHSPA architecture

In the proposal of interference control and MDC in eHSPA architecture [47] a mixed solution of

- Improvement of UL Macro Diversity Combining in Serving NodeB, [43]
- MDC & Cell Interference control in eHSPA architecture - “*only CP over Iur*”, [46].

Is presented as

- partly improved MDC
- partly improved interference control.

The Measurement Report from UE is used as a factor to decide whether User Plane Data Transfer (UPDT) is required for each drift eNodeB’s.

When the channel quality in the Measurement Report of a drift eNodeB is good enough before triggering serving cell change, partly improved UL MDC may be needed for better performance, whereas UL MDC may not be needed when the channel quality of drift eNodeB is bad enough, but partly improved interference control can be utilized.

In the figure 34, the serving eNodeB has two drift e NodeBs where the drift eNodeB (A) is configured for improved MDC and the drift eNodeB (B) for improved interference control

Partly improved MDC – UE RRC measurement report reports higher quality

In this solution UL UPDP indicator is not used, and the improved MDC function is applied on drift eNodeB’s. Only the drift eNodeB’s with correct data should transfer UL data after receiving notification from serving eNodeB.

Partly improved interference control – UE RRC measurement report reports low quality

UL UPDP indicator is set to NOT REQUIRED, and the drift eNodeB’s trigger the Improved Interference Control function and do not transfer uplink user plane to serving eNodeB.

Normal MDC

Also in case where transport resources are not limited, normal MDC is supported by setting UL UPDT indicator to REQUIRED.

