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Overview of UMTS network evolution through radio and transmission feature validation

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Abstract

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Hardware and software validation is a key step in the relationship between the mobile network operator and the vendor. Through this verification process, while executing that functionality or testing a specific hardware, the difference between the actual result and expected result can be better understood and, in turn, this in-depth knowledge acquisition is translated into a tailored usage of the product in the operator's live network.

As a result, validation helps in building a better product as per the customer's requirement and helps satisfying their needs, which positively impacts in the future evolution of the vendor product roadmap implementation process for a specific customer.

This project is based on several Universal Mobile Telecommunication Services (UMTS) network feature validation with the aim to provide an end-to-end in-depth knowledge overview gained in parallel in the areas of radio network mobility processes (cell camping and inter-system handover), Quality of Service improvement for High Speed Downlink Packet Access (HSPA) data users and transport network evolution towards the All-IP era.

Keywords: UMTS, Hybrid Backhaul, IuB over IP, Quality of Service, Handover, Cell Selection, LTE

Contents

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To my family and friends, I warmly want to give thanks for their love, patience, and endless support during my tenure in Bristol. Especially, to my father Jose Rafael and brother Jose Antonio, I really appreciate all the encouragement they have given to me during the hard times. And to the most special person in my life, Nieves, thank you for your love and support to reach this last milestone.

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Jorge Rafael Sevilla Castillo

Madrid, Apr 2016

List of Abbreviations

3GPP	3^{rd} Generation Partnership Project
AAL2	ATM Adaptation Layer Type 2
ADSL	Asymmetrical Digital Subscriber Line
ALCAP	Access Link Control Application Part
ATM	Asynchronous Transfer Mode
AMR	Adaptive Multi-Rate (speech codec)
APN	Access Point Name
ARP	Allocation and Retention Priority
AXC	ATM Cross-Connection
BCCH	Broadcast Control Channel
BER	Bit Error Rate
BFD	Bidirectional Forwarding Detection
BSC	Base Station Controller
BTS	Base Transceiver Station
CBR	Committed Bit Rate
CF	Concatenation Factor
CLI	Command Line Interface
CNBAP	Common Node B Application Part
CS	Circuit Switched
DCH	Dedicated Channel

DNBAP	Dedicated Node B Application Part
DSCP	Differentiated Services Code Point
E-DCH	Enhanced uplink DCH
EPC	Evolved Packet Core
FACH	Forward Access Channel
FTP	File Transfer Protocol
GGSN	Gateway GPRS Support Node
GPS	Global Positioning System
GSM	Global System for Mobile communications
HO	Handover
HHO	Hard Handover
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
IETF	Internet Engineering Task Force
IMA	Inverse Multiplexing over ATM
IMSI	International Mobile Subscriber Identity
IP	Internet Protocol
ITU	International Telecommunications Union
KPI	Key Performance Indicator
LLU	Local Loop Unbundling
LOS	Loss Of Signal
MAC	Medium Access Control

MCO	Major Country Operator
MDCR	Minimum Desired Cell Rate
MIB	Master Information Block
MML	Man Machine Language
MO	Mobile Originated
MPLS	Multi-Protocol Layer Switching
MSC	Mobile Switching Center
MSP	Multiplex Section Protection
MT	Mobile Termination
NNI	Network-Node Interface
NRT	Non Real Time
OAM	Operation, Administration and Maintenance
OPEX	Operational Expenses
OSI	Open System Interconnection
OSS	Operation Support System
PCR	Peak Cell Rate
PDH	Plesiochronous Digital Hierarchy
PDP	Packet Data Protocol
PHB	Per Hop Behavior
PS	Packet Switched
PT	Packetization Timer
PWE3	Pseudo Wire Emulation Edge to Edge
QoS	Quality of Service

RAB	Radio Access Bearer
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio Frequency
RNC	Radio Network Controller
RRC	Radio Resource Control
RSCP	Received Signal Code Power
RT	Real Time
RTT	Round Trip Time
RX	Reception
SC	Scrambling Code
SCC	Serving Cell Change
SCTP	Stream Control Transmission Protocol
SDH	Synchronous Digital Hierarchy
SDU	Service Data Unit
SGSN	Serving GPRS Support Node
SHDSL	Single-Pair High-speed Digital Subscriber Line
SHO	Soft Handover
SIB	System Information Block
STM-1	Synchronous Transport Module Level-1
TCP	Transmission Control Protocol
TDM	Time Division Multiplexing
THP	Traffic Handling Priority

TMSI	Temporary IMSI
ToS	Type of Service
TRB	Traffic Radio Bearer
TX	Transmission
UARFCN	UTRAN Absolute Radio Frequency Channel Number
UBR	Unspecified Bit Rate
UDP	User Datagram Protocol
UE	User Equipment
UMTS	Universal Mobile Telecommunication Services
UNI	User-Network Interface
VCC	Virtual Channel Connection
VPC	Virtual Path Connection
VLAN	Virtual Local Area Network
WBTS	WCDMA Base Transceiver Station
WCDMA	Wideband CDMA Code Division Multiple Access
WTR	Wait To Restore

Introduction

During the last two decades, our society has rapidly adopted the ubiquitous and real time communication model pushed by mobile service operators. Mobile broadband connections accounted for just fewer than 40% of total connections at the end of 2014, but by 2020 will increase to almost 70% of the total. This migration is being driven by greater availability and affordability of smartphones, more extensive and deeper coverage and, of course, a high investment in the evolution of legacy 2G voice service oriented network infrastructures towards high speed data networks, powered by Long Term Evolution (LTE) technology.

To face this serious challenge, network operators have been closely working together with telecom equipment vendors in order to follow the pace set up by 3rd Generation Partnership Project (3GPP) organization. On a yearly basis, new hardware and software features are unveiled in the commercial roadmap agreed with the vendor and the operator has the responsibility to execute the corresponding lab validation campaigns prior to execute a live network deployment.

With this in mind, the next chapters are focused on the 3G feature lab validation activities carried out in the France Telecom Nokia Operational Skill Centre during my tenure in Orange UK (2008 – 2011). Each chapter encompasses the following technical approach:

- *Theoretical background:* before the description of each test case, the reader can find an introduction of the technical context where the feature under test is found.

- *Feature validation:* firstly it will be presented a quick overview of the feature under study. Secondly, it is summarize the purpose of testing from the operator point of view, highlighting the possible benefits which can be brought by the feature. Afterwards, the chapter will show the network designs, recommended parameterizations and configurations required to perform the test itself. The reader should bear in mind that the designs and test cases described herein were used as a deployment reference for the rest of Major Country Operators (MCOs) in France Telecom Group, so the inspection of low-level commands and the description of the network elements' commissioning procedures are relevant for the purpose of the document. Providing installation guidelines of all the new hardware introduced within these chapters was also part of the testbed environment preparation, but not relevant for the scope of the thesis. Each chapter finishes with the presentation of the test results and conclusions, which are translated into recommendations for live network deployment activities.

The test cases presented in this document will give the reader an end to end understanding of the main aspects concerning a 3G network and the interworking with other radio access technologies, such as 2G systems. They are structured as follows:

1) *Mobility:* two features have been selected within this category. 2G and 3G coverage layers are usually overlapped. Under these conditions, the operator must ensure that user is given the best service experience, network camping procedures - that is, when the User Equipment (UE) is firstly switched on - must be oriented to avoid continuous ping-pong between layers, considering the best signal quality. *Chapter 1 Cell Selection Parameter Set* shows what can be done to alleviate this problem. Once a mobile user enters the connected mode, it will experience handover procedures within 3G system, but the lack of 3G coverage at some points of the network usually is translated into an inter-system handover to 2G. However, sometimes this degradation in radio conditions might be just a matter of seconds (3G signal fading, poor in-building coverage…) and the user is unnecessarily degraded to a lower performance coverage layer. The feature introduced in *Chapter 2 2G/3G Inter-System Handover Cancellation* explains how these situations can be avoided.

2) *Quality of Service (QoS)*: if the operator wants to squeeze the era of data monetization, it should firstly fit the network for this purpose. In a scenario where the voice service has turned into a commodity product, the offer of different data tariffs and premium data services is crucial to maintain a competitive advantage in the mobile market. *Chapter 3 QoS Aware HSPA Scheduling* explains how QoS is implemented in a 3G network and what can be done in the radio system to prioritize premium user services. In addition,

due to the relevance of this topic, it is explained the implementation of QoS in current 4G networks.

3) *Transmission:* finally, *Chapter 4 Hybrid Backhaul and Full IP evolution*, will introduce the importance of a hand in hand evolution of transmission network if the operator wants to squeeze the maximum radio capabilities brought by 3GPP standard. Considering that the starting point is a low capacity transmission network with copper-based E1 connections in IuB interface, the chapter explains the evolution path in two steps: first of all, the *Hybrid Backhaul* solution is introduced, which explains how to emulate Asynchronous Transfer Mode (ATM) connections over Fast Ethernet media, showing the path for the second solution tested, *IuB over IP,* which introduces the IP convergence process in the IuB protocol stack and, also, offers a quick overview of how QoS can be controlled by using IP protocol standard specifications.

Chapter 5 Conclusions and future work will summarize the main results obtained on each part and which network evolutions could be studied now that 4G networks are being massively deployed in the mobile ecosystem.

1 Cell Selection Parameter Set

1.1 Theoretical Background

1.1.1 Radio Resource Control

The Radio Resource Control (RRC) handles the control plane signaling of layer 3 between the UEs and the Radio Access Network (RAN). RRC allows a dialogue between the RAN and the UE and also between the core network and the UE. An RRC connection is a logical association between the UE and the RAN used by two peer identities to support the upper layer exchange of information flows. There can only be one RRC connection per UE.

The description of the RRC states given here is based on the 3GPP RRC protocol specification TS 25.331. Figure 1 shows the supported RRC states and state transitions.

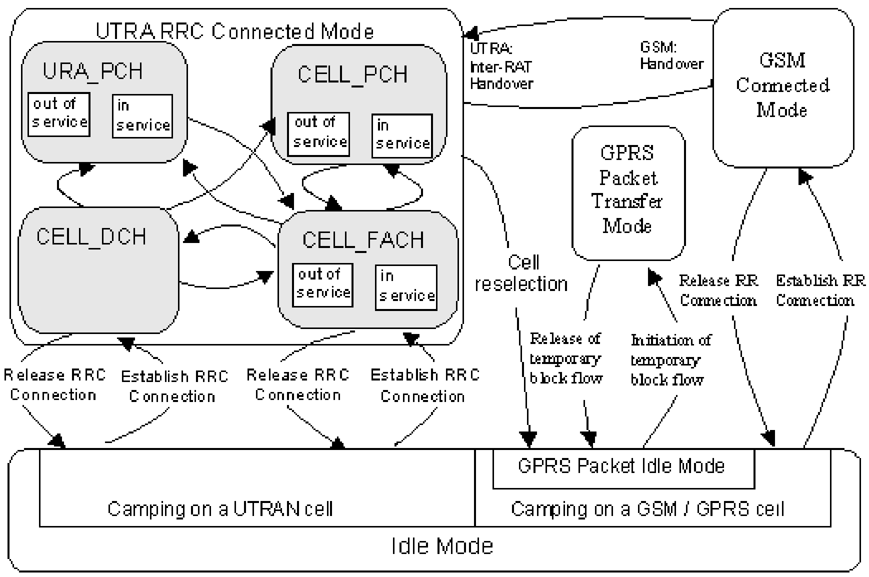


Figure 1. RRC states and state transitions for both UMTS and GSM. The case of study will be only focused on UTRA RRC States.

Since the analysis is focused on UTRAN, according to Figure 1, there are two general states in which the UE can be: idle mode and connected mode.

Idle mode

When the UE is switched on, it selects a Public Land Mobile Network (PLMN) and searches for a suitable cell to camp on. Once the suitable cell is found, the UE tunes itself to the control channel of that cell. Selecting a cell in this manner is known as "camping on the cell".

After the power is switched on, the UE stays in idle mode until it transmits a request to establish an RRC connection. In idle mode, the connection of the UE is closed on all layers of the UTRAN and the UE can be only identifies by Non Access Stratum identities such as International Mobile Subscriber Identity (IMSI), Temporary international Mobile Subscriber Identity (TMSI) or packet TMSI (P-TMSI).

Once in connected mode, the UE will return to idle mode when the RRC connection is released or there is a failure during the RRC establishment.

Connected mode

When a signaling connection exists, there is an RRC connection and the UE is in UTRAN connected mode. In this mode, the position of the UE is known on cell level and can be in one of the following four states: CELL_FACH, CELL_DCH, CELL_PCH or URA_PCH.

The CELL_DCH state is characterized by the allocation of a dedicated transport channel to the UE. The UE is transferred from idle mode to CELL_DCH through the setup of an RRC connection or by establishing a Dedicated Channel (DCH) from CELL_FACH state. Transition from CELL_DCH to idle mode is done through the release of the RRC connection. Transition from CELL_DCH to CELL_FACH is performed when the last active Non Real Time (NRT) DCH is released and there is no Real Time (RT) Radio Access Bearer (RAB). Finally, transition from CELL_DCH to CELL_PCH/URA_PCH cam be performed when during inactive NRT connection, RT service is released.

In CELL_FACH state the UE monitors the Forward Access Channel (FACH). In this state, the UE is able to transmit uplink control signals and may be able to transmit small data packets on the Random Access Channel (RACH). A transition from CELL_FACH to CELL_DCH occurs when a dedicated transport channel is established through explicit signaling. Whilst in CELL_FACH, the UE monitors the FACH continuously and therefore it should be moved to CELL_PCH sub state when the data service has been inactive for a while. When the timer expires, the UE is transferred to CELL_PCH in order to decrease UE power consumption. When the RRC connection is released, the UE is moved back to idle mode.

In CELL_PCH and URA_PCH sub states, the UE listens to the PCH transport channel. The dedicated control channel (DCCH) logical channel cannot be used in this state. If the network wants to initiate any activity, it needs to make a paging request on the PCCH logical channel in the known cells to initiate any downlink activity. The UE initiates a cell update procedure when it selects a new cell in CELL_PCH sate. The only overhead in keeping a UE in PCH state is the potential possibility of cell updating when the UE moves to other cells. To reduce it, the UE is moved to URA_PCH when low activity is observed. The UE is transferred from CELL_PCH to CELL_FACH state either by a packet paging command from Radio Access Network (RAN) or through any uplink access.

It is worth mentioning that an operator may not have activated all the RRC states, being the most common configuration formed by idle mode, CELL_FACH and CELL_DCH states.

1.1.2 System Information Block type 3 and 4

When the UE is switched on, the UE can read the status of the network via the System Information Message broadcasted in the Broadcast Control Channel (BCCH). The System Information Message consists of a Master Information Block (MIB) and several System Information Blocks (SIBs 1, 2, 3, 5, 7 and 11, apart from 4, which is introduced with this feature). The information in these SIBs helps the UE to establish a successful communication with the network.

In this case it is interesting to analyze certain parameters communicated by SIB 3 and SIB 4, which define the cell selection criteria in idle mode and connected mode respectively. This criterion is commanded by the equations shown in 1.2.4.

1.2 Feature validation

1.2.1 Feature Description

Cell Selection Parameter Set feature includes the support of new hysteresis and timer parameters for cell reselection introduced in 3GPP Rel5/Rel6. In addition, System Information Block type 4 (SIB 4) scheduling on the BCCH is added to support different parameters for cell selection and reselection in connected mode.

The utilization of these new parameters (Figure 2) will reduce unnecessary inter-system and inter-frequency toggling, resulting in improved network level Key Performance Indicator (KPI) values and end-user system performance. That is, the user will be spend less time in cell camping process in scenarios where 2G and 3G coverage overlap, and where several frequency layers are deployed in 3G.

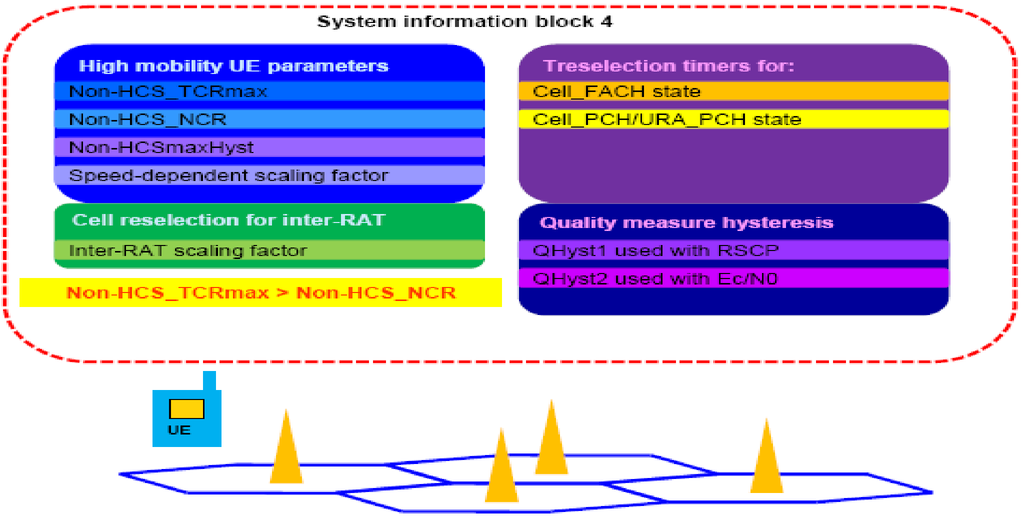


Figure 2. List of parameters included within SYSTEM INFORMATION BLOCK 4 (SIB 4) message

1.2.2 Purpose of validation

The purpose of testing this feature is to investigate how the end-user performance with optimized cell reselections is improved depending on the release of the UE and its RRC state by checking that the corresponding UE cell reselection criteria can be modified via the information element SIB 4 broadcasted by the RAN.

1.2.3 Testbed configuration and settings

A detail of hardware and software levels required for the validation of this feature is included in this section as well as configuration of the correct parameters needed in Node B - also referred in this document as WCDMA Base Transceiver Station (WBTS) - and RNC.

Hardware Settings

RAN hardware equipment	
RNC	Testbed RNC2 (RNC450 Step1 platform)
WBTS	UltraSite Outdoor Supreme (2+2+2, WCEL-1 and WCEL-3)
UE type	
Rel99	Nokia 6680
Rel5	Nokia N95, Samsung SGH630
Rel6	Huawei E270 (data card)

Table 1. RAN equipment and UE involved in the test. Note that WBTS hardware configuration *2+2+2* refers to a Node B configured with 3 sectors, each sector configured with 2 UMTS frequencies, that is, 2 cells.

Software Settings

RAN Software Version	
RNC	RN4.0 Q4 1.15-0_41 P400110S
OMS	R_OMS1_4.42.release_oms_corr30
WBTS	WN5.0 12.4-81_C
AXC	C5.5 BL28.01

Table 2. RAN equipment software level supporting the feature under test. Two pair of software levels are associated to each network element in the RAN: RNC controlling RNC Radio functionalities, OMS dedicated to RNC operation and management, WBTS controlling Node B radio and O&M functionalities and ATM Cross-Connection (AXC) controlling transmission resource board.

Test Layout

Figure 3 introduces a common test layout used during feature validation. Each UE under test is managed by a laptop, allowing trace collection via air interface message collection tools, i.e. NEMO Outdoor. In order to simulate controlled RF conditions, UEs under test are introduced in an RF isolation box connected to the corresponding WCDMA Cell controlled by the Node B. Additionally, an RF attenuator connected between the RF isolation box and the Node B allows the modification of radio conditions, helping to simulate from a cell centre to a cell edge situation. Finally, the Node B is always connected to a controlling RNC, creating the IuB interface.

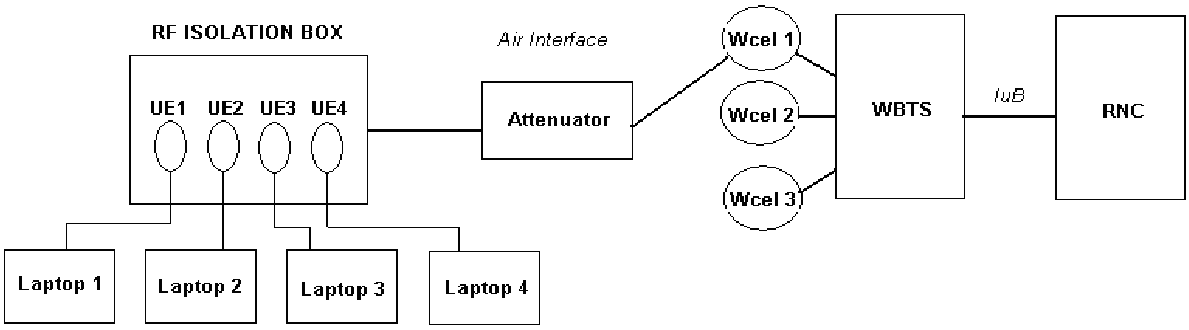


Figure 3. Feature Validation test layout simulating the RAN.

Although not indicated in Figure 3, this RNC is in turn connected to Circuit Switched (CS) and Packet Switched (PS) domains in the testbed core network, allowing the execution of both CS/PS calls accordingly.

Also note the *air interface* layout is replicated in another WCDMA cell (WCEL), the RF isolation box can simultaneously receive RF signal from two different cells. In that case, controlling the attenuation of each RF path, the signal strength of each cell can be adjusted in order to guarantee different radio conditions for cell selection in this case or to simulate a handover between two cells as it will be observed in chapter 2.

RAN parameter Settings

Several parameters have to be checked and 3G intra-frequency neighbor relationships between cells under test have to be created before starting the test:

- In order to allow the UE to perform a cell reselection in connected mode, a neighbor relationship between both target and source cell must be defined. In this case, the neighbor type is intra-frequency and has been created between WCEL 1 (UARFCN=10775, SC=61) and WCEL 3 (UARFCN=10775 and SC=63).

UARFCN indicates the channel number of DL UMTS frequency 2155 MHz (the relationship between UARFCN and frequency is 1 to 5).

Parameterization		
RAN element	**Parameter**	**Target Value**
RNC	*MSActivitySupervision*	**1 min**
RNC	*MaxCellReselections*	**Different from 0**

Table 3. Test case parameterization. If MSActivitySupervision is different from 0, PCH state is enabled. This timer is used in RRC states CELL_PCH and URA_PCH for supervising the inactivity of NRT RAB(s). The timer starts when a state transition to either state is executed. It is stopped when any inactivity of NRT RAB(s) is detected and the UE is switched to CELL_FACH or CELL_DCH state. If MSActivitySupervision is set to 0, the state transition to CELL_PCH or URA_PCH is not allowed. In this case, when inactivity is detected in CELL_FACH state, the UE is switched to IDLE mode. MaxCellReselections specifies the maximum allowed number of cell reselections in CELL_FACH or CELL_PCH state before transition to URA_PCH state. When the UE is in CELL_FACH state, the value of the counter cannot be used as a trigger for the CELL_FACH to URA_PCH transition, but it is used when deciding the target state after the MAC-c entity has sent an inactivity indication to Layer 3. Note that URA_PCH can be only used if PCH states are enabled.

1.2.4 Test Results

In this section are presented the results achieved during the validation of this feature. Each one of the following test cases is discussed individually:

- Verification of parameter modification in SIB 3 and SIB 4.
- Cell Reselection in CELL_FACH state with Release 5 or Release 6 UE
- Cell Reselection in CELL_FACH state with Release 99 UE

Verification of parameter modification in SIB 3 and SIB 4

The aim of this test case is to verify that Release 99, Release 5 and Release 6 UEs can read the messages *SYSTEM INFORMATION BLOCK 3* and *SYSTEM INFORMATION BLOCK 4* when they are enabled in the WBTS.

Modification of the default values of the parameters contained in both SIB messages can be done at WCEL level. Once these changes are confirmed, the WBTS sends the NBAP message *SYSTEM INFORMATION UPDATE REQUEST* to the RNC. This is also verified by analyzing the IuB interface with *Nethawk M5* interface protocol analyzer.

WCEL parameters setting changed are described in Table 4:

Parameterization			
RAN element	**Parameter**	**Initial Value**	**Target Value**
WCEL	*InterRATScaleTresel*	**1**	**1.25**
WCEL	*NonHCSNcr*	**8**	**7**
WCEL	*SpeedScaleTresel*	**0.7**	**0.8**
WCEL	*CellSelQualMeas*	**EcN0**	**RSCP**
WCEL	*QrxLevMin*	**-115 dBm**	**-113 dBm**
WCEL	*QHCS*	**-24 dB**	**-23.5 dB**
WCEL	*NCr*	**8**	**7**
WCEL	*InterFreqScaleTresel*	**1**	**1.25**
WCEL	*NonHCSTcrmax*	**Non Used**	**30 s**
WCEL	*NonHCSTcrmaxHyst*	**Non Used**	**10 s**
WCEL	*Qqualmin*	**-18 dBm**	**-20 dBm**
WCEL	*HCS_PRIO*	**0**	**1**
WCEL	*TcrMax*	**60 s**	**30 s**
WCEL	*TcrMaxHyst*	**Non Used**	**10 s**

Table 4. RAN equipment and UE involved in the test.

At this point it is suggested to verify the Information Elements of SIB3 and SIB4 messages in 3GPP Release 6.12 Specification TS 25.331. There are values which are shown in the same way that they are represented in the WCEL object browser (i.e. same values) and others which are not broadcasted because its implementation is optional or their value is noted as incremental units or steps referred to the whole parameter value list (i.e. value 1.5 can be represented by number 6 when the array of values is segmented in steps of 0.25).

By default, SIB 4 is not broadcasted in the network. Once it is enabled, the UE knows that SIB 4 is present because there is an Information Block in SIB 3, which is always broadcasted, indicating that SIB4 is activated (see Figure 4 and Figure 5).

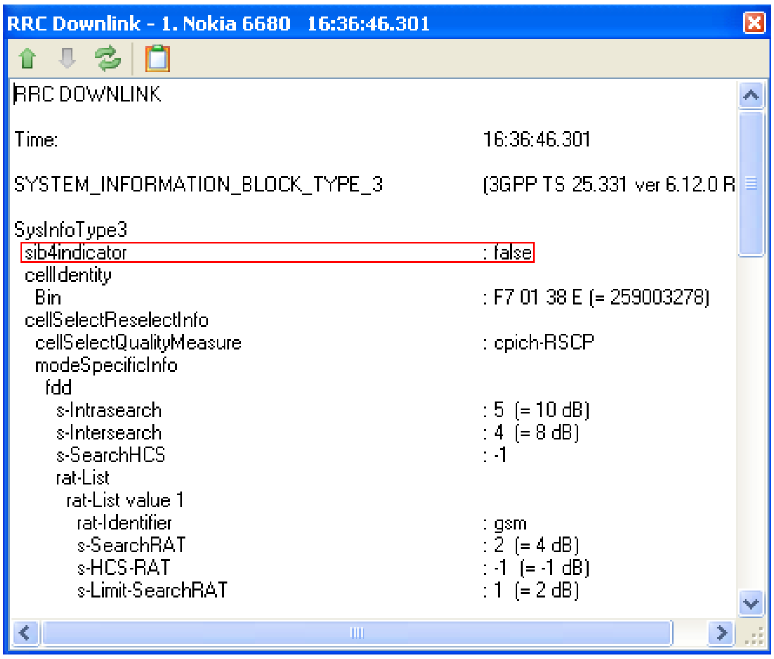


Figure 4. SIB 3 message shows sib4indicator = false when SIB4 is not broadcasted in the cell.

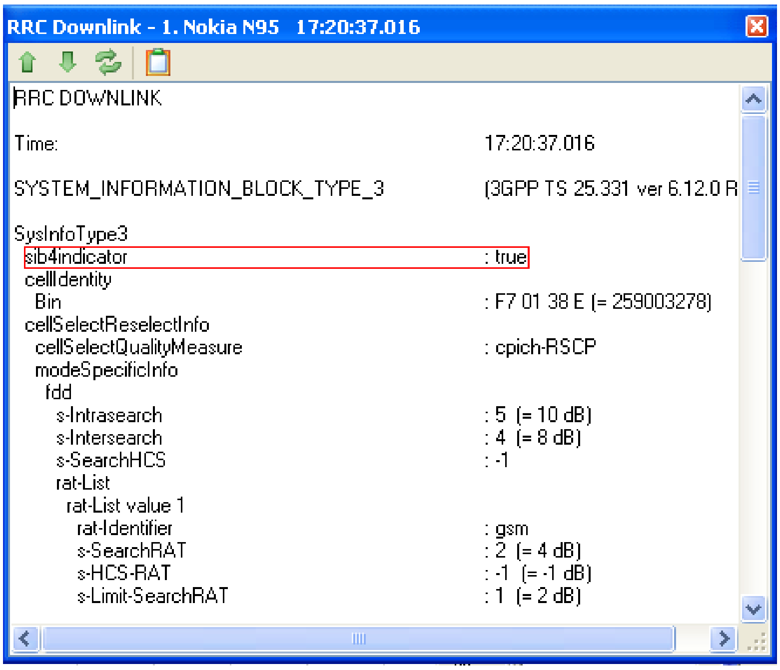


Figure 5. SIB 3 message shows *sib4indicator = true* when SIB4 is broadcasted in the cell.

To verify the parameter changes done before, it is shown the decoding of SIB3 and SIB4 messages sent from the network to Huawei E270 UE through the air interface:

```
Time:                                                          15:31:55.427
SYSTEM_INFORMATION_BLOCK_TYPE_3                                (3GPP TS 25.331 ver 6.12.0 Rel 6)
SysInfoType3
  sib4indicator                                                : true  //SIB4 is broadcasted
  cellIdentity
    Bin                                                        : F7 01 38 E (= 259003278)
  cellSelectReselectInfo
    cellSelectQualityMeasure                                   : cpich-RSCP
    modeSpecificInfo
      fdd
        s-Intrasearch                                          : 5  (= 10 dB)
        s-Intersearch                                          : 4  (= 8 dB)
        s-SearchHCS                                            : -1
        rat-List
          rat-List value 1
            rat-Identifier                                     : gsm
            s-SearchRAT                                        : 2  (= 4 dB)
            s-HCS-RAT                                          : -1  (= -1 dB)
            s-Limit-SearchRAT                                  : 1  (= 2 dB)
        q-QualMin                                              : -20
        q-RxlevMin                                             : -57  (= -113 dBm)
    q-Hyst-l-S                                                 : 0  (= 0 dB)
    t-Reselection-S                                            : 2
    hcs-ServingCellInformation
      hcs-PRIO                                                 : 1
      q-HCS                                                    : 1
      t-CR-Max
        t30
          n-CR                                                 : 7
          t-CRMaxHyst                                          : t10
    maxAllowedUL-TX-Power                                      : 21
  cellAccessRestriction
    cellBarred                                                 : notBarred
    cellReservedForOperatorUse                                 : notReserved
    cellReservationExtension                                   : notReserved
    accessClassBarredList
      accessClassBarredList value 1                            : notBarred
      accessClassBarredList value 2                            : notBarred
      accessClassBarredList value 3                            : notBarred
      accessClassBarredList value 4                            : notBarred
      accessClassBarredList value 5                            : notBarred
      accessClassBarredList value 6                            : notBarred
      accessClassBarredList value 7                            : notBarred
      accessClassBarredList value 8                            : notBarred
      accessClassBarredList value 9                            : notBarred
      accessClassBarredList value 10                           : notBarred
      accessClassBarredList value 11                           : notBarred
      accessClassBarredList value 12                           : notBarred
      accessClassBarredList value 13                           : notBarred
      accessClassBarredList value 14                           : notBarred
      accessClassBarredList value 15                           : notBarred
      accessClassBarredList value 16                           : notBarred
  v4b0NonCriticalExtensions
    sysInfoType3-v4b0ext                                       :
    v590NonCriticalExtension
      sysInfoType3-v590ext                                     :
      v5c0NoncriticalExtension
        sysInfoType3-v5c0ext
          cellSelectReselectInfoTreselectionScaling-v5c0ext
            non-HCS-t-CR-Max
              t30
                n-CR                                           : 7
                t-CRMaxHyst                                    : t10
            speedDependentScalingFactor                        : 8
            interFrequencyTreselectionScalingFactor            : 5
            interRATTreselectionScalingFactor                  : 5
```

```
Time:                                                15:31:57.026

SYSTEM_INFORMATION_BLOCK_TYPE_4                      (3GPP TS 25.331 ver 6.12.0 Rel 6)

SysInfoType4
  cellIdentity
    Bin                                              : F7 01 38 E (= 259003278)
  cellSelectReselectInfo
    cellSelectQualityMeasure                         : cpich-RSCP //CellSelQualMeas parameter OK
    modeSpecificInfo
      fdd
        s-Intrasearch                                : 5  (= 10 dB)
        s-Intersearch                                : 4  (= 8 dB)
        s-SearchHCS                                  : -1
        rat-List
          rat-List value 1
            rat-Identifier                           : gsm
            s-SearchRAT                              : 2  (= 4 dB)
            s-HCS-RAT                                : -1  (= -1 dB)
            s-Limit-SearchRAT                        : 1  (= 2 dB)
        q-QualMin                                    : -20  //Qqualmin parameter OK
        q-RxlevMin                                   : -57  (= -113 dBm) //Qrxlevmin parameter OK
    q-Hyst-l-S                                       : 0  (= 0 dB)
    t-Reselection-S                                  : 2
    hcs-ServingCellInformation
      hcs-PRIO                                       : 1 //HCS_PRIO parameter OK
      q-HCS                                          : 1 //QHCS parameter OK
      t-CR-Max
        t30 //Tcrmax parameter OK
          n-CR                                       : 7 //NCr parameter OK
          t-CRMaxHyst                                : t10 //TcrmaxHyst parameter OK
    maxAllowedUL-TX-Power                            : 21
  cellAccessRestriction
    cellBarred                                       : notBarred
    cellReservedForOperatorUse                       : notReserved
    cellReservationExtension                         : notReserved
  v4b0NonCriticalExtensions
    sysInfoType4-v4b0ext                             :
    v590NonCriticalExtension
      sysInfoType4-v590ext                           :
      v5b0NonCriticalExtension
        sysInfoType4-v5b0ext
          cellSelectReselectInfoPCHFACH-v5b0ext
            q-Hyst-l-S-PCH                           : 0
            q-Hyst-l-S-FACH                          : 0
            q-Hyst-2-S-PCH                           : 2
            q-Hyst-2-S-FACH                          : 2
            t-Reselection-S-PCH                      : 2
            t-Reselection-S-FACH                     : 10
        v5c0NonCriticalExtension
          sysInfoType4-v5c0ext
            cellSelectReselectInfoTreselectionScaling-v5c0ext
              non-HCS-t-CR-Max
                t30             //NonHCSTrmax parameter OK
                  n-CR                               : 7   //NonHCSNCr parameter OK
                  t-CRMaxHyst                        : t10 //NonHCSTcrmaxHyst OK
                speedDependentScalingFactor          : 8   //SpeedScaleTresel OK (Steps = 0.1)
                interFrequencyTreselectionScalingFactor : 5  //InterFreqScaleTresel OK (Steps = 0.25)
                interRATTreselectionScalingFactor    : 5 //InterRatScaleTresel OK (Steps = 0.25)
```

Figure 6. SIB 3 and SIB 4 messages broadcasted by the cell under test after parameter modification.

Finally, it is checked that SYSTEM INFORMATION UPDATE REQUEST is sent in the UL direction of the IuB once the parameters are changed (see Figure 7).

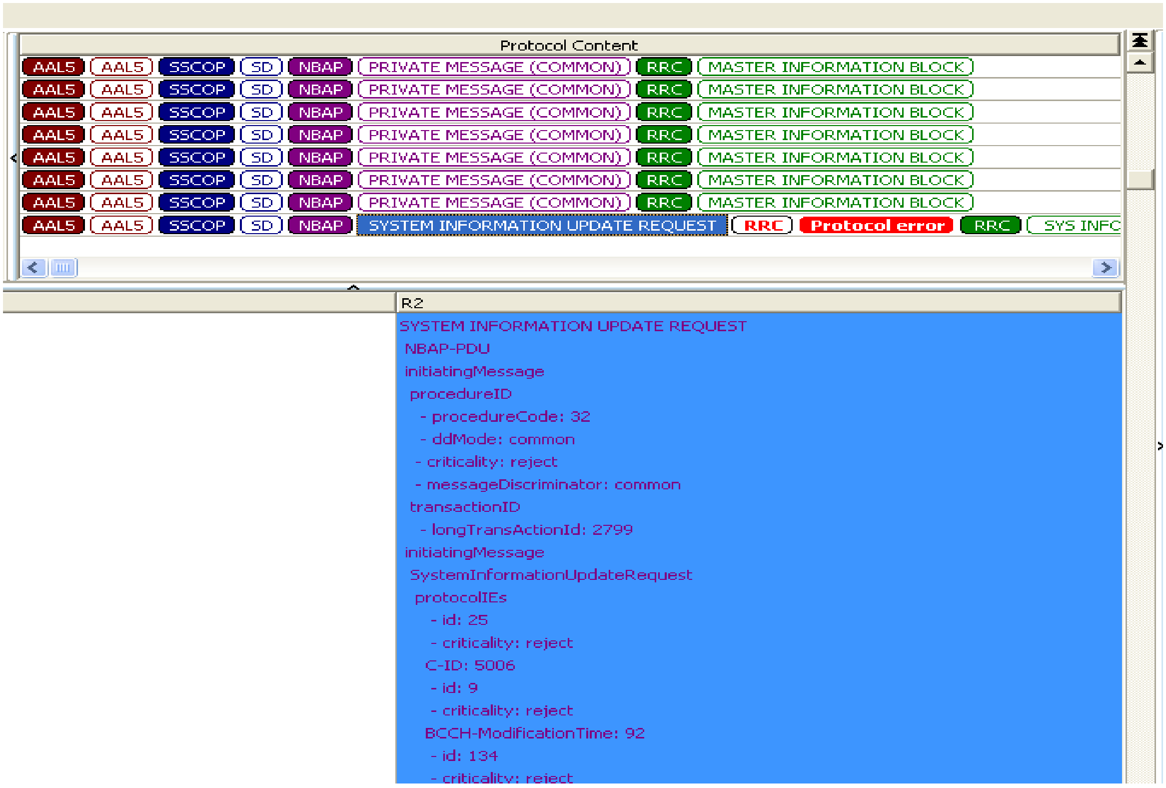


Figure 7. NBAP *SYSTEM INFORMATION UPDATE REQUEST* is sent over the IuB interface.

Cell Reselection in CELL_FACH state with Rel5 or Rel6 UE

This test case will not only be focused on the reselection itself but also to verify that the UE is able to distinguish which parameters to use in both connected and idle situations.

Intra-frequency cell reselection will be made with the UE in both CELL_FACH (the UE will be transferring a small amount of data) and idle mode. For this purpose, the UE will have to select between one of the following parameters: *Qhyst2*, broadcasted in SIB 3 and used in idle mode, and *Qhyst2fach*, broadcasted in SIB4 and used in connected mode.

When BCCH transmission is initiated, *SYSTEM INFORMATION UPDATE REQUEST* message must include all MIB/SB/SIB information needed for normal UE operation. If in SIB 3 it is indicated that SIB4 is present, the UE will use SIB 4 information for cell selection and re-selection in connected mode. Otherwise, SIB 3 information is used in both idle and connected mode.

At this point it is worth mentioning that the use of *Qhyst2fach* is the main difference between performing cell reselections between Release 99 UEs and Release 5/Release 6 UEs. Even though a Release 99 UE is able to read SIB 4 messages, it cannot decipher its content, so this kind of UEs will always use the parameter *Qhyst2* for its cell selection criteria.

Environment and threshold modifications

Scenarios where Ec/N0 measurements are involved are very sensitive to interference. It is important to set up the correct working environment so to have maximum control over Ec/N0 in both WCEL 1 and WCEL 3 RF signals. It was proved that using the same attenuator and avoiding interference with other RF sources eased the achievement of results.

There are two main conditions to fulfill in order to perform a successful reselection between WCEL 1 and WCEL 3 in both idle and connected mode:

For IDLE state:

1) **CPICH Ec/N0 < Qqualmin + Sintrasearch_for_idle_mode;** this equation fixes the threshold from which measurements for cell reselection will be started.

2) **Qhyst2;** once condition 1 is met, Qhyst2 gives the absolute Ec/N0 difference needed to perform a reselection between two cells. It means that a re-selection will take place if $Ec/N0_2$ - $Ec/N0_1$ > Qhyst2, being $Ec/N0_2$ the quality level of the destination cell and $Ec/N0_1$ the quality level of the source cell.

For FACH state:

1) **CPICH Ec/N0 < Qqualmin + Sintrasearch_for_connected mode:** this equation fixes the threshold from which measurements for cell reselection in CELL_FACH state will be started.

2) **Qhyst2fach;** Once condition 1 is met, Qhyst2 gives the absolute Ec/N0 difference needed to perform a reselection between two cells. It means that

a re-selection will take place if $Ec/N0_2$ - $Ec/N0_1$ > Qhyst2fach, being $Ec/N0_2$ the quality level of the destination cell and $Ec/N0_1$ the quality level of the source cell.

As previously said, these conditions will apply for a non-R99 UE. For a R99 UE conditions set for IDLE state are also valid for FACH state.

The strategy followed to verify the functionality in both IDLE and a FACH cell states is the following: same *Sintrasearch* value has been defined for both idle and connected mode, so the cell reselection trigger criteria will be the same (*Qqualmin* remains constant for both states). Therefore, by defining *Qhyst2* < *Qhyst2fach* it will be possible to verify a different cell reselection threshold for idle and connected mode.

Cell Reselection triggering conditions setting

Parameterization		
RAN element	**Parameter**	**Target Value**
WCEL	*Qqualmin*	**-18 dBm**
WCEL	*Sintrasearch for idle mode*	**8 dB**
WCEL	*Sintrasearch for connected mode*	**0.8**
WCEL	*Qhyst2*	**10 dB**
WCEL	*Qhyst2fach*	**4 dB**

Table 5. Parameters involved in cell reselection triggering criteria

Test procedure

The following steps should be followed to verify both cell reselection criteria in IDLE and FACH states:

1) Disable SIB 4 in both cells. It can be verified by analyzing SIB 3 message as indicated in Figure 4.

2) Cell re-selection is performed in IDLE state. First of all, attenuation conditions are set in order to meet condition 1 and then verify that the cell-reselection is done once according to condition 2.

3) Cell re-selection is performed in FACH state. Condition 1 and condition 2 have to be met the same way as in step 2. Since SIB 4 has not been broadcasted, the UE should be using conditions set for idle state.

4) SIB 4 is enabled in both cells. It can be verified by analyzing SIB 3 as indicated in Figure 5.

5) Cell re-selection is performed in IDLE state. The UE should be using idle mode conditions.

6) Cell re-selection is performed in FACH state. The UE should be using FACH state conditions since SIB 4 has been broadcasted.

How to force the UE to send data in FACH state

NEMO Outdoor can be used to monitor the UE RRC state. When the UE is switched on it starts in IDLE mode. A 0 byte ping, running in the background, to the File Transfer Protocol (FTP) server used during the test (ping 192.168.1.2 –l 0 –t) switches the UE to DCH state. If the command is stopped for a few seconds, the RRC status monitor will show that the UE is in FACH state and, after that, the UE can be maintained in this state by re-running the same ping again.

Test Results

Successful results were achieved with Release 5 UE Nokia N95. The crucial point of the test case is that once SIB 4 is enabled, cell reselection in IDLE follows *Qhyst2* criteria, whereas in FACH it will follow *Qhyst2fach*.

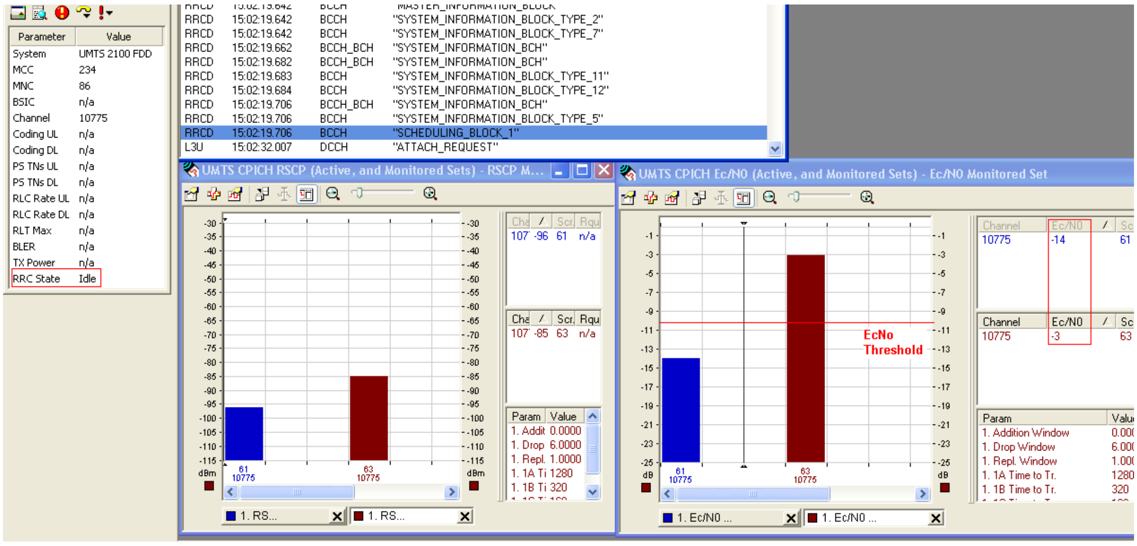


Figure 8. Situation just a timestamp before cell reselection occurs in IDLE mode (Note RRC State = IDLE). Screenshot from NEMO Outdoor, showing RSRP and Ec/N0 levels for both serving (blue) cell and target (red) cell.