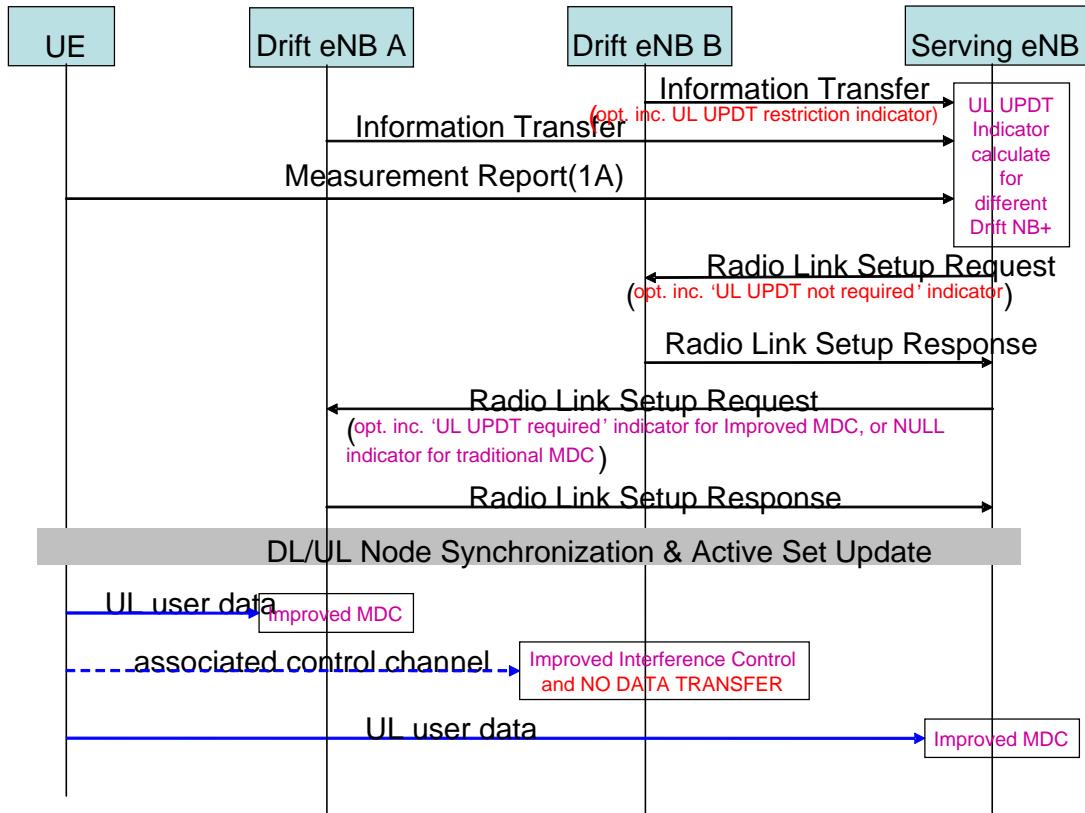


Figure 34 Improved interference control without UL UPDT and improved MDC with UL UPDT [47].

This combined solution provides higher flexibility and better performance with quite high complexity.

4.6.3.1 Implementation aspect

Partly improved MDC

Implementation alternatives described in “Improvement of UL Macro Diversity Combining in Serving NodeB” (4.6.1) apply also here.

Partly improved interference control

In this proposal only the usage of UL DPCCH/E-DPCCH and DL E-RGCH were proposed under the drift eNodeB.

This would need modification to the existing 3GPP 25.211 specification where all HSUPA and UL DCH channels are specified to be setup.

Additionally, when a UE moves to near drift eNodeB with better channel quality, serving eNodeB should trigger serving cell change and serving RNC relocation. It is proposed to introduce a new CAUSE in SRNS relocation in RANAP messages (e.g. relocation for UL UPDT), which trigger the target eNodeB to switch off Improved Interference Control function and to allocate demodulation resource of UL data channels.

If approach as in “MDC & Cell Interference control in eHSPA architecture” - “*only CP over Iur*”, (4.6.2) is utilized and all DCH/E-DCH channels are used, then the NACK sending in drift e NodeB should be implemented.

In this proposal where Measurement Report quality is used for threshold level for low/high quality the threshold should be set according to the available transport resources.

- *Notification message addition needed*
 - Iur RNSAP / Iub NBAP UPDT indicator IE in RL Setup Request (selection between partly improved MDC and partly improved interference control)
 - Iub/Iur FP, notification message to fetch packets from drift eNodeB
 - Iu RANAP, a new CAUSE of SRNS relocation.

4.6.4 Service differentiated uplink macro diversity combining in flat evolved HSPA architecture

In this proposal [48], the possible latency for delay sensitive services if a packet needs to be fetched before it can be forwarded, is tried to be resolved by introducing a service differentiated MDC mechanism for proposal *Improvement of UL Macro Diversity Combining in Serving NodeB*

Service differentiated MDC mechanism can be applied based on QoS requirements or configuration of a certain traffic type, i.e. the serving eNodeB can decide to utilize different MDC schemes according to different services of a UE and indicate the schemes to the drift eNodeB via Iur interface. The serving eNodeB indicates to the drift eNodeB “selective MDC”, “Normal MDC” and “non MDC” schemes as well as the transport resources allocated to the corresponding services accordingly. One or more MDC schemes can be utilized simultaneously for different services. The factors of the selection of MDC schemes by the serving eNodeB include quality of service, occupancy of transport bandwidth, configuration of the operators etc. More specifically, several principles of MDC scheme selection can be utilized.

- “Normal MDC” can be applied to low data rates and delay sensitive services,
- “Selective MDC”, as in “Improvement of UL Macro Diversity Combining in Serving NodeB”
- “Non MDC” can be applied to high data rates and delay insensitive services.

If the transport resources in Iur are stringent, “Selective MDC” or “Non MDC” can be selected, otherwise “Normal MDC” can be selected. For the optimal use of transport resources in Iur, full transport resources need to be allocated for “Normal MDC” cases and only a portion of the transport resources need to be allocated for “Selective MDC” cases.

Take a certain service on E-DCH for example, if “Normal MDC” is selected by the serving eNodeB, the drift eNodeBs will be indicated of this scheme to be applied and full transport resources to be allocated for that service. The drift eNodeBs will then send all MAC-es PDUs of that service non

selectively to the serving eNodeB via Iur FP. If “Selective MDC” is selected by the serving eNodeB, the drift eNodeBs will be indicated of this scheme to be applied and a portion of the transport resources to be allocated. The drift eNodeBs will then select MAC-es PDUs of the corresponding service which have the right CRC check to be incorporated in the Iur FP frame only if the instruction from the serving eNodeB is received. If “Non MDC” is selected by the serving NodeB and the drift NodeBs are indicated accordingly, the drift eNodeBs will not allocate transport resources and no MAC-es PDUs of the corresponding service will be sent to the serving eNodeB via Iur FP.

4.6.4.1 Implementation alternative

A MDC selection algorithm based on delay sensitive services and on real time load of the Iur interface needs to be implemented – for “selective MDC” same implementation options apply as in *Improvement of UL Macro Diversity Combining in Serving NodeB*

- *Notification message addition needed*
 - Iub/Iur FP, notification message to fetch packets from drift eNodeB
 - Iur RNSAP / Iub NBAP option activation information element

4.7 Summary of the proposals for enhanced MDC in flat architecture made by 3GPP

In the first proposal, “Improvement of UL Macro Diversity Combining in Serving NodeB”, the idea for serving eNodeB is to ask packets from drift eNodes in case serving eNodeB detects incorrect CRC’s in received data frames. In this solution data packets would load the Iur only when asked by serving eNodeB, but the delay seen by the application can grow vastly due to the proposed mechanism. Additionally the CRC check as the trigger will only work for UL DCH channels not for E-DCH.

The second proposal, “MDC & Cell Interference control in eHSPA architecture”, proposes four different options for selecting the Iur traffic: full MDC (user and control plane), No MDC, only control plane over Iur (no user plane) and selective user plane and control per UE. This proposals benefit is that its effect on existing specifications is minimal – only an indicator for selected MDC mode would be required. The “star” of this proposal is the option where only the control plane of a call would be established over Iur once the threshold of adding a radio link in drift eNodeB is triggered.

The third proposal, “Proposal of interference control and MDC in eHSPA architecture”, is a combination from the first two proposals. Here the selected operation mode ‘CRC check’ or ‘only control plane over Iur’ would be based on the channel quality in the UE’s measurement report. Same notes apply as in the above proposals plus that the implementation complexity here would grow quite high.

The fourth proposal, “Service Differentiated Uplink Macro Diversity Combining in Flat Evolved HSPA Architecture”, tries to solve the delay problems caused in the first proposal where the serving eNodeB needs to ask packets from the drift eNodeB. The serving eNodeB can select a suitable MDC scheme from normal MDC, selective MDC or no MDC based. Considering the transport resources, if transport resources are stringent the eNodeB could select the selective MDC or even the no MDC option. Considering the service characteristics low data rates and delay sensitive services could use the normal MDC scheme.

5. ENHANCED MDC PROPOSAL COMPARISON IN FLAT ARCHITECTURE

The comparisons of the different MDC proposals are based on five contributions that are considered as the main factors:

- Complexity of the implementation
- Transport resource need
- Radio performance in inter eNodeB soft handover
- Latency
- Needs for additions in existing specifications

5.1 Complexity of the implementation

The implementation complexity is evaluated based on new signaling requirements that each proposal requires.

5.1.1 Improvement of UL macro diversity combining in serving NodeB

This proposal is based on exchange of Iur/Iub FP inband signalling for notifying the drift eNodeB, that it should forward its correctly received data packets to the serving eNodeB.

The implementation would require a new FP control frame type for the notification messages [22].

In addition, also a RNSAP & NBAP indicator (a new information element) for activating this proposal would be required.

Implementation complexity: Moderate.

5.1.2 MDC & Cell interference control in eHSPA architecture

In this proposal the load of Iur transmission capacity can be affected by selection between the following MDC options: no MDC, only control plane over iur or normal MDC.