Initial situation is displayed in Figure 8, where CPICH RSRP and Ec/N0 is shown for both the current serving cell (WCEL-1, blue) and the target cell (WCEL-2, red) where the reselection should occur. According to the parameters set in Table 5, CPICH $Ec/N0_1 < -10$ dB and $Ec/N0_2 - Ec/N0_1 = 11$ dB > *Qhyst2,* thus the reselection in IDLE mode occurs since conditions 1 and 2 for IDLE mode are met.

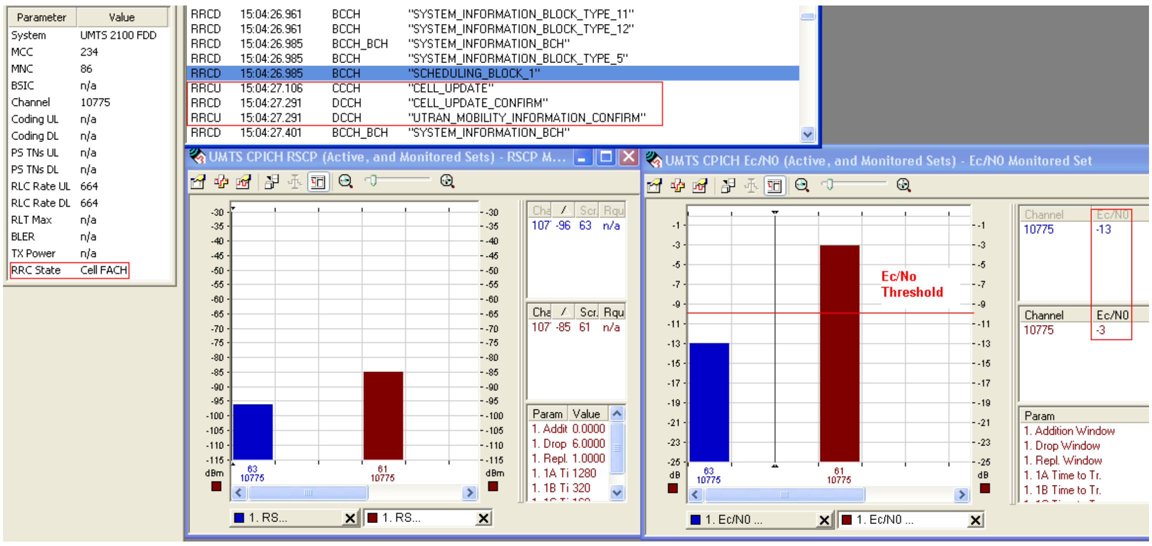


Figure 9. Situation just a timestamp before cell reselection occurs in FACH state (Note RRC State = Cell FACH).

Once the UE has been forced to enter CELL_FACH state, it can be observed in Figure 9 the radio status the timestamp just before the reselection is triggered. At this point, CPICH $Ec/N0_1$ < -10 dB and $Ec/N0_2$ – $Ec/N0_1$ = 10 dB > *Qhyst2.* Additionally, SIB 4 is disabled at this stage, so *Qhyst2fach* is not available yet. Note that in CELL_FACH state, cell reselection is advertised by the UE with the message *CELL UPDATE*.

On the other hand, when SIB 4 is enabled, the condition to trigger cell reselection will be given by *Qhyst2fach* parameter. Figure 10 shows the timestamp before cell reselection occurs, where CPICH $Ec/N0_1$ < -10dB and *Qhyst2fach* < $Ec/N0_2$ – $Ec/N0_1$ = 7 dB < *Qhyst2*.

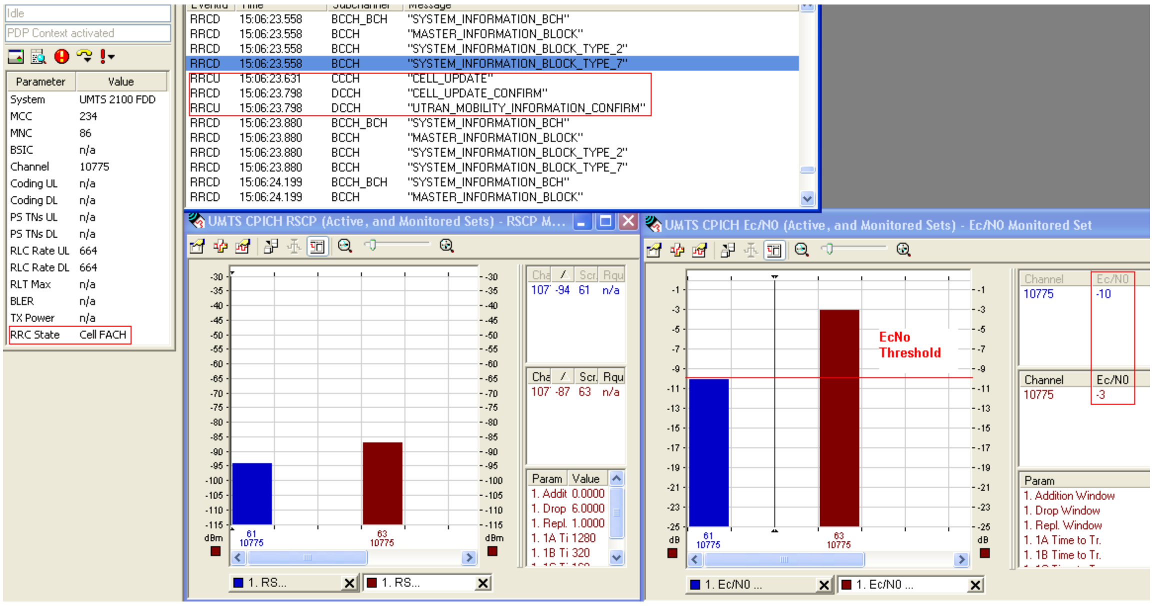


Figure 10. Situation just a time stamp before cell reselection occurs in FACH state. SIB 4 is enabled, so now *Qhyst2fach* is the threshold which triggers the reselection. Note again that a *CELL UPDATE* message is sent from the UE.

Two issues were detected during the execution of the test:

- *Issue 1:* When repeating the same test using Samsung SGH 630 and Huawei E270 there is a particular behavior detected once SIB 4 is enabled. When the UE is in FACH state, the first reselection was triggered by the parameter *Qhyst*2 instead of *Qhyst2fach.* However, from the second cell reselection onwards *Qhyst2fach* was the threshold selected by the UE. This problem was related to UE chipset problem: Nokia N95 uses Nokia chipset, whereas Samsung and Huawei use Qualcomm. A successful test performed with a Sony Ericsson UE, with Ericsson chipset confirmed that the problem detected with Qualcomm was chipset dependant.

- *Issue 2:* The range of values for *Qhyst2* and *Qhyst2fach* parameters goes from 0 to 40 dB. In the worst case scenario of setting *Qhyst2* = 40 dB, theoretically the UE will never perform a cell reselection according to the conditions previously explained. However, when the Ec/N0 difference between source and target cells is nearly 16 dB, the UE always performs a cell reselection. It not only happened with *Qhyst2* set to 40dB, but also with values greater than 18 dB. One of the possible causes behind this behavior could be associated to the dynamic signal detection range of the UE.

Cell reselection in CELL_FACH state with R99 UE

Successful results were achieved for this scenario. The expected behavior was witnessed: a R99 UE can read SIB 4 messages but cannot modify its cell reselection criteria for CELL_FACH state according to Qhyst2fach. In both IDLE and FACH states the cell reselection is triggered by *Qhyst2* criteria.

1.2.5 Test Conclusions

Validation of the feature *Cell Selection Parameter Set* proved that:

- SIB 3 and SIB 4 messages are correctly broadcasted and their information blocks can be modified by the operator.

- Release 99, Release 5 and Release 6 UEs trigger the same cell reselection threshold when SIB 4 is disabled for both idle and connected mode.

- Release 5 and Release 6 UEs modify their triggering criteria for cell reselection in connected mode according to the parameter *Qhyst2fach* once SIB 4 is broadcasted. The trigger criterion in idle mode remains unmodified.

- Release 99 UE can read SIB 4 messages but its trigger criterion for connected mode is still controlled with the parameter *Qhyst2*.

Issue 1 explained in section 1.2.4 reflects the importance of IOT (inter-operability test) in feature testing. The operator should take into account the different kind of handsets present in its network and deploy new features accordingly. In this case, probably it was not worth for the operator to invest in this kind of features since majority of the users still had Global System for Mobile communications (GSM) or R99 UEs at the time of the test. In addition, Release 6 UEs at that very first stage were mainly represented by data dongles usually oriented for static conditions.

2 Inter-System Handover Cancellation

2.1 Theoretical Background

2.1.1 Handover in Mobile networks: a quick overview

Mobile networks allow users to access services while on the move so giving end users “freedom” in terms of mobility. However, this freedom does bring uncertainties to mobile systems. The mobility of end users causes dynamic variations both in the link quality and the interference level, sometimes requiring that a particular user change its serving base station. This procedure is known as Handover (HO).

Handover is the essential component for dealing with the mobility of end users. It guarantees the continuity of the wireless services when the mobile user moves across cellular boundaries.

In first-generation cellular systems like AMPS, handovers were relatively simple. Second-generation systems like GSM and PACS are superior to 1G systems in many ways, including the handover algorithms used. More sophisticated signal processing and handover decision procedures were incorporated in these systems, hence substantially reducing handover decision delays. Since the introduction of CDMA technology, new handover algorithms and types were developed in order to cope with new mobility scenarios unveiled with 3G systems and the interaction of these with legacy GSM technologies.

2.1.2 Types of handover in 3G WCDMA systems

There are four different types of handovers in WCDMA mobile networks. They are: Intra-system HO, Inter-system HO, Hard Handover (HHO), Soft Handover (SHO) and Softer Handover.

Intra-System Handover

Intra-system HO occurs within one radio system. It can be further divided into Intra-frequency HO and Inter-frequency HO. Intra-frequency occurs between cells belonging to the same WCDMA carrier, while Inter-frequency occurs between cells operating on different WCDMA carriers.

Inter-system HO

Inter-system HO takes place between cells belonging to two different Radio Access Technologies (RATs) or different Radio Access Modes (RAMs). The most frequent case for this type is expected between WCDMA and GSM/EDGE systems and this is the focus of the work in this section.

Handover between two different CDMA systems also belongs to this type. An example of inter-RAM HO is between UTRA FDD and UTRA TDD modes.

Hard Handover (HHO)

HHO is a category of HO procedures in which all the old radio links of a mobile communication are released before the new radio links are established. For real-time bearers it means a short disconnection of the bearer. However, for non-real time bearers HHO is lossless. Hard handover can occur as intra or inter-frequency handover.

Soft Handover (SHO) and Softer HO

During soft handover, a mobile simultaneously communicates with two (2-way SHO) or more cells belonging to different Base Stations of the same RNC (intra-RNC) or different RNCs (inter-RNC). In the downlink (DL), the mobile receives both signals for maximal ratio combining; in the uplink (UL), the mobile code channel is detected by both Base Stations (2-way SHO), and is routed to the RNC for selection combining. Two active power control loops participate in soft handover, one for each Base Transceiver Station (BTS).

In the softer handover situation, a mobile is controlled by at least two sectors under one Base Station, the RNC is not involved and there is only one active power control loop. SHO and softer HO are only possible within one carrier frequency and therefore, they are intra-frequency handover processes.

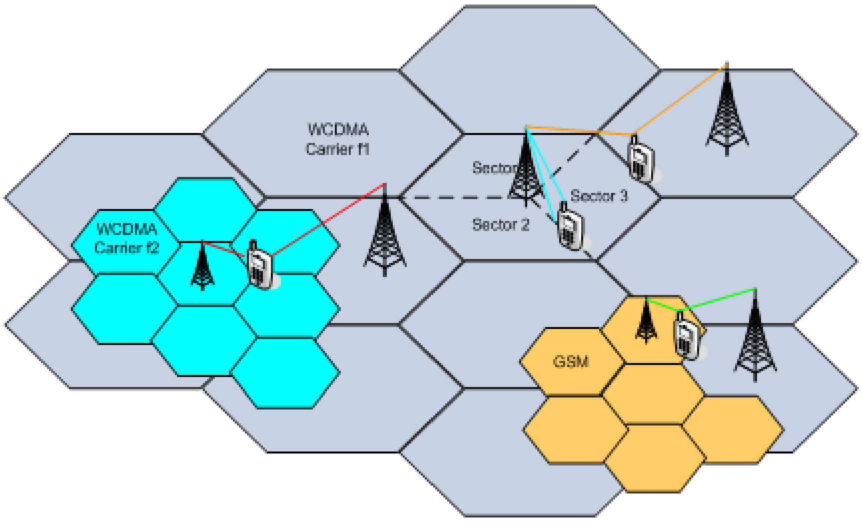


Figure 11. Different HO scenarios. Red color links represents an inter-frequency handover between a 3G macro cell (f1) and microcell (f2) system. Light blue links show a softer handover situation between sector 2 and sector 3 of the same base station. Links in orange depicture a soft handover situation. Green links show an inter-system handover between GSM and WCDMA.

2.1.3 Objectives of handover

Handover can be initiated in three different ways: mobile initiated, network-initiated and mobile assisted.

- **Mobile Initiated:** the mobile makes quality measurements, selects the best base station and switches to it, with the network's cooperation. This type of handover is generally triggered by the poor link quality measured by the mobile.

- **Network Initiated:** the base station makes the measurements and reports to the RNC which makes the decision whether to handover or not. Network initiated handover is executed for reasons other than radio link control, i.e. to control traffic distribution between cells. An example of this is the base station-controlled Traffic Reason Handover (TRHO). TRHO is a load-based algorithm that changes the handover threshold for one or more outgoing adjacencies for a given source cell depending on its load. If the load of the source cell exceeds a given level, and the load in a neighboring cell is below another given level, then the source cell will shrink its coverage, handing over some traffic to the other cell. Therefore, the overall blocking rate can be reduced, leading to a greater utilization of the cell resource.

- **Mobile Assisted:** here both the network and the mobile make measurements. The mobile reports the measurement results from nearby base stations and the network makes the decision to hand over or not.

The objectives of handover can be summarized as follows:

1) Guarantee the continuity of wireless services when the mobile user moves across the cellular boundaries.

2) Keep required QoS levels.

3) Minimize the interference level of the whole system by keeping the mobile linked to the strongest base station/s.

4) Roaming between different networks.

5) Distributing load from hot spot areas (load balancing).

The trigger that can be used for the initiation of a handover process could be the UL or DL link quality, the changing of service, the speed variation, traffic reasons or O&M (Operation & Maintenance) intervention.

2.1.4 Handover procedures and measurements

The handover procedure can be divided into three phases: measurement, decision and execution as shown in Figure 12.

In the handover measurement phase, the necessary information needed to make the handover decision is measured. Typical downlink measurements performed by the mobile are the Ec/N0 and Received Signal Code Power (RSCP) of the Common Pilot Channel (CPICH) of its serving cell and neighboring cells. For certain types of handover, other measurements are needed as well. For example, in an asynchronous network like

UTRA FDD (WCDMA), the relative timing information between the cells needs to be measured in order to adjust the transmission timing in soft handover to allow coherent combining in the Rake receiver. Otherwise, the transmissions from different base stations would be difficult to combine and especially the power control operation in soft handover would suffer additional delay.

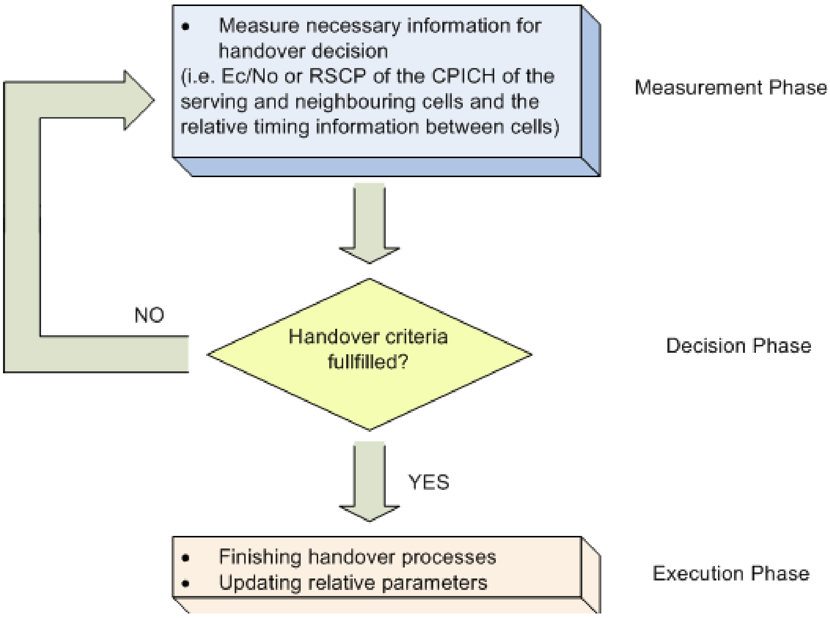


Figure 12. Handover Procedure

In the handover decision phase, the measurement results are compared against the predefined thresholds and then it is decided whether to initiate the handover or not. Different handover algorithms have different trigger conditions.

In the execution phase, the handover process is completed and the relative parameters are changed according to the different types of handover. For example, in the execution phase of the soft handover, the mobile enters or leaves the soft handover state, a new base station is added or released, the active set is updated and the power of each channel involved in soft handover is adjusted.

2.1.5 Soft Handover (SHO)

Soft handover was introduced by CDMA technology. Compared to conventional hard handover, soft handover has quite a few inherent advantages. However it also has the disadvantages of complexity and extra resource consumption. Planning of soft handover overhead is one of the fundamental components of the radio network planning and optimization. In this section, the basic principles of soft handover are presented.

Principles of soft handover

Soft handover is different from the traditional hard handover process. With hard handover, a definite decision is made on whether to handover or not and the mobile only communicates with one base station (BS) at a time. With soft handover, a conditional decision is made on whether to handover or not. Depending on the changes in pilot signal strength from the two or more BSs involved, a hard decision will eventually be made to communicate with only one. This normally happens after it is clear that the signal coming from one BS is considerably stronger than those coming from the others. In the interim period of soft handover, the mobile communicates simultaneously with all the BSs in the active set. The difference between hard and soft handover is that the first one happens on a time point, whereas the second one lasts for a period of time.

Figure 13 shows the basic process of hard and soft handover (2-way case). Assuming there is a mobile terminal moving from cell1 to cell2, BS1 is the mobile's original serving BS. While moving, the mobile continuously measures the pilot signal strength received from the nearby BSs. With hard handover shown as (a) in figure 3, the trigger of the handover can be simply described as:

If $(pilot\_Ec/Io)_2$ - $(pilot\_Ec/Io)_1$ > *D and* BS_1 *is the serving BS*

Handover to BS_2*;*

Else

Do not handover;

End

Where $(pilot\_Ec/Io)_1$ *and* $(pilot\_Ec/Io)_2$ are the received pilot Ec/N0 from BS_1 *and* BS_2 respectively; *D* is the hysteresis margin.

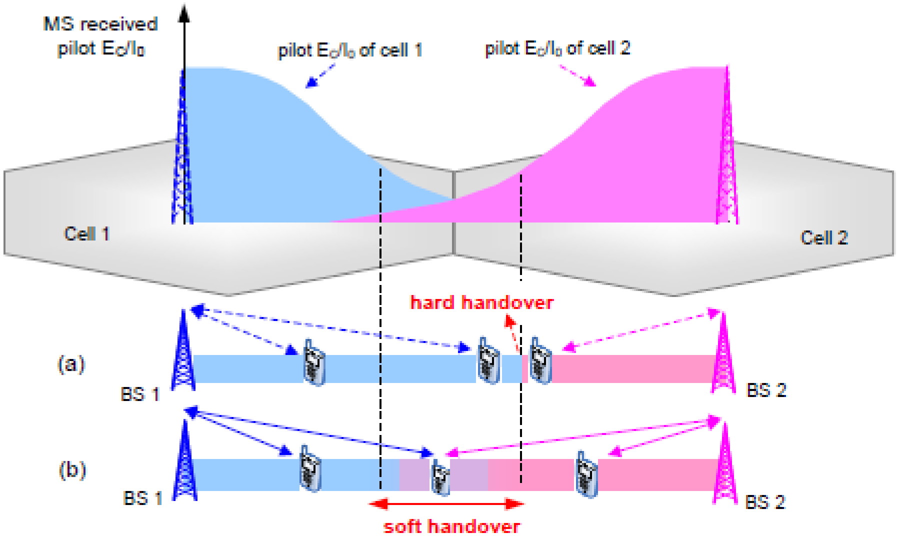


Figure 13. Comparison between hard and soft handover.

The reason for introducing hysteresis margin in the hard handover algorithm is to avoid the so called "ping-pong effect", the phenomenon which occurs when a mobile moves in and out of a cell boundary, producing frequent hard handovers. Apart from mobility of the user equipment, fading effects of the radio channel can also make the "ping-pong" effect even more serious. By introducing the hysteresis margin, this effect is mitigated because the mobile does not handover immediately to the best BS. High margin values may mitigate the "ping-pong" effect. However, a big margin means more delay. Moreover, the mobile causes extra interference to neighboring cells due to poor link quality during the delay. Therefore, hard handover wise, the value of hysteresis margin is fairly important. When hard handover occurs, the original traffic link with BS1 is dropped before setting up the new link with BS2.

In the case of soft handover, show as (b) in Figure 13, before $(pilot\_Ec/Io)_2$ goes beyond $(pilot\_Ec/Io)_1$, as long as the soft handover trigger condition is fulfilled, the mobile enters the soft handover state and a new link is set up. Before BS_1 is dropped (handover dropping condition is met), the mobile communicates with both BS_1 and BS_2 simultaneously.

The soft handover process is not the same in the different transmission directions. Figure 14 illustrates this. In the uplink, the mobile transmits the signals to the air through its omnidirectional antenna. The two BSs in the active set can receive the signals simultaneously because for the frequency reuse factor of one in CDMA systems. Then, the signals are passed forward to the RNC for selection combining. The better frame is selected and the other is discarded. Therefore, in the uplink, there is no extra channel needed to support handover.

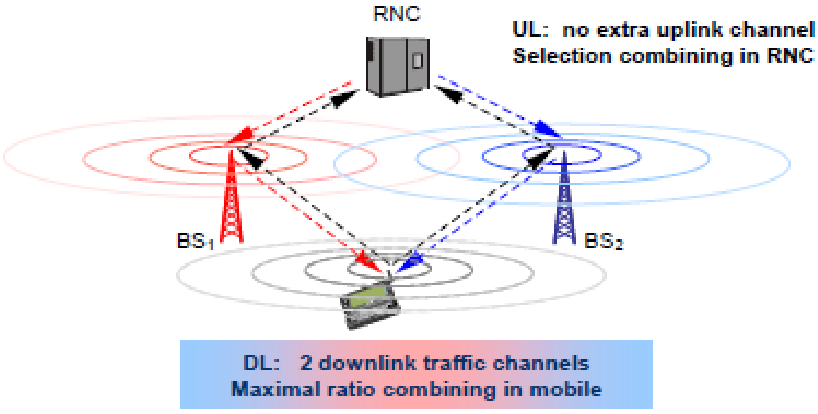


Figure 14. Soft Handover principles.

In the downlink, the same signals are transmitted through both BSs and the mobile can coherently combine the signals from different BSs since it sees them as just additional multipath components. Normally maximum ratio combining strategy is used, which provides an additional benefit called macro diversity. However, to support soft handover in the downlink, at least one extra downlink channel (2-way SHO) is needed. This extra downlink channel impacts on the interference level in the air interface, hence adding extra interference to other users. Thus, to support soft handover in the downlink, more resource is required. As a result, in downlink direction, the performance of the soft handover depends on the trade-off between the macro diversity gain and the extra resource consumption.

Soft Handover Algorithm

The performance of soft handover is related closely to the algorithm. Figure 15 shows the IS-95A soft handover algorithms.

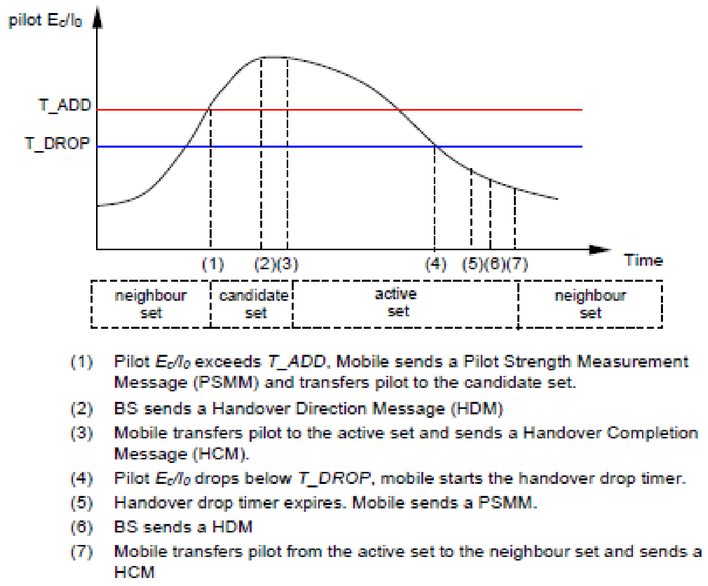


Figure 15. IS-95A soft handover algorithm (EIA/TIA/IS-95A developed by Qualcomm).

The active set is the list of cells that currently have connections to the mobile, the candidate set is the list of cells that are not presently used in the soft handover connection, but whose pilot Ec/Io values are strong enough to be added to the active set; the neighboring set (or monitored set) is the list of cells that the mobile continuously measures, but whose pilot Ec/Io values are not strong enough to be added to the active set.

In IS-95A, the handover threshold is a fixed value of received pilot Ec/Io. It is easy to implement, but has difficulty in dealing with dynamic load changes. Based on the IS-95A algorithm, several modified CdmaOne algorithms were proposed for IS-95B and cdma2000 systems with dynamic rather than fixed thresholds.

In WCDMA, more complicated algorithm is used, as illustrated in Figure 16.

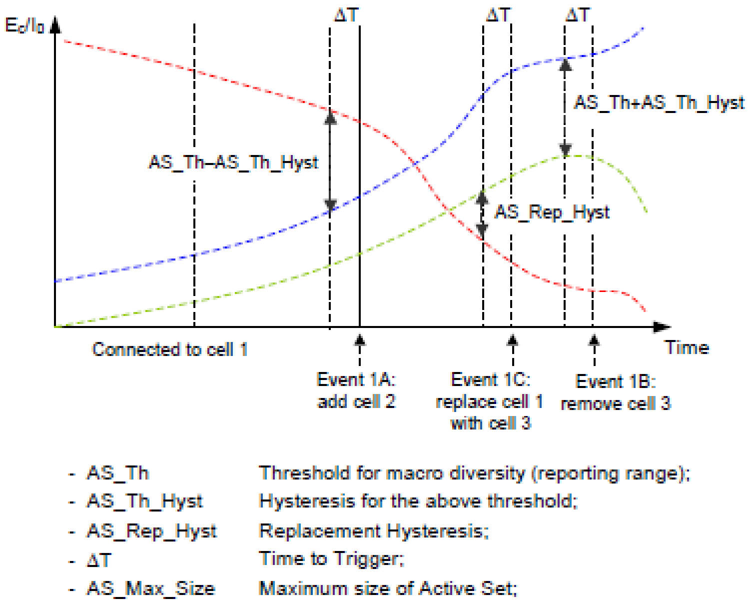


Figure 16. WCDMA soft handover algorithm (ETSI TR 125 922)

The WCDMA soft handover algorithm can be described as follows:

- If *pilot Ec/Io > Best pilot Ec/Io – (AS_Th – AS_Th_hyst)* for a period of ΔT and the active set is not full, the cell is added to the active set. This is called Event 1A or Radio Link Addition.

- If *pilot Ec/Io < Best pilot Ec/Io – (AS_Th + AS_Th_hyst)* for a period of ΔT, then the cell is removed from the active set. This is called Event 1B or Radio Link Removal.

- If the active set is full and *Best_candidate_pilot_Ec/Io > Worst_Old_pilot_Ec/Io + AS_Rep_Hyst* for a period of ΔT, then the weakest cell in the active set is replaced by the strongest candidate cell. This is called Event 1C or Combined Radio Link Addition and Removal. The maximum size of the active set in Figure 6 is assumed to be two.

Where *pilot Ec/Io* is the measured and filtered quantity of Ec/Io of CPICH; *Best_pilot_Ec/Io* is the strongest measured cell in the active set; *Best_candidate_pilot_Ec/Io* is the strongest measured cell in the monitored set; *Worst_Old_pilot_Ec/Io* is the weakest measured cell in the active set.

In the WCDMA algorithm, relative thresholds rather than an absolute threshold are used. Compared to IS-95A, the greatest benefit of this algorithm is its easy parameterization with no parameter tuning being required for high and low interference areas due to the relative thresholds.

Soft Handover Features

Compared to the traditional hard handover, soft handover shows some advantages, such eliminating the “ping-pong” effect and smoothing the transmission (there is no break point in soft handover). No “ping-pong” effect means lower load on the network signaling and with soft handover, there is no data loss due to the momentary transmission break that happens in hard handover.

Apart from handling mobility, there is another reason for implementing soft handover in CDMA; together with power control, soft handover is used as an interference-reduction mechanism. Figure 17 shows two scenarios. In the top one, shown as (a), only power control is applied; in the lower one, shown as (b), power control and soft handover are both supported. Assuming the mobile is moving from BS_1 to BS_2. At the current position, the pilot signal received from BS_2 is already stronger than the one from BS_1. This means that BS_2 is better than BS_1.

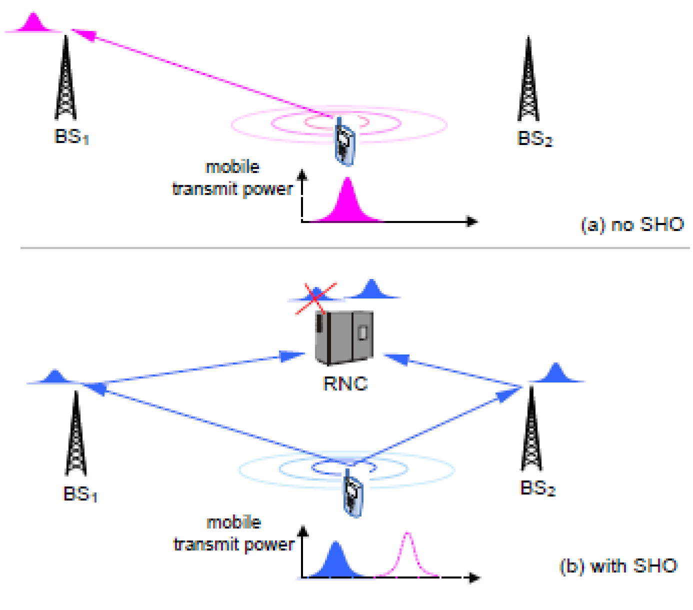


Figure 17 Interference reduction by SHO in uplink

In scenario (a) the power control loop increases the mobile transmit power to guarantee the QoS in the uplink when it moves away from its serving BS, BS_1. In scenario (b), the mobile is in soft handover status: BS_1 and BS_2 both listen to the mobile simultaneously.

The received signals, then, are passed forward to the RNC for combining. In the uplink direction, selection combining is used in soft handover. The stronger frame is selected and the weaker one is discarder. Because BS_2 is better than BS_1, to meet the same QoS target, the required transmit power (in blue) from the mobile is lower compared to the power (in pink) needed in scenario (a). Therefore, the interference contributed by this mobile in the uplink is lower under soft handover because soft handover always keeps the mobile linked to the best BS. In downlink direction, the situation is further complex. Although the maximum ratio combining gives macro diversity gain, extra downlink channels are needed to support soft handover.

Summarizing the features of soft handover:

1) Advantages:

- Less “ping-pong” effect, leading to reduced load on the network signaling and overhead.
- Smoother transmission with no momentary stop during handover.
- No hysteresis margin, leading to lower delay.
- Reduced overall uplink interference, leading to:
    - Better communication quality for a given number of users.
    - More users (greater capacity) for the same required QoS.
    - Less time constrains on the network. There is a longer mean queuing time to get a new channel from the target BS, which helps to reduce the blocking probability and dropping probability of calls.

2) Drawbacks:

- More complexity in implementation than hard handover.
- Additional network resources are consumed in the downlink direction (code and power resources).

2.1.6 Handover between WCDMA and GSM: Inter System Handover

Handover between WCDMA and GSM allows legacy GSM network to be used to give fallback coverage for WCDMA technology. This means that subscribers can experience seamless services, which was of importance to the earlier commercial launches.

In this section, features such as cell-reselection between WCDMA and GSM, compressed mode measurements, WCDMA-to-GSM cell-change order, handover from WCDMA to GSM and handover from GSM to WCDMA will be covered.

In addition, at the end of the section it will be presented a live network optimization feature which aims to reduce the amount of unnecessary handovers between both technologies in line with operator network planning evolution.

Introduction to Inter System Handover

Third-generation mobile services were introduced throughout the world. Although WCDMA technology was initially deployed to cover urban areas, many operators felt the need to provide nationwide coverage from the very start. GSM networks have a global footprint that provides access to mobile services, such as voice, circuit-switched and packet-switched data, short message service (SMS) and multimedia messaging service (MMS). Those operators which already had a GSM network wanted to capitalize on their investments when migrating to WCDMA technology. A third-generation mobile terminal equipped with both WCDMA and GSM technology would put the end-user in contact with seamless mobile service.

Dual mode WCDMA-GSM mobile terminals of this kind require an interworking mechanism between WCDMA and GSM technologies. For instance, if the user has established a voice call using WCDMA, and then moves outside WCDMA coverage, the voice call needs to be handed over to GSM without any perceived disturbance.

Main challenges

Several challenges had to be overcome to achieve interworking between WCDMA and GSM. First, to get feasible technical solutions for the mobile terminal and network implementations, some restrictions had to be set. For example, in the early discussions it was proposed that the mobile terminal should be able to have a voice call in WCDMA while sending data in GSM. However, this capability was restricted in the standard, allowing the mobile terminal to communicate with only one of the technologies at a time.

Another challenge was to minimize the changes to the existing GSM infrastructure (backwards compatibility). The solution is based in message encapsulation. As it can be seen in Figure 18, when the network sends a message in WCDMA, to order handover to GSM, part of the WCDMA message includes a GSM message, which looks exactly the same as if it had been sent on the GSM radio interface. This part of the WCDMA message is extracted in the mobile terminal and processed as if it has been received as a regular GSM message in GSM. The same principle is used for handover from GSM to WCDMA, and when the information is passed in the interfaces between network nodes.

For handover from GSM to WCDMA, the length of the handover message is also an important factor, since handover performance deteriorates with larger handover messages. Likewise, the bit rate of the GSM radio interface limits its ability to carry large WCDMA handover messages. To handle this situation, instead of signaling each parameter of the actual configuration, the network can signal a small size reference to a pre-defined WCDMA radio channel configuration, which is either stored in the mobile terminal (default configuration) or sent to the mobile terminal in broadcast messages. The pre-defined WCDMA radio channel configuration describes bit rates, data block sizes and other radio parameters of voice or video call service.

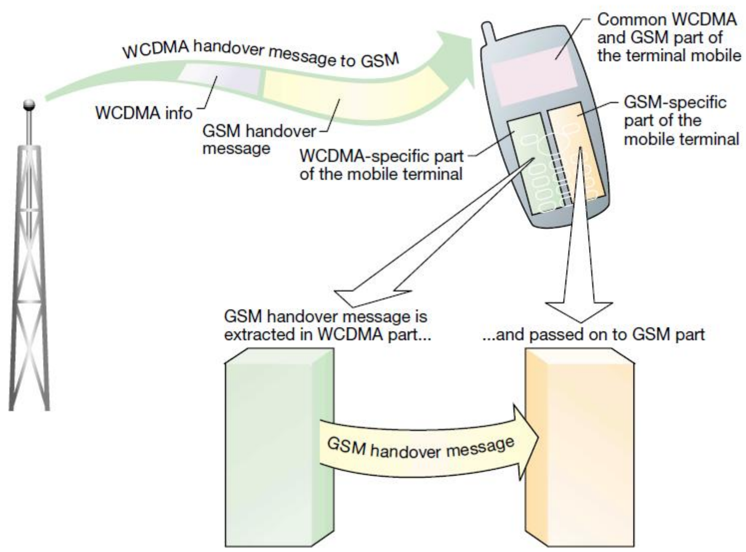


Figure 18. Encapsulation of GSM handover message as part of WCDMA handover message

Although the network solely communicates with the mobile terminal using one access technology at a time, the mobile terminal needs to perform measurements on GSM while communicating in WCDMA and vice versa. In order to achieve that, mobile terminals which have a single radio receiver are required to perform a process called compressed mode.

Compressed Mode

Compressed mode is a radio path feature that enables the UE to maintain the current connection on a certain frequency while performing measurements on another frequency. This allows the UE to monitor neighboring cells on another frequency or RAT, typically GSM. Compressed mode means that transmission and reception are halted for a short time – a few milliseconds – to perform a measurement on another frequency or RAT. The required transmission/reception gap is produced without any loss of DCH user data by compressing the data transmission in the time domain.

The following methods are used to compress the data transmission:

- *Halving the spreading factor*: This temporarily doubles the physical channel data rate in the radio channel. The same amount of data can be sent in half the time it would normally take. Halving the spreading factor does not affect the DCH user data rate. This method is usually applied to CS services.
- *Higher layer scheduling*: This mechanism reduces the DCH user data rate in the radio channel by restricting the high bit rate transport format combinations (TFCs). This method is usually applied to PS services.

The Transmission/Reception (TX/RX) gap always has seven slots. A gap can be places within one frame or within two consecutive frames, depending on the compressed mode method.

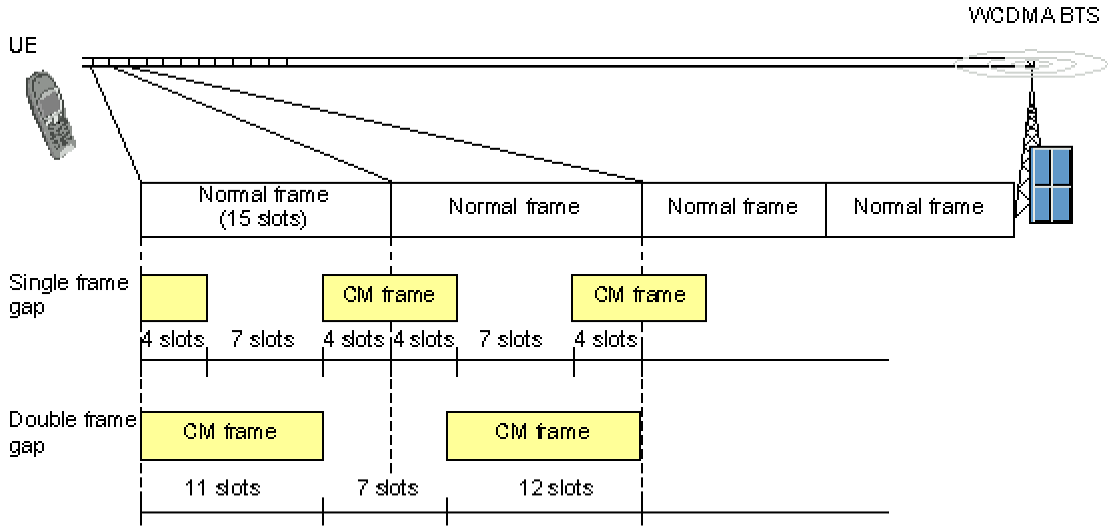


Figure 19. Example of transmission gaps created with compressed mode

The UE informs the RNC whether or not it requires compressed mode to perform inter-frequency or inter-RAT measurements. Usually, a UE equipped with a single receiver requires downlink compressed mode to perform inter frequency and GSM measurements.

If, on the other hand, the mobile terminal contains separate WCDMA and GSM radio receivers, it can use each receiver in parallel, performing GSM measurements without compressed mode in the downlink. Nonetheless, each solution – compressed mode and dual receivers – reduces talk time due to higher power consumption in the terminal.

Other challenges

In idle mode, standby time of the mobile terminal is mainly affected by how often it needs to wake up to monitor radio channels and perform measurements for cell re-selection. Since a dual-mode terminal must measure WCDMA and GSM cells, this has a negative effect on standby time compared to GSM-only mobile terminals. To improve standby time, the mobile terminal is allowed to inhibit measurements on the other access technology (for example, WCDMA when in GSM) when the quality of the current access technology is adequate for the network settings. Furthermore, compared to re-selection between GSM cells, the measurement requirements in the standard are more relaxed for re-selection between WCDMA and GSM cells.

2.1.7 Mobility procedures between WCDMA and GSM

There are two basic modes of operation for handling mobility:

- Mobile terminal-controlled mode.
- Network-controlled mode.

In the mobile terminal-controlled mode, the mobile terminal selects the cell to which it will connect. However, the network can broadcast various parameters to influence this process.

In the network-controlled mode, the network explicitly orders the mobile terminal to connect to a specific cell. Ordinarily, the network bases its decisions on measurement information provided by the mobile terminal. For either mode of operation, the network should consider cells that use each access technology. Besides radio link quality, the network might also consider other aspects when selection the cell, for example current load of the established service.

Two procedures have been defined by which the network can order the mobile terminal to connect to a cell using another technology, namely the handover and cell change order procedures. These are employed when the mobile terminal uses a dedicated channel. The handover procedure provides a higher level of service, since it involves a preparation phase in which resources in the target cell are reserved prior to the actual handover. Accordingly, the handover procedure is employed when the mobile terminal is provided circuit switched service, for instance, voice. The cell change order procedure applies when the mobile terminal is provided packet switched services, such as web browsing.

Cell re-selection between WCDMA and GSM

While in WCDMA, the mobile terminal performs cell re-selection in idle mode and in connected mode when common channels are used for packet switched service.

The dual-mode mobile terminal re-selects a GSM cell when that cell is ranked higher than the current WCDMA cell or any other WCDMA cell. WCDMA and GSM cells are ranked together according to signal strength. This same type of ranking applies in GSM.

When performing cell-reselection in WCDMA, the mobile terminal either measures GSM cells continuously or when the quality of the serving WCDMA cell falls below a given threshold. The mobile terminal is only allowed to select a new WCDMA or GSM cell when the average received quality and average signal strength exceed a minimum threshold. The minimum-quality threshold (signal-to-noise ratio) ensures that the mobile terminal can receive the information transmitted by the potential target cell. The minimum threshold for signal strength ensures that the network can receive the information for cell re-selection transmitted by the mobile terminal in the target cell. This criterion also takes into account the maximum transmit power that the mobile terminal is allowed to use when accessing the cell and the maximum radio frequency output power that the mobile terminal can transmit.

Frequent re-selections can be avoided with mechanism such as penalty time and temporary offset. Likewise, mechanisms are defined to keep fast-moving mobile terminals from re-selecting small-sized cells when a large overlay cell has been configured.

The network can configure these options by broadcasting parameters in the WCDMA cell.

When the mobile terminal is actively providing packet-switched data service in WCDMA and re-selects a GSM cell, it establishes the radio connection to the GSM base station subsystem (BSS) and then initiates the routing area update procedure. During this procedure, the core network may retrieve information from the UMTS Terrestrial Radio Access Network (UTRAN) on the context of the mobile terminal, which includes any data packets waiting in the downlink queue. When complete, the connection to UTRAN is released. Finally, the core network confirms the routing area update. Figure 20 shows the message sequence after cell-reselection from WCDMA to a GSM cell in idle mode.