The following addition has been proposed in RNSAP [52] and NBAP [53] for the MDC option selection.

A new Information Element, called the “*Transport Bearer Not Requested Indicator*” has been added into radio link setup, addition and reconfiguration procedures to indicate that:

- transport bearer shall not be established – DCH/E-DCH not over Iur
- transport bearer may not be established – lets the drift NodeB to decide whether to establish the DCH/E-DCH or not

In the above mentioned procedures the SRNC could indicate to the DRNC the EDCH MAC-d flows where a transport bearer is not requested, and accordingly the DRNC could indicate to the SRNC the EDCH MAC-d flows where a transport bearer has not been setup.

This would permit the SRNC/DRNC to permit the granularity to setup the EDCH MAC-d flow for signalling only and the transfer of SRBs thereby permitting the transfer of Cell Interference information [46].

Implementation complexity: Simple.

5.1.3 Proposal of interference control and MDC in eHSPA architecture

This is mixed proposal from the first two proposals, thus the implementation options are a same as in the first two proposals.

Implementation complexity: Complicated.

5.1.4 Service differentiated uplink macro diversity combining in flat evolved HSPA architecture

In this proposal the serving eNodeB can select a suitable MDC scheme from normal MDC, selective MDC (as in [43]) or no MDC.

The selection of the suitable MDC option could be done as in [44] by additions in NBAP and RNSAP.

In case of selective MDC usage the same principles apply as in [43], where the notification messages for fetching packets from drift eNodeB should be signaled using frame protocol.

Implementation complexity: Moderate.

Table 6 Comparison of implementation complexity in enhanced MDC proposals.

Proposal	Implementation Complexity
Improvement of UL Macro Diversity Combining in Serving NodeB	Moderate
MDC & Cell Interference control in eHSPA architecture	Simple
Proposal of interference control and MDC in eHSPA architecture	Complex
Service Differentiated Uplink Macro Diversity Combining in Flat Evolved HSPA Architecture	Moderate

5.2 Transport resource need

The transport resource need here is compared to the case where normal MDC would be used, where both user and control plane are carried over the Iur interface.

5.2.1 Improvement of UL macro diversity combining in serving NodeB

Less – only control plane and user plane on request.

5.2.2 MDC & Cell interference control in eHSPA architecture

Here the case where only control plane over Iur is established is under consideration.

Less – only control plane data.

5.2.3 Proposal of interference control and MDC in eHSPA architecture

Less – only control plane and/or user plane on request.

5.2.4 Service differentiated uplink macro diversity combining in flat evolved HSPA architecture

Less – only control plane and user plane on request, when selective MDC in use.

Table 7 Comparison of transport resource need in enhanced MDC proposals.

Proposal	Transport resource need
Improvement of UL Macro Diversity Combining in Serving NodeB	Less than normal MDC
MDC & Cell Interference control in eHSPA architecture	Less than normal MDC and the other proposals (only control plane)
Proposal of interference control and MDC in eHSPA architecture	Less than normal MDC
Service Differentiated Uplink Macro Diversity Combining in Flat Evolved HSPA Architecture	Less than normal MDC

5.3 Radio performance in inter eNodeB soft handover

In an inter NodeB SHO situation the SIR target in serving NodeB can be adjusted based on BER/BLER in DCH case and HARQ indications in E-DCH case, but in all proposals, where Iur user plane traffic is limited, the SIR target under drift eNodeB can not be adjusted since the lack of BER/BLER or HARQ information over Iur, thus possibly resulting in a slight interference increase under drift eNodeB.

It should also be noted here, that none of these proposals require any UE modifications.

5.4 Latency

Here the expected latency increase on user plane data flow is compared between the proposals.

5.4.1 Improvement of UL macro diversity combining in serving NodeB

A clear increase of the standard deviation of the latency in the network caused by situations where packets are fetched over Iur on request is expected.

5.4.2 MDC & Cell interference control in eHSPA architecture

No impact.

5.4.3 Proposal of interference control and MDC in eHSPA architecture

Increase of the standard deviation of the latency in the network, in *Improvement of UL Macro Diversity Combining in Serving NodeB* Architecture branch. *MDC & Cell Interference control in eHSPA architecture* proposal does not introduce any latency in the network.

5.4.4 Service differentiated uplink macro diversity combining in flat evolved HSPA architecture

Increase of the standard deviation of the latency in the network caused by situations where packets are fetched over Iur on request, when selective MDC in use.

Table 8 Comparison of latency in enhanced MDC proposals.

Proposal	Latency
Improvement of UL Macro Diversity Combining in Serving NodeB	Increased latency due to fetching packets from drift eNodeB
MDC & Cell Interference control in eHSPA architecture	No impact
Proposal of interference control and MDC in eHSPA architecture	Increased latency due to fetching packets from drift eNodeB / No impact
Service Differentiated Uplink Macro Diversity Combining in Flat Evolved HSPA Architecture	Increased latency due to fetching packets from drift eNodeB

5.5 Needs for additions to existing 3GPP specifications

Last the additions needed by each proposal to the current 3GPP specifications are evaluated.

5.5.1 Improvement of UL macro diversity combining in serving NodeB

This proposal requires additions to the following 3GPP specifications for selecting the activation of this proposal: RNSAP - 3GPP TS 25.423 [52] and NBAP - 3GPP TS 25.433 [53].

Notification messages between serving and drift eNodeB's using frame protocol, to request packets from drift eNodeB in proposal 25.427, UTRAN Iur/Iub interface user plane protocol for DCH data streams [54].

5.5.2 MDC & Cell interference control in eHSPA architecture

This proposal requires additions to the following 3GPP specifications for selection of the MDC option: RNSAP - 3GPP TS 25.423 [52] and NBAP - 3GPP TS 25.433 [53].

5.5.3 Proposal of interference control and MDC in eHSPA architecture

This proposal needs the additions as mentioned in the two above proposals.

5.5.4 Service differentiated uplink macro diversity combining in flat evolved HSPA architecture

This proposal requires additions to the following 3GPP specifications for selecting the activation of this proposal: RNSAP - 3GPP TS 25.423 [52] and NBAP - 3GPP TS 25.433 [53].

Notification messages between serving and drift eNodeB's using frame protocol, to request packets from drift eNodeB in proposal 25.427 [54].

Table 9 Additions to existing 3GPP specifications.

Proposal	specification	Note
Improvement of UL Macro Diversity Combining in Serving NodeB	RNSAP - 3GPP TS 25.423 NBAP - 3GPP TS 25.433 Frame Protocol - 3GPP TS 25.427	Activation of the option FP used for notification message
MDC & Cell Interference control in eHSPA architecture	RNSAP - 3GPP TS 25.423 NBAP - 3GPP TS 25.433	Activation of the option
Proposal of interference control and MDC in eHSPA architecture	RNSAP - 3GPP TS 25.423 NBAP - 3GPP TS 25.433 Frame Protocol - 3GPP TS 25.427 RANAP - 3GPP TS 25.413	Activation of the option FP used for notification message A new CAUSE of SRNS relocation.
Service Differentiated Uplink Macro Diversity Combining in Flat Evolved HSPA Architecture	RNSAP - 3GPP TS 25.423 NBAP - 3GPP TS 25.433 Frame Protocol - 3GPP TS 25.427	Activation of the option FP used for notification message

5.5.5 Summary

In flat architecture a large increase in transport capacity would be needed once connecting eNodeBs to support SHO and normal MDC. In this thesis we have presented four different proposals for improving the UL MDC in HSPA flat architecture, thus trying to reduce the needed transport capacity between eNodeBs

Comparing the different proposals, case 1 *Improvement of UL Macro Diversity Combining in Serving NodeB* appears hardly attractive due to possible high latency when requesting packets over Iur and new inband signaling functionality.