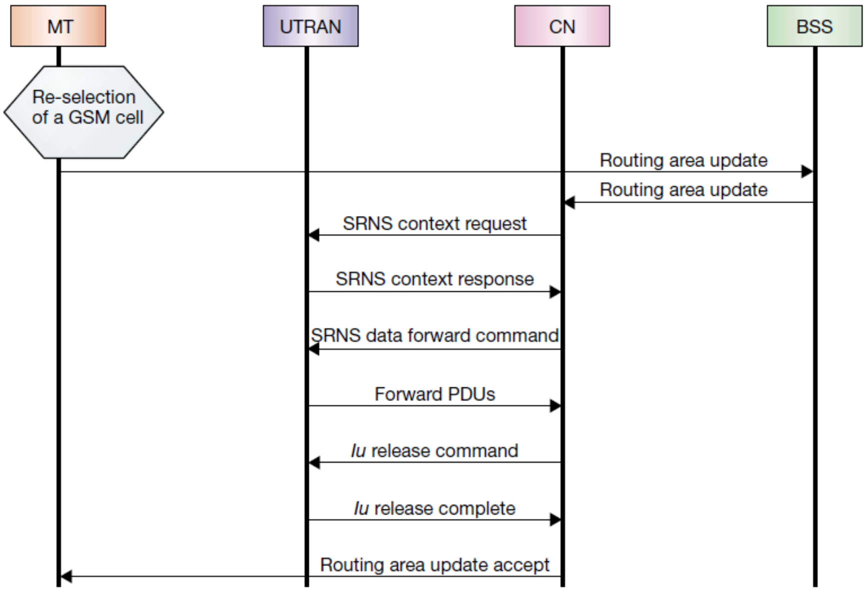


Figure 20. WCDMA to GSM cell re-selection signaling flow.

WCDMA to GSM Cell Change Order

The mobile terminal measures GSM cells and sends measurement reports to the network, which orders the mobile terminal to switch to GSM. The measurement procedure and the use of compressed mode are identical to that described below for the WCDMA to GSM handover procedure.

The signaling in the cell change order procedure is identical to that in the cell reselection procedure explained in Figure 20 except that the network selects the target GSM cell and initiates the procedure by sending a cell change order from the UTRAN message. This message includes the information on the target GSM Cell.

Handover from WCDMA to GSM

Figure 21 shows the message sequence for handover from WCDMA to GSM. When the mobile terminal has a circuit switched service and the signal strength fails below a given threshold, the WCDMA network orders the mobile terminal to perform GSM measurements. Typically, the mobile terminal is instructed to send a measurement report when the quality of a neighboring GSM cell exceeds a given threshold and the quality from WCDMA is unsatisfactory.

When UTRAN receives the measurement report message, it initiates the handover, given that all the criteria for handover has been fulfilled –for example, provided the mobile terminal is not involved in services that require WCDMA. UTRAN then asks the target BSS to reserve resources. The target BSS prepares a handover command message, which includes the details of the allocated resources. This GSM message, which is sent to the mobile terminal via the WCDMA radio interface, is transferred within a container that is transparently passed on by the different network nodes.

When the mobile terminal receives the handover command, it moves to the target GSM cell and establishes the radio connection in accordance with the parameters included in the handover command message. The mobile terminal indicates successful completion of the handover by sending a handover complete message to the BSS, after which the GSM network initiates the release of the WCDMA radio connection.

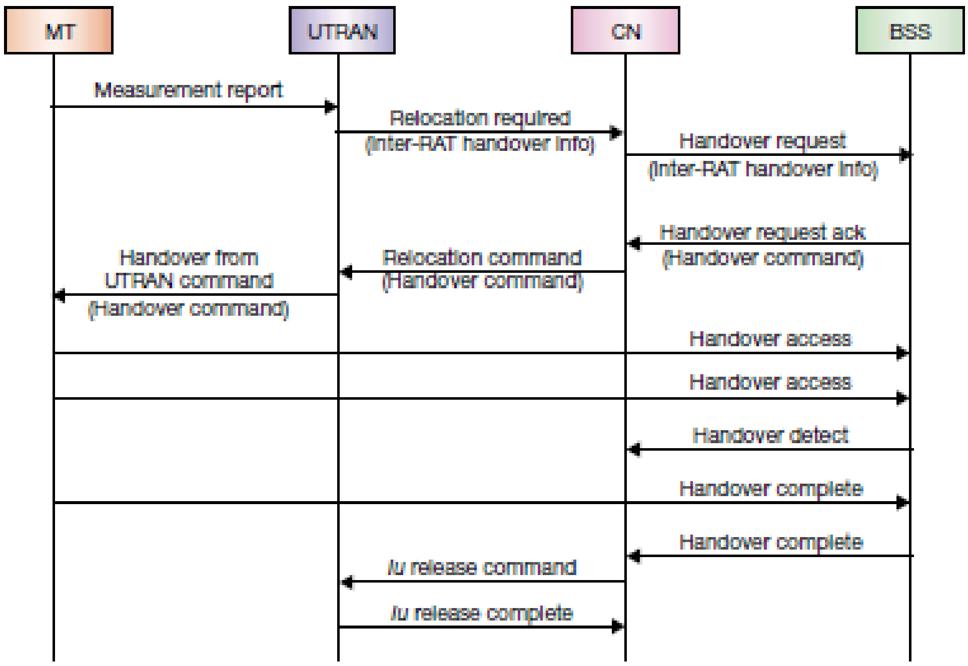


Figure 21. WCDMA to GSM handover signaling flow.

Handover from GSM to WCDMA

Figure 22 shows the message sequence for handover from GSM to WCDMA. The network orders the dual-mode mobile terminal to perform WCDMA measurements by sending the measurement information message, which contains information on neighboring WCDMA cells and the criteria for performing and reporting measurements.

When handover to WCDMA criteria has been met, the BSS initiates the allocation of resources to the WCDMA cell. Encapsulated in these messages, BSS also sends information to UTRAN on the WCDMA capabilities of the mobile terminal.

When the resources of the WCDMA target cell have been allocated, UTRAN compiles the handover-to-UTRAN-command message, which typically includes the identity of the pre-defined configuration for the service in use. This message is then sent transparently to the mobile terminal through the core network and BSS.

Once the mobile receives the handover-to-UTRAN command message it tunes to the WCDMA frequency and begins radio synchronization. The mobile terminal then indicates that the handover was successful by sending the handover-to-UTRAN-complete message after which the resources in GSM are released.

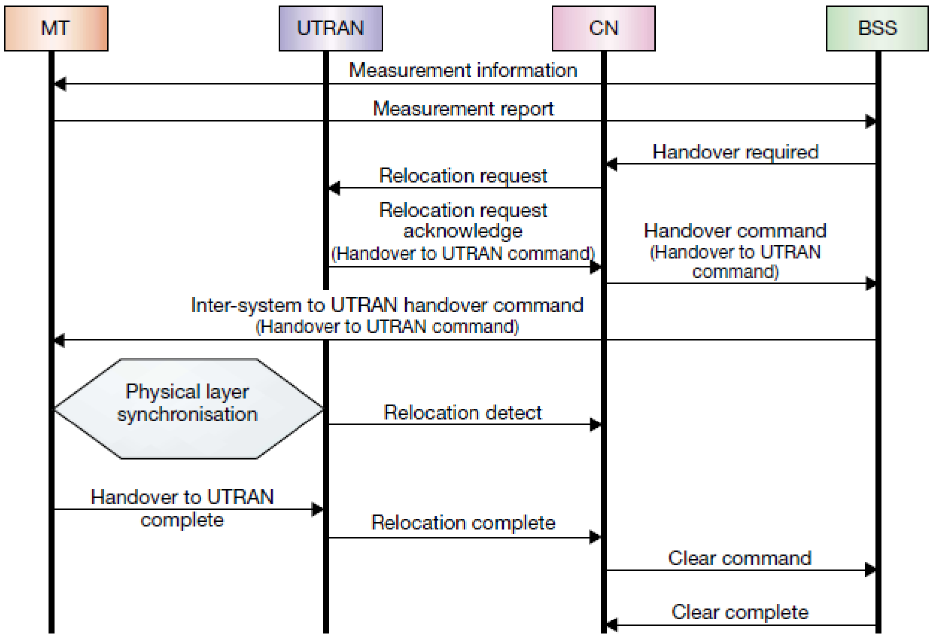


Figure 22. GSM to WCDMA handover signaling flow.

From coverage fallback to network optimization

As described above, the first WCDMA commercial networks provided basic coverage fallback to GSM. This fallback was merely the first step on the way towards a true seamless network, where WCDMA and GSM, together with other access technologies, combine to form a single network.

There are two important areas in this evolution. The first relates to minimize the perceived impact on the user when the mobile terminal changes between WCDMA and GSM. The Third-generation Partnership Project (3GPP) has been working on enhancements to the WCDMA and GSM standard that reduces the interruption in user data transfer from seconds to fractions of a second during packet-switched service.

The other area relates to the ability of the system to select the access technology that is best capable of providing the requested service and quality. This includes the triggering criteria for moving between GSM and WCDMA access technologies. By triggering a change of radio access technology on, for example, the requested service type, it is possible to provide the appropriate quality of service for the call, and to increase the overall capacity if the system.

It is inside the latter area where the WCDMA feature *Inter System Handover Cancellation* falls into. With this functionality the 3G network is able to interrupt the handover procedure between WCDMA and GSM if the cancellation trigger conditions are met. That will help to avoid unnecessary handovers in areas where the radio conditions in 3G are temporarily degraded, improving 3G network KPIs.

2.2 Feature Validation

2.2.1 Feature description

Inter System handover from WCDMA to GSM/EDGE can be triggered due to connection quality or radio coverage reasons (uplink DCH quality, UE TX power, downlink DPCH power, CPICH RSCP or CPICH Ec/N0). During the handover process, the WCDMA network conditions may change so that handover is not needed anymore.

It is during the inter system measurement phase when the UE also measures intra frequency WCDMA neighbors. If these measurements indicate that the conditions have improved in the WCDMA layer so that the predefined cancellation thresholds are exceeded, the RNC stops the handover and compressed mode measurements.

An active set update procedure during the measurements causes the inter system handover cancellation. The RNC should cancel the inter system measurements in the UE when the following cancellation triggers are met:

➢ Event 1E for CPICH Ec/N0:

- RNC starts inter system measurements in the UE upon receiving an event 1F-triggered measurement report, this is, when CPICH Ec/N0 measurement result of all the active set cells becomes worse than or equal to the absolute threshold.
- The UE cancels event 1F by sending an event 1E-triggered measurement report to the RNC if the CPICH/EcN0 measurement result of the active set cells again becomes better or equal than the cancellation threshold.
- When the ISHO cancellation is enabled for CPICH Ec/N0 conditions, once the RNC receives event 1E notification during the measurement phase it will de-activate the compressed mode and cancel all the inter system measurements initiated for the UE by sending *RRC MEASUREMENT CONTROL REQUEST* message with the measurement command information element set to *release*.

The same mechanism applies to the cancellation trigger event 1E for CPICH RSCP.

Figure 23 summarizes the steps and benefits of ISHO Cancellation feature.

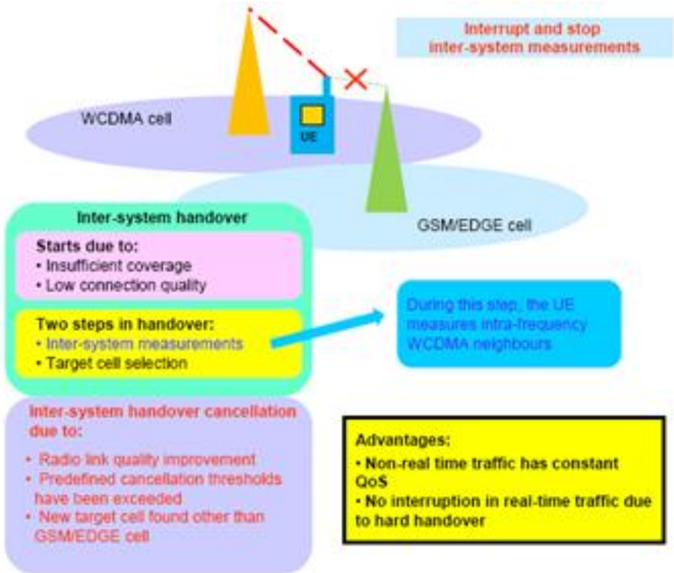


Figure 23. Inter System Handover Cancellation overview

Message Flow

Figure 24 shows the message exchange in both Uu interface (UE – WBTS) and IuB interface (WBTS – RNC). Radio Resource Control (RRC) messages are exchanged between the RNC and UE and Node B Application Part (NBAP) messages are exchanged between the WBTS and the RNC and are transparent for the user.

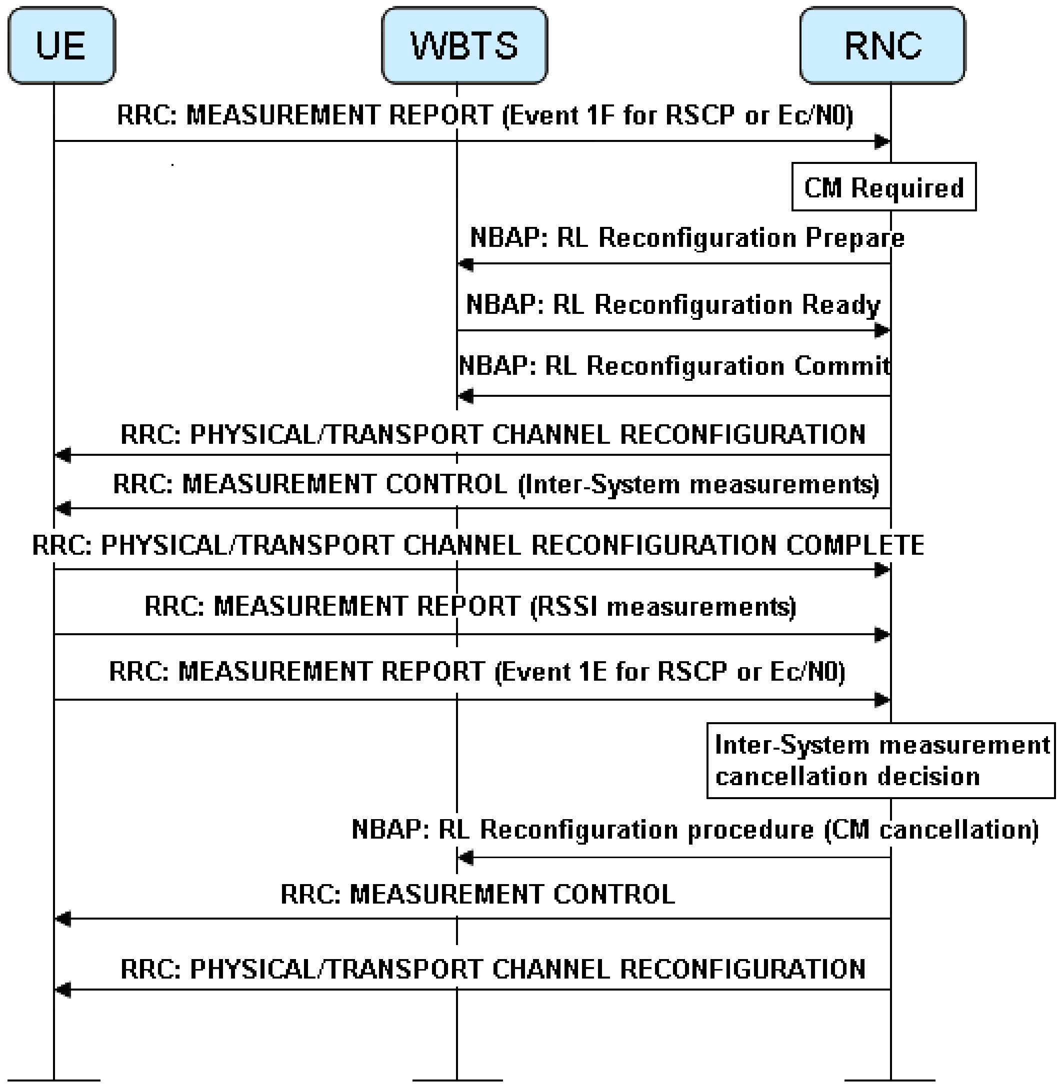


Figure 24. Message flow within RAN and UE associated to Inter System Handover Cancellation

It can be observed in which step the cancellation decision takes place and how it is communicated to UE. There are 3 main phases:

1) UE reports event 1F to RNC, indicating that RSCP signal (or Ec/N0) is under a configured threshold. At that moment, the RNC triggers two sub-procedures:

- Radio Link Reconfiguration with WBTS; and
- Physical Channel Reconfiguration with UE, so it can enter Compressed Mode and measure an inter system carrier signal level (i.e. 2G RSSI)

2) It is at this stage where the feature allows the UE also to measure and report the signal level of intra system carriers. If the UE reports an event 1E, indicating that RCSP signal (or Ec/N0) is over a configured threshold, the RNC evaluates the ISHO cancellation.

3) Finally, the RNC will trigger again two sub-procedures again to re-establish the channel configuration in 3G:

   - Radio Link Reconfiguration with WBTS; and
   - Physical Channel Reconfiguration.

2.2.2 Purpose of validation

Purpose of this feature validation is to test the interruption of compressed mode procedure after triggering inter-system handover measurements from WCDMA to GSM/EDGE based on radio coverage (CPICH RSCP) and connection quality (CPICH Ec/N0) with both Adaptive Multi-Rate speech codec (AMR) and PS NRT data calls.

In order to replicate a mobility scenario, all the cells involved in the test (3G and 2G), are combined and fed into an isolation box where the UE is placed. The power of each individual cell can be controlled manually via the attenuators, so mobility from each cell centre can be recreated by increasing/decreasing the signal levels (see Figure 25).

Test procedure will be divided in two different sections: those referred as intra WCEL will cancel the inter-system handover without changing the source cell, whereas those referred as inter WCEL will cancel the ISHO by using different source/target cell pairs. The latter cases are also broken down in two: cancellation via soft handover and cancellation via inter-frequency handover.

RSCP cancellation will be tested in both intra and inter WCEL scenarios, whereas Ec/N0 cancellation will be only tested in intra WCEL. The sensitivity of Ec/N0 variation and the lack of a complete interference-free environment make it difficult to test an inter WCDMA cell case.

In this case it will only be interesting to analyze the RRC message flow occurring in the Air interface, so NEMO Outdoor tracing tool is only needed.

Successful results will be achieved if:

- There is no voice disruption or noticeable quality degradation for CS AMR calls,
- 50 MByte FTP download can be finished without major throughput degradation; and
- ISHO is cancelled according to the predefined conditions for each scenario.

2.2.3 Testbed configuration and settings

A detail of hardware and software levels required for the validation of this feature is included in this section as well as configuration of the correct parameters needed in both WBTS and RNC.

Hardware Settings

3G RAN and Core Network Equipment	
RNC	Testbed RNC2 (RNC450 Step1 platform)
WBTS	UltraSite Outdoor Supreme (2+2+2, WCEL-1)
MSC	Testbed MSC M99
MGW	Testbed MGW W91
SGSN	Testbed Pre-prod SGSN
2G BSS	
BSC	Testbed BSC 09
BTS	UltraSite Indoor 246
UE	
R99	Nokia 6680 (used for CS testing)
Rel6	Huawei E270 data card (used for PS testing)

Table 6. RAN, BSS and UE equipments involved in the test.

Software Settings

3G RAN	
RNC	RN4.0 Q4 1.15-0_41 P400110S
OMS	R_OMS1_4.42.release_oms_corr30
WBTS	WN5.0 12.4-81_C
AXC	C5.5 BL28.01
2G BSS	
BSC	BSS12 CD 7
BTS	CX5 CD 4.0

Table 7. RAN and BSS equipment software version.

Test Layout

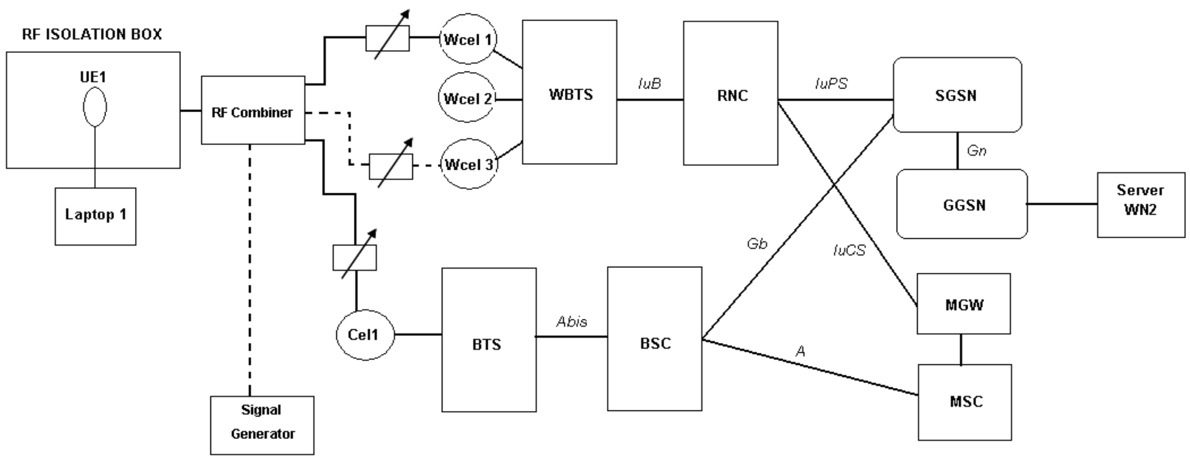


Figure 25. End-to-end validation setup. Signal Generator and WCEL3 were included in those tests indicated in section 2.2.4.

Parameter Settings

The following set of parameters has to be set prior to the initialization of the test case. Before each parameter it is indicated the network entity where it is located:

Parameterization		
RAN element	**Parameter**	**Target Value**
RNC	*Handover of AMR Service to GSM*	**Yes**
RNC	*Handover of NRT PS Service to GSM*	**Yes**
RNC	*ISHO Cancellation*	**Enabled**
RNC	*GSMMeasRepInterval*	**2 s**
RNC	*GSMMaxMeasPerido*	**21**

Table 8. Parameter settings for both RSCP and Ec/N0 cancellation test case. *GSMMeasRepInterval determines the measurement reporting interval for periodical inter-RAT measurements. GSMMaxMeasPeriod indicates the maximum number of periodical inter-RAT measurement reports determines the maximum allowed duration of the GSM measurement before an inter-system handover is performed. If the RNC is not able to execute the handover to GSM, it stops the GSM measurement after the UE has sent the predefined number of measurement reports to the RNC, in this case, 21.*

Parameterization		
RAN element	**Parameter**	**Target Value**
RNC	*ISHO Cancellation caused by RSCP*	**Enabled**
RNC	*GSM Handover caused by CPICH RSCP*	**Enabled**
RNC	*CPICH RSCP HHO cancellation*	**-90 dBm**
RNC	*CPICH RSCP HHO threshold*	**-95 dBm**

Table 9. Parameter settings for CPICH RSCP trigger.

Parameterization		
RAN element	**Parameter**	**Target Value**
RNC	*ISHO Cancellation caused by Ec/N0*	**Enabled**
RNC	*GSM Handover caused by CPICH Ec/N0*	**Enabled**
RNC	*CPICH Ec/N0 HHO cancellation*	**-90 dBm**
RNC	*CPICH Ec/N0 HHO threshold*	**-95 dBm**

Table 10. Parameter settings for CPICH Ec/N0 trigger.

To create a neighboring relationship between a 3G WCEL and a 2G CEL, an inter-system adjacency has to be created in both objects. The information requested for each case is listed in Table 11 and Table 12:

WCDMA System Information			
Parameter	**Value**	**Parameter**	**Value**
MCC	**234**	WBTS ID	**6**
MNC	**86**	LCR ID	**1**
UARFCN	**10700**	Cell ID	**5006**
DL SC	**61**	RAC	**102**
URA	**1**	SACB	**0**
SAC	**5006**	CPICH	**33 dBm**
PRACH	**21 dBm**	DPDCH	**24 dBm**
RNC ID	**3952**	LAC	**102**

Table 11. WCDMA system information required to create a neighboring relationship in a 2G cell.

GSM System Information			
Parameter	**Value**	**Parameter**	**Value**
MCC	**234**	BCF	**246**
MNC	**86**	BTS	**246**
Cell ID	**9246**	BAND	**1800**
BCC	**2**	NCC	**1**
LAC	**9**	Max UE Power on RACH	**24 dBm**
BCCH ARFCN	**866**	Max UE Power on DCH	**21 dBm**
PRACH	**21 dBm**	DPDCH	**24 dBm**
RNC ID	**3952**	LAC	**102**

Table 12. 2G system information required to create a 2G neighboring relationship in a 3G WCEL.

Counters

The suggested counters which will give valuable information for this test case correspond to the counter family *Inter System Handover (M1010).* In particular, the counters to be used are:

- *M1010C204*: gives the number of ISHO cancellations triggered by CPICH RSCP for RT services.
- *M1010C203*: gives the number of ISHO cancellations triggered by CPICH Ec/N0 for RT services.

2.2.4 Test Results

In this section are presented the results achieved during the validation of this feature. Each one of the following cases is presented individually:

- **ISHO cancellation triggered by CPICH RSCP intra WCEL**
- **ISHO cancellation triggered by CPICH Ec/N0 intra WCEL**
- **ISHO cancellation triggered by CPICH Ec/N0 inter WCEL I**
- **ISHO cancellation triggered by CPICH RSCP inter WCEL II**

ISHO cancellation triggered by CPICH RSCP intra WCEL

Successful results have been met for both AMR and PS NRT calls when validating this scenario. Figure 26shows the RRC message flow captured with NEMO Outdoor for the CS AMR case.

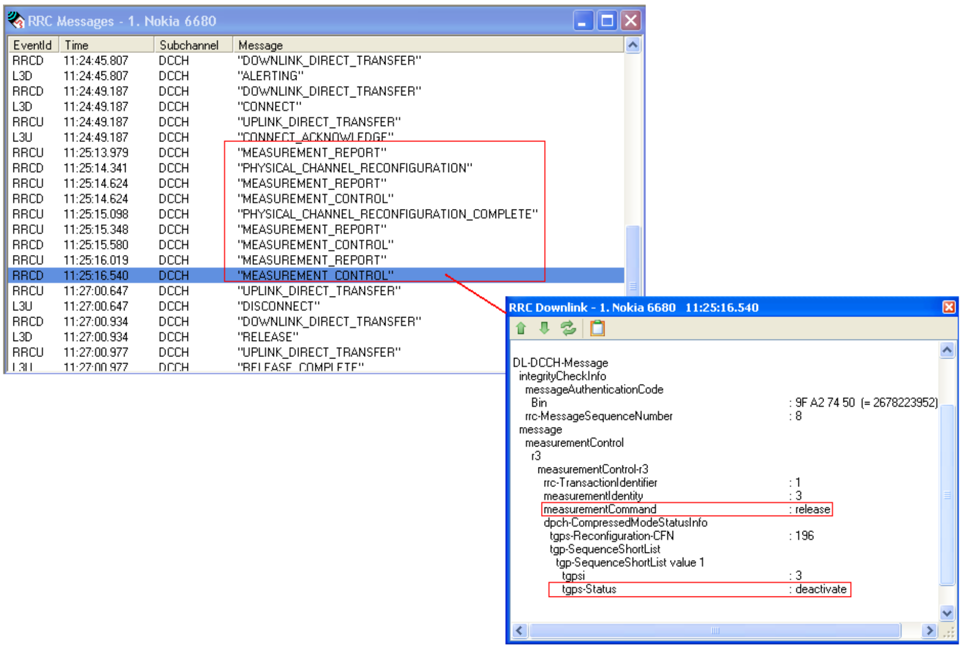


Figure 26. RRC message flow for RSCP triggered ISHO cancellation. Key messages and information elements are highlighted in red.

First of all, when the -95 dBm threshold is triggered due to low CPICH RSCP level, the UE sends event 1F in the first *MEASUREMENT REPORT* message. Then, the RNC sends the message *PHYSICAL CHANNEL RECONFIGURATION* and orders the UE to start *compressed mode*. At this moment, the WCDMA signal is still below the cancellation threshold of -90 dBm, so the UE starts measuring the 2G signal defined as adjacency. The results of this measurement are shown in the third *MEASUREMENT REPORT* message shown in Figure 27:

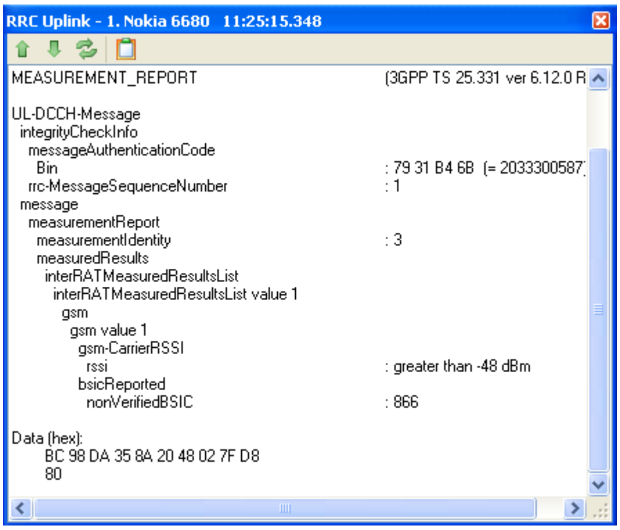


Figure 27. GSM related MEASUREMENT REPORT message

Once the attenuation is decreased in the source WCDMA cell, the cancellation threshold, set to -90 dBm, is trespassed and the cancellation mechanism triggered. Then, the UE reports this situation by sending event 1E in the last *MEASUREMENT REPORT* (Figure 28):

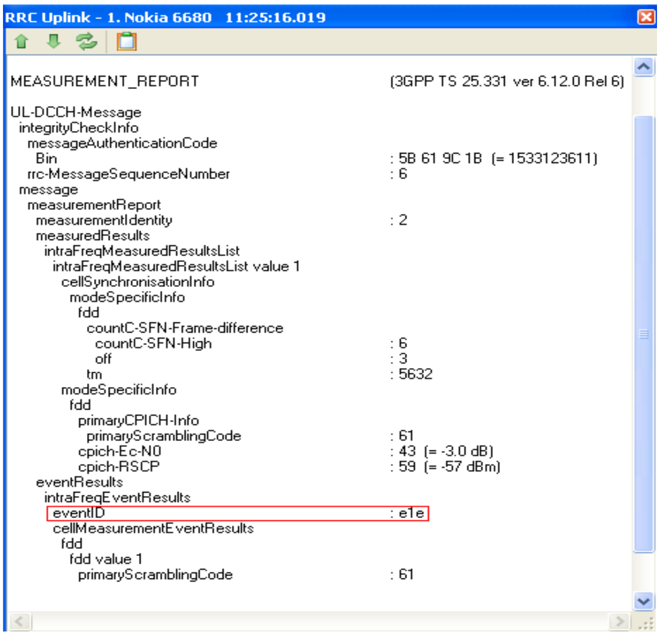


Figure 28. MEASUREMENT REPORT message. Highlighted in red, the information element showing event 1E. Note that RSCP value is greater than -90 dBm.

Upon reception of event 1E, the RNC communicates the UE to stop compressed mode and, therefore, the measurement of the 2G signal. This is done by sending *MEASUREMENT CONTROL* message.

The decoded information associated to this message can be seen in Figure 16. There is a key information block indicating the cancellation of compressed mode which is *tgps-Status = deactivate* (*tgps* refers to the transmission gap explained in Figure 19). Apart from that, a second information block indicates *measurementCommand = release*. This block informs the UE to release all the measurements with the given *measurementIdentity* block in this message. In this case, the measurement identity to cancel is 3, which is the one used to measure inter-RAT frequencies (see Figure 27).

ISHO cancellation triggered by CPICH Ec/N0 intra WCEL

Successful results have been achieved in this test case for both AMR and PS NRT call. The following changes in the test environment and the parameters were done to ease the test procedure:

1) In order to control the Ec/N0 fluctuation around the zone of interest defined by the threshold set in Table 10, a -10 dBm AWGN signal of 5MHz @ 2140 MHz (frequency related to UARFCN = 10700) is introduced in the system by using the HP Signal Generator E4432B. By doing that, the interference injected to the WCDMA signal can be controlled and the Ec/N0 variation can be controlled more accurately, as a result.

2) It was also advisable to increase the parameter *CPICH Ec/N0 HHO Time Hysteresis* in RNC. This parameter determines the time period during which the CPICH Ec/N0 of the active set cell must stay lower than the threshold *HHOEcNoThreshold* before the UE can trigger the reporting event 1F. When the measured CPICH Ec/N0 of all active set cells has become worse that the threshold in question, the RNC starts inter-frequency or inter-RAT (GSM) measurements in compressed mode for the purpose of hard handover. By doing that, the Ec/N0 fluctuation ping-pong effect, which may lead to wrong results, can be avoided.

In this case the message flow obtained is quite similar to the one Figure 24. Firstly, once Ec/N0 drops below -9 dB, the UE sends a *MEASUREMENT REPORT* (reporting event 1F) and the RNC sends the subsequent *PHYSICAL CHANNEL RECONFIGURATION* so the UE can start compressed mode. The ISHO is interrupted (compressed mode stopped) once the Ec/N0 raises up to -7 dB (see Figure 29):

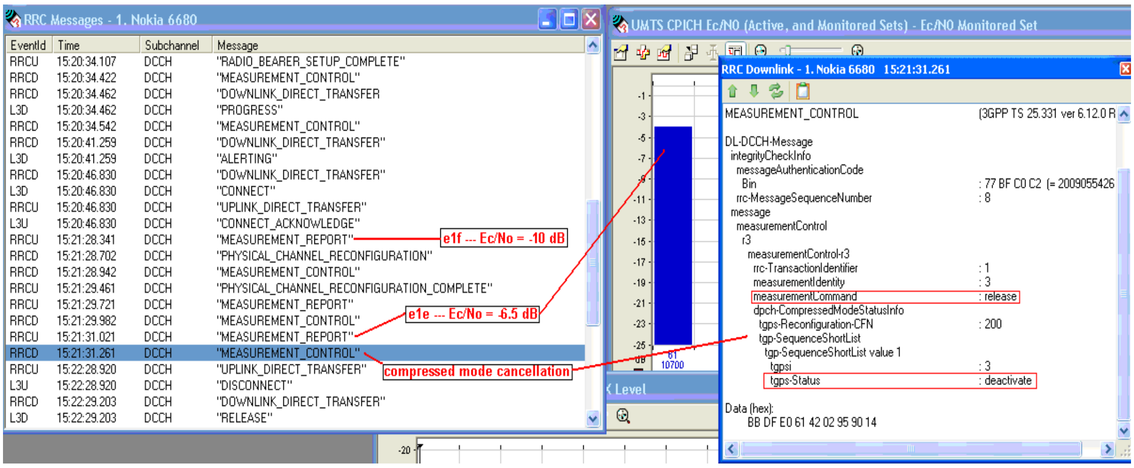


Figure 29. Message flow for Ec/N0 triggered ISHO cancellation.

Finally, correct execution of ISHO cancellation in both cases can be checked by using the counters shown in Figure 30, which were enabled in section 2.2.3.

2009-03-27 13:30:00 / 15min	
WBTS-6 WCEL-1 M1010C203 ISHO CANCEL DUE TO CPICH ECNO FOR RT	0
WBTS-6 WCEL-1 M1010C204 ISHO CANCEL DUE TO CPICH RSCP FOR RT	1
WBTS-6 WCEL-1 M1010C207 ISHO CANCEL DUE TO CELL ADDITION FOR RT	0
WBTS-6 WCEL-1 M1010C208 ISHO CANCEL DUE TO CELL REPLACEMENT FOR RT	0
2009-03-27 17:30:00 / 15min	
WBTS-6 WCEL-1 M1010C203 ISHO CANCEL DUE TO CPICH ECNO FOR RT	1
WBTS-6 WCEL-1 M1010C204 ISHO CANCEL DUE TO CPICH RSCP FOR RT	0
WBTS-6 WCEL-1 M1010C207 ISHO CANCEL DUE TO CELL ADDITION FOR RT	0
WBTS-6 WCEL-1 M1010C208 ISHO CANCEL DUE TO CELL REPLACEMENT FOR RT	0

Figure 30. Counters C203 and C204 show the successful ISHO Cancellation for both RSCP and Ec/N0 scenarios.

ISHO cancellation triggered by CPICH Ec/N0 inter WCEL I

In previous scenarios, the cancellation has been achieved because the attenuation in the source WCDMA cell has been increased. In a live network situation, it represents that the UE is moving back again from the WCDMA cell edge to the WCDMA cell centre.

This section moves forward and aims to proof that ISHO cancellation can be also triggered by and adjacent WCDMA cell with the same frequency than the source

WCDMA cell, i.e. by performing a soft handover, in case the UE moves away from the source cell and, for a short period of time, goes through a 2G coverage area.

In this case, an adjacency to a WCDMA cell for the same frequency has to be created so a soft handover between both WCDMA cells can be performed (WBTS used is Outdoor Supreme with SC = 63). The objective is to force the UE into a soft handover situation once it has entered the compressed mode zone (CPICH RSCP level below -95 dBm) and has taken into account the GSM cell amongst the measurement reports (so the UE will be likely to perform an ISHO).

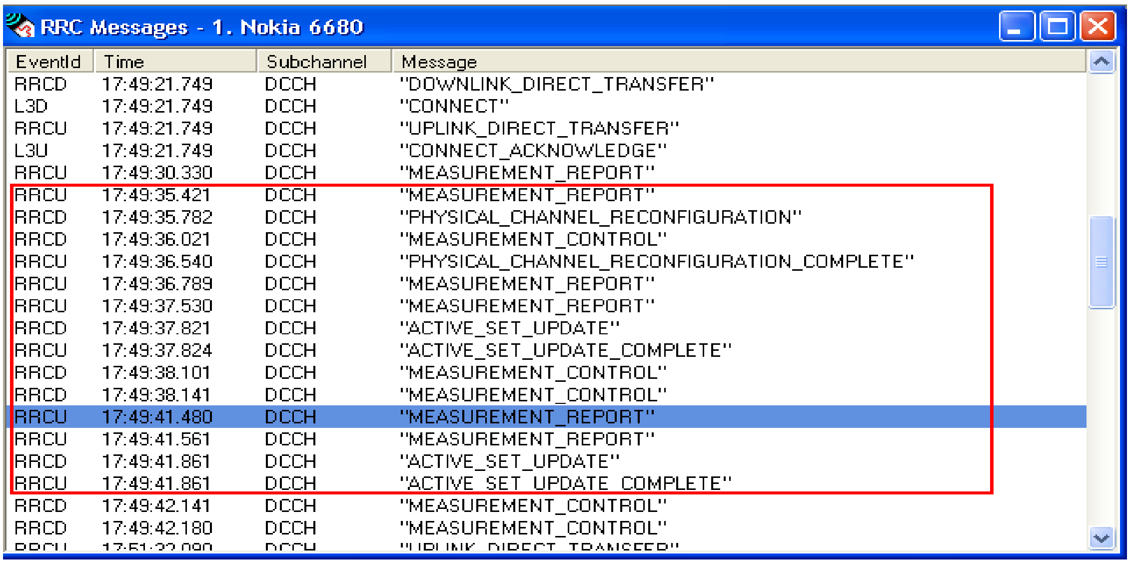
The condition to remain in 3G, therefore the ISHO is cancelled, is to add the new 3G signal (i.e. WCEL 3) in the active set before the synchronization with WCEL 1 is completely lost. A full attenuation of WCEL 1 before WCEL 3 is added to the active set may cause either an ISHO or an eventual drop in the call.

After several attempts, the following set of parameters had to be changed in order to achieve successful results:

Parameterization		
RAN element	**Parameter**	**Target Value**
RNC	*Measurement averaging window*	**20 s**
RNC	*Minimum measurement interval*	**20 s**
RNC	*HHORscpCancelTime*	**320 ms**
RNC	*Neighbor cell search period*	**20**

Table 13. Additional parameters to modify. *Measurement averaging window* = 20 s, will maintain the UE in compressed mode for 20 s, so the signal of new cells can be introduced in the measurement (i.e. WCEL 3) and taken into account in the internal UE handover decision algorithms. *Minimum measurement interval* = 20s, will interrupt 2G frequency measurement for 20 s in case of unsuccessful ISHO, thus allowing 3G frequency measurements in the meantime. Cancellation time *(HHORscpCancelTme)* determines the time period during which the CPICH RSCP of the active set cell must stay better than the threshold *HHORscpCancel* before the UE can trigger the reporting event 1E. *Neighbor cell search period* determines the number of periodical inter-RAT (GSM) measurement reports, starting from the first report after measurement setup, during which a handover to GSM is not possible. This period allows the UE to find and report all the potential GSM neighbor cells before the handover decision is made.

The message flow obtained in a successful scenario is shown in Figure 31:


RRC Messages - 1. Nokia 6680

EventId	Time	Subchannel	Message
RRCD	17:49:21.749	DCCH	"DOWNLINK_DIRECT_TRANSFER"
L3D	17:49:21.749	DCCH	"CONNECT"
RRCU	17:49:21.749	DCCH	"UPLINK_DIRECT_TRANSFER"
L3U	17:49:21.749	DCCH	"CONNECT_ACKNOWLEDGE"
RRCU	17:49:30.330	DCCH	"MEASUREMENT_REPORT"
RRCU	17:49:35.421	DCCH	"MEASUREMENT_REPORT"
RRCD	17:49:35.782	DCCH	"PHYSICAL_CHANNEL_RECONFIGURATION"
RRCD	17:49:36.021	DCCH	"MEASUREMENT_CONTROL"
RRCU	17:49:36.540	DCCH	"PHYSICAL_CHANNEL_RECONFIGURATION_COMPLETE"
RRCU	17:49:36.789	DCCH	"MEASUREMENT_REPORT"
RRCU	17:49:37.530	DCCH	"MEASUREMENT_REPORT"
RRCD	17:49:37.821	DCCH	"ACTIVE_SET_UPDATE"
RRCU	17:49:37.824	DCCH	"ACTIVE_SET_UPDATE_COMPLETE"
RRCD	17:49:38.101	DCCH	"MEASUREMENT_CONTROL"
RRCD	17:49:38.141	DCCH	"MEASUREMENT_CONTROL"
RRCU	17:49:41.480	DCCH	"MEASUREMENT_REPORT"
RRCU	17:49:41.561	DCCH	"MEASUREMENT_REPORT"
RRCD	17:49:41.861	DCCH	"ACTIVE_SET_UPDATE"
RRCU	17:49:41.861	DCCH	"ACTIVE_SET_UPDATE_COMPLETE"
RRCD	17:49:42.141	DCCH	"MEASUREMENT_CONTROL"
RRCD	17:49:42.180	DCCH	"MEASUREMENT_CONTROL"

Figure 31. Message flow for RSCP triggered ISHO cancellation due to the addition of WCEL 3 to the active set.

Highlighted in red is the relevant message flow to be analyzed:

1) *MEASUREMENT REPORT:* The UE sends event 1F because the source WCDMA cell has been attenuated and the reported RSCP (-96 dBm) is below the threshold (-95 dBm).

2) *PHYSICAL CHANNEL RECONFIGURATION:* The RNC orders the UE to activate compressed mode, as explained in 2.2.1.

3) *MEASUREMENT CONTROL:* The RNC informs about possible inter-RAT candidate cells. Only the 2G cells defined as adjacency of the source WCDMA cell are shown.

4) *PHYSICAL CHANNEL RECONFIGURATION COMPLETE:* The UE informs the RNC that has entered in compressed mode.

5) *MEASUREMENT REPORT (I):* The UE reports the 2G adjacent cell signal level (-74 dBm).

6) *MEASUREMENT REPORT (II):* The UE reports the 3G adjacent cell (WCEL 3) signal level (-99 dBm) and sends event 1A to the RNC, so it is added to the active set (see Figure 32).

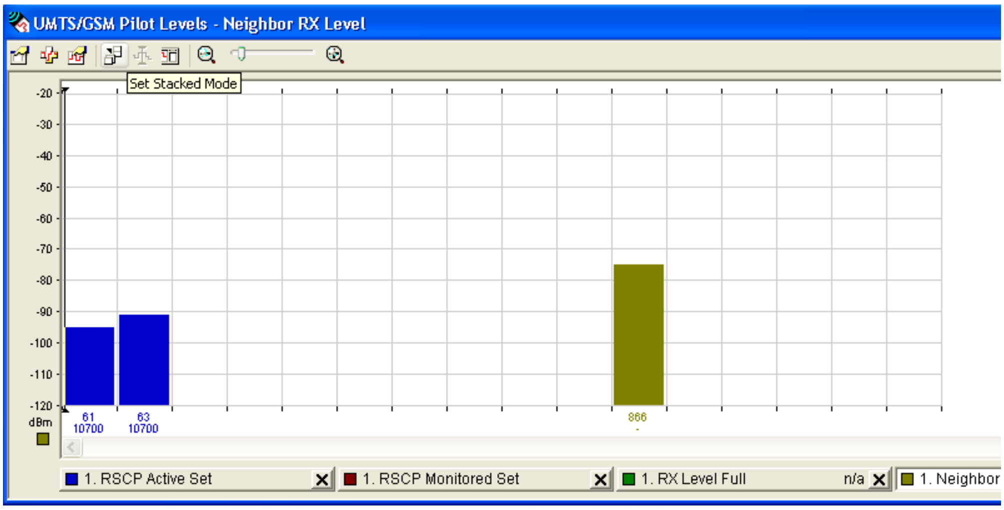


Figure 32. WCEL 3 (SC=63) becomes part of the Active Set whilst the UE is still reporting the 2G signal (green bar). Once WCEL 3 gets better than the RSCP ISHO cancellation threshold, ISHO is cancelled.

7) *ACTIVE SET UPDATE and ACTIVE SET UPDATE COMPLETE:* both *RNC* and UE are aware of the new active set.

8) *MEASUREMENT CONTROL*: RNC informs the UE about Tx/Rx time difference controls.

9) *MEASUREMENT CONTROL*: RNC orders the UE to release the measurement reports related to inter-RAT and to deactivate compressed mode because one of the cells in the Active Set (WCEL 3 in this case) has reached the cancellation threshold.

10) *MEASUREMENT REPORT:* The UE reports event 1E indicating that WCEL 3 has reached the cancellation threshold.

11) *MEASUREMENT REPORT:* The UE reports event 1B. Serving cell WCEL 1 is removed from the active set and the handover concluded.

12) *ACTIVE SET UPDATE and ACTIVE SET UPDATE COMPLETE*: both RNC and UE are aware of the new active set.

ISHO cancellation triggered by CPICH RSCP inter WCEL II

Since the situation explained in the previous test has shown beneficial results for the operator, the purpose of this section is to verify whether ISHO can be cancelled due to an IFHO.

To proceed correctly, an inter-frequency adjacency has to be added. It can be done by maintaining the same scenario as in Figure 25, but changing the frequency of WCEL 3, for instance to UARFCN = 10725.

The aim of the test is to introduce WCEL 3 once the measurement of the 2G signal has started. Note that, in this case, no active set update procedure is involved since the target cell has got a different frequency.

After several unsuccessful attempts it can be concluded that ISHO cancellation cannot be triggered by an IFHO because once the UE enters in compressed mode, it is only capable to measure two frequencies at a time. If it is taken into account that one of frequencies that he UE is always measuring is the one from the source cell, it only will be allowed to measure an extra frequency (3G or 2G).

The RNC proceeds in the following manner: RNC knows about the existence of two kinds of adjacencies, defined by the inter-frequency (ADJI) and inter-system (ADJG) objects. Once the UE reports event 1F, the RNC orders the UE to start compressed mode and prioritizes inter-frequency measurements over inter-system measurements by giving the correct information to the UE inside *MEASUREMENT CONTROL* messages. Being 3G the preferred system, inter-frequency measurements are performed first. Once the UE cannot manage to find WCEL 3, otherwise an ISHO cannot be forced, a measurement control message is received from the RNC cancelling the 3G inter-frequency measurement and ordering the inter-RAT measurement. Once the UE starts measuring 2G cells, there is no way to measure again WCEL 3, even though its attenuation is decreased in order to meet the cancellation threshold, and the ISHO is performed.

2.2.5 Test Conclusions

Validation of the feature Inter System Handover Cancellation has proved that:

- ISHO cancellation can be triggered by RSCP for both intra and inter WCDMA cell scenarios, provided that the same frequency is involved.
- ISHO cancellation can be triggered by Ec/N0 in intra WCDMA cell scenario.

Nowadays, with optimized services integrated in the 3G network it is beneficial for the operator to maintain the users in the WCDMA layer rather than in 2G network, provided that correct load and coverage levels are met in the cell. Introducing inter-system handover cancellation in the network optimizes both the user experience and operator mobility KPIs, in particular CS ISHO drop rate and PS ISHO drop rate, by avoiding unnecessary 2G transitions that may be triggered when the UE remains temporarily in cell edge situations.

3 QoS Aware HSPA Scheduling

3.1 Theoretical Background

3.1.1 Introduction: What is QoS?

First of all, I would like to introduce what does the term QoS (Quality of Service) refers to in cellular networks. QoS in cellular networks is defined as the capability of the cellular service to provide a satisfactory service which includes voice quality, signal strength, low call blocking and dropping probability, high data rates for data applications, etc… In network-based services QoS basically depends on the following factors:

- **Throughput:** the rate at which the packets go through the network. Maximum rate is always preferred, indeed.
- **Delay:** this is the time which a packet takes to travel E2E (end-to-end). Minimum delay is always preferred.
- **Packet Loss Rate:** percentage of packets lost during data transmission. This should be also as low as possible.
- **Packet Error Rate:** errors present in a received packet due to corrupted bits. This indicator should be kept as minimum as possible.
- **Reliability:** this concept is related to the availability of the data connection.

It is for these reasons that providing QoS has been a great challenge in the past and it continues to be hot topic as there is still a lot of scope to provide better service standards.

3.1.2 Why is QoS needed?

Imagine you are in the middle of a phone call and you are hardly able to hear what your friend is talking over the phone of the call drops when you are talking something important. These things are highlight undesirable and are the major concern of the operators when providing service to their customers, as the number of complaints should be dramatically reduced.

Communication plays a major role in today's world and to support it, QoS has to be given a major priority. It is important to differentiate the traffic based on priority levels. This is when the concept of traffic class and prioritization arises: it is important to differentiate the traffic based on priority level. Some traffic classes should be given higher priority over other classes, for example: voice should be given a higher priority compared to data traffic as voice is still considered as the most important service (apart from emergency call service, which should be classified as the top prioritize service). In addition, it should be noted that more preference has to be given to customers who pay a premium to get better service, without affecting the remaining customers who pay the standard price.

It is this last point where the feature test proposed herein is focused: provide more radio and transmission resources to those non-real time High Speed Downlink Packet Access (HSDPA) data VIP users versus standard tariffs under congested conditions.

Nevertheless, further background should be provided in order to understand the test case.

3.1.3 QoS Challenges

In wireless mobile networks, QoS refers to the measurement of a system with good transmission quality, service availability and minimum delay. Nowadays, 4G systems are expected to have a reliability of at least 99.999, referred to as the five-nine reliability.

The major challenges when considering QoS in cellular networks are varying rate channel characteristics, bandwidth allocation, fault tolerance and handoff support among heterogeneous wireless networks. It is not a coincidence that each protocol layer involved in the communication process (including physical, MAC, IP, TCP and application) has got their own mechanisms to provide QoS, because it is important to guarantee QoS in each layer if we want to have a consistent QoS policy in the whole network. Other challenge is efficient usage of the spectrum as it is a scarce resource and this is where bandwidth allocation plays a key role.

The problem is even complex when data and voice services have to be supported: voice services are very delay sensitive and require real-time service. On the other hand, data services are less delay sensitive but are highly intolerant to packet loss and packet error rate. So both these factors have to be considered for providing QoS for voice and data services.

3.1.4 UMTS QoS Architecture

In 1G and 2G networks, such as GSM, there was only one aspect of QoS to take into account: voice. Providing quality speech was the major concern. In 3G networks, though, QoS has to be provided for voice as well as data. Still priority is given for voice services as they are considered as the primary service. They are very delay sensitive and require real-time service. Data services, mainly comprised of text and multimedia, are less delay sensitive but better throughput and less or no packet loss rate are expected.

In this section, UMTS QoS architecture at every layer is described, together with their functionalities. Further down, they are described the different QoS classes and attributes involved.

Basically, since end-to-end (E2E) QoS should be preserved all the nodes from the transmitter to the receiver need to cooperate with each other. QoS is defined during subscription, and the related information is saved on the Core Network (CN). When a user sends a service request, the CN negotiates with the UTRAN and the User Equipment (UE) according to the subscribed QoS. If the negotiation is successful, a set of QoS parameters accepted by all the nodes can be obtained. Then, each network element provides the services for this user based on these parameters. It is very important to note that the user can be satisfied with the E2E services only when all the nodes meet the QoS requirements.

In the UTRAN, the QoS is determined by the QoS management strategy as shown in Figure 33.

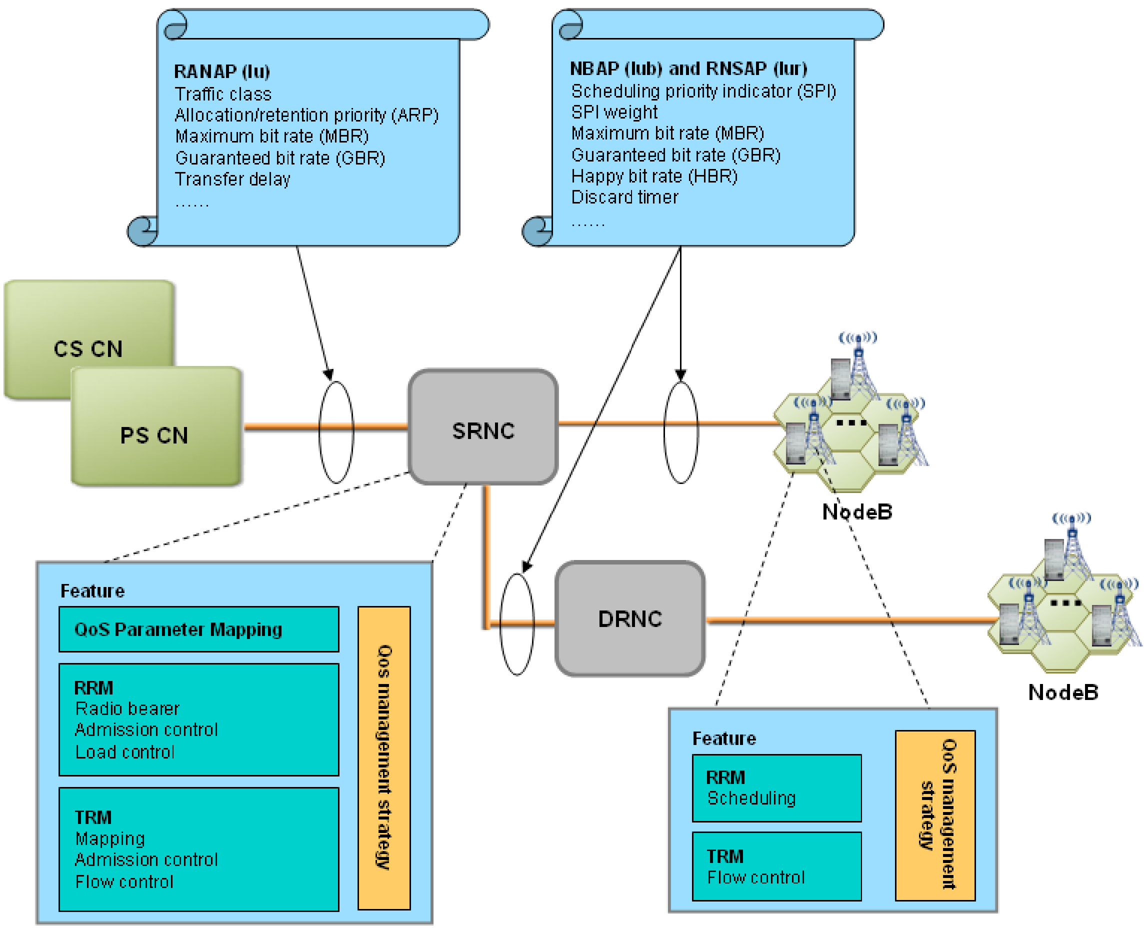


Figure 33. UTRAN QoS Management strategy. This figure provides a high-level description of the UTRAN network and an introduction of the main parameterization which can be applied on each network element to apply a consistent QoS policy across all UTRAN interfaces (Iu, Iur and IuB).

The purpose of UTRAN QoS management is to ensure the QoS and to provide differentiated services (noted as DiffServ from now on) to maximize the number of satisfied users.

Following a Core to Node B description order, as per Figure 33, the basic procedure for QoS management is as follows:

1) CN sends the related QoS parameters to the RNC on the Iu interface.

2) According to the QoS management strategy, the RNC maps the QoS parameters to the parameters that can be used by the UTRAN, and then, the RNC shares part of these parameters to the Node B.

3) Based on these parameters and the QoS management strategy, the RNC and Node B perform resource allocation and management tasks, such as Radio Resource Management (RRM), Transmission Resource Management (TRM) and DiffServ for different users based on their subscription profiles.

3.1.5 Overview of different levels of QoS

An End-to-End (referred to as E2E from now on) service implies that the communication takes place from one Terminal Equipment (TE) to another. The user of network services is provided with a QoS and it is the user who decides whether QoS is acceptable or not. A bearer service, with clearly specified characteristics and functionalities, is to be set up from source to destination to meet the network QoS requirement. The layered architecture of UMTS bearer service is shown in Figure 34. Bearer services provide QoS based on services provided by the immediate layer below.

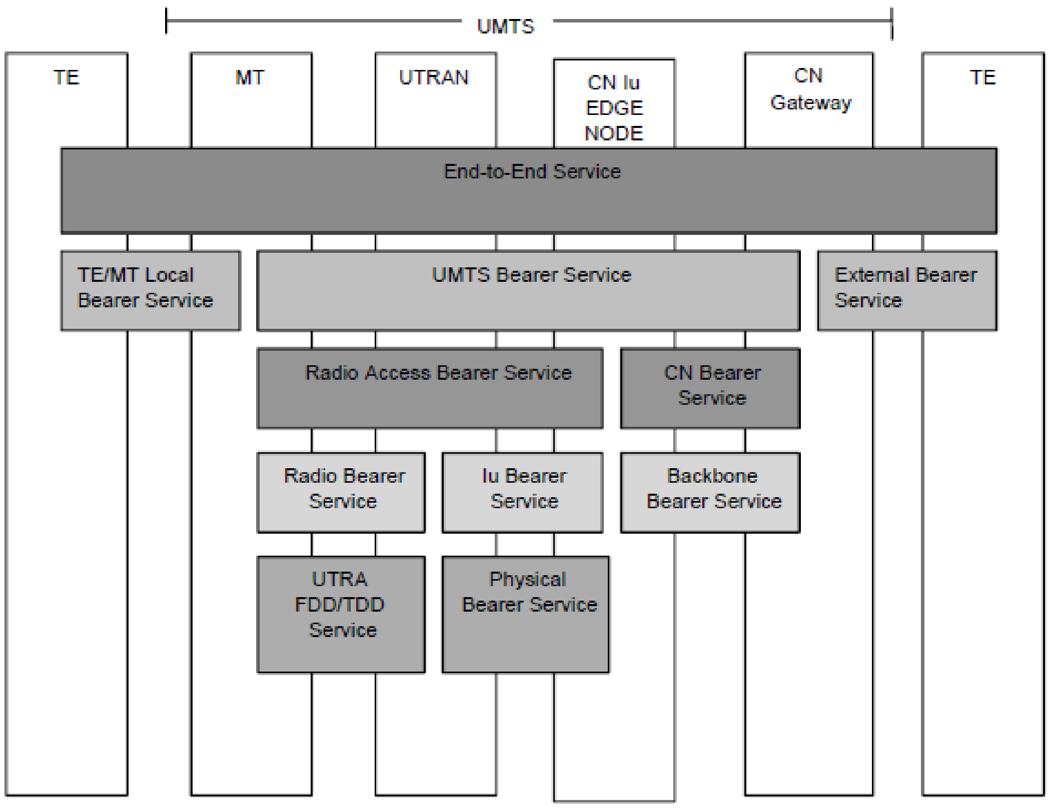


Figure 34. UMTS QoS Architecture [3GPP TS 23.107 version 4.1.0 Release 4]. Each bearer service on a specific layer offers its individual services using services provided by the layers below.

E2E Service and UMTS Bearer Service

As shown in Figure 34, the E2E service layer is the topmost layer of the QoS architecture. It makes communication possible from one TE to the other. It is depictured that a TE is connected to the UMTS network by means of a Mobile Termination (MT). The E2E services used by a TE will be realized by the layers below, namely TE/MT local bearer service, a UMTS bearer service and external bearer service. The UMTS operator offers services provided by the UMTS bearer service. Thus UMTS bearer service provides the UMTS QoS.

Radio Access Bearer Service and Core Network Bearer Service

The UMTS Bearer service is comprised of two parts which are the Radio Access Bearer service and the Core Network Bearer service. Both these services take care of the Bearer service over the network topology, taking into consideration attributes such as mobility and mobile subscriber profiles. The Radio Access Bearer Service makes provision for the transport of signaling and user data between MT and Core Network (CN) Edge Node with QoS adequate to the negotiated UMTS bearer service or with default QoS for signaling.

The CN Bearer Service of the UMTS core network connects the UMTS CN Edge Node with the CN Gateway to the external network. This service controls and utilizes the backbone network efficiently in order to provide the contracted UMTS bearer service.

Radio Bearer Service and RAN Access Bearer Service

The Radio Access Bearer Service is supported by a Radio Bearer (RB) Service and a RAN Access Bearer Service. The RB Service covers all aspects of the radio interface transport. To support unequal error protection, RAN and MT have the ability to segment/reassemble the user flows into the different subflows requested by the Radio Access Bearer Service. The segmentation/reassemble is given by the Service Data Unit (SDU) payload format signaled at Radio Access Bearer establishment.

Backbone Network Service

The CN Bearer Service uses a generic Backbone Network (BN) Service. The BN Service covers the layer 1/layer 2 functionality and is selected according to the operator’s choice in order to fulfill the QoS requirements of the CN Bearer Service.

3.1.6 UMTS QoS Classes and Attributes

QoS Classes

There are four different QoS classes, namely:

- Conversational class
- Streaming class
- Interactive class
- Background class

The main differences between these QoS classes are how delay sensitive the traffic is. Conversation class is meant for very delay sensitive traffic, whereas Background class is the most delay insensitive class.

Conversational and Streaming classes are used to serve real-time traffic flows which are very sensitive to delay. Examples of conversational and streaming classes include real-time services like voice services, video telephony and data streams.

Interactive and Background (also called best-effort) classes are mainly meant for applications such as World Wide Web (WWW), e-Mail, FTP, instant messaging services, etc… Since these classes are less delay sensitive compared to conversational and streaming, both provide better error rate by means of enhanced channel coding techniques and retransmissions. This means that packet retransmission is done whenever packet error/packet loss/packet order mismatch occurs. The reason is that these classes are delay insensitive but expect high throughput and less error rates. The main difference between Interactive and Background class is that Interactive class is mainly used for applications like interactive e-Mail and interactive Web browsing, while Background class is meant for background traffic, e.g. background e-Mail download or background file downloading. The scheduling algorithm gives more priority to interactive class than background; therefore, background applications use the transmission resources only when the interactive applications do not need them.

Traffic class	Conversational class conversational RT	Streaming class streaming RT	Interactive class Interactive best effort	Background Background best effort
Fundamental characteristics	- Preserve time relation (variation) between information entities of the stream Conversational pattern (stringent and low delay)	- Preserve time relation (variation) between information entities of the stream	- Request response pattern - Preserve payload content	- Destination is not expecting the data within a certain time - Preserve payload content
Example of the application	- voice	- streaming video	- Web browsing	- background download of emails

Table 14. UMTS QoS Classes [3GPP TS 23.107 version 4.1.0 Release 4].

Conversational Class

Applications which use this class include telephony speech, voice over IP and video conferencing. Real-time conversation is always performed between humans and so this is the only scheme where the required characteristics are strictly given by human perception.

Real-time conversation scheme is characterized by that the transfer time should be low because the conversational nature of the scheme and at the same time the time variation between information entities in the stream should be preserved in the same way as for the real time streams. The maximum transfer delay is dictated by how much delay the humans can tolerate for audio and video. Therefore, the bounds for acceptable transfer delay are very stringent, and if transfer delay is not low enough then it affects the quality. The transfer delay should be lower and stringent than the round trip delay for this class.

Streaming Class

Applications for this class includes listening to or looking at real time video (or audio). This scheme is characterized by that the time variations between information entities (sample packets) within a flow shall be preserved, although it does not have any requirements on low transfer delay.

Interactive Class

Applications for this class include Web browsing, database retrieval, server access, etc… Interactive traffic is a communication scheme which is characterized by the request-response pattern of the end user. Round trip delay and low error rate are the most important attributes for this class.

Background Class

This is a service class in which the applications run in the background. E-Mail program running in the background is an example for this kind of service (it sleeps for most of the time and wakes up when email arrives). Other examples include instant messaging, FTP downloads, etc… Background traffic is characterized by that the destination is not expecting the data within a certain time. Thus this class is less delay sensitive, but the contents should be delivered with low error rate.

Finally, the main QoS attributes are presented.

QoS Attributes

UMTS bearer services attributes describe the service provided by the UMTS network to the user of the UMTS bearer service. A set of QoS attributes (QoS profile) specifies this service. Below is a list with the main attributes:

- ***Maximum bit rate (kbps)*****:** MBR is defined as the maximum number of bits delivered by the UMTS and to the UMTS at a Service Access Point (SAP) within a period of time, divided by the duration period. The maximum bit rate is the upper limit a user or application can accept or provide. The purpose of this attribute is:

  - To limit the delivered bit rate to applications or external networks with such limitation; and

  - To allow maximum user bit rated to be defined for applications able to operate with different rates.

- ***Guaranteed bit rate (kbps):*** GBR is defined as the guaranteed number of bits delivered by UMTS at a SAP within a period of time (provided that there is data to deliver), divided by the duration period. The purpose of this attribute is to describe the bit rate the UMTS bearer service shall guarantee to the user or application.

- ***Delivery order:*** it indicates whether the UMTS bearer shall provide in-sequence SDU delivery or not. The purpose of this attribute is to know whether out-of-sequence SDU is allowed or not.

- ***Maximum SDU size (octets):*** it is defined at the maximum SDU size for which the network shall satisfy the negotiate QoS. The purpose of this attribute is that it is used for admission control and policing optimization transport.

- ***SDU format information (bits):*** it defines the list of possible exact sizes of SDUs.

- ***SDU error ratio:*** it indicates the fraction of SDUs lost or detected as error packets. SDU error ratio is defined only for conforming traffic, so it is used to configure the protocols, algorithms and error detection schemes.

- ***Residual bit error rate:*** it indicates the undetected bit error ratio in the delivered SDUs. If no error detection is requested, Residual bit error ratio indicates the bit error ratio in the delivered SDUs. The purpose is that it is used to configure radio interface protocols, algorithms and error detection coding.

- ***Delivery of erroneous SDUs*****:** it indicates whether SDUs detected as erroneous should be delivered or discarded. This is used to decide whether error detection is required or not and also whether frames detected as errors should be thrown or not.

- ***Traffic delay (ms):*** it is defined as the maximum delay for 95^{th} percentile of the distribution of delay for all delivered SDUs during the lifetime of a bearer service, where delay for an SDU is defined as the time from request-to-transfer an SDU at one SAP till it is delivered at the end point SAP.

- ***Traffic Handling Priority (THP):*** THP specifies the relative importance of handling of all SDUs belonging to the UMTS bearer compared to the SDUs of other bearers.

- ***Allocation/Retention Priority (ARP):*** ARP specifies the relative importance compared to other UMTS bearers for allocation and retention of the UMTS bearer. The ARP attribute is a subscription attribute which is not negotiated from the mobile terminal.

These QoS parameters are sent by the CN to the UTRAN on the Iu interface when the service is set up. Based on these QoS parameters, the UTRAN allocates appropriate radio resources to users to ensure the QoS, user fairness, and DiffServ.

As it will be shown in the test case, THP and ARP policies are used to establish differentiation within interactive class bearers and between interactive and background class bearers.

Table 15 shows the relationship between bearer traffic class and bearer traffic attributes.

Traffic class	Conversational class	Streaming class	Interactive class	Background class
Maximum bitrate	X	X	X	X
Delivery order	X	X	X	X
Maximum SDU size	X	X	X	X
SDU format information	X	X		
SDU error ratio	X	X	X	X
Residual bit error ratio	X	X	X	X
Delivery of erroneous SDUs	X	X	X	X
Transfer delay	X	X		
Guaranteed bit rate	X	X		
Traffic handling priority			X	
Allocation/Retention priority	X	X	X	X

Table 15. QoS UMTS bearer attributes defined for each bearer traffic class Classes [3GPP TS 23.107 version 4.1.0 Release 4].

Now that the reader has a better understanding of QoS concept, the chapter continues with a more detailed overview of how this concept is implemented in a UMTS network and which are the available mapping mechanisms across the different network elements and interfaces within the UMTS Radio Access Network, prior to a more detailed explanation of *QoS Awareness HSPA Scheduling* test case, which is focused on how to prioritize non-real time traffic users on the Uu interface.

3.1.7 UTRAN QoS Mapping Mechanism

As it was shown in the introduction (Figure 33), CN QoS parameters are mapped to UTRAN QoS parameters. All these parameters ensure the QoS of the services provided for users.

The inputs of the QoS mapping are CN QoS parameters and the outputs are both radio QoS parameters and transport QoS parameters. This mapping is implemented by the RNC.

The output of the QoS mapping is applied in the related functions of the RNC, sharing the Node B parameters over IuB interface.

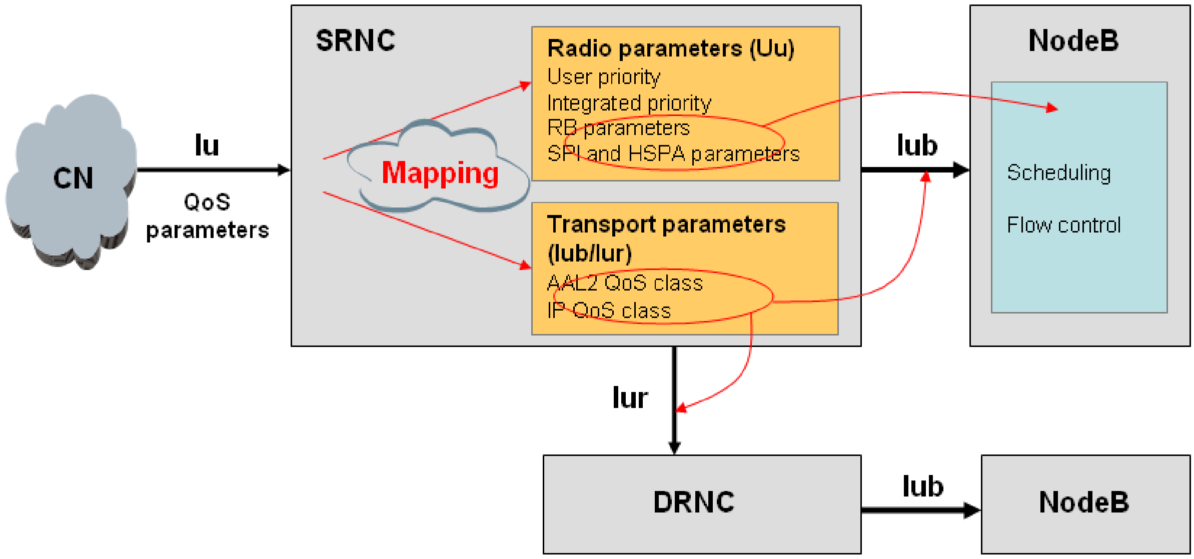


Figure 35. UMTS QoS mapping mechanism. Note that, at RNC level, CN QoS parameters are mapped into Radio and Transmission. This is because scarcity may appear in both kinds of resources; hence QoS policy has to be consistent at both radio and TX layers. It is also highlighted which parameterization might apply to the Node B, being SPI and HSPA parameters a first approach to the feature under test in this chapter.

Uu Radio QoS Mapping

Uu, which is the air interface, radio QoS parameters are used to manage the radio resources on the Uu interface. This mapping is implemented by the RNC and comprises different procedures:

- RAB-to-RB Mapping
- User Priority Mapping
- RAB Integrated Priority Mapping
- HSPA SPI Mapping and GBR Mapping

RAB-to-RB Mapping

The RAB setup request initiated by the CN carries the QoS parameters, describing QoS requirements. Based on these parameters, the RNC selects the appropriate RB parameters, such as the bearer channel type, channel parameters, RLC mode, data transmission parameters and power control parameters. The RB parameters provide the basic configuration information about the RB service. Part of this information is sent to the Node B on the IuB interface.

RAB-to-RB mapping considers all the QoS parameters of the CN.

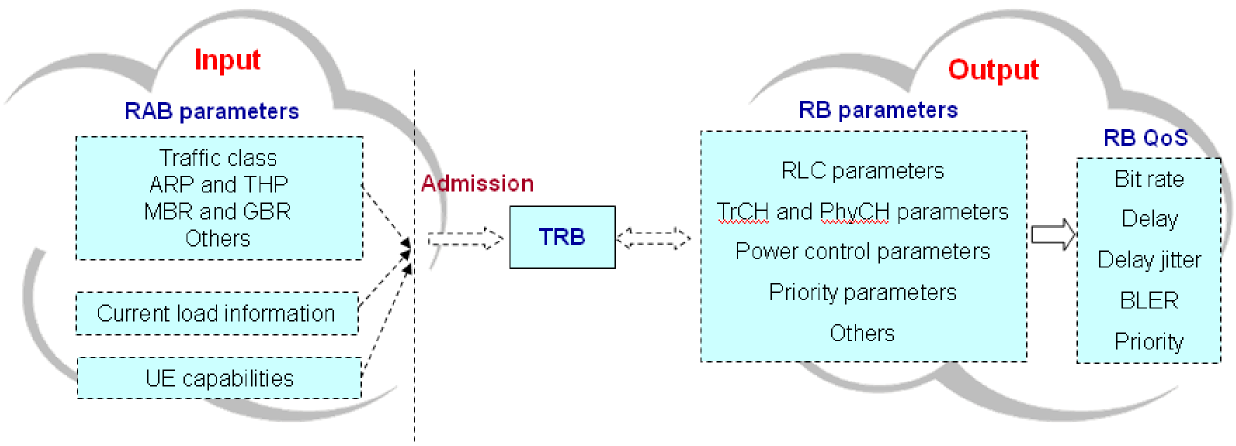


Figure 36. RAB-to-RB mapping. Here it is depictured the different parameters shared between the CN and the RNC related to QoS. TRB stands for Traffic Radio Bearer, and contains the already mapped RB parameters to be shared between RNC and Node B, including Qos parameters (noted as RB QoS). Note that this information sharing is a key part of the admission control checks when establishing a Radio Access Bearer Service.

User Priority Mapping

The allocation/retention priority (ARP) reflects the subscribed priority. Based on the ARP, UTRAN can provide DiffServ for users with different priorities, that is, with different tariffs.

User priorities in the UTRAN are classified into gold, silver and copper. The mapping from ARP values to user priorities can be configured by the telecom operator, but usually follows the mapping shown in Table 16.

ARP value	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
User priority	Gold	Gold	Gold	Gold	Gold	Silver	Silver	Silver
ARP value		**9**	**10**	**11**	**12**	**13**	**14**	**15**
User priority		Silver	Silver	Copper	Copper	Copper	Copper	Copper

Table 16. User Priority Mapping. ARP values range from 1 to 15. In the test case, however, RAN software version only allowed up to 12 values.

RAB Integrated Priority Mapping

The RAB integrated priority is used for access control and load control by the RNC. In case of congestion or resource insufficiency, services with a higher priority are processed first.

For each service of a user, a priority mapping is performed considering the following order of factors: traffic class, ARP, THP and bearer type. In turn, each factor has multiple values which are also sequenced as shown in Figure 37.

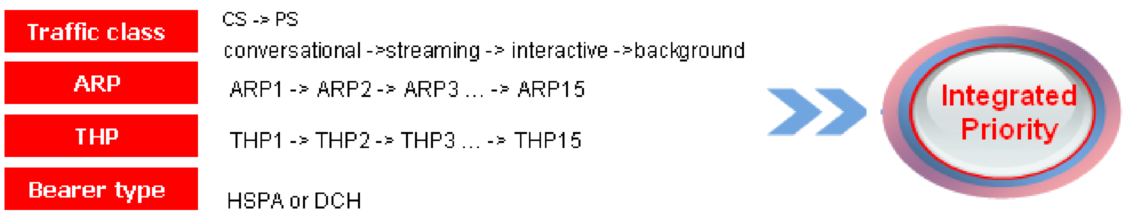


Figure 37. RAB Integrated Priority Mapping.

HSPA SPI Mapping and GBR Mapping

The Scheduling Priority Indicator (SPI) informs about the priority of a RAB. It is used for resource allocation during HSPA scheduling and flow control. The SPI mapping considers the traffic class, user priority and THP as it will be shown in the test case.

Based on the SPIs and user rate, the SPI weights can be determined to provide DiffServ for HSPA users. Generally, a user with the highest SPI weight obtains the required QoS first when the resources are insufficient and has more chances of being scheduled when the resources are sufficient. In this way, the user experience is improved. Table 17 shows the SPI mapping.

Traffic Class	User Priority	THP	SPI
SRB	NA	NA	15
IMS Signaling	NA	NA	14
Conversational	Gold	NA	13
	Silver		13
	Copper		13
Streaming	Gold	NA	12
	Silver		12
	Copper		12
Interactive	Gold	1	10
	Gold	2	9
	Gold	3 ~ 15	8
	Silver	1	7
	Silver	2	6
	Silver	3 ~ 15	5

Traffic Class	User Priority	THP	SPI
	Copper	1	4
	Copper	2	3
	Copper	3 ~ 15	2
Background	Gold	NA	8
	Silver		5
	Copper		2

Table 17. SPI mapping. SPI mapping considers Traffic Class, User Priority and THP.

The CN does not set the GBRs for interactive and background class. To provide the basic rates for these two classes, the RNC supports GBR setting. GBRs vary with user priorities.

Direction	Gold	Silver	Copper
Downlink	256 kbit/s	128 kbit/s	64 kbit/s
Uplink	256 kbit/s	128 kbit/s	64 kbit/s

Table 18. GBR mapping to User Priority. According to the QoS to be offered to non real time services, GBR might be set for both interactive and background class. GBR is configured according to User Priority, Traffic Class, THP and bearers (R99/HSPA).

Once the SPI and GBR mapping are performed by the RNC, the results are sent to the Node B over IuB interface, which will be used as inputs for the air interface scheduling algorithm.

Transport QoS Mapping on IuB/Iur interfaces

IuB and Iur transport networks can be differentiate data packets based on their priorities and then provide DiffServ. The main task of the IuB/Iur transport QoS mapping is to match different services of different users to appropriate QoS classes so that different services on the IuB and Iur interfaces can obtain different QoS. This mapping is performed, again, by the RNC through the Radio Link (RL) setup procedure.

Depending on the transport mode used in the transmission network, IuB/Iur transport QoS mapping consists of:

- Service Mapping over ATM
- Service Mapping over IP

These two transport modes will be described in the next chapter, where ATM-to-IP transmission evolution is analyzed.

Service Mapping over ATM

ATM Adaptation Layer Type 2 (AAL2) QoS classes of ATM support the transport bearers with the following rates:

- Committed bit rate (CBR)
- Real-time variable bit rate (RT-VBR)
- Non-real-time variable bit rate (NRT-VBR)
- Unspecified bit rate (UBR)
- Unspecified bit rate with a guaranteed bit rate (UBR+)

Transport bearers of different types provide different QoS. If the IuB transport network uses the ATM mode, the mapping from services to AAL2 QoS classes can be configured by the telecom operator. The mapping considers the traffic class, THP only for interactive traffic class, CN domain type and RB type. Generally speaking, real-time services are mapped to high-priority queues to obtain higher QoS on the transport network. Figure 38 shows service mapping over ATM.

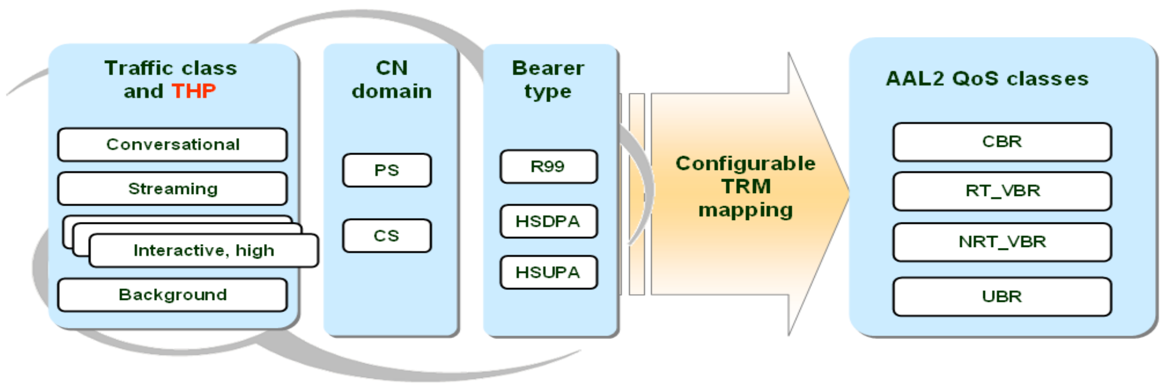


Figure 38. Service mapping over ATM process is part of Transmission Resource Management (TRM) procedure.

Service Mapping over IP

In the DiffServ model of the IP transport network, the IP QoS classes are:

- Expedited Forwarding (EF)
- Assured Forwarding 1 (AF1)
- Assured Forwarding 2 (AF2)
- Assured Forwarding 3 (AF3)
- Assured Forwarding 4 (AF4)
- Best Effort (BE)

The priority of an IP queue is identified by the Differentiated Service Code Point (DSCP) in the header of an IP packet; hence queues with different priorities can obtain different QoS. An in-depth overview about IP prioritization is provided in the next chapter, where IuB over IP is analyzed.

If the IuB transport network uses the IP mode, the mapping from services to IP QoS classes can be configured by the telecom operator. The mapping considers the traffic class, THP only for interactive class, CN domain type and RB type.

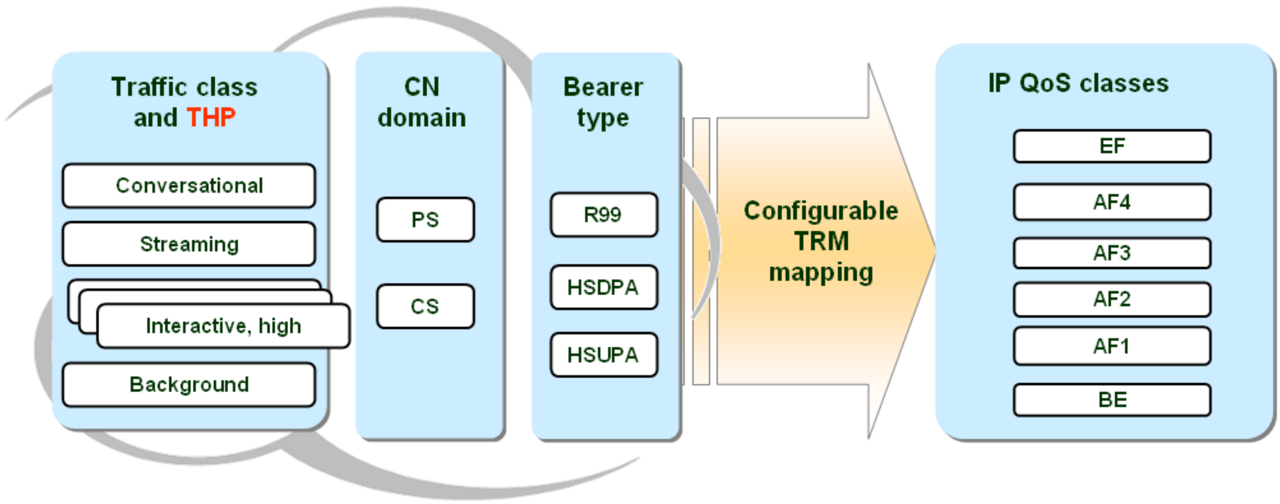


Figure 39. Service mapping over IP process is part of Transmission Resource Management (TRM) procedure.

Once QoS mapping mechanism has been understood, the chapter continues with an explanation of UTRAN QoS management.

3.1.8 UTRAN QoS Management

Overview

During this section it has been introduced that QoS management strategy is to try its best to ensure the QoS for each user and to provide DiffServ for different users; therefore meeting the requirements of more users.

Such strategy is implanted by the specific functions. From the beginning of the service setup, RB function, rate control, power control and handover are performed for the user to ensure QoS and service continuity. In addition, features such as load control, HSPA scheduling and IuB flow control are performed among different users for resource allocation to provide DiffServ and maximize system capacity. Power control, handover and load balance are out of the scope of this document, but just for the awareness of the reader, these other features can be used for QoS assurance completion. For example, to handle congestion in massive events (stadiums, concerts…) it is very common that mobility load balance strategies are implemented on top of the mechanisms explained here in, based on the automatic redirection of users to less loaded cells, both intra or inter Node B.

Figure 40 shows the UTRAN QoS management mechanism.

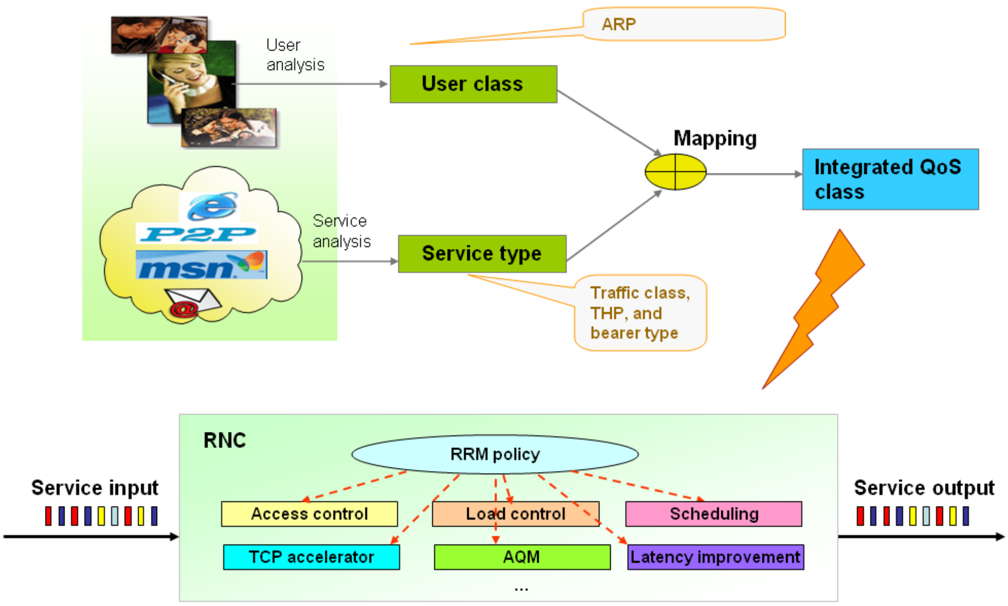


Figure 40. UTRAN QoS Management. Thinking on an E2E vision, the system embraces both user class and service type concepts and creates an integrated QoS class. The RNC, in turn, will adapt its Radio Resource Management (RRM) features – Access Control, Load Control, Scheduling, TCP accelerator, Access Queue Management, Latency Improvement – according to the QoS policy.

How can be the QoS guaranteed for a single user?

Single user Qos can be guaranteed by implementing a series of functions. One purpose is to ensure the user requirement for its basic QoS by carrying the user services on the appropriate channels and setting corresponding parameters. The second purpose is to ensure service continuity by monitoring the link quality when the user is in mobility conditions. So it can be said that there are two phases in this process:

- QoS guarantee during service setup
- QoS guarantee after service setup

Guaranteeing QoS during Service Setup

The functions to be performed for guaranteeing QoS during service setup are channel type selection and admission control.

When a service setup request is initiated, the RB function selects an appropriate channel type such as R99 or HSPA channel according to service attributes such as the traffic class and MBR. The R99 channel can provide an MBR of 384 kbps, requiring dedicated radio resources. In comparison, the HSPA channel can provide an MBR of 28.8 Mbps (3GPP Release 7) and even higher, according to technology development. The HSPA channel resources, though, can be shared and, therefore, the service rate may vary with the channel environment and the user priority. As a result, selecting an appropriate channel type based on the service attributes is an important step for guaranteeing QoS.

Once the channel type is determined, an appropriate cell needs to be selected to provide services. The admission control of each cell prevents the cell from being overloaded due to the admission of too many users. This function monitors the cell load, predicts the load increase after a new service is admitted and determines whether the admission will lead to an overload state. Admission control ensures the QoS of admitted services and the QoS of the new service after it is admitted. If a new user is rejected because the cell is overloaded, the new user will attempt to access another cell with the same coverage.

Guaranteeing QoS after Service Setup

The functions to be performed for QoS guarantee after service setup are as follows:

- **Power control:** After service setup, power control enables the user data to be transmitted with the appropriate power. It ensures correct data reception and at the same time avoids a bad usage of power resource.