Case 2 *MDC & Cell Interference control in eHSPA architecture* seems to provide a good compromise between implementation complexity and degradation of the air interface (as do other proposals), resulting in a small but sensible expectation of an economic benefit, at least for relative expensive transport network implementations, like E1's.

Case 3 *Proposal of interference control and MDC in eHSPA architecture* has the disadvantage of unfavorable increase in signaling and complexity of implementation plus the possible high latency when requesting packets over Iur

Case 4 Service Differentiated Uplink Macro Diversity Combining in Flat Evolved HSPA Architecture could be utilized together with case 2, better than with case 1

Of these four proposals [43], [46], [47], [48], the author suggests for implementation and usage the case 2 *MDC & Cell Interference control in eHSPA architecture* with the following additions in mind:

- transport network is considered comparatively expensive
- background and interactive traffic classes only
- drift eNodeB's should be commanded to send NACK for all received data packets, even for correctly received packets.

In case transport resources are not considered a limiting factor normal MDC should be used also in evolved HSPA flat architecture.

6. CONCLUSIONS AND CONSIDERATIONS

6.1 Results and contribution

3GPP has contributed four proposals how the link capacity and interference control could be handled in flat architecture. These proposals were evaluated and compared resulting in a proposal for minimum transmission capacity increase and simple implementation.

The best proposal, for keeping the transmission increase relatively low for MDC and also considering the ease of implementation on top of the current 3GPP specifications was found to be as follows, based on [46]:

In this solution only control plane would be established over Iur links between eNodeB's in SHO situation, thus limiting the required transmission capacity on Iur links between eNodeB's for control plane only. Both, the serving and drift eNodeB's would receive the uplink DCH/E-DCH flows as usual; the drift eNodeB would just flush the user plane traffic without forwarding it on Iur link.

To achieve an increased level of SHO/MDC management the solution would impact upon the following procedures:

- *Radio Link Setup*
- *Radio Link Addition*
- *Synchronized Radio Link Reconfiguration Preparation*
- *Unsynchronized Radio Link Reconfiguration*

In the above mentioned procedures the SRNC could indicate to the DRNC the DCH or EDCH flows where a transport bearer is not requested, and accordingly the DRNC could indicate to the SRNC the DCH/EDCH flows where a transport bearer has not been setup.

This would permit the SRNC/DRNC to permit the granularity to setup the DCH/EDCH flow for signaling only and the transfer of SRBs thereby permitting the transfer of Cell Interference information.

In this solution problems will arise when the serving eNodeB does not receive packets correctly, but the drift eNodeB signals to the UE it does – which causes the UE to start transmission of the next packet. In this scenario the packet transmitted by the UE is simply lost.

Solution could be that the drift eNodeB always signals to the UEs that packets were *not* received correctly, by sending NACK.

6.2 Future consideration for MDC in flat architecture

The main driver for improving the MDC in flat architecture is the transmission network cost. In general the transport costs are highest for plesiochronous transport networks. Operators who use plesiochronous technology for transport networks are naturally very interested in developing enhanced MDC options.

One way towards more precise interference control in serving eNodeB, but slight increase in required Iur transmission capacity compared to the proposed solution in 6.2, could be the Predictive MDC.

The prediction based forwarding strategy is using the measured UL signal level of the flows at the serving eNodeB. Based on this information, the quality of the next reception is predicted. The drift eNodeB is forwarding the correctly received frames over the Iur interface only in case *Start Forwarding* command has been received from serving eNodeB. The forwarding is continued until a *Stop Forwarding* command is received in drift eNodeB. The clear advantage of this approach is that there is no additional latency on traffic over Iur, like fetching packets, improved interference control but for the expense of Iur transmission capacity.

Once the transmission network cost degrade like in ATM the need for optimizing MDC in flat architecture gets less important. Finally, in case Ethernet is available for backbone transmission networks the benefits of using enhanced MDC options shall not outweigh the radio savings anymore.

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