- **Mobility management:** When the user moves to the cell edge, the QoS may degrade due to radio conditions. The handover function can direct the user to a more suitable cell in time to ensure the service continuity.
- **Rate Control:** If the service is set up on the DCH, the RNC can detect whether the transmit power for this user is limited in the uplink or downlink. If the transmit power is limited, the data transmission capability may be affected and call drop may occur. To ensure the QoS in this case, the system reduces the service rate or performs an inter-frequency or inter-RAT handover to select a more suitable cell.

- **HSDPA resource management:** If the service is set up on the HSPA channel, the HSPA scheduling function ensures that the user is able to obtain the basic QoS. For example, for a delay-sensitive service, this function ensures that the packet transmission delay is within an acceptable range; for a throughput-sensitive service, this function ensures that the rates provided are not lower than the GBR.

- **User experience improvement:** If the service is set up on the HSPA channel, the HSPA scheduling function ensures that the user is able to obtain the basic QoS. For example, for a delay-sensitive service, this function ensures that the packet transmission delay is within an acceptable range; for a throughput-sensitive service, this function ensures that the rates provided are not lower than the GBR.
    - For the voice, the de-jitter function can be applied in IP transport. When the IuB/Iur interface uses the IP mode, data packets may not be transmitted in sequence. In this case, the de-jitter function can restore the data transmission order and limit the transmission delay within an acceptable range.

    - For the TCP service, the RNC may have features such as TCP Performance Enhancer (TPE) and Active Queue Management (AQM) to improve QoS. TPE aims at a service with only one TCP connection and increases the data transmission rate at the TCP layer. AQM aims at a service with multiple TCP connections and improves the QoS of the TCP connections with a small amount of data.

How can be different services provided amongst different users?

The objective of DiffServ is to serve as many users as possible with limited resources; hence meeting the requirements of more users.

DiffServ Provision Principles

The DiffServ provision principles are as follows:

- Providing DiffServ for users with different priorities, with high-priority users being served preferentially.

- Providing DiffServ for services with different traffic classes:

    - A CS service has a higher priority than a PS service

    - Within PS services, delay-sensitive services have higher priorities than throughput-sensitive services.

    - Emergency services are always provided preferentially.

As seen before, the provision of DiffServ requires the mapping of the following parameters:

- ***User Priority:*** Different users have different priorities. The ARPs sent from the CN indicate the subscribed priorities. Based on the ARPs, users are classified into 15 priorities. In the UTRAN, users are classified into three priorities, namely gold, silver, and copper. Therefore, the user priority mapping is based on the ARP to provide DiffServ for users in the UTRAN.

- ***RAB integrated priority:*** this parameter is set on the basis of the RAB and with reference to the traffic class, user priority, THP and bearer type. It is used for the provision of DiffServ during Access Control (AC) and load control by RNC.

- ***SPI and SPI weight:*** The SPI is used to indicate the priority of each HSPA service. The SPI weight is determined on the basis of the SPI and used to provide the HSPA DiffServ.

DiffServ Provision

DiffServ provision is described as follows:

- **DiffServ provision during service setup:** During channel type selection, the processing is based on service attributes. Generally, CS services have stable rates and a high requirement for low delay. Therefore, they are carried on the R99 channel to use dedicated radio resources and to obtain required bandwidths. In comparison, PS services usually have a huge amount of data to transmit in burst mode. Therefore, they are carried on the HSPA channel to improve the resource sharing degree and to ensure the basic QoS.

  During admission control, the provision of DiffServ is based on traffic classes. Compared with PS services, high-priority CS services such as the AMR voice service have lower admission limits and higher access success rates.

  If the service admission fails, a service with a higher integrated priority can preempt the resources of a service with a lower integrated priority to increase the access success rate. Whether the integrated priority considers the traffic class first or the user priority first can be determined by the telecom operator. Generally, it is recommended that the traffic class be considered first. Therefore, CS services can have higher integrated priorities than PS services and can preempt the resources of PS services. In this way, the access probability can be increased and the overall user satisfaction can be improved.

  During admission control, emergency services are assigned the highest priority and therefore they have the highest access success rate.

- **Congestion control after service setup:** If the system enters the basic congestion state, there are two methods for ensuring the system stability. One is to decrease the rates of admitted users by reserving resources for new services. The other is to reduce the cell load by performing operations such as handover. If the system enters the overload state, it terminates the services of some users to reduce the load rapidly. Users with low integrated priorities are preferentially selected for congestion relief to ensure the overall QoS of the cell.

Whether the integrated priority considers the traffic class first or the user priority first can be determined by the telecom operator. It is recommended that the traffic class be considered first. Therefore, CS services can have higher priorities than PS services and delay-sensitive services can have higher priorities than throughput-sensitive services within PS services. In this way, the impact of congestion control on user experience can be reduced.

As the reader can imagine, during congestion control, emergency services are not selected for congestion relief.

HSPA DiffServ Provision

DiffServ HSPA resources are shared among multiple users. PS services are usually carried on the HSPA channel. In R8, the CS AMR voice service can also be carried on the HSPA channel.

HSPA scheduling and flow control determine the resource allocation among users in real time. During resource allocation, both service-based DiffServ and user-based DiffServ can be provided.

- **Serviced-based DiffServ provision:** Services carried on the HSPA channel are classified into delay-sensitive services and throughput-sensitive services. They are listed in Table 19.

Type	Delay-sensitive service	Throughput-sensitive service
QoS	Low traffic volume Short acceptable delay	High traffic volume High throughput
Service	Signaling VoIP service CS AMR service	Streaming service Interactive service Background service IMS signaling

Table 19. HSPA Service classifications

For different services, different QoS is provided. For example, for a delay-sensitive service, the scheduling function limits the packet transmission delay within an acceptable range; for a throughput-sensitive service, this function ensures that provided rates are not lower than the GBR. Users are more sensitive to the QoS of delay-sensitive services. Therefore, the requirement for this kind of QoS is met first during scheduling.

3GPP TS 23.107 defines only four traffic classes, which cannot fully reflect the requirements for QoS. For example, a Web page may contain video streams in addition to texts and pictures. All of email, video website browsing, and Bit Torrent (BT) download may be mapped to the background class, but they have different QoS requirements. After service setup, the RNC can further identify and classify the traffic classes and attributes and then provide appropriate QoS to improve user experience.

- **User-based DiffServ provision:** User-based DiffServ is mainly aimed at throughput-sensitive services. The provision is described as follows:
    - The CN does not set the GBRs for the interactive class and background class. The RNC, however, can set the GBRs based on user priorities. The HSPA scheduling function ensures that users with different priorities obtain different GBRs.

    - The RNC can also set Happy Bit Rate (HBR) which determines the throughput expected by the user based on a study on user experience. When the rate for a user reaches the HBR, the scheduler decreases the scheduling probability for the user.

    - The SPI weight is set on the basis of the SPI and user rate range, and the SPI considers both the user priority and the traffic class. The SPI weight is always used in throughput-sensitive services. Users with higher SPI weights have more chances to obtain required resources and satisfied user experience.

Now the reader is in a position to understand the following test case, based on a lab test simulation of HSPA Scheduling feature and the QoS guarantee when the scarce resource is found at transmission level (air interface congestion was harder to be simulated due to a limitation in the number of UEs).

3.2 Feature Validation

3.2.1 Feature description

QoS Aware HSPA Scheduling allows service and subscriber differentiation for HSPA NRT traffic classes.

The feature supports different tariff plans for NRT traffic classes: premium services and subscribers can have higher priority over low tariff broadband HSDPA data traffic.

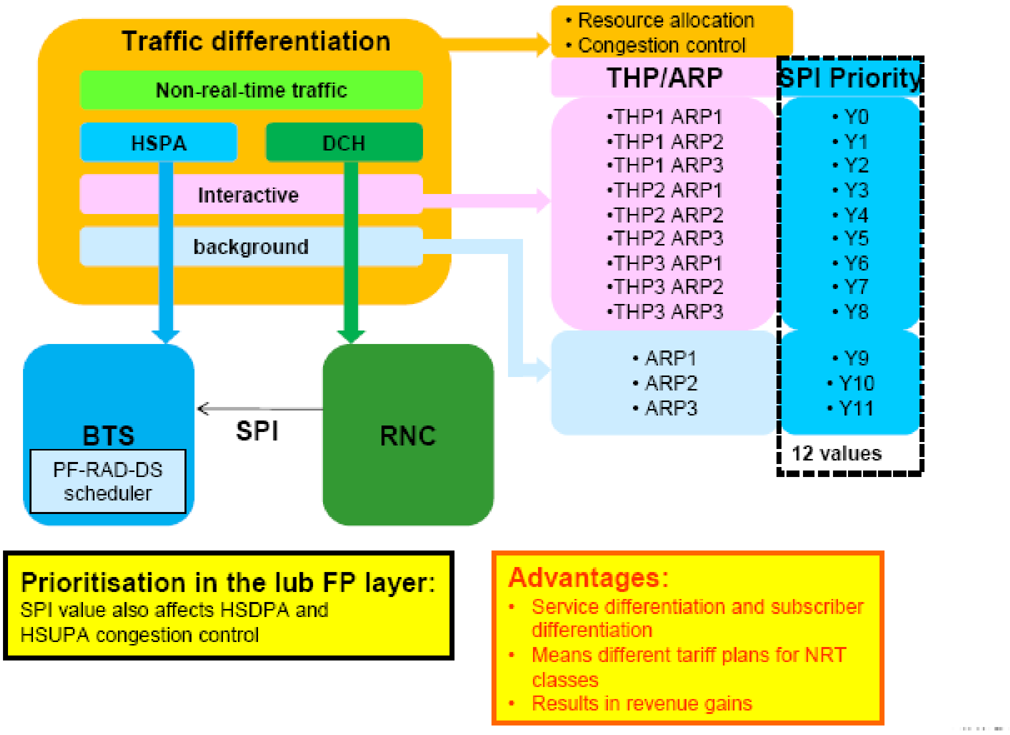


Figure 41. Service QoS Aware HSPA Scheduling feature – key highlights.

The diagram presented in Figure 41 summarizes the concepts involved in HSPA scheduling which have been reviewed in the previous sections: a customized differentiation strategy can be applied to non-real-time traffic by modeling the network resource allocation and congestion control mechanisms. As explained before, this modeling consists of mapping a given traffic class (plus its corresponding THP/ARP parameters) into different Service Priority Indicators (SPI) which are taken into account by HSPA packet schedulers within the Node B.

These schedulers weight different priority queues based on their SPI values. There is a weight value per SPI on the Node B, which sets the magnitude for how often queues of different SPI classes are scheduled in relation to other SPI classes. Note that in the introduction chapter, 15 SPI values have been introduced. However, due to RAN software limitations, the test case reflects only the mapping for 12.

Usually, HSDPA uses Proportional Fair Resource Packet Schedules (PFR). However, to support this feature a new scheduler type is implemented: Proportional Fair Required Activity Detection with Delay Sensitivity (PF-RAD-DS), which will be explained hereunder.

PFR vs. PF-RAD-DS

The Proportional Fair Resource (PFR) algorithm utilizes the radio channel state information from the UEs in its scheduling decisions. The PFR principle is to maximize the relative instantaneous channel quality (ratio of instantaneous throughput to average throughput) for scheduling in the following 2ms TTI. The relative instantaneous channel quality is calculated every 2 ms TTI using the Channel Quality Indicator (CQI) information reported by the UE and the information from previous transmissions.

Scheduling metric for each UE is calculated every TTI as follows:

$$\textit{Scheduling metric} = TP_{inst} / TP_{mean}$$

where TP_{inst} is the predicted throughput of priority queue for the TTI being scheduled and TP_{mean} is the mean throughput of the priority queue in the past. TP_{mean} is decreased when priority queue is not scheduled and increased otherwise. It is calculated over 100 TTIs if nothing prevented the scheduling of the priority queue.

With this method a user is prioritized if it has good instantaneous conditions compared to the average level or has been served with little throughput in the past.

At each scheduling interval of 2ms, Packet Scheduler selects the user which has the best scheduling metric among users that can be scheduled in the next TTI.

On the other hand, PF-RAD-DS modifies the scheduling metric of the actual PFR scheduler by scaling it according to the QoS parameters. As it has been explained before, these QoS parameters are shared between Node B and RNC.

The QoS parameters communicated between RNC and Node B via NBAP message in order to setup the queue priority are Guaranteed Bit Rate (GBR) or Nominal Bit Rate (NBR), Scheduling Priority Indicator (SPI) and Discard Timer (DT).

The QoS parameters managed exclusively by the WBTS are the Scheduling Weight and the Congestion Control for each SPI.

Scheduling Priority Indicator and Scheduling Weights

The operator can prioritize the traffic of different characteristics by configuring a mapping from RAB parameters (Traffic Class, Traffic Handling Priority, Allocation Retention Priority) into SPI values to the RNC.

The Node B uses the SPI value (range 0…15) to select which Scheduling Weight (range 0…100) to apply for each priority queue and to control which users are served in resource limited situation. Higher priority users are served first. The weights are used to control how often priority queues of different priorities are scheduled in relation to each other. Proportion is defined with factor:

$$SchWeight(SPI_N)+\sum SchWeight(SPI_{DATA})$$

where SchWeight (SPI_N) is the weight of class N and ∑SchWeight (SPI_{DATA}) is the sum of weights from queues with data.

For example, if background class is mapped to SPI 0 and given weight 1 and interactive class is mapped to SPI 1 and given weight 2, then the SPI class 1 is scheduled twice as often as SPI class 0. Note that the scheduling rate depends also on the PFR metric, terminal capabilities and available data amount in priority queues.

Discard Timer

The DT defines the maximum time a MAC-d PDU of streaming traffic class is allowed to stay in Node B buffer before being scheduled or discarded. Node B uses the value to improve the scheduling metric of a priority queue as the expiration time for the packet approaches, eventually forcing the queue to be scheduled.

Since streaming traffic class is still not present in the network, DT will be an irrelevant parameter for the test.

Guaranteed Bit Rate, Nominal Bit Rate and Congestion Control policy

Node B uses GBR to ensure that priority queue is scheduled at least as often as it is needed to fulfill the GBR requirement. Scheduling rate of GBR/NBR queues is determined according to their required scheduling activity:

$$Activity = \frac{GBR}{Tsch}$$

where GBR is in bits per 2 ms TTI and T_{sch} is the average transport block size of the priority queue.

For example, in the situation of:

- HS-PDSCH codes in a cell
- 1 User scheduled per TTI
- UE category 6 (maximum amount of bits per TTI is 7298 bits)
- Guaranteed Bit Rate of 384 kbps (768 bits per 2ms TTI)

in optimal radio conditions UE needs to be scheduled 384000/7298 = 52.6 TTIs.

If the cell has capacity left after GBR and NBR queues, the scheduler allocates the remaining capacity to all priority queues with data in buffers. This means that the activity is:

$$Activity = \frac{GBR}{Tsch} + SchWeight(SPI_N) + \sum SchWeight(SPI_{DATA})$$

The SPI classes with GBR need only a small weight, because the actual GBR parameter is used to calculate the needed scheduling rate of the priority queue. Any non-zero weights allocate additional capacity on top of GBR. This way, remaining capacity is distributed to other users.

GBR and NBR are configured in Node B by using the same information element present in the NBAP message received from the RNC, so they are treated similarly in the scheduler. The difference is that NBRs always have lower SPI than GBRs so the overload handling fulfils the NBRs only when GBRs do not use all available capacity.

The congestion control policy parameter can be used to define the treatment of each SPI class in case of IuB congestion.

Air interface overload control and prioritization

Admission Control in the RNC ensures that no more GBR queues are admitted into a cell than can be served in all available scheduling time.

However, after admission, a sudden increase in amount of AMR traffic can cause reduction of the capacity available for HSDPA. For NBR queues, no admission control is done, so the scheduling time requirement of GBR and/or NBR queues could exceed the total available scheduling time in a cell. The radio conditions could also change so that not all GBR and NBR queues can be served within the available scheduling time. For this reason, Node B performs fast overload control in order to satisfy scheduling needs in SPI order. If lower priority queues do not fit into available scheduling time, fast overload control temporarily deprioritizes them in the scheduling.

Each TTI, the algorithm calculates a required activity factor for each priority queue, which the priority queue needs to be scheduled in order to fulfill the possible GBR or NBR requirement in current conditions.

The activity factor is used to control which priority queues are candidates to be scheduled in current TTI by summing the activity factors of all queues starting from the highest SPI class and within SPI class from queue having the lowest activity factor and comparing it to the maximum load. The lowest one is used instead of the highest to satisfy as many GBR queues as possible, while preventing one terminal in bad radio conditions from blocking all the other GBR queues. Queues without GBR or NBR are given zero activity factor and the remaining capacity is divided to those according to Scheduling Weights after satisfying GBR and NBR queues.

The RNC maps, according to the operator settings, the SPI from the RAB QoS parameters (TC, THP and ARP) and delivers it to the packet schedulers.

The SPI used in the RNC for resources required by the RAB is defined based on the RAB QoS parameters. In case of HS-DSCH and Enhanced uplink DCH (E-DCH) transport channels, the priority is also sent to the Node B as an SPI value.

Message flow

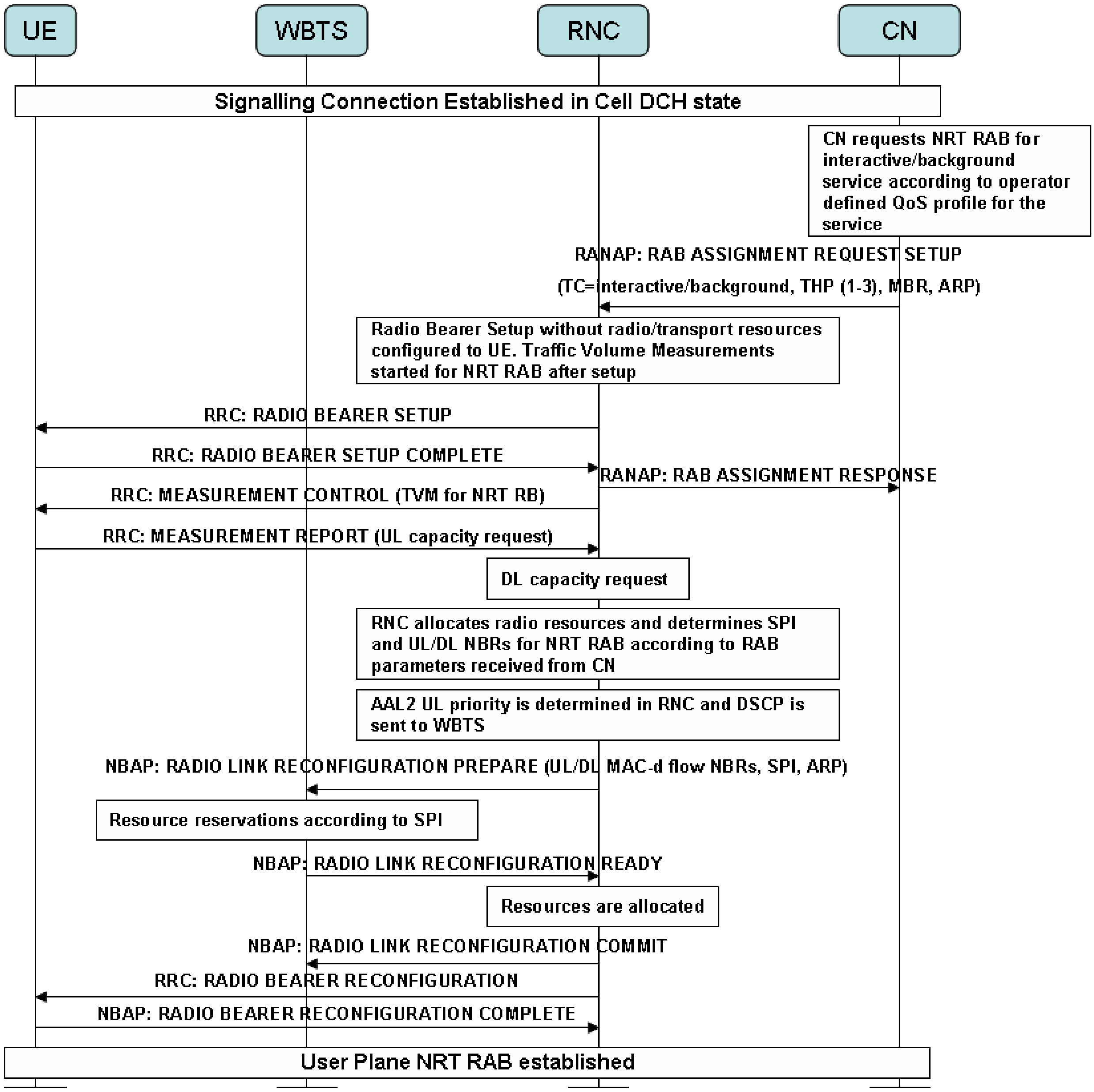


Figure 42. Relevant message flow between RAN and CN. WBTS represents the Node B network element.

The message flow in Figure 42 explains the different stages through which the Core Network and the RAN are synchronized to ensure a given QoS level at UE side:

1) The Core Network sends QoS associated parameterization (Traffic Class, THP & ARP) to RAN (RNC) via RAB ASSIGNMENT REQUEST SETUP message.

2) The RNC establishes the Radio Bearer with the UE (associated to its Radio Access Bearer) via RRC messaging and, once it guarantees the resource availability, the RNC accepts the assignment requests sent from the CN.

3) Once the UE starts the data download session, according to the Traffic Volume Measurement (TVM) reported by the UE and the transmission resource availability, RNC will trigger the resource prioritization phase:

   a. RNC communicates the SPI to WBTS within RADIO LINK RECONFIGURATION PREPARE message. Remember that SPI value is decided based on Traffic Class/THP/ARP mapping in RNC.

   b. WBTS checks whether air interface scheduling can be made according to SPI weight and confirms it with the RNC, which in turn, confirms the new resource allocation (RADIO LINK RECONFIGURATION READY / RADIO LINK RECONFIGURATION COMMIT).

   c. Finally the RNC communicates the UE the new Radio Bearer parameterization based on the new resource allocation. (RADIO BEARER RECONFIGURATION / RADIO BEARE RECONFIGURATION COMPLETE).

3.2.2 Purpose of validation

Purpose of this test case is to verify that *HSDPA QoS Aware Packet Scheduling* expected behavior is correct under different QoS priority and scheduling weight parameterization.

Basically, four different users are given different QoS parameters in order to achieve different kinds of traffic to be scheduled as explained in the previous section. UE behavior will be recorded before and after the activation of the feature for a latter post-analysis.

QoS Provisioning			
UE ID	**Traffic Class**	**THP**	**ARP**
UE1	Interactive NRT HSPA	1	1
UE2	Interactive NRT HSPA	2	2
UE3	Background NRT HSPA	-	1
UE4	Background NRT HSPA	-	2

Table 20. UE QoS provisioning. As far as service prioritization is concerned, UE1 > UE2 > UE3 > UE4.

As far as the procedure is concerned, each UE will perform the same 50 MB file FTP download from an FTP server in feature disabled/enabled scenarios under the same Radio Frequency (RF) conditions. A 5 second separation between the start of the different UE downloads will be beneficial to appreciate the throughput behavior.

During the download process, the following interfaces will be analyzed and recorded:

- Air Interface (Tool: NEMO Outdoor 4)
- IuB / IuPs (Nethawk M5 protocol analyzer)

Besides interface monitoring, UE achieved throughput will be monitored with the traffic measurement tool *NetPerSec*.

In each scenario, once the downloads are finished, tester will have to wait for the Radio Network Controller (RNC) to output the list of the counters involved, which are detailed in *Counters in 3.2.3*, before moving to the next scenario.

Finally, throughput, interface traces and counters analysis in each one of the proposed situations will bring to the final test conclusions.

3.2.3 Testbed configuration and settings

A detail of hardware and software levels required for the validation of this feature is included in this section as well as configuration of the correct parameters needed in WBTS and RNC.

In addition, it is detailed the procedure in order to allocate the correct QoS profiles for each user involved in the test.

Hardware Settings

3G RAN and Core Network Equipment	
RNC	Testbed RNC2 (RNC450 Step1 platform)
WBTS	UltraSite Outdoor Supreme (2+2+2, WCEL-1)
MSC	Testbed MSC M99
MGW	Testbed MGW W91
SGSN	Testbed Pre-prod SGSN
UE	
R99	Nokia N95, Samsung SGH630
Rel6	Huawei E270 data card

Table 21. RAN (RNC, WBTS), CN (MSC, MGW, and SGSN) and UE hardware involved in the test.

Software Settings

3G RAN	
RNC	RN4.0 Q4 1.15-0_41 + On Top Modules (RRC_QXQX.IMG and RRC_QXQX.IMG
OMS	R_OMS1_4.43.release_oms_corr17
WBTS	WN5.0 12.4-96_C
AXC	C5.5 BL6.0

Table 22. RAN Software level supporting QoS Aware HSPA Scheduling. AXC refers to the Nokia Siemens TX board in UltraSite base station. OMS refers to the Nokia Siemens O&M board in the RNC.

Test layout

The following testbed layout is required to execute the feature test. Note that 4 UEs will be introduced inside an RF box, connected to WBTS cell 1 by means of an RF jumper. Together with a variable attenuator, it helps to simulate the live network air interface radio conditions. The remaining network elements are divided into Radio Access Network (WBTS and RNC) and Core Network - Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN), which connects to an FTP server through a simulated backbone -. Note that only PS-domain Core Network is required due to the nature of the test.

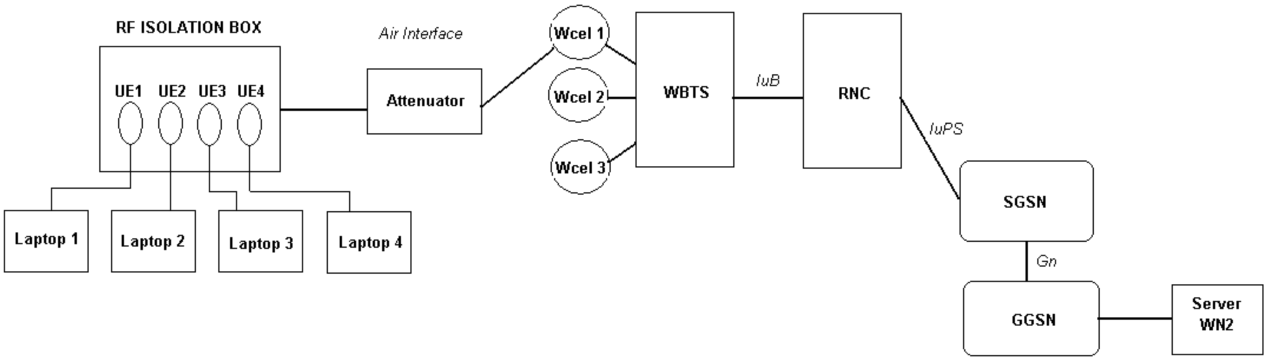


Figure 43. E2E scenario setup for the validation

Feature dependencies and activation

The following features have to be activated in advance in order to support this new feature implementation:

- Basic HSDPA with QPSK and 5 codes
- Dynamic HSDPA Transport Scheduling
- HSDPA Dynamic Resource Allocation
- HSDPA Code Multiplexing
- High Speed Uplink Packet Access (HSUPA)
- QoS Aware HSPA Scheduling

The activation of these features is explained in *Parameter Settings* in section 3.2.3

Feature license verification

In NSN software, each feature has an associated license which must be also activated so to implement the functionality. RNC is the RAN network entity which manages the license/feature activation.

The following Man Machine Language (MML) command will show the list of active licenses:

ZW7I:FEA,LIM:FSTATE=LIM;

Within the list of active licenses it should appear the one related to this feature, which is identified as **RU00236 HSDPA QoS Aware Scheduling.**

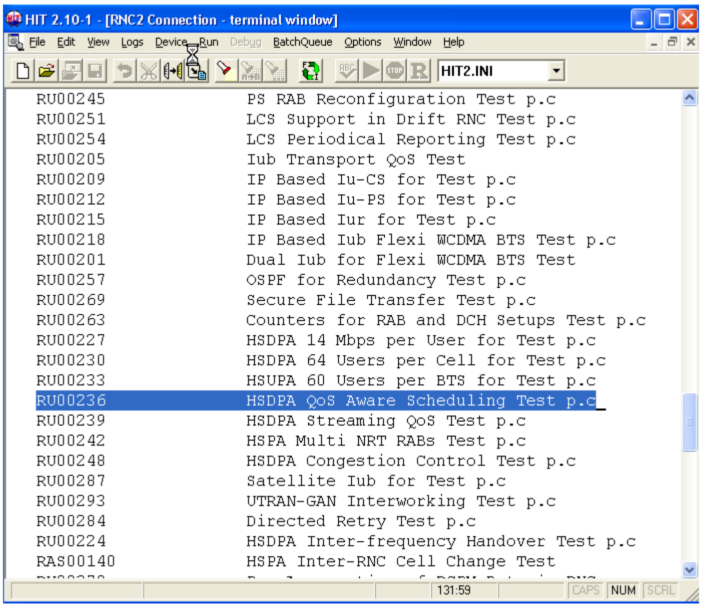


Figure 44. RNC MML ZW7I:FEA,LIM:FSTATE=LIM command outputs the list of features licensed in the RNC

To activate the feature related to this license, firstly it has to be checked whether the feature is deactivated or not, with the command **ZW7I:FEA,LIM:FSTATE=OFF;.** This command lists all the features along with their feature number, which will be necessary for the activation. Finally, it has to be introduced the command which will enable the feature: **ZW7M:FEA=1089:ON;**

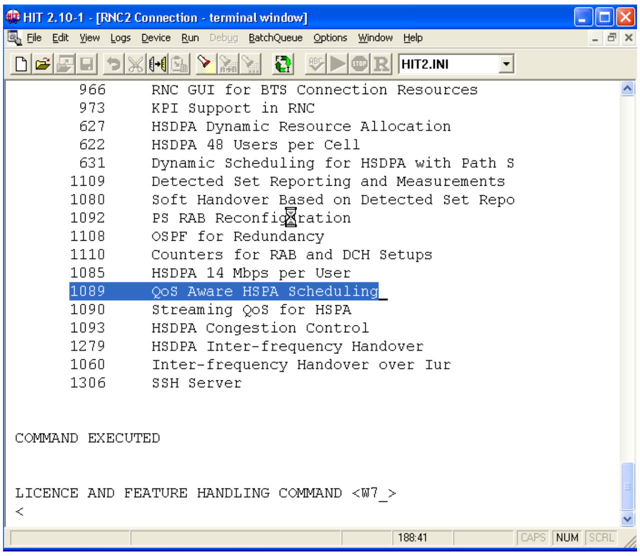


Figure 45. RNC MML ZW7I:FEA,LIM:FSTATE=ON command printout.

Parameter Settings

The following set of parameters has to be set prior to the beginning of the test case. Before each parameter, it is indicated the network entity where it is located:

Parameterization		
RAN element	**Parameter**	**Target Value**
WBTS	*HSDPAEnabled*	**Enabled**
WBTS	*HSUPAEnabled*	**Enabled**
WBTS	*HSPAQoSEnabled*	**Enabled**
WBTS	*HSPDSCHCodeSet*	**Use only 5 codes**
RNC	*HSDPADynamicResourceAllocation*	**Enabled**
RNC	*ARPWeight*	**Default**

Table 23. Parameter settings for the test. *HSDPAEnabled* and *HSUPAEnabled* activate HSPA functionality in the cell. *HSPAQoSEnabled* activates *Qos Aware HSPA Scheduling* feature in the cell. *HSPDSCHCodeSet = use only 5 codes* enables basic HSDPA code range. TX resource in the scenario under test will be limited, so a maximum 3.6 Mbps DL throughput will be enough. *HSDAPDynamicResourceAllocation* enables flow control in IuB Frame Protocol, which helps to mitigate packet retransmissions under TX congested scenarios. *ARPWeight* defines ARP specific weights that are used to calculate target transmission and receiving powers for NRT DCH connections (PrxTargetPS / PtxTargetPS). These target powers are used in HSDPA dynamic resource allocation functionalities. The UE specific weight is calculated by multiplying the traffic class specific weight with this ARP specific weight.

SPI values are set up for the different traffic classes taking into account their THP and ARP. Taking into account that SPI values in this software version ranges from 1 to 12 (lower to higher priority, reserved for signaling use) and the QoS configuration for each UE involved in the test is highlighted, the following values have been selected:

QoS Provisioning				
UE ID	Traffic Class	THP	ARP	SPI
UE1	Interactive NRT HSPA	1	1	11
UE2	Interactive NRT HSPA	2	2	7
UE3	Background NRT HSPA	-	1	2
UE4	Background NRT HSPA	-	2	1

Table 24. QoS traffic policies for each UE involved in the test case

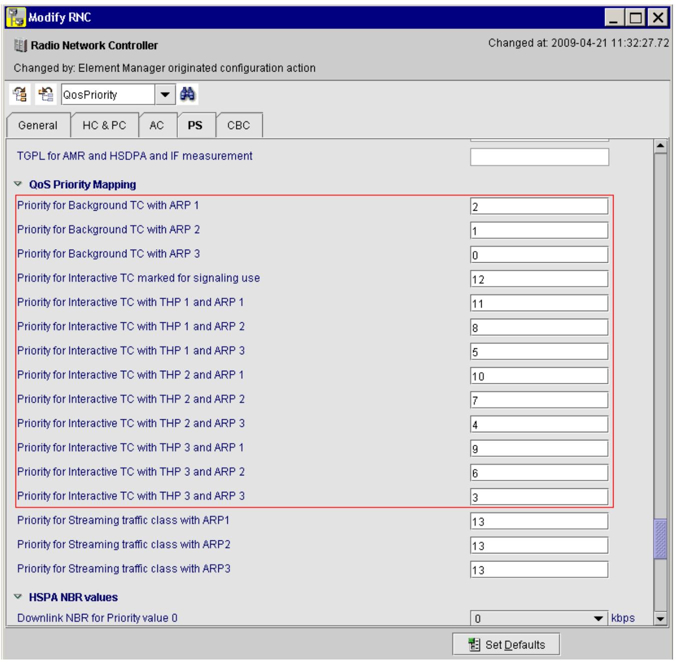


Figure 46. RNC QoS Priority Mapping table. The operator can define which is the SPI value assigned to each THP/ARP combination. In this test, the mapping in Table 24 will be followed.

HLR configuration for QoS differentiation

THP and ARP QoS parameters for UEs have to be setup in the HLR. Here is the detailed information of the procedure and date needed to configure these new QoS profiles, according to Table 20.

The following lines detail the procedure followed to configure the different USIM QoS profiles for each UE.

UE1: Samsung SGH-Z630

SIM number: 8944122340012129429

SIM ID: S80397

IMSI: 234860000037656

PDP Context ID: 2 (WN2 server)

New QoS profile: *Interactive NRT HSPA + THP=1 + ARP=1.* The following MML command has to be introduced in the HLR for its creation:

```
ZMYQ:INDEX=33,NAME=RU10TEST1:CLASS=I(interactive),ORDER=Y,DELERR=N,SDUM
AX=1500,DWNMAX=16000,UPMAX=8640,BER=7,SDUERR=5,PRIOR=1(THP);
```

GPRS Data: Once the QoS profile is created, the GPRS data for this particular IMSI has to be updated with the following MML command:

```
ZMNM:IMSI=234860000037656::PDPID=2,ALLOC=1(ARP),QOSP=33:DISPL=Y;
```

UE2: Huawei E270

SIM number: 8944122340012129437

SIM ID: S80398

IMSI: 234860000037657

PDP Context ID: 2 (WN2 server)

New QoS profile: ***Interactive NRT HSDPA/HSPA + THP=2 + ARP=2***. The following MML command has to be introduced in the HLR for its creation:

```
ZMYQ:INDEX=34,NAME=RU10TEST2:CLASS=I(interactive),ORDER=Y,DELERR=N,SDUM
AX=1500,DWNMAX=16000,UPMAX=8640,BER=7,SDUERR=5,PRIOR=2(THP);
```

GPRS Data: Once the QoS profile is created, the GPRS data for this IMSI has to be updated with the following MML command:

```
ZMNM:IMSI=234860000037657::PDPID=2,ALLOC=2(ARP),QOSP=34:DISPL=Y;
```

UE3: Nokia N95

SIM number: 8944122340012136390

SIM ID: SIM-3

IMSI: 234860000038353

PDP Context ID: 2 (WN2 server)

New QoS profile: *Background NRT HSDPA/HSPA + ARP=1*. The following MML command has to be introduced in the HLR for its creation:

```
ZMYQ:INDEX=35,NAME=RU10TEST2:CLASS=B(background),ORDER=Y,DELERR=N,SDUMA
X=1500,DWNMAX=16000,UPMAX=8640,BER=7,SDUERR=5;
```

GPRS Data: Once the QoS profile is created, the GPRS data for this IMSI has to be updated with the following MML command:

```
ZMNM:IMSI=234860000038353::PDPID=2,ALLOC=1(ARP),QOSP=35:DISPL=Y;
```

UE4: Huawei E270

SIM number: 8944122340012129460

SIM ID: S80401

IMSI: 234860000037660

PDP Context ID: 2 (WN2 server)

New QoS profile: *Background NRT HSDPA/HSPA + ARP=2*. The following MML command has to be introduced in the HLR for its creation:

```
ZMYQ:INDEX=35,NAME=RU10TEST2:CLASS=B(background),ORDER=Y,DELERR=N,SDUMAX=1500,DWNMAX=16000,UPMAX=8640,BER=7,SDUERR=5;
```

GPRS Data: Once the QoS profile is created, the GPRS data for this IMSI has to be updated with the following MML command:

```
ZMNM:IMSI=234860000037660::PDPID=2,ALLOC=2(ARP),QOSP=35:DISPL=Y;
```

Counters

The suggested counters which will give valuable information for this test case correspond to the counter family *Cell Throughput WBTS (M5002).* In particular, these counters will be used:

- *M5002C16*: controls the total acknowledged data in MAC-hs PDUs for SPI 11 (UE1).

- *M5002C12*: controls the total acknowledged data in MAC-hs PDUs for SPI 7 (UE2).

- *M5002C7*: controls the total acknowledged data in MAC-hs PDUs for SPI 2 (UE3).

- *M5002C6*: controls the total acknowledged data in MAC-hs PDUs for SPI 1 (UE4).

3.2.4 Test Results

In this section are presented the results achieved during the validation of this feature. Each one of the following cases is presented individually:

- Behavior with feature deactivated
- Behavior with feature activated

Behavior with feature deactivated

As explained in feature overview section, this situation reflects the usage of Proportional Fair Resource scheduler in WBTS. Not for conclusions though, the results shown below will be used as throughput reference against the throughput when the feature is active.

For this first step, the parameter *HSPAQoSEnabled* is set to *not in use for HStransport*.

The following table shows the throughput results achieved in Proportional Fair Scheduler conditions:

UE ID	PFR Throughput rate
UE1 (Samsung SGH-Z630)	818.5 Kbps
UE2 (Huawei E270)	845.7 Kbps
UE3 (Nokia N95)	816.7 Kbps
UE4 (Huawei E270)	838.7 Kbps
Total HSDPA cell throughput	**3.32 Mbps**

Table 25. Average throughput per UE (during simultaneous FTP DL) with Proportional Fair scheduler under same radio conditions. As expected, all the UEs are evenly sharing all the available resources, considering that the available bandwidth on IuB interface is 2 E1s, which represent around 4 Mbps.

To verify that UE QoS parameters have been setup correctly in terms of THP and ARP value allocation, it is advisable to verify them in the RANAP message *RAB ASSIGNMENT REQUEST* sent through the IuPS interface from the SGSN to the RNC every time a UE requests PDP context activation. These parameters should match with those defined in the HLR profile of each individual UE.

Through Figure 47 to Figure 50, the reader can verify that for each user (UE1 to UE4), the Core Network is communicating the QoS parameterization (Traffic Class, THP and ARP), configured manually on the HLR, to the RNC. Please note that Traffic Class is present at the very beginning of the RAB ASSIGNMENT REQUEST message and that THP and ARP information is communicated together. In addition, check that THP and ARP value “1” is represented as “highest”, whereas value “2” is represented by the numeric figure.

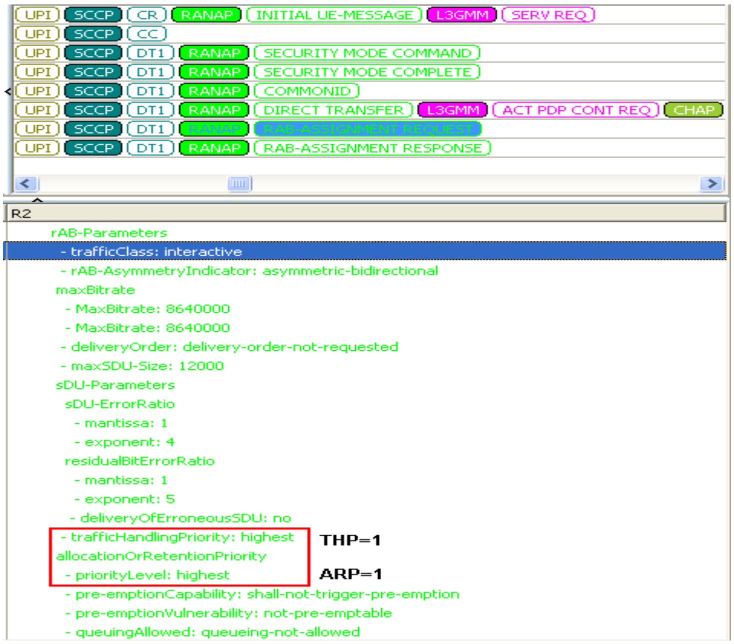


Figure 47. Nethawk trace on Iu-PS: RAB ASSIGNMENT REQUEST for UE1 (traffic class interactive, THP=1, ARP=1)

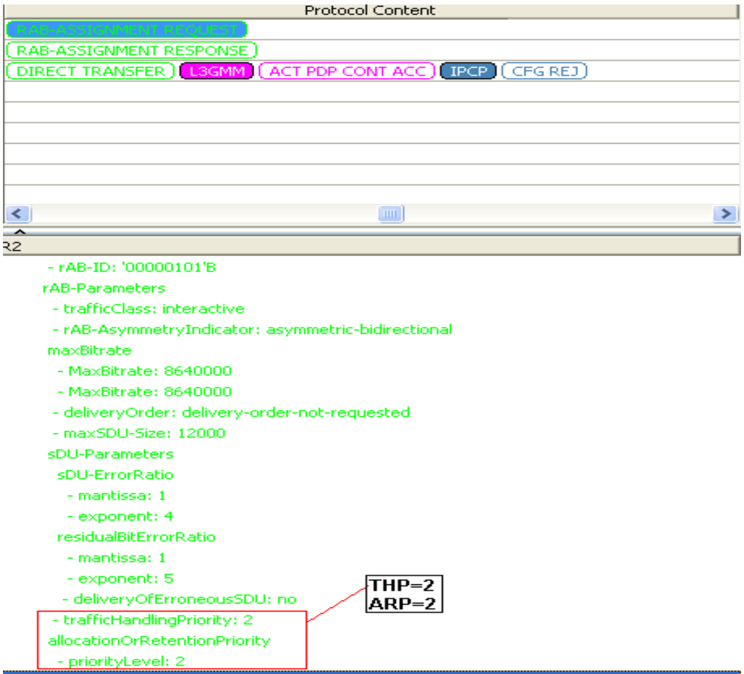


Figure 48. Nethawk trace on Iu-PS: RAB ASSIGNMENT REQUEST for UE2 (traffic class interactive, THP=2, ARP=2)

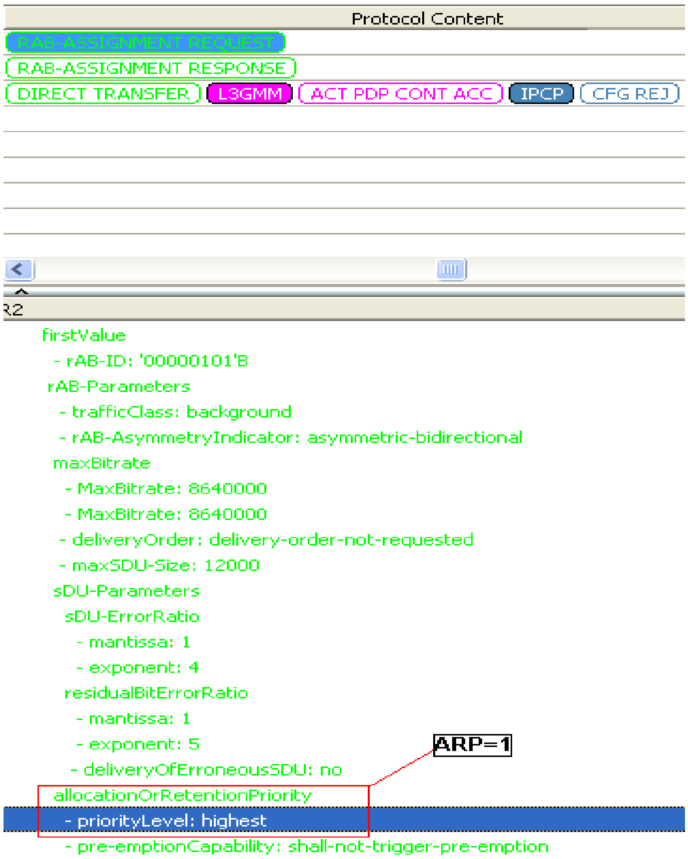


Figure 49. Nethawk trace on Iu-PS: RAB ASSIGNMENT REQUEST for UE3 (traffic class background, ARP=1)

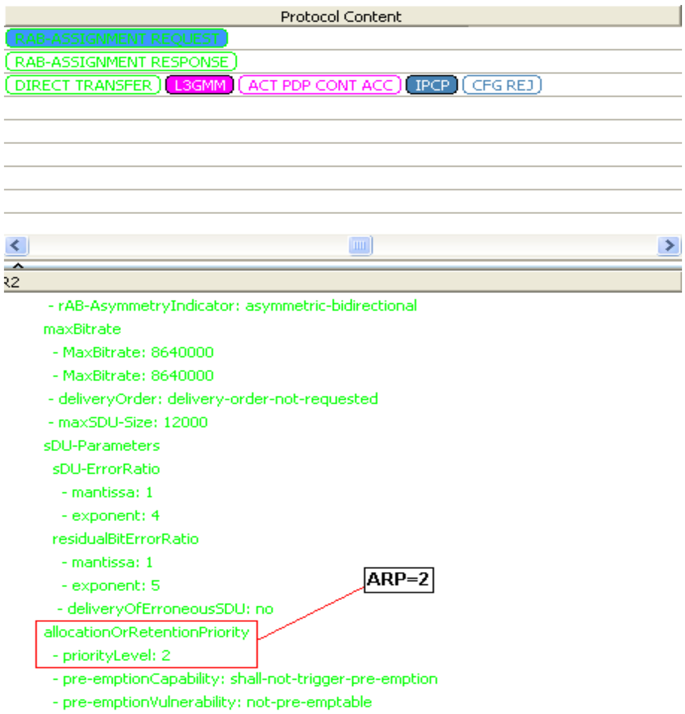


Figure 50. Nethawk trace on Iu-PS: RAB ASSIGNMENT REQUEST for UE4 (traffic class background, ARP=2)

What it is expected in this scenario is that, even though the RAB ASSIGNMENT REQUEST configures the expected QoS parameters as per each user profile, the RNC will automatically assign an SPI value equal to 0 to all at them, which means that all users are scheduled according to the proportional fair algorithm. This SPI value is communicated from the RNC to the WBTS via the NBAP message *RADIO LINK RECONFIGURATION PREPARE.*

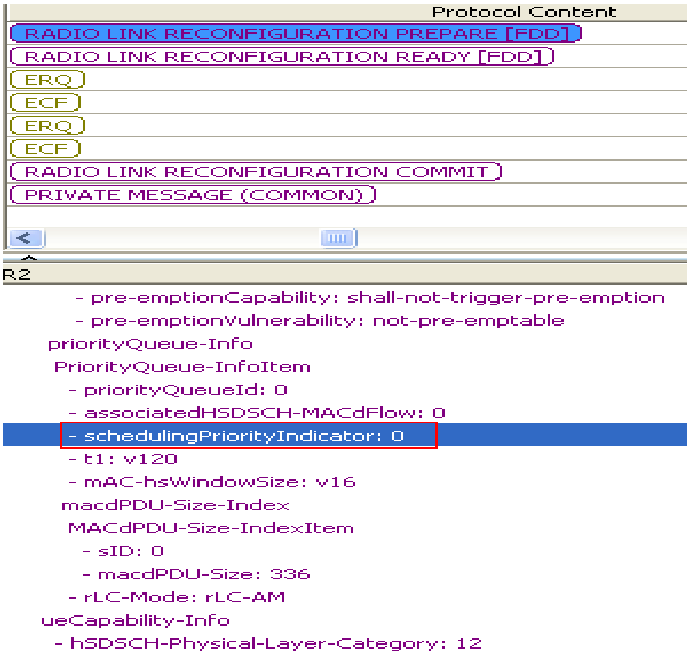


Figure 51. Nethawk trace on IuB: RADIO LINK RECONFIGURATION PREPARE with SPI=0

Finally, a review of the counter family M5002 will confirm that all data processed in the WBTS belongs to MAC-hs PDUs with SPI = 0.

WBTS-6 WCEL-1 M5002C0 CCH DATA VOLUME FOR CELL UL	2
WBTS-6 WCEL-1 M5002C1 CCH DATA VOLUME FOR CELL DL	46
WBTS-6 WCEL-1 M5002C2 E-DCH DATA VOLUME FOR SERVING CELL UL	106
WBTS-6 WCEL-1 M5002C3 E-DCH DATA VOLUME FOR NON-SERVING CELL IN SERVING E-DCH RLS UL	0
WBTS-6 WCEL-1 M5002C4 E-DCH DATA VOLUME FOR NON-SERVING CELL IN NON-SERVING E-DCH RLS UL	0
WBTS-6 WCEL-1 M5002C5 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 0	229455
WBTS-6 WCEL-1 M5002C6 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 1	0
WBTS-6 WCEL-1 M5002C7 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 2	0
WBTS-6 WCEL-1 M5002C8 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 3	0
WBTS-6 WCEL-1 M5002C9 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 4	0
WBTS-6 WCEL-1 M5002C10 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 5	0
WBTS-6 WCEL-1 M5002C11 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 6	0
WBTS-6 WCEL-1 M5002C12 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 7	0
WBTS-6 WCEL-1 M5002C13 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 8	0
WBTS-6 WCEL-1 M5002C14 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 9	0
WBTS-6 WCEL-1 M5002C21 HS_TOTAL_DATA	241784
WBTS-6 WCEL-1 M5002C22 TOTAL HSUPA DATA FOR SPI 0	102

Figure 52. M5002C4 counter shows that all data scheduled in the WBTS belongs to queue with SPI=0.

Behavior with feature activated

First of all, in this scenario, the WCEL parameter *HSPAQoSEnabled* is set to *in use for HS NRT channel.* The expected behavior in this situation will allow the operator to perceive a noticeable difference in throughput between users belonging to each one of the different QoS categories setup in their USIM profiles.

Table 26 shows the comparison of the average throughput achieved with the new scheduler algorithm, PF-RAD-DS, against the previous one, PFR. Notice the dramatic decrease in throughput for UEs 3 and 4 (over 50% downlink throughput penalty) and the expected downlink throughput improvement brought by the feature for both UE1 and UE2. Hence, it is clearly demonstrated that the higher the SPI weight assigned to a specific user, the higher the downlink throughput obtained by that user.

UE ID	Assigned SPI	PF-RAD-DS	PFR
UE1 (Samsung SGH-Z630)	11	1193.2 Kbps	818.5 Kbps
UE2 (Huawei E270)	7	1068.6 Kbps	845.7 Kbps
UE3 (Nokia N95)	2	483.3 Kbps	816.7 Kbps
UE4 (Huawei E270)	1	327.2 Kbps	838.7 Kbps
Total HSDPA cell throughput (Mbps)		**3,07 Mbps**	**3.32 Mbps**

Table 26. Average throughput achieved with each scheduling algorithm during a simultaneous FTP download service under same radio conditions. It is demonstrated that if $SPI_{UE1} > SPI_{UE2} > SPI_{UE3} > SPI_{UE4}$, then DL $Throughput_{UE1} > Throughput_{UE2} > Throughput_{UE3} > Throughput_{UE4}$.

A parallel analysis may bring to pre-estimate the result with the feature activated based on the results obtained in a proportional fair scenario. If we consider the total throughput achieved in the previous situation (3.32 Mbps) and consider the SPI weights assigned to each user with the feature enabled, we can calculate the weighted average downlink throughput per user:

UE ID	Assigned SPI	Weight	PFR-RAD-DS Estimation	Deviation
UE1	11	11/21	1739.1 Kbps	+ 545,9 Kbps
UE2	7	7/21	1106.6 Kbps	+ 38 Kbps
UE3	2	2/21	316.2 Kbps	- 167,1 Kbps
UE4	1	1/21	158.1 Kbps	- 169,1 Kbps
	21			

Table 27. Estimated weighted average throughput with PF-RAD-DS.

Checking the results in Table 27, it can be observed that the estimations are quite accurate compared to the real results obtained for UE2, 3 and 4. However, the deviation with the best (UE1) figure is bigger, which might bring to the conclusion that the algorithm performs an adjustment to keep fairness in the system by slightly penalizing the UE with the highest throughput. Nevertheless, these deviations need to consider slight changes in radio conditions which may arise during the test and server behavior in both situations. In fact, there is a deviation in total cell throughput of around 300 Kbps between test 1 and test 2.

On the other hand, *RAB ASSIGNMENT REQUEST* messages from Iu-PS show the same information witnessed in the previous case since the UEs are still configured with the same USIM QoS profile.

However, in this case, different SPI has been allocated. This new SPI assignments can be seen by analyzing the message *RADIO LINK RECONFIGURATION PREPARE*. The expected values have to match with those defined in the RNC (*QoSPriorityMapping table*) and specified in Table 24.

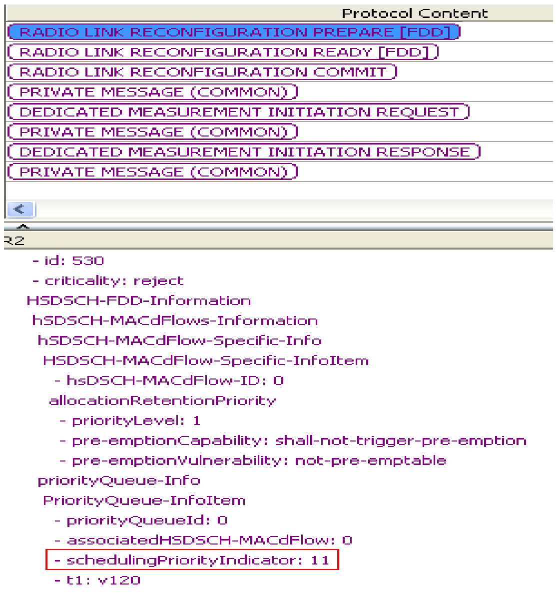


Figure 53. Nethawk trace on IuB: RADIO LINK RECONFIGURATION PREPARE for UE1 (SPI=11)

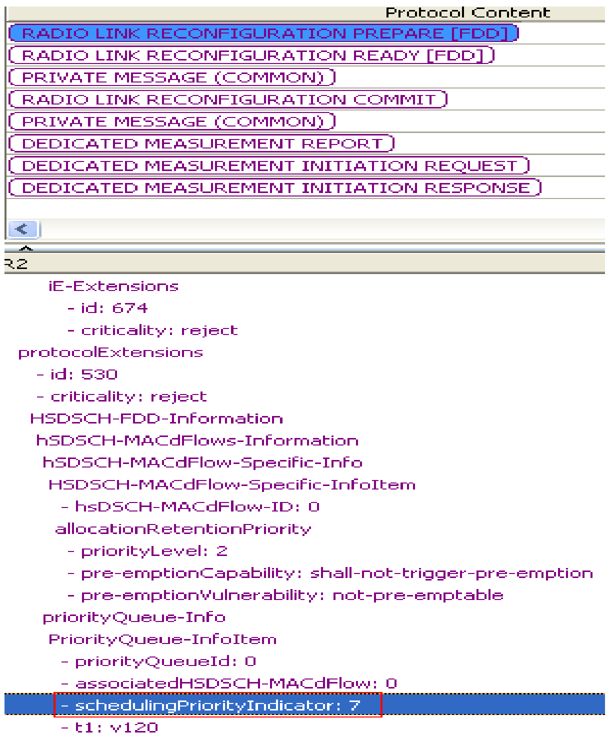


Figure 54. Nethawk trace on IuB: RADIO LINK RECONFIGURATION PREPARE for UE2 (SPI=7)

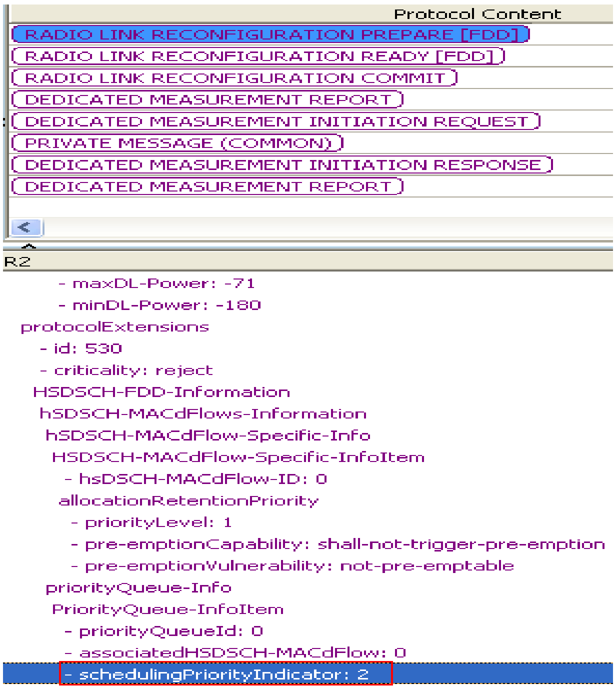


Figure 55. Nethawk trace on IuB: RADIO LINK RECONFIGURATION PREPARE for UE3 (SPI=2).

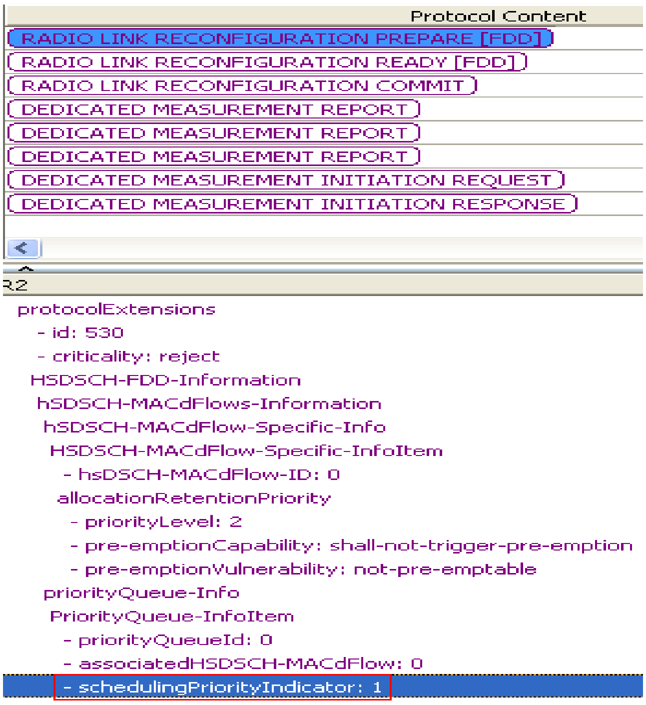


Figure 56. Nethawk trace on IuB: RADIO LINK RECONFIGURATION PREPARE for UE4 (SPI=1)

Finally, the review of counters M5002 show valuable information about the amount of MAC-hs data acknowledged by each prioritization class queue, according to the SPI mapping communicated via *RADIO LINK RECONFIGURATION PREPARE* messages. In this case, only UE2 (SPI=7) and UE3 (SPI=2) activity was recorded, as shown in Figure 57. A case was reported to NSN support personnel after the test case, because results for UE1 (SPI=11) and UE4 (SPI=1) should also have been recorded.

WBTS-6 WCEL-1 M5002C0 CCH DATA VOLUME FOR CELL UL	3
WBTS-6 WCEL-1 M5002C1 CCH DATA VOLUME FOR CELL DL	5
WBTS-6 WCEL-1 M5002C2 E-DCH DATA VOLUME FOR SERVING CELL UL	23637
WBTS-6 WCEL-1 M5002C3 E-DCH DATA VOLUME FOR NON-SERVING CELL IN SERVING E-DCH RLS UL	0
WBTS-6 WCEL-1 M5002C4 E-DCH DATA VOLUME FOR NON-SERVING CELL IN NON-SERVING E-DCH RLS UL	0
WBTS-6 WCEL-1 M5002C5 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 0	0
WBTS-6 WCEL-1 M5002C6 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 1	0
WBTS-6 WCEL-1 M5002C7 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 2	302417
WBTS-6 WCEL-1 M5002C8 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 3	0
WBTS-6 WCEL-1 M5002C9 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 4	0
WBTS-6 WCEL-1 M5002C10 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 5	0
WBTS-6 WCEL-1 M5002C11 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 6	0
WBTS-6 WCEL-1 M5002C12 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 7	936861
WBTS-6 WCEL-1 M5002C13 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 8	0
WBTS-6 WCEL-1 M5002C14 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 9	0
WBTS-6 WCEL-1 M5002C15 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 10	0
WBTS-6 WCEL-1 M5002C16 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 11	0
WBTS-6 WCEL-1 M5002C17 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 12	0
WBTS-6 WCEL-1 M5002C18 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 13	0
WBTS-6 WCEL-1 M5002C19 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 14	0
WBTS-6 WCEL-1 M5002C20 TOTAL ACKNOWLEDGED DATA IN MAC-HS PDUS FOR SPI 15	0
WBTS-6 WCEL-1 M5002C21 HS_TOTAL_DATA	1340155

Figure 57. M5002C7 and M5002C12 shows the activity recorder for UE2 and UE3 respectively

3.2.5 Test conclusions

Validation of the feature QoS Aware HSPA Scheduling has proved that:

- New QoS parameters can be modified successfully in WBTS, RNC and HLR network elements.

- With the feature disabled, Proportional Fair scheduler assigns SPI=0 (same weight) for all the users, providing fairness in resource sharing.

- With the feature enabled, Proportional Fair Required Activity Detection with Delay Sensitivity scheduler assigns different SPI values according to the USIM QoS profile of each user, leading to an operator-controlled resource sharing.

- In addition, it is worth mentioning that the throughput ratio between users with different SPI, is maintained even though other users are releasing resources by finishing their downloads. It proofs that empty resources are allocated to users with higher SPIs.

These positive conclusions may lead the operator to see the feature as a good mechanism to reduce heavy user data traffic in high load situations for those users not paying premium fares.

A deeper analysis will conclude that this feature is useful in cases where the UE which is meant to be limited in throughput is camping in a cell with other users on it. The idea then will be to change its QoS profile in the HLR in order to allocate the UE with a lower SPI in comparison with the rest of users in the cell. Moreover, if it is also considered the worst case scenario where the UE which has been SPI-limited is camping in a cell where there are no other UEs, this limitation will not affect to its throughput since no other users with higher SPI values to compete with, hence no multi-user scheduling takes place.

Alternatively, this could be a workaround in situations where the operator wants to reduce the traffic of those users reaching the GB/month cap (as per the conditions of standard fares) and there exist a problem to dynamically adjust the maximum bit rate of the user in the HLR.

All facts considered, it can be concluded that this feature will be useful for the life network together with a dynamic mechanism allowing a QoS profile change in the HLR for the selected users whenever the cell congestion threshold is reached.

3.3 Network Evolution: QoS in 4G networks

3.3.1 Overview of QoS Management

In the same way that it is for 3G, QoS is a key indicator of Evolved Packet System (EPS) performance. As shown in Figure 58, an EPS consists of an Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and an Evolved Packet Core (EPC). QoS management is a mechanism that helps an EPS meets service quality requirements.

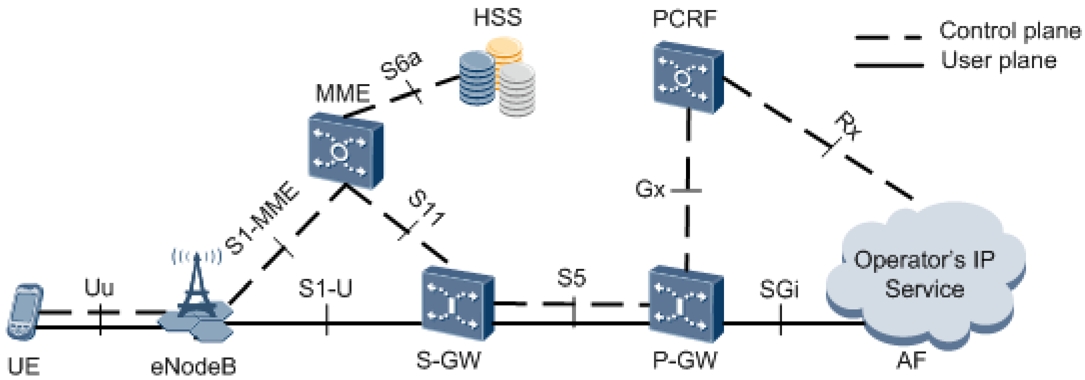


Figure 58. EPS architecture. The network elements herein indicated are: AF: application function; eNodeB: e-UTRAN Node B; HSS: Home Subscriber Server; MME: Mobility Management Entity; PCRF: Policy and Charging Rules Function; P-GW: Packet Data Network Gateway; S-GW: Serving Gateway; UE: User equipment

QoS management is performed on EPS bearers. The NEs function regarding QoS is described as follows:

- The PCRF dynamically generates QoS policies and sends them to the P-GW, which implements them. During QoS policy implementation, the P-GW determines the service data flow (SDF) according to the traffic flow template (TFT) and binds the SDF to an available EPS bearer. The TFT is dynamically generated by the PCRF or, if PCRF is unavailable, it can be statically configured on P-GW.

- S-GW manages packet routing and forwarding and maps the S5 interface bearer to the S1 interface bearer.

- MME obtains UE subscription data from the HSS and transfers the QoS parameters among the NEs.
- HSS stores UE subscription data and subscribed QoS policies.
- The eNode B establishes UE bearers and schedules UE data based on the QoS parameter settings and the status of radio and transport resources. The eNode B uses differentiated resource management and allocation policies to meet QoS requirements of UE bearers.

3.3.2 Basic Principles

EPS Bearer Architecture

In the EPS, the basic unit for QoS management is an EPS bearer, upon which SDFs are created. The same QoS management policies are applied to SDFs on the same EPS bearer. These policies include a scheduling policy and a radio bearer policy. To provide different QoS management policies for different SDFs, these SDFs must be mapped to different EPS bearers.

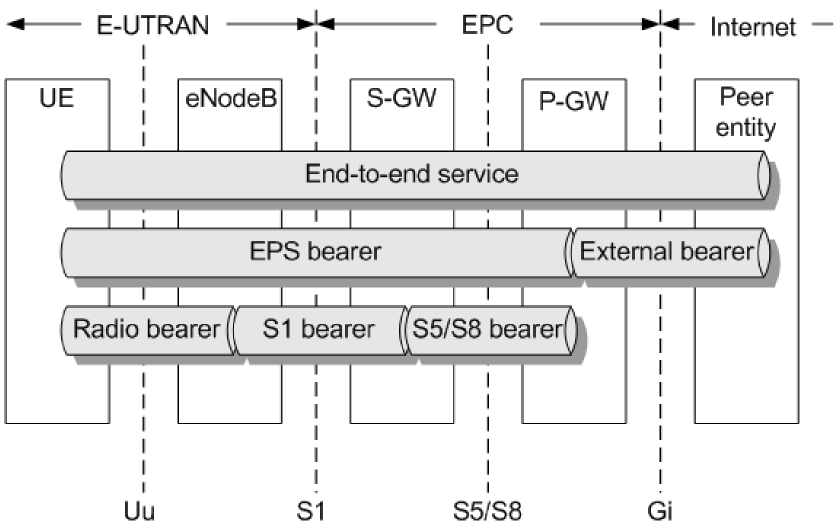


Figure 59. EPS bearer architecture according to 3GPP TS 36.300 specifications

In LTE, an EPS bearer carries one or more SDFs with the same QoS attribute between the UE and P-GW. In Figure 59, the bearer between the UE and eNode B is radio bearer, and the bearer between the eNode B and S-GW is S1 bearer. The radio bearer and S1 bearer form the E-UTRAN radio access bearer (E-RAB). The end-to-end bearers in the EPS are divided by layer, and QoS management is performed based on layers.

EPS Bearer Types

EPS bearers can be divided into GBR and non-GBR bearers.

- Based on dedicated bearers, **GBR bearers** are used for real-time services, such as voice, video, and real-time gaming.

- **Non-GBR bearers** are used to carry non-real-time services, such as emails, File Transfer Protocol (FTP) services, and Hypertext Transfer Protocol (HTTP) services.

EPS bearers can also be divided into default and dedicated bearers.

- **Default bearer**: Allocated by the EPC to a UE when the UE initially accesses the EPS. If the UE have multiple Access Point Names (APNs), the EPS sets up a default bearer for each APN, such as different default bearers for IMS APN and Internet APN. The default bearer remains established to ensure a short delay for the UE to start a service and provide the UE with always-on IP connectivity. The default bearer is a non-GBR bearer.

- **Dedicated bearer:** Set up for a UE if the default bearer cannot meet the QoS requirements. A dedicated bearer can generally meet more stringent QoS requirements than the default bearer. Multiple dedicated bearers can be set up for a UE simultaneously. The EPC sets up dedicated bearers for a UE based on QoS requirements. A dedicated bearer can be a GBR or non-GBR bearer.

Up to eight bearers with different QCIs can be set up between the eNode B and the UE.

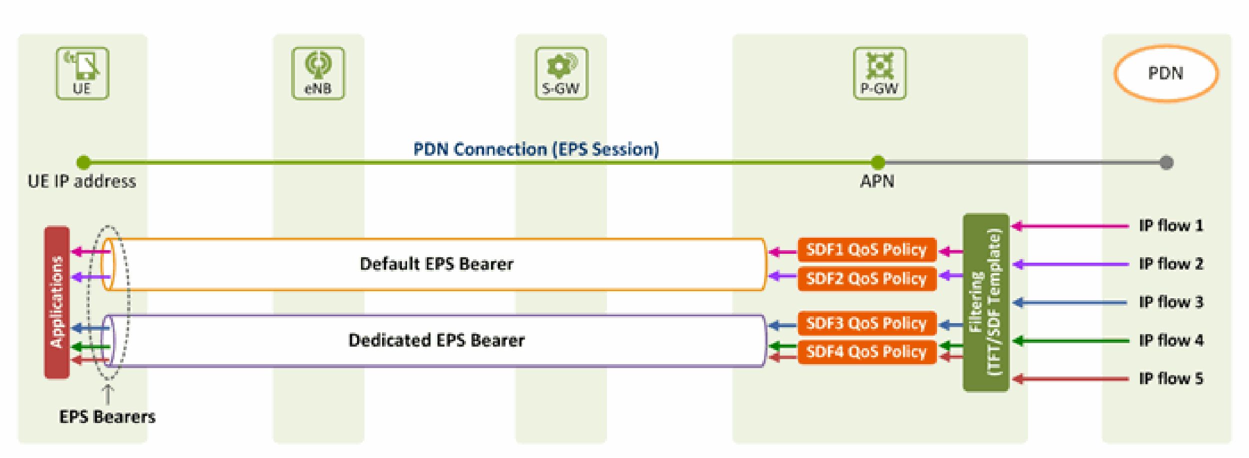


Figure 60. SDF mapping to EPS bearers.

Bearer-level QoS Parameters

The EPS provides various packet services such as videophones, audio, video, web browsing, and email. Subscriber requirements vary according to the service type. For example, subscribers demand clear voice, uninterrupted video streaming, and fast web browsing. The EPS maps these requirements to QoS parameters, which can be recognized and processed by each NE. These parameters are:

- **QCI:** The QoS class identifier (QCI) consists of standardized QCI and extended QCI. According to 3GPP specifications, nine standardized QCIs are defined for different services based on QoS requirements, and extended QCIs ranging from 10 to 254 provide diverse services based on different QoS requirements. These QCIs standardize QoS requirements. Each QCI specifies a set of requirements for the priority, delay, and packet loss rate of a resource type. QCIs are transmitted between network nodes, without requiring negotiation and large-scale transmission of QoS parameters. The EPS implements QoS management policies based on the QCIs. SDFs with different QCIs are mapped to different EPS bearers.

- **ARP:** Already introduced in 3G networks, an allocation/retention priority (ARP) is the priority of an EPS bearer during resource allocation. The parameter specifies whether a bearer can be pre-empted. Based on the ARP, the eNode B decides whether to accept or reject a bearer establishment or modification request when resources are insufficient. In addition, the eNode B uses the ARP to determine which bearers will be released during network congestion.

- **GBR and MBR:** A GBR is the bit rate guaranteed to a GBR bearer and the maximum bit rate (MBR) is the maximum bit rate provided for a GBR bearer. The EPS admits all SDFs at bit rates lower than or equal to the GBR by reserving resources and rejects all SDFs at bit rates higher than MBR. If the bit rates of SDFs are higher than the GBR but lower than the MBR, the EPS rejects the SDFs when the network is congested.

- **UE-AMBR or APN-AMBR:** An Aggregate Maximum Bit Rate (AMBR) is used by the EPS to limit the total bit rate of a group of non-GBR bearers within the AMBR. AMBRs are categorized as follows:

  - **UE-AMBR:** per UE aggregate maximum bit rate. Bandwidth management based on UE-AMBR limits the total bit rates used by all the non-GBR bearers created by the UE.

  - **APN-AMBR:** per APN aggregate maximum bit rate. Bandwidth management based on APN-AMBR limits the total bit rates of all the non-GBR bearers created by a UE under an Access Point Name (APN).

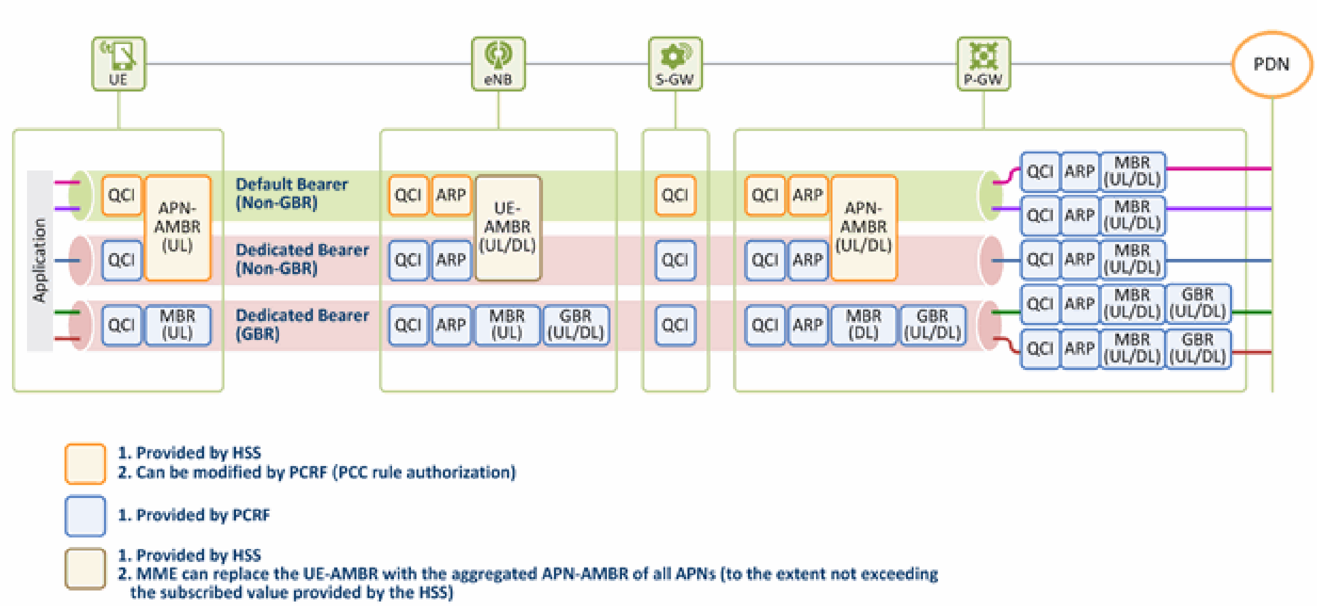


Figure 61. QoS Provisioning in LTE

3.3.3 ENode B QoS Management Policies

Subscribers' subscription data is stored on the HSS. When a UE initiates a service request, the P-GW/S-GW and eNode B provide the service for the UE based on the QoS subscription data stored on the HSS and the QoS parameters delivered by the PCRF.

ENode B QoS management consists of radio QoS management and transport QoS management. Radio QoS management ensures the quality of services on radio bearers, and transport QoS management ensures the quality of services on the S1 bearer.

During the service setup request phase, the Uu interface and transport network execute admission control on the services, and the eNode B supports only those services that are admitted. Meanwhile, the eNode B maps the QoS parameters and the differentiated services code points (DSCPs) for QoS management.

After a service is set up, the eNode B performs QoS management on services based on QCIs. To ensure the quality of high-priority services, admission control is performed on low-priority services when the Uu interface and transport network are congested. This procedure ensures service continuity based on QoS management during UE movements.

In order to introduce these mechanisms, the single subscriber case is explained.

QoS Guarantees for a Single Subscriber

QoS management provides QoS guarantees for an entire service process implemented during the service setup request phase and post-service-setup phase.

- **Service Setup Request Phase:** The service setup request phase requires QoS parameter mapping and admission control based on the availability of cell resources.

    - **QoS Parameter Mapping:** During the service setup request phase, the eNode B maps the QoS parameters of a service, such as the QCI, GBR, and MBR, to the service's radio bearer and transport parameters, providing consistent QoS parameters for eNode B QoS management.

Two types of QCI configurations can be set up in the eNode B at radio level:

- ***ENode B-level QCI**:* maps QoS parameters to scheduling priorities and to the radio link control (RLC) and Packet Data Convergence Protocol (PDCP) transmission modes and transport parameters.
- ***Cell-level QCI:*** maps QoS parameters to service-based discontinuous reception (DRX), scheduling request indicator (SRI) and handover parameters.

Transport parameter configuration maps QoS parameters to transport parameters in S1/X2 interfaces, based on DSCP differentiation at IP layer.

- **Cell-level Admission Control:** Admission control in each cell prevents an excessive number of subscribers from accessing the cell and ensures that the cell is not overloaded. Admission control is performed on the Uu interface and on the transport network. A service is admitted only when it successfully passes both.

  - **Admission control on the Uu interface:** it helps ensure the quality of admitted services and expected quality of new services. It applies to both GBR and non-GBR services. Admission control is performed on GBR services based on the PUCCH (Physical Uplink Control Channel) resources, UE capability, cell load status, and QoS satisfaction rate. It is performed on non-GBR services based on only PUCCH resources.
  - ***Admission control on the transport network:*** different admission control policies are applied to services based on the occupation rate of transmission bandwidths and service types, ensuring the quality of admitted services and improving access success rates of high-priority services.

- **Post-Service-Setup Phase:** Post service setup request phase requires power control and mobility management to help ensuring QoS policies.

- **Power Control:** After a service is set up, power control limits the transmit power for the service within an appropriate range. This function ensures correct data reception and improves power efficiency. Based on power control and scheduling, the block error rate (BLER) can converge to the target value.

- **Mobility Management:** Service quality may deteriorate when a UE moves to the cell edge. By using the handover function, the eNode B promptly triggers a handover to enable the UE to be served by another cell and thereby ensures service continuity.

- **Scheduling:** Scheduling consists of downlink and uplink scheduling. In scheduling, the eNode B determines the scheduling priorities of radio bearers and UEs based on the input QoS parameters and the quality of PUSCH and PDSCH. This maximizes system throughput while meeting UEs' QoS requirements. Scheduling helps ensure basic quality for services. For example, scheduling ensures acceptable transmission delay for data packets of delay-sensitive voice over IP (VoIP) services, and ensures the service rate and packet delay budget (PDB) for GBR services.

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QoS Management Methods

ARP-based QoS Management

ARP-based QoS management ensures equal subscriber resource use in traditional packet services. Requirements of high-priority subscribers cannot be fully met with these traditional services.

ARP-based QoS management provides DiffServ by using admission and congestion control based on service priority information contained in subscription data.

During the setup of an E-UTRAN radio access bearer (E-RAB), the EPC transmits an ARP (which includes subscription data) to the eNode B. The eNode B then maps the ARP to a service priority (gold, silver, or bronze). A larger ARP value indicates a lower priority. The probability that the services fail admission control is higher when the network is congested.

ARPs	Service Priority
1 to 5	Gold
6 to 10	Silver
11 to 15	Bronze

Table 28. Mapping between ARPs and Service Priority.

The eNode B next determines load control policies for services based on ARPs or service priorities. For example, different admission thresholds are set for gold, silver, and bronze services for admission control; different resource release thresholds or rate decrease thresholds are set for gold, silver, and bronze services for congestion control.

This method is the direct evolution of the *QoS Aware HSPA Scheduling* feature explained in the previous chapter.

QCI-based QoS Management

3GPP specifications define standardized QCIs 1 to 9 for different service types, indicating the corresponding service quality requirements and service priorities. However, using only these QCIs is not enough to provide different services for different subscribers.

In this situation, 3GPP specifications introduce extended QCIs 10 to 254, enabling operators to define their own QCIs.

Table 29 describes standardized QCIs and some extended QCIs.

Type	QCI Value	Priority	Packet Delay Budget (PDB)	Packet Loss Rate	Example Service
3GPP-defined QCIs for GBR services	1	2	100 ms	10^{-2}	Conversational voice
	2	4	150 ms	10^{-3}	Conversational video
	3	3	50 ms	10^{-3}	Real-time gaming
	4	5	300 ms	10^{-6}	Streaming (non-conversational video)
3GPP-defined QCIs for non-GBR services	5	1	100 ms	10^{-6}	IP Multimedia Subsystem (IMS) signaling
	6	6	300 ms	10^{-6}	Video (buffered streaming) and Transmission Control Protocol (TCP)-based services
	7	7	100 ms	10^{-3}	Voice, video (live streaming), and interactive gaming
	8	8	300 ms	10^{-6}	Video (buffered streaming) and TCP-based services
	9	9			
Operator-defined QCIs	130			N/A	IMS and voice-related signaling (gold)
	131			N/A	Gaming and other low-delay services (gold)
	….				
	150			N/A	IMS and voice-related signaling (silver)
	151			N/A	Gaming and other low-delay services (silver)
	….				
	170			N/A	IMS and voice-related signaling (bronze)
	171			N/A	Gaming and other low-delay services (bronze)
	….				

Table 29 Examples of standardized QCIs and extended QCIs

3.3.4 Future testing

This section has been included within the scope of this project to introduce the QoS mechanisms included in evolved radio networks, such as Long Term Evolution (LTE). After analyzing the QoS management architecture and QoS management methods that are implemented by the eNode B, it can be seen that service prioritization can be achieved by following a similar rationale. The Enhanced proportional Fair (EPF) scheduling mechanism used in LTE considers two basic parameters in order to prioritize a single user data bearer: QCI – which is newly introduced in 4G networks as a way to establish QoS differentiation within a variety of services (refer to Table 29) and Allocation Retention Priority (ARP), which can be used to establish bearer pre-emption priorities within services associated to the same or different QCIs. Thus, the test shown in the previous section could be replicated also in a 4G network for future study by forcing a transmission congested scenario and observing what is the behavior in a multi-user scenario when:

- Different users are assigned bearers with different QCIs and same ARP values. In this case it should be observed that higher throughput is obtained the higher the QCI (in descending order, that is, a QCI 7 bearer is prioritized over a QCI 9 bearer).
- Different users are assigned bearers with the same QCI but different ARP values. It should be observed that, starting a test with low ARP users triggering downlink congestion, once a higher ARP user initiates a data service, lower ARP users' resources will be pre-empted, increasing the throughput of the new coming user.

4 IuB evolution: hybrid backhaul and full IP solutions

4.1 Theoretical Background

4.1.1 Introduction

In a society where communication technology is becoming more and more relevant and where the “always-on” user experience is a must, it is very important that the network supporting radio technologies evolves even faster.

In particular, the mobile communication sector has been experiencing vast changes during the last two decades. The development and deployment of third generation radio technologies (UMTS, HSxPA, and HSPA+) have been the enablers for mobile broadband and, together with the smartphone, tablet and dongle market success, have made it possible for the users to access real-time information from their mobile devices. As a result, it is being confirmed the trend which delegates voice data services to a secondary paper in front of data services, which have experienced an exponential growth.

However, the evolution in radio access technologies and user equipments should not be the only success factor to consider. Transmission access network evolution and dimensioning, in particular, is key to support second, third and fourth radio network generations and, in most cases, a barrier for these technologies to perform at their maximum capacity.

The basic function of transmission network is to convey signaling and user data between radio network equipment - Base Station Controller (BSC) and RNC- and remote base stations - BTS and Node B- that is for 2G and 3G; and between eNode B and EPC in case of 4G communications.

Given the importance of the economic investment associated to the deployment of a network across a large geographical area, choosing the appropriate transmission mechanism and equipments is a key strategic decision which directly impacts the business competitiveness. That is the main reason why the operator should balance the cost-effectiveness of the solution and the quality of service to be offered.

First radio access network deployments were intended to support 2G standards, which were mainly focused on voice services. For that reason, the operator decided to deploy Time Division Multiplexing (TDM) transmission-based technology, focused on connection-oriented circuit switching.

Later on, with the arrival of 3G standards, data services came to the picture. At the beginning, the existing TDM network was able to cope with the initial data traffic growth, but soon appeared the first limitations to carry a type of traffic for which it was not initially designed.

For that reason, operators decided to migrate their transmission network to a fresh data transport oriented technology. In fact, due to the presence of internet protocol stack across the fixed network, IP/Ethernet packet-switching technology was adopted as the new reference across mobile networks. In addition, the election of a universal standard allowed the operator to leverage the large-scale economies provided by the Ethernet-based packet technologies.

Nevertheless, considering the investment already made in TDM network, the new investment required to deploy an All-IP based network and the huge amount paid for the radio spectrum, most operators decided to postpone the migration.

By the end of 2008, the increasing user demand for greater bandwidths and data-hungry services pushed the operators to think about the technology transition on their transmission network if they wanted to keep their future competitive position in the market, also considering that the evolution towards 4G technology started to be a hot topic in the roadmap of the operator portfolio.

For the mid and long term, this migration has turned into great opportunities for the operator, ensuring both technical (4G ready networks) and economical (savings in OPEX after all the traffic has been swapped to IP technology) competitive position with the possibility to converge mobile and fixed network services.

All things considered, this chapter wants to introduce the reader to the technical challenge that the smooth network transition brought to the operators by analyzing different solutions focused on the IuB interface, which is the last mile link where the Node B connects to. The reader will find a brief overview on legacy transmission technologies, so it can be understood why an expansion of this kind of media could turn into an inefficient strategy; followed by the core section, the hybrid backhaul, which emulates ATM over Ethernet transport solution that I personally configured and tested for first time in the operator where I developed this project. The analysis shown herein should be taken from the operator point of view at that particular point in time.

Finally, it is also shown the validation results obtained when configuring and testing the performance of an “all-IP” based IuB, solution which established the critical milestone into transmission network design evolution.

4.1.2 Legacy IuB Transport Solution

A look into the past: the role of ATM in 3G Access Networks

A cellular access network connects Node Bs to RNCs (Radio Network Controllers) via IuB interface. The IuB interface is a complex set of protocols handling all aspects of Node B-to-RNC communication, including media, signaling and Operation, Administration and Maintenance (OAM) over ATM. ATM, in turn, can be transported over various TDM links.

In practice, most Node B connections range from a fractional E1 to several E1s bundled as an Inverse Multiplexing over ATM (IMA) group. RNC connections are usually either E1s or Synchronous Transport Module Level-1s (STM-1s).

Early releases of the 3G standard defined the Node B-to-RNC connection as purely TDM connection. In the ATM layer, Node Bs and RNCs were connected via a direct ATM link, without intermediate ATM switching. The definition provides the following functions:

- Independence of the underlying transmission layer.
- Definition of groups of several TDM links as one logical link using the ATM IMA mechanism
- Ability to carry voice and data over the same link.
- Implementation of statistical multiplexing between different applications on the same Node B maintaining QoS.

Introduction of ATM Switching into the Access Networks

Release 4 of 3GPP standard formally described how to perform ATM switching in the access network, and how to provide the QoS guaranties required for the successful operation of 3G applications.

ATM switching in the access network provides two major advantages:

- The ability to configure RNCs with STM-1 interfaces instead of E1s, thus drastically reducing the cost of the RNC. Consider the cost of deploying copper-based E1s (capacity ≈ 2Mbps) versus optical fiber based STM-1 (capacity ≈ 155Mbps)

- Savings in bandwidth consumption.

Current deployments demonstrate that it is not cost-effective to deploy E1 links in the RNC. STM-1, on the other hand, has proved to be a far less expensive solution, even with the cost of intermediate ATM switching.

In a TDM-based network, the link between the Node B and the RNC has a granularity of E1. Although fractional E1 connections are feasible, these are usually reserved for sub-E1 rates, such as the ones required in GSM networks.

This bandwidth allocation is part of the basic design of the Node B. However, ATM concentration in the access network can improve bandwidth utilization. For example, if the peak traffic to/from a Node B is estimated to be 3 Mbps, then two E1 interfaces (2 x 2.048 Mbps) must be allocated to the Node B at the TDM level. On the other hand, an ATM switch concentrating traffic from 10 Node Bs can concentrate from 40 Mbps (10 x 2 E1) to 30 Mbps (10 x 3 Mbps, or only 15 E1s) without violating the basic bandwidth allocation rule of 3 Mbps per Node B.

Statistical Multiplexing Based on Peak and Sustained rate

An ATM link can contain many ATM virtual circuits, each with its own parameters. The main parameters are the Peak Cell Rate (PCR) and the Sustained Cell Rate (SCR).

The peak cell rate controls the maximum permissible cell rate, whereas the sustained rate is the average connection rate. A Node B may transmit at the peak rate for a short period of time only (controlled by the maximum burst size), which is typically lower than 50ms. Over longer intervals, traffic must be controlled by the sustained cell rate, typically much lower. In the real world, only few Node Bs transmit at the peak rate (i.e. hotspot areas), whereas the majority transmits at the sustained rate.

ATM concentration in the access layer eases to maintain the peak rate of the connection at high level, thus ensuring short delays. As the number of Node Bs transmitting concurrently at the peak rate can be statistically bounded, bandwidth must be allocated for the sustained rate for all the Node Bs, with the peak rate allocated to only some. As a result, bandwidth consumption is significantly lower. Nonetheless, there is a lower chance that all Node Bs send a burst of traffic simultaneously with the resulting loss of ATM cells. This can easily be computed based on the ATM policing and shaping mechanisms, which guarantee cell rate in compliance with 3G standards.

Multiplexing based on usage statistics

Bandwidth allocation per Node B is based on the maximum concurrent bandwidth demanded by users being served by the specific Node B. While it is desirable to provide full service to all users in any scenario, this is economically impossible.

As with any mass service, statistical assumptions about overall cell usage can safely be made. For example, in GSM voice-based deployments, network designs assume that not all subscribers will make a call at the same time. If they do, some will be rejected. 3G services are subject to the same design considerations. In effect, due to the burst nature of data, network planning must rely on the statistical nature of usage patterns. Unlike ATM statistical multiplexing (which allows users to send high rate traffic over short periods of time and then forces them to reduce the rate), usage statistical multiplexing is based on the assumption that not all subscribers user the network concurrently. Consequently, this multiplexing method may vary with changes in usage patterns. As it is the nature of data to adapt the application to the available bandwidth, usage-based multiplexing can be implemented even if the service level is sometimes degraded.

Higher Savings

Reducing bandwidth consumption is always a recommended approach. However, depending on the network structure and design, the reduction ration may vary between operators.

When using leased-lines or licensed radio frequencies (for microwave links) to build a network, lower bandwidth consumption translates into direct savings in Operational Expenditure (OPEX). This reduction involves more than only the monthly cost of leasing the lines and the radio frequencies. In addition, when bandwidth consumption is reduced, the access network becomes smaller. Service providers can then manage a smaller transmission network with less expensive interfaces, less equipment cards and less manpower.

4.1.3 Understanding the challenge

In an ATM-based transport scenario, a 3G cellular access network can be deployed in one of the following configurations:

- RNCs with E1 ports connected to the Node Bs via pure TDM transmission network.

- RNCs with STM-1 ports and Node Bs with E1 ports. In this configuration, ATM switches deployed along the connection convert E1s originating in the Node Bs to STM-1s by:

    - Co-locating ATM concentration devices with the RNC.

    - Putting in place ATM concentration devices within the access network.

The following sections describe the advantages and disadvantages of each approach.

Deployment over Pure TDM Transmission

ATM switching in the access network is recommended, but is not technically mandatory.

It is possible to build a network connecting an E1 port from a Node B directly to an E1 port from the RNC (basic ATM configuration which is usually considered in a lab environment). This approach, however, lacks the advantage of using STM-1 ports in the RNC and ATM concentration in the network that results in savings in bandwidth and network costs, as well as not being suitable for network dimensioning and scalability.

Co-location of ATM switches in RNCs

A second alternative is to deploy an ATM switch co-located with the RNC. In this scenario, the access network carries TDM connections from the Node Bs to the ATM switch; the switch concentrates E1s into a single STM-1, which in turn is connected to the RNC.

RNCs can then be configured with STM-1 ports, resulting in a more economical network structure. However, bandwidth consumption is still based on the peak demand of every Node B, without ATM concentration.

ATM Concentration devices within the access network

The deployment of ATM switches in the access network is therefore the most efficient and cost-effective implementation. The switches concentrate traffic from Node Bs into VC-4 containers, enabling an economical RNC configuration.

The cost of using ATM switches in the access

ATM access networks are necessary, but expensive, as ATM is an expensive technology. Moreover, the installation of a simple ATM switch for traffic concentration includes the addition of ATM hardware, as well as support of a significant number of Plesiochronous Digital Hierarchy (PDH) and Synchronous Digital Hierarchy (SDH) interfaces.

Imagine a typical scenario in which STM-1 links concentrate traffic from Node Bs. For example, a switch can concentrate traffic from a channelized STM-1 with 52 active channels (E1s), with 20 E1s from local Node Bs.

The total number of E1s is 72 and therefore a channelized STM-1 is no longer sufficient. Concentration must be performed at the ATM level, as TDM concentration results in the need for additional STM-1s, which is a waste of bandwidth considering that an STM-1 handles up to 63 E1s and the additional STM-1 will be carrying only 9.

As already described, an ATM switch can easily compress traffic originally carried on 72 E1s into one VC-4. However, the ATM switch must connect to 72 E1 ports and one STM-1 port. Therefore, to enable ATM concentration, the following components must be added:

- An ATM switch with 72 E1 interfaces and one STM-1 interface
- An additional STM-1 interface in the transmission network
- Additional 72 E1 interfaces in the transmission network.

The above configuration is extremely expensive and casts a shadow on the cost-effectiveness of ATM concentration in the access network. Clearly, a far more economical solution is required.

The extra costs of maintaining IMA groups

IMA is a low level protocol transporting ATM over multiple E1 links. It configures multiple physical links as a single ATM link, and adds and drops physical links without affecting traffic.

The capability to add and drop TDM capacity from the IMA link without affecting ATM traffic is extremely powerful but costly. IMA is implemented at the hardware level, and therefore all the links in the same IMA group must reside on the same interface card.

Continuing with the previous example, we can assume that the 72 E1 connections are originated in 36 Node Bs, where each one is connected via an IMA group of two E1s. If the operator plans to upgrade the Node B links to an IMA group of 4 E1s, two options are available:

- Deploy an ATM switch with 72 E1 interfaces and upgrade them when traffic volume increases, or

- Deploy an ATM switch with 144 E1 interfaces, leaving room for future IMA expansion.

The first option is extremely complicated. When upgrading the network connection of the Node Bs from two to four E1 links, the new links must all be allocated to the same interface card. At some point in time, a new ATM interface card will be needed, requiring a rewiring of the physical cables. The resulting upgrade is a traffic-affecting cable management procedure.

The second option of reserving ports for future use is simple, but requires investing in equipment that will not be used until needed, if at all, which has been demonstrated to be the case. The deployment of ATM interfaces based on future upgrade plans is not economically justifiable for an operator due to uncertain changes in the traffic volume and transport technologies.

All in all, assigning E1 links to IMA groups according to future network upgrades situates the operator in a difficult position. In addition, upgrade procedures are very complex and may demand traffic-affecting cable changes. The alternatives are expensive and require initial rollouts for unpredictable future scenarios.

Next section shows the next step to follow when the operator requires a capacity upgrade without dismantling the legacy TDM resources

4.1.4 Hybrid Backhaul Solution Overview

Hybrid backhaul, the next step

High Speed Packet Access (HSPA) is one of the crucial evolutionary steps of 3G networks development. Starting with 1.8 Mbps, users will experience downlink peak rates of up to 3.6 Mbps, 7.2 Mbps and 14.4 Mbps provided in steps*. However, widening the air interface between the user equipment (UE) and base station is not enough at all:

also the IuB interface between the Node B and RNC must be dimensioned accordingly; that implies the need to evolve from 2 Mbps, which is an E1 capacity, to greater bandwidths.

Current backhaul networks are often low-dimensioned to support such an evolution. This particularly happens when transport capacity is leased: the OPEX (Operational Expenses) of additional leased lines is prohibitive when the operator aim is to decouple capacity expenses with cost per bit. In contrast to traditional E1 lines, Ethernet-based services have the potential to separate cost from capacity – that is, to provide the bandwidth required for HSPA and capping the associated OPEX at once. Ethernet can be applied either as a substitute or as a complementary solution: in the first case all cell site traffic is carried over Ethernet; in the second case, the E1 is kept to carry all-delay sensitive traffic (Operation & Maintenance traffic included) and Ethernet is used for HSDPA only.

The way the operators may act is a two-step deployment, moving smoothly from the current E1 architecture to a total Ethernet-based backhaul with a hybrid solution as an intermediate milestone. The next paragraphs show which would be a reasonable way to achieve the final "All-IP" goal.

**HSDPA rates till 3GGP R5. With the introduction of higher capacity modulations (i.e. 64QAM), the implementation of MIMO techniques and N-carrier support, HSDPA speeds have evolved to 337.5 Mbps in 3GPP R11. For further information, please refer to 3GPP TS 25.306 documentation.*

Network Trend: near, medium and long term scenario

When considering R99 and HSPA traffic, the operator can deploy different transport backhaul strategies depending on the traffic growth forecast of each of the aforementioned technologies. At this point, three different alternatives may be taken into account.

First of all, there will be scenarios in which HSPA can still fit into the current infrastructure without expensive upgrades (i.e. microwave upgrades in a "pay as you grow" model) at near/medium term in areas where large amounts of data are not expected, that is, rural areas.

On the other hand, if only HSDPA explodes but HSUPA demand can still be met without further investments, the operator may consider to tactically separating HSDPA from R99 and HSUPA transport technologies.

Finally, if the growth model is shared evenly by both HSDPA and HSUPA then it will be positive to separate HSPA from R99.

For each one of these cases, the following points show different implementation possibilities divided according to the deployment feasibility.

Near Term Scenario

In a near term scenario, HSDPA or HSPA offloading is still based on E1 connections as far as the Node B is concerned, following the rule N E1s and M E1s, where N+M <= 8. Three different ways to divide the network traffic can be chosen:

- **Pure voice/data split:** RT DCH (R99) over NxE1 and NRT DCH (R99) + HSPA over MxE1.
- **R99/HSPA split**: RT/NRT DCH (R99) over NxE1 and HSPA over MxE1.
- **R99+HSUPA/HSDPA split:** RT/NRT DCH + HSUPA over NxE1 and HSDPA over MxE1.

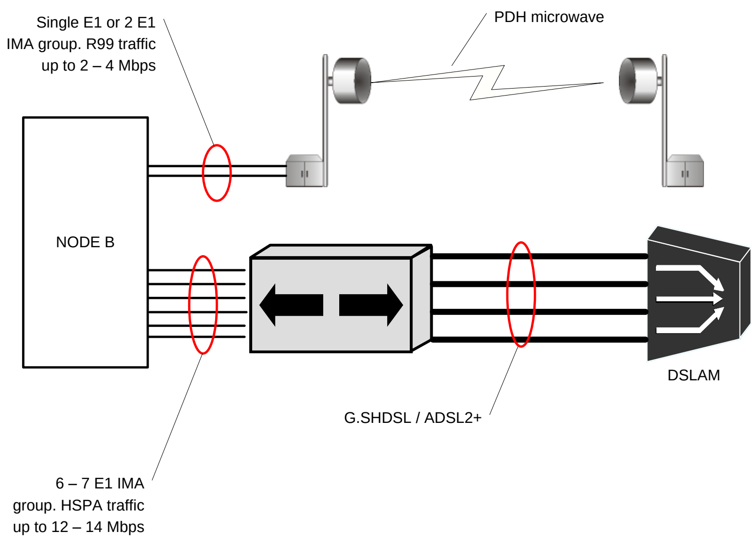


Figure 62. Near trend scenario. Example of R99/HSPA traffic split at Node B site. Even though leased PDH microwave radio links may still be present, the operator can ease OPEX by using own transport technologies such as G.SHDSL or ADSL2+.

Mid-Term Scenario

In a mid-term scenario, Ethernet technology is introduced directly into the Node B in order to bring a cost-effective way to transport high amounts of data traffic. This implies a significant step forward in order to remove legacy leased lines and use the own operator Local Loop Unbundling (LLU) solutions. In this very first step, though, E1 connections will still be in place, but kept to the minimum required for them to pay off the initial investment. This situation has driven the operators to deploy the so mentioned **hybrid backhaul solution**. Again, depending on the way the operator chooses to split the traffic, two interesting configurations come to the picture:

- **Pure voice/data split:** RT DCH (R99) over NxE1 and NRT DCH (R99) + HSPA over Ethernet.

- **R99/HSPA split:** RT/NRT DCH (R99) over NxE1 and HSPA over Ethernet.

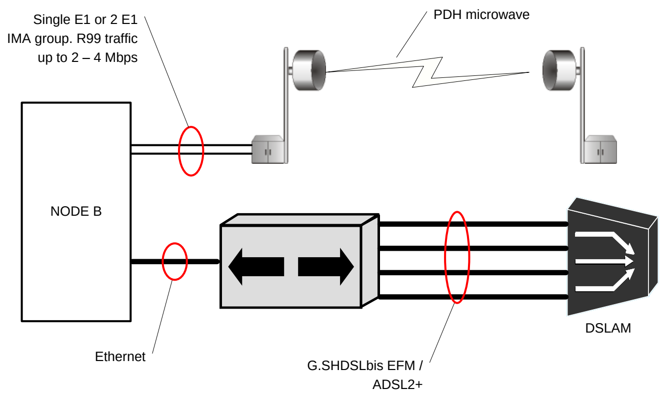


Figure 63. Medium trend scenario. Example of R99/HSPA traffic split at Node B site. Note that Ethernet interfaces are available in the Node B, hence increasing the capacity for HSPA. New technologies such as G.SHDSLbis can boost HSUPA rates up to 11 Mbps (2 x G.SHDSLbis pairs) – 16 Mbps (3 x G.SHDSLbis pairs) and ADSL2+ may offer HSDPA rates up to 20 Mbps (1 x ADSL2+ pair) – 40 Mbps (2 x ADSL2+ pairs).

Long Term Scenario

Finally, the long term scenario converges onto a full IP-based backhaul. Since ATM is not present any more, direct Ethernet connections from the Node B can be used and legacy E1 connections removed. In this case, all the advantages associated to IP networking can be applied to the transport backhaul. For example, as it will be shown in section 4.2.3 *Testbed configuration and settings*, traffic can be separated per Virtual

Local Area Network (VLAN)-basis with a specific QoS profile depending on the type of data (voice/packet).

However, there is an important disadvantage to consider. Since synchronization has been usually conveyed over PDH/SDH connections, new methods such as Global Positioning System (GPS) or timing over packet techniques, may be implemented in the Node B in order to recover the system synchronization.

Again, different topologies can be taken into account when considering this solution.

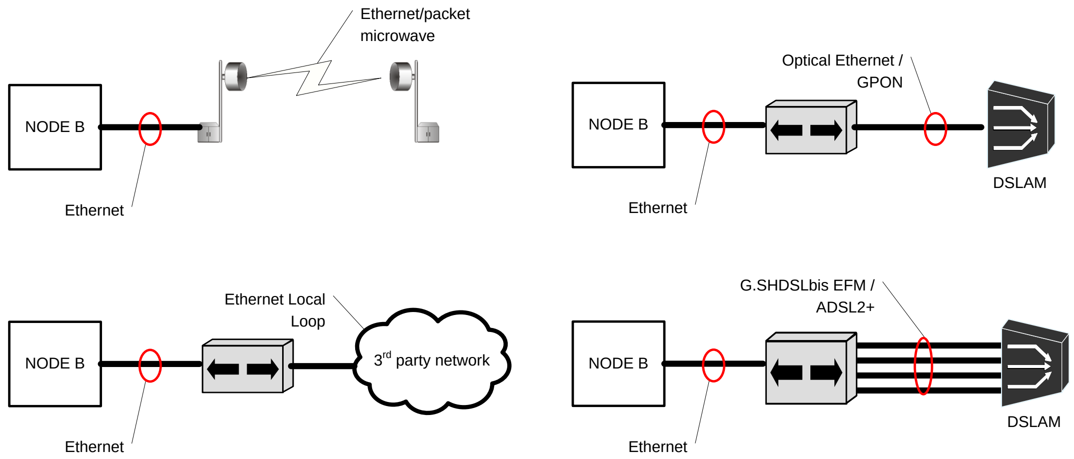


Figure 64. Long term scenario. Node B backhaul is purely based on Ethernet interfaces. Different transport technologies may be considered to reach the RNC: packet microwave, optical Ethernet, third party network Ethernet Local Loop or the same G.SHDSL.bis EFM / ADSL2+ solution shown in medium trend scenario.

4.2 Hybrid Backhaul Feature Validation

4.2.1 Hybrid Backhaul feature description

As it has been mentioned before, hybrid backhaul enables the number of E1 lines to be reduced to a limited number, and for HSPA traffic to be offloaded to packet-based services. It embraces a series of changes including Ethernet interfaces for Node B, RNC site gateways and base station/RNC transport efficient features.

The case to be covered in this study is based on offloading only the HSPA portion of the IuB traffic. It may result in a number of benefits:

- **Relaxed QoS:** HSPA tolerates better both delay and packet loss. In case of HSDPA is in the Node B where the packet scheduling takes place. The RNC only has to control Node B buffer status, making the functionality less time critical.
- **Relaxed restoration time:** if the packet service is disrupted due to transmission issues in the offload path, only HSPA becomes unavailable, while dedicated traffic channel (DCH) services continue and Node B maintains normal operation.
- **High-quality Node B synchronization and secure OAM:** TDM link is still active to distribute the clock reference and supply OAM services to the different Node B.

Live network wise, DSL (Digital Subscriber Line) fits well in these properties. Wholesale DSL products are widely available and service can be provided also at remote locations. The wholesale supplier provides Point-to-Multipoint connectivity between base station sites and RNC sites. Last mile connections are physically based on Asymmetrical Digital Subscriber Line (ADSL), the aggregate traffic is passed to the mobile network as an Ethernet trunk.

Fundamentals

Hybrid backhaul is based on IuB ATM service emulation over a packet-switched network, according to the Pseudo Wire Emulation Edge to Edge specification (PWE3) of the Internet Engineering Task Force (IETF)*.

One of the main advantages of this kind of system is that the ATM layer remains intact, so all the processing in the RNC remains the same. The way the system deals with it is further explained: traffic is first split into separated ATM Virtual Path Connections (VPC) and Virtual Channel Connections (VCC). Both VPCs and VCCs are then mapped onto different paths, being TDM or Ethernet at an external PWE3 gateway (in-build in the Node B from an uplink perspective and external equipment, Tellabs 8630 router in this case, needed from the RNC point of view). ATM cells going through the Ethernet path are then concatenated, to become the payload of an Ethernet packet. This kind of encapsulation has been specified by the IETF pseudo wire emulation edge-to-edge (PWE3).

In order to ensure robustness and to avoid packet loss across the transport network, the traffic between the Node B and the PWE3 gateway is routed using Multi Protocol Layer Switching (MPLS) pseudo wires.

MPLS is a highly scalable data-carrying mechanism whose purpose is to encapsulate packets of various network protocols. In an MPLS network, data packets are assigned labels. Packet-forwarding decisions are made based on the contents of this label, without the need to examine the packet itself. This allows the operator to create end-to-end circuits, called pseudo wires across this document, across any type of transport medium, using any protocol. The primary benefit is to eliminate dependence on a particular Data Link Layer technology such as ATM, Frame Relay, SONET or Ethernet, and to eliminate the need for multiple Layer 2 networks to satisfy different types of traffic. MPLS belongs to the family of packet-switched networks.

MPLS operates at an Open System Interconnection (OSI) model layer that is generally considered to lie between Layer 2 (Data Link layer) and Layer 3 (Network Layer).

The label mechanism used for the Node B and PWE3 gateway to implement the pseudo wire across the packet-switched network is detailed in section 4.2.3 *Testbed configuration and settings.*

Concatenation factor, packetization timer and frame structure

Two of the cornerstones of the hybrid backhaul solution, and primarily the ATM emulation over Ethernet, are the **concatenation factor** and the **packetization timer** parameters.

The **concatenation factor** is the amount of ATM cells introduced in an Ethernet packet. In order to avoid IP fragmentation issues, up to 28 cells can be concatenated in one packet, leading to an Ethernet frame of 1510 bytes (1484 bytes of ATM data, taking into account 53 bytes per ATM cell). The efficiency increases exponentially with the number of ATM cells per pseudo wire packet (see Figure 65).

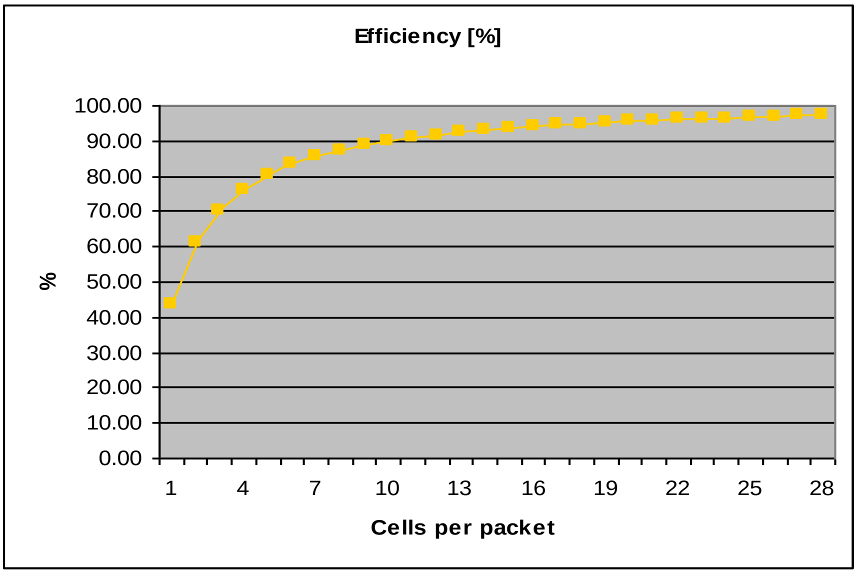


Figure 65. Efficiency vs. Concatenation Factor. The graph shows the efficiency, in %, achieved per Ethernet frame depending on the amount of ATM cells per packet (concatenation factor). It is assuming that both VLAN tag and Control Word are included. Efficiency is measured in terms of ATM data per Ethernet frame. Note that high efficiency values of around 80% are achieved with only 5 cells/packet and over 90% with 10 ATM cells/packet.

This increase in data efficiency per packet goes hand in hand with a decrease in the overhead percentage introduced per Ethernet frame depending on the concatenation factor used, as shown in Figure 66.

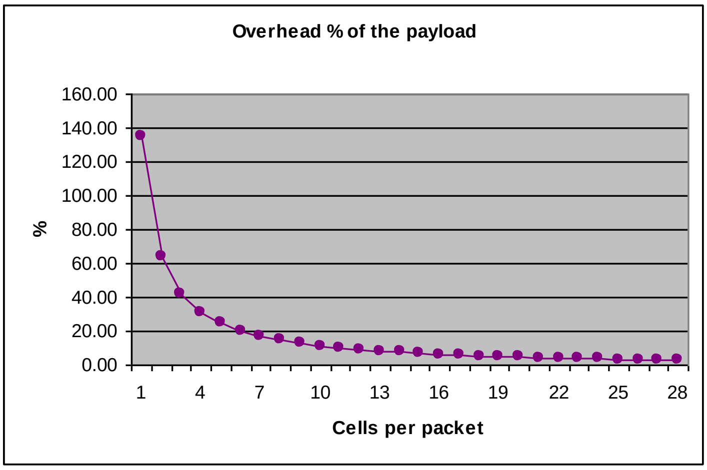


Figure 66. Overhead vs. Concatenation Factor. The graph shows a drastic drop in the % overhead as the amount of cells per packet increases.

On the other hand, the **packetization timer** defines the maximum time allowed to create an Ethernet frame (by encapsulating ATM cells) before it is scheduled for forwarding. A small packetization timer will introduce little delay in the creation of a packet, whereas a large one will ensure that packets are big enough, hence minimizing the overhead and increasing the efficiency.

The actual packet size depends then on the concatenation factor, the packetization timer and the load of the tributary VCCs.

After concatenation, a control word is optionally appended. If VCCV-BFD is used, the control word is required. The format of the control word is depicted in Figure 67. It is also shown the MPLS shim format as well as the way these packets are formatted within the equipment under test:

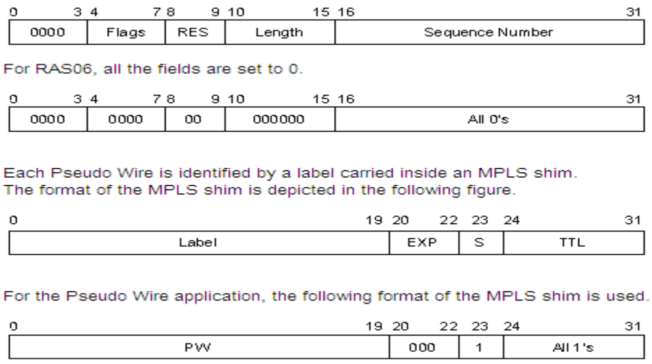


Figure 67. **Control Word and MPLS shim formats. From top to bottom: control word format, vendor X control word implementation; MPLS shim format and vendor X implementation.**

The concatenated ATM cells, together with the control word and the MPLS shim are encapsulated inside IPv4 packets. These IP packets are further encapsulated inside Ethernet frames, ending in the following Ethernet structure (Figure 68).

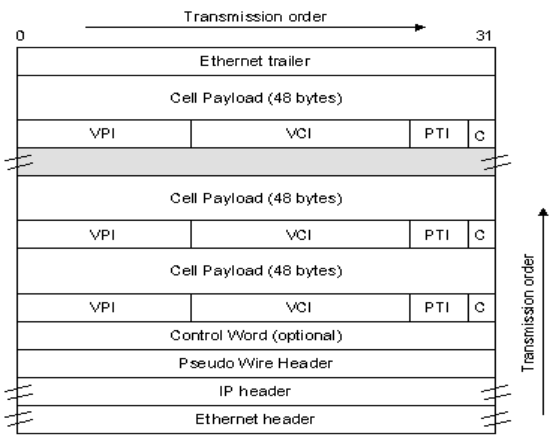


Figure 68. Structure of the Ethernet carrying a Pseudo Wire packet. Note the transmission order and the concatenation of ATM cells, each one containing its correspondent header and payload fields.

In order to understand the physical implications in the RAN, it is worth showing a layout (Figure 69) of how the ATM cell is transported across the IuB when a Pseudo Wire solution is implemented.

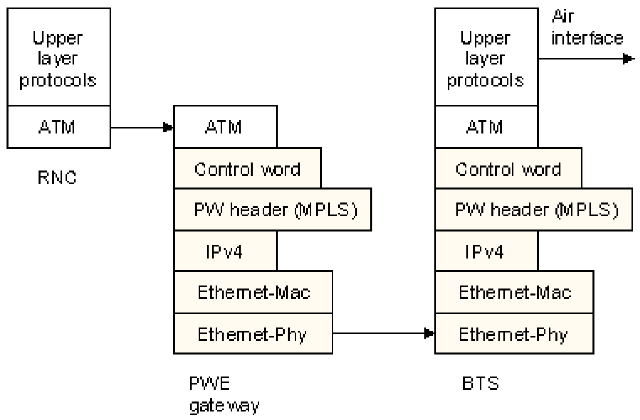


Figure 69. ATM transport across the IuB interface. PWE gateway and BTS are the entities responsible for the encapsulation/de-encapsulation of the ATM cells. The RNC is unaware of the pseudo wire implementation, making the solution a lot more interesting for the deployment phase.

By analyzing the protocol stack, hybrid backhaul is fully transparent to the RNC. An RNC external transport node (PWE gateway) connects to the Ethernet-based packet network on one side and presents STM-1 and ATM interfaces to the RNC on the other. This PWE gateway function has been specified by IETF and is supported by multiple vendors of general purpose.

However, there have to be changes in the Node B transport functionality. The new transport interface boards will have to support both Fast Ethernet and E1 connections as well as being compatible with the PWE3 standard. This level of integration brings several benefits compared to stand-alone gateways:

- No separate installation is needed, which means no dedicated power supply, no cabling, etc…
- Fast installation and commissioning.
- Easy to manage via Node B O&M existing connections.

- Smooth future transition to native IuB over IP solution: since the ATM layer is removed from the protocol stack, a stand-alone PWE3 gateway would become obsolete.

The next section offers a detailed description of the testing environment used for the implementation and validation of this solution, covering the practical and physical aspects of the theoretical concepts presented during this section.

4.2.2 Purpose of Validation

The purpose of this section is to show an in-depth analysis of the hybrid backhaul implementation as a step towards full IP backhaul by describing and showing:

- How the system emulates ATM transportation by giving an overview of the technical solution. As a result of this investigation I created an excel macro which matches ATM cells to Ethernet bandwidth according to the parameters related to pseudo wire encapsulation, which will be introduced in next sections. This tool could be helpful for network planners in their transmission dimensioning tasks.

- How to integrate a hybrid backhaul solution based on Tellabs 8600 equipment in an ATM scenario. In this section, it will be presented the configuration scenarios I tested in the Skill Centre lab premises. This represents one of the major challenges of this project since it was the first time Tellabs 8600 was used in France Telecom Group and I was responsible for the very first validation. The results and configuration guidelines gathered in this project were one of the key documentation followed in other MCOs within the Group in order to deploy the solution across their local networks.

- Validation results obtained for hybrid backhaul scenario in both lab and End-to-End campaign in live network.

- Analysis and tuning of the parameters related to hybrid backhaul solution under non-ideal conditions of delay and packet loss.

4.2.3 Testbed Configuration and Settings

In addition to the before mentioned RAN network elements (RNC and Node B), the whole end-to-end scenario including UEs, laptops, Core Network elements, interfaces, additional routers, switches and servers should support the preferred new features in terms of configuration, licenses and available bandwidth. The following subsections list all the elements used during this validation phase.

Requirements

The following network hardware and software was used during testbed validation:

1. RNC with RAS06 RN3.0 software level.

2. Transmission and Transport:

- 16 Mbps user plane capacity in the IuB (TDM link, 2 x E1 IMA group, and Fast Ethernet connection).

- Core Network and application server connectivity not limiting testing (i.e. SIM QoS profile provisioned in the HLR supporting at least a DL speed of 7.2 Mbps).

- Hybrid backhaul feature activated in RNC.

- Macro Indoor Node B (UltraSite) equipped with IFUH transmission card for ATM Cross-Connect (AXC). IFUH provides two Fast Ethernet interfaces and one Gigabit Ethernet interface. It requires only one slot in the AXC subrack and is fully compatible with AXUA and AXUB type of ATM Cross-Connection Units. TDM links are routed via IFUD E1 transport interface.

- Distributed Indoor Node B (Flexi) equipped with FTJA. FTJA transmission module provides two Fast Ethernet interfaces, one Gigabit Ethernet interface and four E1 interfaces.

- External PWE3 gateway: Tellabs 8630 router.

3. Node B (Indoor macro and distributed solution) with the following software levels:

    - NODE B: RAS06 WN4.0 or newest.
    - AXC: RAS06 C3.0 or newest (Indoor macro only).

4. Other Dependencies:

    - CS core network:
        - MSC with M13 software level or newest.
        - MGW with U3B software level or newest.
    - PS core network:
        - SGSN with SGN3 software level or newest.
    - O&M network:
        - NetAct management system with OSS4.2 software level or newest.
    - GSM network:
        - BSC with S11.5 or S12 software level.

Test Tools

Several tools are required for this validation: UEs, USB dongles, protocol analyzers, laptops, antenna line devices such as RF attenuators and feeders, and cabling (Fast Ethernet cables, coaxial cables and optical fibers). The detail for each one of them is described below:

1. R99 WCDMA UEs

    - Non-Nokia models used in the operator’s network: Qualcomm chipset 6275, e.g. Samsung SGH-Z630.
    - Nokia N95

2. UEs with E-DCH (HSUPA) enabled Cat 4-5 / HSDPA Cat 7-10 (16QAM + 10/15 codes).

- Data cards or handset models that operator aims to use in the commercial network: Qualcomm chipset 7200, e.g. Huawei E270 data card.

3. Laptop with Windows XP + SP2 to be used for HSPA dial up and UE message tracing with different logging tools: NEMO Outdoor (air interface tracing) and Wireshark (Ethernet interface tracing)

4. Nethawk M5 IuB/Iu protocol analyzer.

5. Spirent Ethernet impairment tool. This tool was used during the study of delay and packet loss impact in hybrid backhaul validation.

6. Fixed and adjustable attenuators, RF cabling to simulate air interface radio conditions, coaxial cables, Fast Ethernet Cat 5 cables and single-mode fiber for STM-1 links.

Configuration scenarios

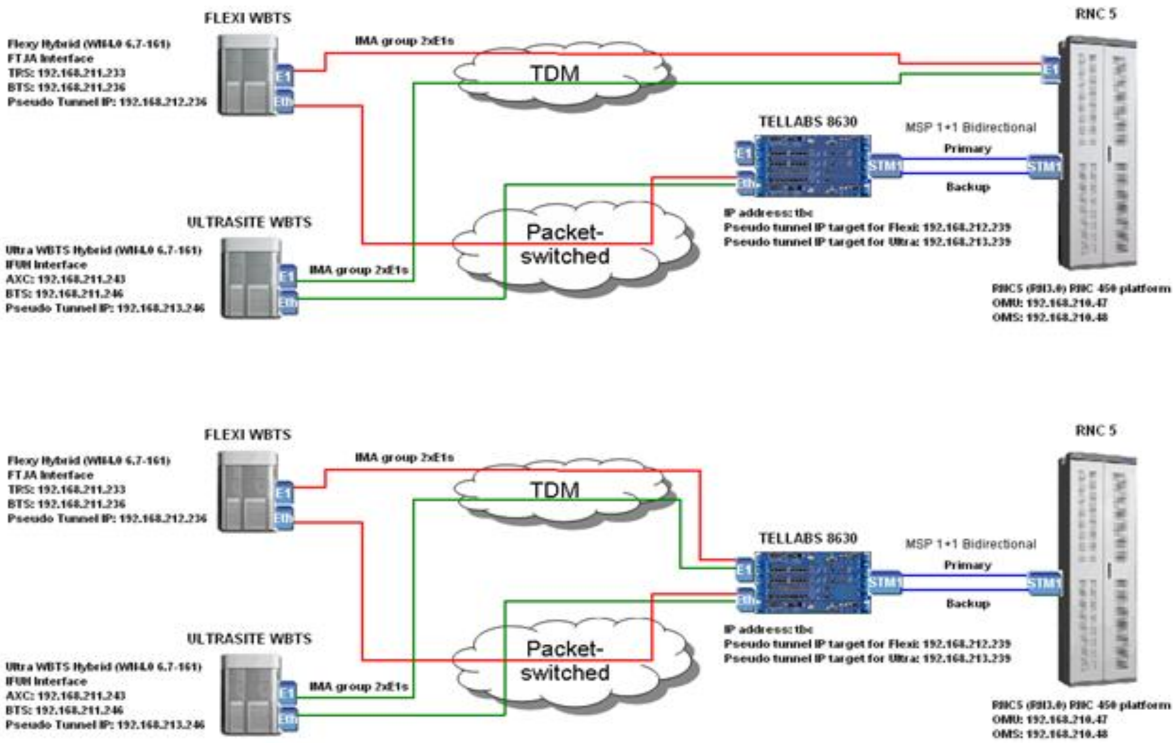


Figure 70. Hybrid Backhaul configurations tested during this validation. Two different IuB layouts are presented: the top one connects on one interface the E1 links directly to the RNC and needs a second interface to terminate the STM-1 connection, whereas the second one aggregates all the ATM traffic in the PWE3 gateway and presents only a single STM-1 interface towards the RNC.

Two different configurations of Hybrid Backhaul are tested (see Figure 70). In both cases, HSPA is offloaded from the TDM links and is conveyed over fast Ethernet media until the PWE3 gateway (Tellabs 8630), where the transport is converted again into pure ATM and sent to the RNC's Network Interface for SDH connections (NIS board) via channelized STM-1.

However, since Tellabs 8630 has also the functionality of an ATM cross-connector, TDM links can be either terminated directly into the RNC's Network Interface for PDH connections (NIP board) or cross-connected in Tellabs 8630 in order to combine all the traffic into the same channelized STM-1 link towards the RNC.

The second option offers advantages in terms of connectivity. It can be more cost-effective to aggregate TDM links and Fast Ethernet connections near the Node B into one traffic gateway and make use of only STM-1 optical fiber infrastructure towards the RNC rather than use parallel TDM and STM-1, raising the cost of the IuB link. In addition, no more than one interface connection is needed in the RNC, so extra board capacity is released.

Nonetheless, it is also worth mention that the first option can be more reliable in terms of link failures produced by a malfunction of Tellabs 8630 router. In this case, all the traffic could be easily routed back through the TDM links, causing no major impact for both user and operator. So again, system robustness versus cost-efficiency comes to light.

Redundancy configuration based on Multiplex Section Protection (MSP) scheme

In addition, note that in both cases the STM-1 link between the PWE3 gateway and the RNC is duplicated. The purpose of that is to apply redundancy in the transport node, to protect the link against possible failures on either the physical links or the interface cards controlling the end points. After a bit of research on the link protection mechanisms supported by both PWE3 gateway and RNC, SDH Multiplex Section Protection 1+1 (MSP 1+1), defined in the standard ITU-T G.783, was chosen.

In the basic MSP functionality, the service line (primary link) is protected using a secondary line (backup link) which is called the protection line: if an error occurs, for instance a Loss of Signal (LOS), the protection mechanism switches over to the protection line. In the variant MSP 1+1, the user traffic is simultaneously transmitted over the working and protection link in order to minimize the protection switching time, which means that in the egress direction the traffic is copied in both sections. In the reception direction, the selector is used to choose the traffic from either working or protection sections. At the far end, the line delivering the signal in best conditions is the selected one.

MSP protection scheme has two operation modes: the revertive and non-revertive operational mode.

In the **revertive mode**, the traffic is switched back from the protecting link to the working link once this has recovered from the fault. To prevent a frequent operation of the protection switch because of an intermittent failure, the faulty section needs to remain error-free for a fixed period of time before it is used again as the working channel. This period is called Wait-to-Restore (WTR) time.

In the **non-revertive mode,** the traffic is not switched back to the other link once the fault is solved. That means that non-revertive mode does not have a preferred working link and switching will only happen upon failure detection.

Both operation modes have been tested in order to verify the most convenient in terms of traffic drop and network element behavior (PWE3 gateway and RNC in this case).

Transport network configuration

This section describes the steps followed for the configuration of a hybrid backhaul network. Apart from the validation itself, this step was key in the development of the project due to the intensive amount of concepts related to transport network and the lack of existing guidelines to configure Tellabs 8630 equipment for this brand new solution.

The main contents of this section are:

- Tellabs 8630 configuration.
- RAN transport commissioning: Node B and RNC.

In order to diversify the nature of this validation, two different transport configuration strategies are used and implemented separately on each type of Node B, UltraSite and Flexi. In case of UltraSite Node B, all HSPA traffic will be carried on a single ATM Virtual Circuit (VC), whereas for the second one HSPDA and HSUPA traffic will be split into two VCs. That will help to test the different ATM cross-connection possibilities given by the PWE3 gateway (Tellabs 8630 equipment).

Table 30 and Table 31 show the ATM parameterization used in both kind of Node B:

Interface Board	VP	VC	Service Type	PCR (cps)	MDCR (cps)	UBR Share	IuB Protocol
IFUH	4		CBR	40000			
		48	UBR+	40000	25000	1	AAL2 USER PLANE (HSPA)
IFUD	0		UBR	4528			
		32	UBR	4528			O&M
	3		CBR	8981			
		33	CBR	319			CNBAP (*)
		34	CBR	600			DNBAP (*)
		40	CBR	319			AAL2 SIGNALING
		47	CBR	5708			AAL2 USER PLANE (DCH)

Table 30. ATM Configuration for UltraSite NODE B

(*)In the 3GPP UTRAN architecture, **NBAP** (**Node B Application Part)** is the signaling protocol responsible for the control of the Node B by the RNC. NBAP is subdivided into Common and Dedicated NBAP (C-NBAP and D-NBAP), where Common NBAP controls overall Node B functionality, and Dedicated NBAP controls radio links to specific user equipment. NBAP forms part of the IuB interface. NBAP handles two kinds of Procedures for different NBAP functionalities: Common Procedures for Managing Logical O&M Functions for Controlling BCCH Broadcast for creating new Node B Communication Context; and Dedicated Procedures for handling procedures of an existing Node B Communication Context in a TTP/CCP.

Interface Board	VP	VC	Service Type	PCR (cps)	MDCR (cps)	UBR Share	IuB Protocol
FTJA	2		CBR	40000			
		48	UBR+	40000	5000	0.5	AAL2 USER PLANE (HSDPA)
		49	UBR+	40000	5000	0.5	AAL2 USER PLANE (HSUPA)
	0		UBR	4528			
		32	UBR	4528			O&M
	1		CBR	8981			
		33	CBR	312			CNBAP
		34	CBR	600			DNBAP
		40	CBR	312			AAL2 SIGNALING
		47	CBR	6000			AAL3 USER PLANE (DCH)

Table 31. ATM Configuration for Flexi NODE B

It is also worth mentioning that one of the main challenges prior to testing was the lack of a simultaneous monitoring solution for all the RNC logical interfaces (IuB, Iu-PS and Iu-CS). Due to the way the RAN elements and the Core Network were connected in the lab, the only solution was to monitor one interface at a time or use multiple Nethawk analyzers, which incremented the cost of testing. During the development of this project I realized that by using internal ATM properties in the RNC there was a more efficient way to monitor all the interfaces at once by using single equipment. The technique implemented for this purpose will be shown in the section *Monitoring solution with Nethawk M5 protocol analyzer.*

Configuration in Tellabs 8630 (PWE3 gateway)

RNC did not support ATM over Ethernet at the time of the validation. Therefore, Tellabs 8630 Access Switch, emulating PWE3 gateway function, was used. In this network element of the IuB is where the traffic conveyed over PWE3 tunnel is converted into pure ATM and transferred to the RNC via STM-1 (in second configuration of Figure 10, traffic carried over E1 links is merged into the STM-1 as well).

Performance of ATM over Ethernet traffic depends basically on two parameters involved in the creation of layer 2 Ethernet packets as explained in the section *4.2.1 Concatenation factor, packetization timer and frame structure*:

- ***Concatenation Factor (CF)*****:** this parameter refers to the maximum number of ATM cells per packet. It can be configured between 0-28 cells, leading to an Ethernet frame of 1510 bytes.

- ***Packetization Timer (PT)*****:** this parameter refers to the maximum time to wait for ATM cells to be introduced into the Ethernet packet before it is transmitted.

As we have seen already, there is a trade-off between both parameters in order to achieve better efficiency in the IuB interface.

In this very first stage, it is tested an ideal scenario in which delay, packet loss and jitter are not considered, so fixed values for **concatenation factor (CF = 26)** and **packetization timer (PT = 5000µs)** are used.

Second step of the testing phase will be focused on finding the appropriate combination of CF and PT in non-ideal conditions. It will be achieved by using an Ethernet impairment tool in order to control the delay, packet loss and jitter variables affecting the communication across the Ethernet connection.

Physical interfaces and Command Line Interface (CLI) configuration

In order to understand the syntax used during the configuration of Tellabs 8630 for the hybrid backhaul design, a layout of its physical structure is presented in Figure 71.

For further reference, since the configuration was done from factory default settings I have decided to introduce all the preliminary steps required. All CLI commands used in both technical overview of the system and configuration appear in bold.

Interfaces

Tellabs 8630 Access Switch uses backplane architecture. This means that all the cards are front-access type. Its slot-based configuration enables a customized use of different swappable interface card modules, each one providing a different kind of physical connectivity.

According to the connectivity requirements specified in the design, the following interface cards will be used:

- 8 x 10/100 Base-TX interface card, for Fast Ethernet connections.
- 4 x STM-1 ATM interface card, for SDH connections.
- 24 x E1 Multiservice interface card, for PDH connections.

MODULE 1	MODULE 0	
4 x STM-1 / ATM	8 x STM-1 / POS	Slot 6
2 x 1000 BASE X	8 x STM-1 / POS	Slot 7
24 x E1	8 x 10/100 BASE TX	Slot 8
4 x STM-1 / ATM	4 x STM-4	Slot 9
POWER	COMMUNICATIONS	Slot 14

Figure 71. Tellabs 8630 physical configuration. Tellabs 8630 access switch is physically divided in slot-based interface cards (Power, Operation and Maintenance and transport interfaces). The Module/Slot numbering shown is the nomenclature used by the system to configure each one of the interface cards.

Each interface is labeled according to the following pattern:

[port_type] SLOT/MODULE/PORT

Slot and module number are shown in Figure 71. When numbering the ports, they follow an ascendant numeration beginning from the far right of each module.

The port_type field refers to the kind of connection. The following types are used in the next sections:

port_type	Connection type
so	STM-1
fe	Fast Ethernet
pdh	E1
ima	IMA group

Table 32. Port type connections in Tellabs 8630

CLI configuration for system management

For configuration purposes, access to Tellabs 8630 CLI (Command Line Interface) can be done both locally and remotely.

Local configuration is mandatory for setting up the switch when no IP address has been previously assigned to the management port. Once it is done, the equipment can be accessed using a Telnet-based application, like HyperTerminal. The following settings are suggested by the manufacturer in order to establish a local connection using the serial port RS-232:

- Bits per second: 38400 bps
- Data bits: 8
- Parity: None
- Stop bits: 1
- Flow control: None

Once the connection is done, the first command to type in order to access privilege mode is **enable.**

Any configuration changes will be stored in the *running configuration*, which represents the current configuration of the router, being the boot file used by the system after each restart. It means that all the commands introduced take immediate effect.

Running configuration can be inspected with the command **show running config** in any command access mode (see scheme in Figure 72).

Before starting any configuration procedure it is advisable to assign an IP address in order to work remotely. The following sequence of commands shows the procedure followed:

TELLABS>ena

TELLABS#configure terminal //abbreviate terminology is accepted. Equivalent command will be **conf t**

TELLABS(config)#interface mfe 14/0 //Refers to management fast Ethernet port located in slot 14 – module 0.

TELLABS(cfg-if[mfe14/0])#no shutdown //whilst shutdown typed on its own shuts down the IP interface (signal is cut between layers 2 and 3), by adding **no** at the beginning of the command, the contrary effect is achieved.

TELLABS(cfg-if[mfe14/0])#ip address 192.168.210.35/27

Initial H/W and S/W configuration

To move into internal configuration steps, the internal logic architecture might be previously understood. Each slot is provided with an internal flash memory containing the software needed to control the corresponding unit. The master unit is located in slot 14 and contains both Ethernet RJ-45 and serial RS-232 management ports.

A given H/W and S/W configuration of Tellabs 8630 is called *snapshot*. It can be stored into the flash memory of the master unit. Different *snapshot* files can be generated, allowing the creation of fallback environments in case the current configuration gets corrupted.

The following commands are useful when managing snapshots and installing new hardware/software into the equipment:

- Creation/removal of running-configuration and recognition of installed hardware:

    - Creation: snapshot-config create flash: [FILE_NAME]

    - Deletion: snapshot-config delete flash: [FILE_NAME]

    - H/W reset and recognition: hw-inventory add-all-units clean-start etsi

    - Restore the desired snapshot: **snapshot-config restore flash:[FILE_NAME]**

    - In case that an extra hardware unit is needed, it should be configured individually. In the presented configuration, an extra slot (slot 6) is needed to allow the redundancy required for MSP1+1 bidirectional protection of the STM-1 link, since both working and protected links must be allocated in different interface cards:

      hw-inventory slot 6 add unit clean-start

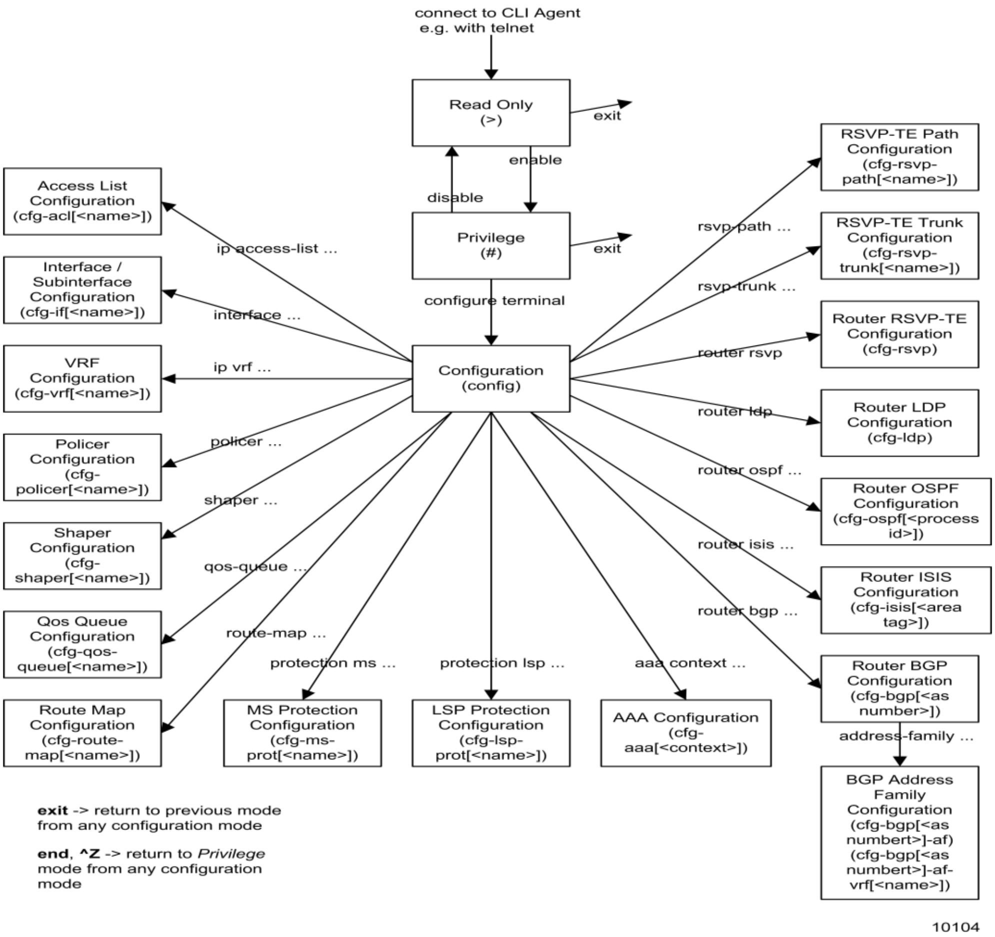


Figure 72. Tellabs 8630 CLI command hierarchy. This scheme represents the different access levels (read only, privilege and configuration). Every change that involves a modification of the switch functionality has to be done at config level.

- Software Upgrade: This step is only required when a new software release is provided by the vendor. The current configuration contains the latest version, which is dived into different files depending on the target hardware unit. This division is usually done between master and slave units:

  - Master slot (14): **cbz2712_2.7.169**
  - Slave slot (6,7,8 and 9): **lbz2713_2.7.169**

  Upload of the required files via FTP connection on the Ethernet management port is enabled with the command: **ftp-server enable**.

  Every slot has to be upgraded individually. The command sequence to follow is:

```
TELLABS(config)#boot system slot[slot]flash:[file_name]upgrade

TELLABS(config)#exit
```

```
TELLABS#reload-sw slot[slot]
```

Running software version can be double-checked with the command **show sw-version slot[slot]**

CLI configuration for Hybrid Backhaul

Using MPLS protocol and PWE3 tunneling, HSPA traffic is carried from each NODE B to Tellabs 8630 using the following criteria. It only applies to the traffic conveyed over the packet switched network:

- A pair of PWE3 tunnels (one tunnel per VC) is created from Flexi NODE B, each of them carrying HSDPA and HSUPA.

- A single PWE3 tunnel is necessary from UltraSite NODE B, since all HSPA traffic is conveyed over a single VC.

Any configuration related with the TDM links is only dedicated to the way the traffic is cross-connected internally from the E1 interface towards the STM-1.

1) *Configuration for HSPA traffic*

- **Creation of pseudo tunnels used in packet switched network**

  It must be taken into account that each tunnel needs to be labeled uniquely inside the MPLS domain, since it is used as identification.

  Although one path would be sufficient for the current configuration of UltraSite NODE B, a second one is also created just in case there is a future change in the VC configuration (HSDPA and HSUPA conveyed through different VCs).

  Flexi NODE B pseudo tunnel

  Flexi_hsdpa (id=161): **pwe3 circuit flexi_hsdpa 161 mpls manual**

  Flexi_hsupa (id=162): **pwe3 circuit flexi_hsupa 162 mpls manual**

UltraSite NODE B pseudo tunnel

Ultra_hsdpa (id=163): **pwe3 circuit ultra_hsdpa 163 mpls manual**

Ultra_hsupa (id=164): **pwe3 circuit ultra_hsupa 164 mpls manual**

- **Interface definition**

The interfaces involved in the different connections have to be configured in order to match the ATM traffic parameters expected end to end between the RNC and the Node B (VPs and VCs, traffic definitions…). The values and parameters used match the ones in Tables 1 and 2.

STM-1 link between Tellabs 8630 and RNC

In the configuration where only HSPA traffic is switched via Tellabs 8630, this link should contain one VP per NODE B and 2 VCs per VP, each one dedicated for HSDPA and HSUPA traffic.

VP definition for Flexi Node B

```
TELLABS(config)# interface so9/1/2#atm#2 //Number 2 identifies VP_ID for Flexi NODE B

TELLABS(cfg-if[so9/1/2#atm#2])#atm supp-serv-cat cbr

TELLABS(cfg-if[so9/1/2#atm#2])#atm supp-serv-cat ubr

TELLABS(cfg-if[so9/1/2#atm#2])#atm traffic-params servcat cbr confdef cbr.1 pcr 40000 40000 cdvt 5000 5000
```

VP definition for UltraSite Node B

```
TELLABS(config)# interface so9/1/2#atm#4 //Number 4 identifies VP_ID for UltraSite NODE B

TELLABS(cfg-if[so9/1/2#atm#4])#atm supp-serv-cat cbr

TELLABS(cfg-if[so9/1/2#atm#4])#atm supp-serv-cat ubr

TELLABS(cfg-if[so9/1/2#atm#4])#atm traffic-params servcat cbr confdef cbr.1 pcr 40000 40000 cdvt 5000 5000
```

VC definition for Flexi NODE B

VC 48 & 49:

TELLABS(config)# interface so9/1/2#atm#2.48 //Number 48 identifies VC dedicated for HSDPA traffic

TELLABS(cfg-if[so9/1/2#atm#2.48])# atm usage switched //Switched indicates that ATM traffic will be routed through this interface and not terminated there.

TELLABS(cfg-if[so9/1/2#atm#2.48])# atm cell concatenation 26 5000 //concatenation factor=26 and packetization timer=5000 µs.

TELLABS(cfg-if[so9/1/2#atm#2.48])# atm traffic-params servcat ubr confdef ubr.1 pcr 40000 40000 //At the time of configuration the software release of Tellabs 8630 did not support traffic class ubr+, hence mdcr parameter is not shown. Tellabs has committed to release this ATM service category in next releases.

TELLABS(cfg-if[so9/1/2#atm#2.48])# pwe3 circuit flexi_hsdpa //Association between the interface and its corresponding mpls tunnel.

TELLABS(cfg-if[so9/1/2#atm#2.48])# no shutdown //Activates the interface

TELLABS(config)# interface so9/1/2#atm#2.49 //Number 49 identifies VC dedicated for HSUPA traffic

TELLABS(cfg-if[so9/1/2#atm#2.49])# atm usage switched

TELLABS(cfg-if[so9/1/2#atm#2.49])# atm cell concatenation 26 5000

TELLABS(cfg-if[so9/1/2#atm#2.49])# atm traffic-params servcat ubr confdef ubr.1 pcr 40000 40000

TELLABS(cfg-if[so9/1/2#atm#2.49])# pwe3 circuit flexi_hsupa

TELLABS(cfg-if[so9/1/2#atm#2.49])# no shutdown

VC definition for UltraSite NODE B

VC 48 & 49:

TELLABS(config)# interface so9/1/2#atm#4.48 //VC 48

TELLABS(cfg-if[so9/1/2#atm#4.48])# atm usage switched

TELLABS(cfg-if[so9/1/2#atm#4.48])# atm cell concatenation 26 5000

TELLABS(cfg-if[so9/1/2#atm#4.48])# atm traffic-params servcat ubr confdef ubr.1 pcr 40000 40000

TELLABS(cfg-if[so9/1/2#atm#4.48])# pwe3 circuit ultra_hsdpa

TELLABS(cfg-if[so9/1/2#atm#4.48])# no shutdown

TELLABS(config)# interface so9/1/2#atm#4.49 //VC 49

TELLABS(cfg-if[so9/1/2#atm#4.49])# atm usage switched

TELLABS(cfg-if[so9/1/2#atm#4.49])# atm cell concatenation 26 5000

TELLABS(cfg-if[so9/1/2#atm#4.49])# atm traffic-params servcat ubr confdef ubr.1 pcr 40000 40000

TELLABS(cfg-if[so9/1/2#atm#4.49])# pwe3 circuit ultra_hsupa

TELLABS(cfg-if[so9/1/2#atm#4.49])# no shutdown

Fast Ethernet link terminating MPLS tunnels between NODE B and Tellabs 8630

Tunnel definition for Flexi NODE B

TELLABS(config)# interface fe8/0/1

TELLABS(cfg-if[fe8/0/1])# label-switching //Enables LSP protocol in the interface.

TELLABS(cfg-if[fe8/0/1])# ip address 192.168.212.239/24 //Pseudo tunnel IP target for Flexi NODE B

TELLABS(cfg-if[fe8/0/1])# qos mapping enable //configures internal QoS to IP/MPLS header bit mapping in use.

TELLABS(cfg-if[fe8/0/1])# no shutdown

Tunnel definition for UltraSite NODE B

TELLABS(config)# interface fe8/0/2

TELLABS(cfg-if[fe8/0/2])# label-switching

TELLABS(cfg-if[fe8/0/2])# ip address 192.168.212.249/24 //Pseudo tunnel IP target for UltraSite NODE B

TELLABS(cfg-if[fe8/0/2])# qos mapping enable

TELLABS(cfg-if[fe8/0/2])# no shutdown

- **Bridging the tunnels between each NODE B and Tellabs 8630**. By doing this, routes are configured from NODE B and associated to their respective PWE3 circuits which will then drive traffic until STM-1.

Configuration of static mapping IP-MPLS to ATM for Flexi NODE B

TELLABS(config)# mpls static-ftn push-ip 192.168.212.236/32 192.168.212.239 192.168.212.236 mpls 0x0 // IP addresses correspond respectively to: IP destination addresses which can use this route (in this case it can be use by a unique route towards Flexi NODE B, hence netmask is /32)- IP Source (tunnel endpoint IP address) – IP destination (Flexi NODE B). "mpls" indicates that this protocol is the only one allowed in this route. This command provides Tellabs 8630 with the route where to forward VCs coming from STM-1 ATM interface

TELLABS(config)# mpls static-ftn push-and-lookup-for-vc flexi_hsdpa vc-qos ef 161 e-lsp 192.168.212.236 name MPLSfabric:1161 //Circuit 1161 between STM-1 ATM and Fast Ethernet interfaces will forward HSDPA VC through pseudo wire with label 161, being "expedited forwarding" the QoS applied to the VC. Different type of QoS services can be applied depending on the type of traffic to be carried, being: Expedited Forwarding (EF), Assured Forwarding (AF1, AF2, AF3 and AF4) and Best Effort (BE). HSPA traffic qualifies under the category of BE since it is not time-critical. However, since this is the only traffic to be carried in the pseudo wire, it is assigned the highest QoS type possible.

TELLABS(config)# mpls static-ftn push-and-lookup-for-vc flexi_hsupa vc-qos ef 162 e-lsp 192.168.212.236 name MPLSfabric:1162 //Circuit 1162 between STM-1 ATM and Fast Ethernet interfaces will forward HSUPA VC through pseudowire with label 162, being "expedited forwarding" the QoS applied to the VC.

TELLABS(config)# mpls static-ilm pop-ip fe8/0/1 192.168.212.239 //This command provides Tellabs 8630 with the interface and tunnel endpoint IP address to look for ATM traffic (VCs) over Ethernet VCs coming from Node B.

TELLABS(config)# mpls static-ilm pop-for-vc flexi_hsdpa 161 e-lsp name MPLSfabric:2161 //Circuit 2161 will forward HSDPA VC from pseudowire with label 161 terminated at Fast Ethernet interface to STM-1 ATM interface.

TELLABS(config)# mpls static-ilm pop-for-vc flexi_hsupa 162 e-lsp name MPLSfabric:2162//Circuit 2162 will forward HSUPA VC from pseudowire with label 162 terminated at Fast Ethernet interface to STM-1 ATM interface.

Configuration of static mapping IP-MPLS to ATM for UltraSite NODE B

TELLABS(config)# mpls static-ftn push-ip 192.168.213.246/32 192.168.212.249 192.168.213.246 mpls 0x0

TELLABS(config)# mpls static-ftn push-and-lookup-for-vc ultra_hsdpa vc-qos ef 163 e-lsp 192.168.213.246 name MPLSfabric:1163

TELLABS(config)# mpls static-ftn push-and-lookup-for-vc ultra_hsupa vc-qos ef 164 e-lsp 192.168.213.246 name MPLSfabric:1164

TELLABS(config)# mpls static-ilm pop-ip fe8/0/2 192.168.212.249

TELLABS(config)# mpls static-ilm pop-for-vc ultra_hsdpa 163 e-lsp name MPLSfabric:2163

TELLABS(config)# mpls static-ilm pop-for-vc ultra_hsupa 164 e-lsp name MPLSfabric:2164

2) Configuration for non-HSPA traffic

In current configuration, a 2 x E1 IMA group link is set between NODE B and the RNC carrying both RT DCH and NRT DCH R99 traffic. The required synchronization for the Node B will be provided through this link as well.

In this section it is covered the situation in which the IMA group is set up through Tellabs 8630 and the transported ATM traffic is cross-connected into the before mentioned STM-1 link towards the RNC, hence combining both HSPA and R99 traffic.

The physical architecture of Tellabs 8630 shows four interfaces in Unit 8 – Module 1. Each of them can map up to 6 E1s, so a total of 24 E1s are allowed. The procedure to follow in this case is, first of all, mapping the E1s coming from the NODE B onto each interface and then create the corresponding IMA group.

- Definition of internal pseudowire architecture to make an internal ATM cross-connection between E1 and STM-1 interfaces. Cross-connection will be done at VP level.

  TELLABS(config)# pwe3 circuit flexi 2000 mpls manual //Circuit 2000 will carry traffic coming from Flexi NODE B

  TELLABS(config)# pwe3 circuit ultra 2001 mpls manual //Circuit 2001 will carry traffic coming from UltraSite NODE B

- Configuration of E1 interfaces

  E1 definition for Flexi NODE B

  TELLABS(config)# interface pdh8/1/6 //First E1

  TELLABS(cfg-if[pdh8/1/6])# pdh framed

  TELLABS(cfg-if[pdh8/1/6])# interface pdh8/1/6:0

  TELLABS(cfg-if[pdh8/1/6:0])# pdh timeslots-all

  TELLABS(cfg-if[pdh8/1/6:0])# port-protocol atm

  TELLABS(config)# interface pdh8/1/7 //Second E1

  TELLABS(cfg-if[pdh8/1/7])# pdh framed

  TELLABS(cfg-if[pdh8/1/7])# interface pdh8/1/7:0

  TELLABS(cfg-if[pdh8/1/7:0])# pdh timeslots-all

  TELLABS(cfg-if[pdh8/1/7:0])# port-protocol atm

  E1 definition for UltraSite NODE B

  TELLABS(config)# interface pdh8/1/0 //First E1

  TELLABS(cfg-if[pdh8/1/0])# pdh framed //Creation of IMA group is allowed

  TELLABS(cfg-if[pdh8/1/0])# interface pdh8/1/0:0

  TELLABS(cfg-if[pdh8/1/0:0])# pdh timeslots-all

  TELLABS(cfg-if[pdh8/1/0:0])# port-protocol atm

  TELLABS(config)# interface pdh8/1/1 //Second E1

  TELLABS(cfg-if[pdh8/1/1])# pdh framed

  TELLABS(cfg-if[pdh8/1/1])# interface pdh8/1/0:0

TELLABS(cfg-if[pdh8/1/1:0])# pdh timeslots-all

TELLABS(cfg-if[pdh8/1/1:0])# port-protocol atm

- Configuration of STM-1 link in order to support the new traffic specifications

TELLABS(config)# interface so9/1/2

TELLABS(cfg-if[so9/1/2])# atm if-type uni

TELLABS(cfg-if[so9/1/2])# interface so9/1/2#atm#1 //VP_ID=1 for E1 links connected to Flexi NODE B

TELLABS(cfg-if[so9/1/2#atm#1])# atm usage switched

TELLABS(cfg-if[so9/1/2#atm#1])# atm traffic-params servcat cbr confdef cbr.1 pcr 8981 8981 cdvt 5000 5000 //Traffic definition for a 2E1 TDM link

TELLABS(cfg-if[so9/1/2#atm#1])# pwe3 circuit flexi //Association of internal pseudowire circuit "flexi" with VP 1

TELLABS(cfg-if[so9/1/2#atm#1])# no shutdown

TELLABS(cfg-if[so9/1/2])# interface so9/1/2#atm#3 //VP_ID=3 for E1 links coming from UltraSite NODE B

TELLABS(cfg-if[so9/1/2#atm#3])# atm usage switched

TELLABS(cfg-if[so9/1/2#atm#3])# atm traffic-params servcat cbr confdef cbr.1 pcr 8981 8981 cdvt 5000 5000

TELLABS(cfg-if[so9/1/2#atm#3])# pwe3 circuit ultra //Association of internal pseudowire circuit "ultra" with VP 3.

TELLABS(cfg-if[so9/1/2#atm#3])# no shutdown

- IMA group definition for each pair of E1s.

TELLABS(config)# interface ima8/1 //IMA is not a physical interface, but a logical association of physical interfaces

TELLABS(cfg-if[ima8/1])# atm ima member pdh8/1/6:0 //Aggregation of first E1 link of Flexi NODE B IMA group

TELLABS(cfg-if[ima8/1])# atm ima member pdh8/1/7:0 //Aggregation of second E1 link of Flexi NODE B IMA group

TELLABS(cfg-if[ima8/1])# atm if-type uni

TELLABS(cfg-if[ima8/1])# interface ima8/1.1 //Definition of VP 1 for Flexi NODE B

TELLABS(cfg-if[ima8/1.1])# atm usage switched

TELLABS(cfg-if[ima8/1.1])# atm traffic-params servcat cbr confdef cbr.1 pcr 8981 8981 cdvt 5000 5000

TELLABS(cfg-if[ima8/1.1])# pwe3 circuit flexi //Both IMA and STM-1 VP 1 traffic will be cross-connected internally via this pseudowire

TELLABS(cfg-if[ima8/1.1])# no shutdown

TELLABS(config)# interface ima8/2

TELLABS(cfg-if[ima8/2])# atm ima member pdh8/1/0:0 //Aggregation of first E1 link of UltraSite NODE B IMA group

TELLABS(cfg-if[ima8/2])# atm ima member pdh8/1/1:0 //Aggregation of second E1 link of UltraSite NODE B IMA group

TELLABS(cfg-if[ima8/2])# atm if-type uni

TELLABS(cfg-if[ima8/2])# interface ima8/2.3 //Definition of VP 3 for UltraSite NODE B

TELLABS(cfg-if[ima8/2.3])# atm usage switched

TELLABS(cfg-if[ima8/2.3])# atm traffic-params servcat cbr confdef cbr.1 pcr 8981 8981 cdvt 5000 5000

TELLABS(cfg-if[ima8/2.3])# pwe3 circuit ultra //Both IMA and STM-1 VP 3 traffic will be cross-connected internally via this pseudowire

TELLABS(cfg-if[ima8/2.3])# no shutdown

- Bidirectional definition of internal ATM cross-connections.

TELLABS(config)# mpls static-ftn bridge flexi ima8/1.1 so9/1/2#atm#1

TELLABS(config)# mpls static-ftn bridge flexi so9/1/2#atm#1 ima8/1.1

TELLABS(config)# mpls static-ftn bridge ultra ima8/2.3 so9/1/2#atm#3

```
TELLABS(config)# mpls static-ftn bridge flexi so9/1/2#atm#3 ima8/2.3
```

Link redundancy

In order to secure the STM-1 link against any breakages or hardware faults, MSP 1+1 bidirectional protection was configured between Tellabs 8630 and the RNC. For this purpose, a so called protection group is created taking into account the following internal protection rules:

- High slot numbers are protected by lower ones
- Interfaces located on different modules, i.e. module 0 and module 1, within the same slot, cannot be protected by MSP. Only interfaces situated on different slots can be MSP-protected.

In this case the interface so9/1/2 (STM-1) situated in slot 9 is protected by interface so6/1/2 (STM-1) situated in slot 6.

```
TELLABS(config)# protection ms MyProtection //Protection group "MyProtection" is created

TELLABS(config)# primary so9/1/2 backup so6/1/2 bidirectional
```

Node B transmission commissioning

Node B commissioning embraces two major stages: radio commissioning and transmission commissioning. Radio commissioning configures the NODE B in terms of sectors, power and frequencies to use and is out of the scope of this project. This section is focused on the steps followed to set up the necessary transmission configuration in both NODE B platforms, Flexi and UltraSite, for a hybrid backhaul solution. A series of screenshots will guide the reader through the commissioning process followed to configure a hybrid backhaul scenario.

Flexi NODE B commissioning

Figure 73 presents the user interface of a NODE B Element Manager. It shows a visual description of the NODE B hardware configuration and cells commissioned. It can be distinguished the System Module (FSMB), which is the main processing unit of the NODE B, the RF modules (FRGC and FRGD) and the transmission module (FTJA). Transmission configuration can be accessed via the Commissioning Wizard.

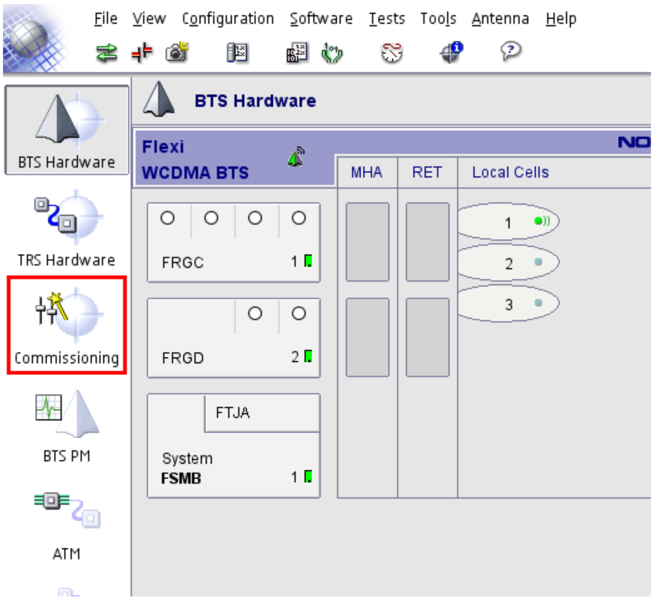


Figure 73. NODE B Element Manager User Interface. Access to Flexi NODE B Commissioning Wizard is highlighted in red. On the left hand side, the reader can check the current hardware configuration and the number of cells configured and their status: radiating (green light) and non radiating.

- **Interface definition**

First step consists on activating the number of required E1s in the transmission module, FTJA in this case. In order to do that the *In Use* field needs to be checked. Since they will be included within an IMA group, the correspondent IMA identity, 33 by default, has to be selected under the *IMA Group* field. In addition, one of the E1 links included in the IMA group has to be defined as the synchronization source for the NODE B. Synchronization is fed directly from the RNC through this physical link.

At the same time, Fast Ethernet interface (interface 2 in this case), to be used for HSPA traffic, has to be enabled (by checking *In Use* field again). See Figure 74 for reference.

- **Traffic descriptors definition**

User is prompted to define a series of ATM patterns to associate to each one of the necessary VP/VC connections (Figure 75). The parameters to fill in should match the ones defined in Table 31.

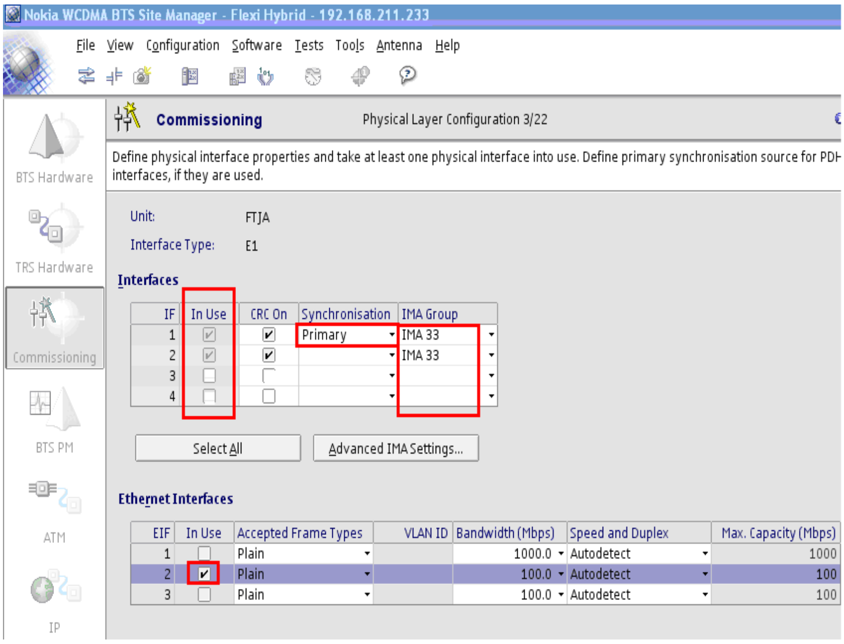


Figure 74. Definition of E1, IMA group and Ethernet interfaces.

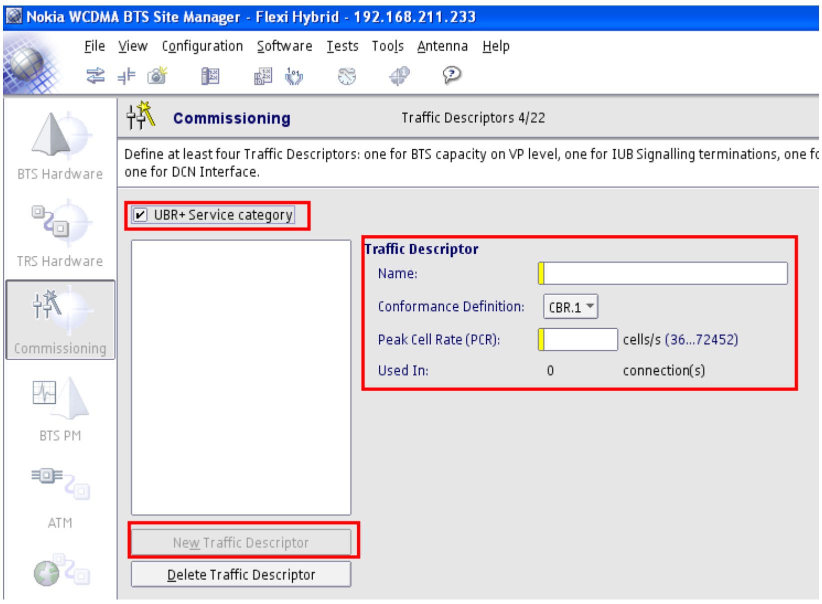


Figure 75. VP/VC traffic descriptor configuration.

- **ATM over Ethernet settings**

If pseudowire tunnel end-point IP address is defined in Tellabs 8630, the source point has to be configured in the NODE B. As per Flexi NODE B configuration, two pseudowire are configured, one for HSDPA and the other for HSUPA traffic.

Tunnel definition

Local IP: 192.168.212.236 (the tunnel source point IP address)

Subnet Mask: 255.255.255.0 (/24)

Remote IP Address: 192.168.212.239 (tunnel far endpoint in Tellabs 8630)

Next Router: 192.168.212.239 (no intermediate node is in between Tellabs and Flexi NODE B)

Pseudowire parameter definition

MPLS Header Label TX: 161 (1st wire) **or 162** (2nd wire)

MPLS Header Label RX: 161 (1st wire) **or 162** (2nd wire)

Max. Cells per Frame: 26 (it matches the parameter defined in the PWE3 gateway)

Packetization Timer: 5000µs

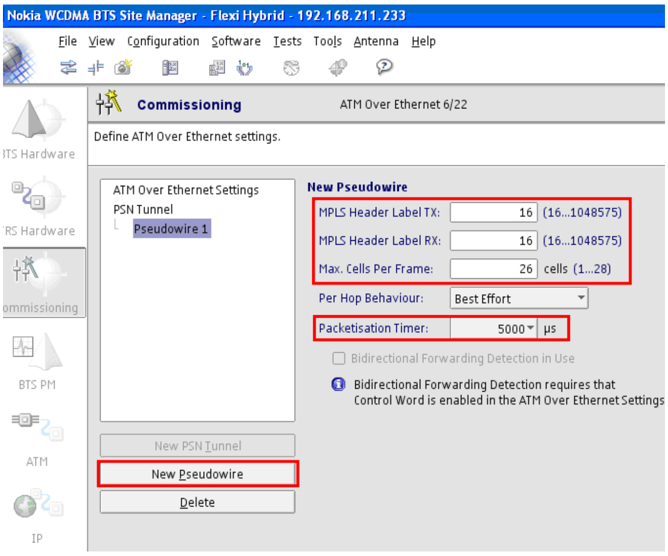


Figure 76. ATM over Ethernet Settings. The pseudowire configuration menu is shown. Tunnel definition can be accessed from PSN Tunnel option. The equipment also allows the definition of QoS policies (Per Hop Behavior field), which were out of the scope of this validation.

- **Definition of IuB termination points**

This is the final step regarding transport commissioning. Transport type, traffic type and protocol are mapped together according to the parameters defined in Table 31.

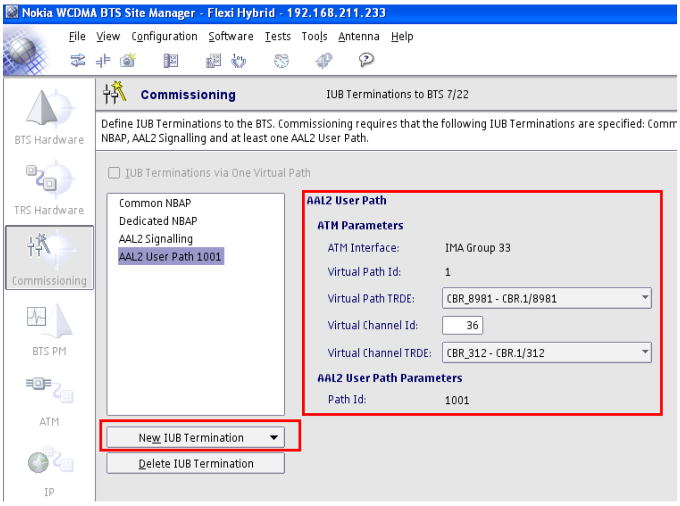


Figure 77. IuB termination points. Note that for the first AAL2 User Path (used for non-HSPA traffic) an IMA group ATM interface is used. In the definition of the extra two AAL2 paths used, the ATM interface type will be the PWE3 tunnels defined in the previous step.

UltraSite NODE B commissioning

In contrast with Flexi NODE B, UltraSite NODE B embraces its transmission media in a stand-alone entity embedded into its cabinet. It is the so called ATM Cross-connection Controller (AXC). Being a different hardware module from the one used with Flexi NODE B, the configuration differs slightly from the previous one.

- ***AXC Hardware View – Physical interface configuration***

AXC consists of two different kind of modules: AXU (ATM Cross-connection Unit), in charge of ATM processing, and interface (IF) cards (Figure 78).

In order to implement a hybrid backhaul solution two different types of IF cards are required: IFUD, equipped with 8 x E1 TDM interfaces, and IFUH, provided with 2 Fast Ethernet interfaces.

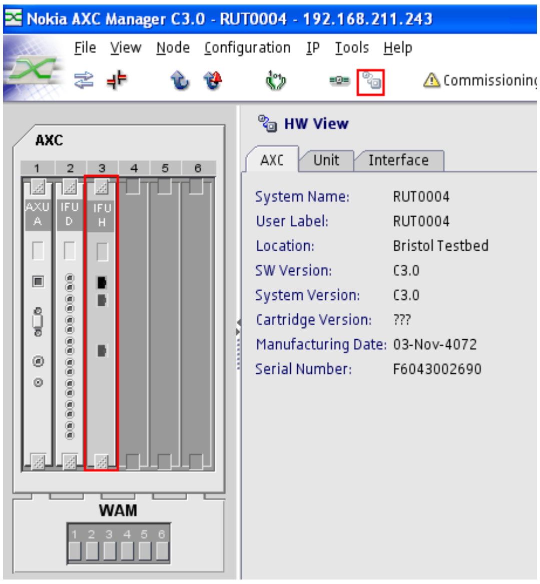


Figure 78. AXC hardware overview. IFUH card is highlighted in red. This is the interface providing the extra Fast Ethernet connection required to implement the Hybrid Backhaul Solution.

Whilst the tabs *AXC* and *Unit* offer information about hardware and software details, the one useful in terms of physical configuration is the tab *Interface* (Figure 79). The desired Fast Ethernet interface is selected and configured with the following parameters: **Limited Ethernet Bandwidth = 100Mbps, Speed and Duplex = Auto negotiation, no VLAN**.

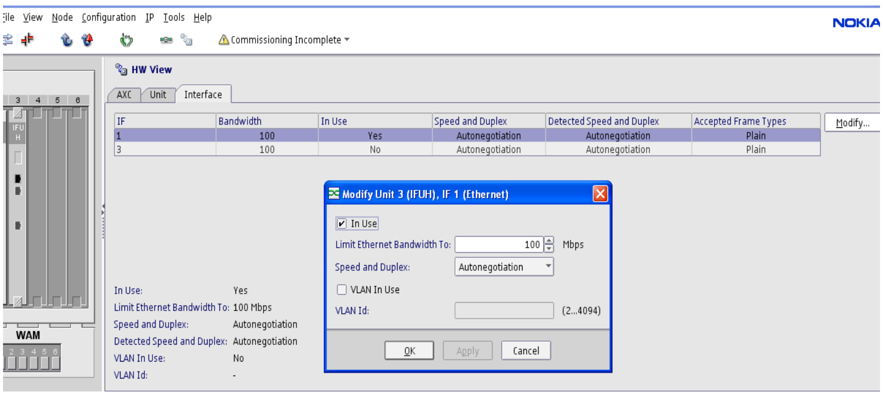


Figure 79. IFUH card- Fast Ethernet Interface configuration.

A similar process to the one followed for Flexi NODE B is repeated to configure a 2 E1 TDM interface (parameters for each Interface type=E1, Line Type=Multi Frame G.704 and Bit Error Rate (BER) mode=10^{-3}) in IFUD card.

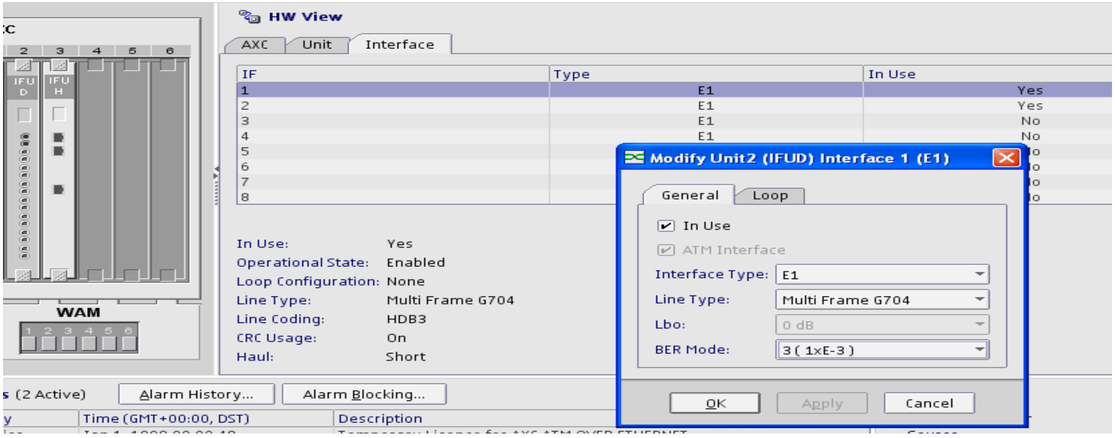


Figure 80. IFUD board – E1 interface configuration

Once the E1 interfaces have been set up, the IMA group can be created the same way than in Flexi Node B.

- ***AXC ATM View***

This view provides three different tabs: *ATM*, *IUB Terminations to BTS* and *ATM over Ethernet.* The first one manages the creation of VPs and VCs and it is specific for each interface. The second one is common for all of them, and configures the IuB interface protocol structure. Finally, *ATM over Ethernet* provides the parameters for tunnel configuration associated to the Hybrid Backhaul functionality.

Once in *ATM* tab*,* a new VP can be created over the desired interfaces by clicking *New…* Then, *New Cross connection* menu appears, where the associated VCs and traffic descriptors can be created and attached (see Figure 81).

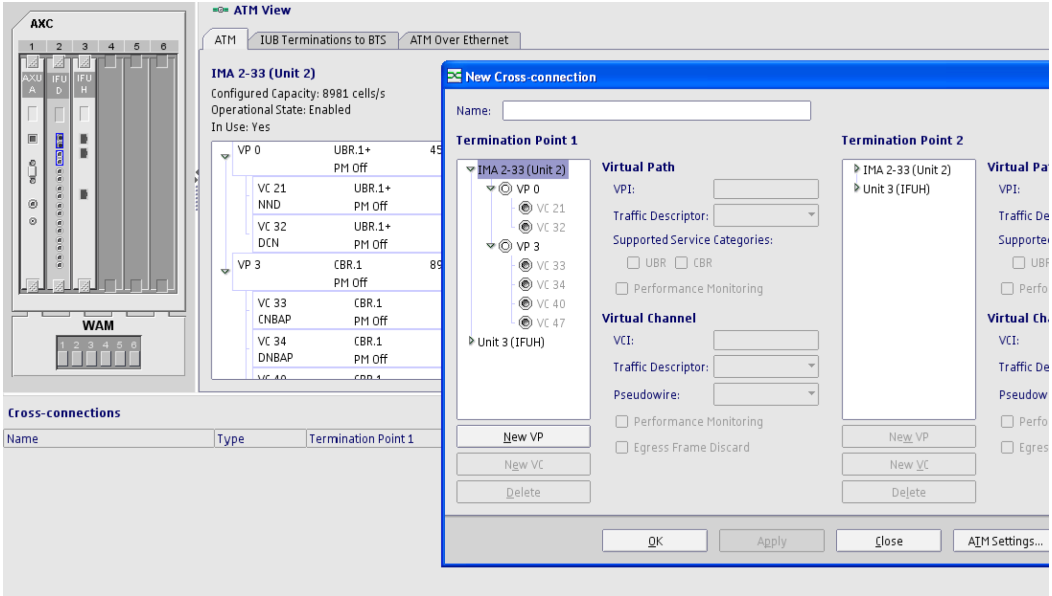


Figure 81. IFUD board – VP/VC definition

Note that depending on the interface selected (IFUD or IFUH) the properties of a VC may change, in the way that in the IFUH interface you can define a VC as a pseudo wire but not in the IFUD. The pseudo wire option depends on the definition explained in the *ATM over Ethernet* tab.

Likewise, *IuB Termination to BTS* follows the configuration shown in Table 30 (see Figure 82).

Note: when defining the different IuB protocols Common Node B Application Part (CNBAP), Dedicated Node B Application Part (DNBAP), etc… it will appear an option called *WAM.* It stands for Wideband Application Manager and it is the telecom master module in charge of OAM and internal NODE B processing.

Depending on the position of this module in the cabinet subrack and the amount of WAM modules per NODE B, the parameter WAM id (i.e. WAM 2) may change. In order to avoid further extension on the topic, a single WAM configuration has been implemented.

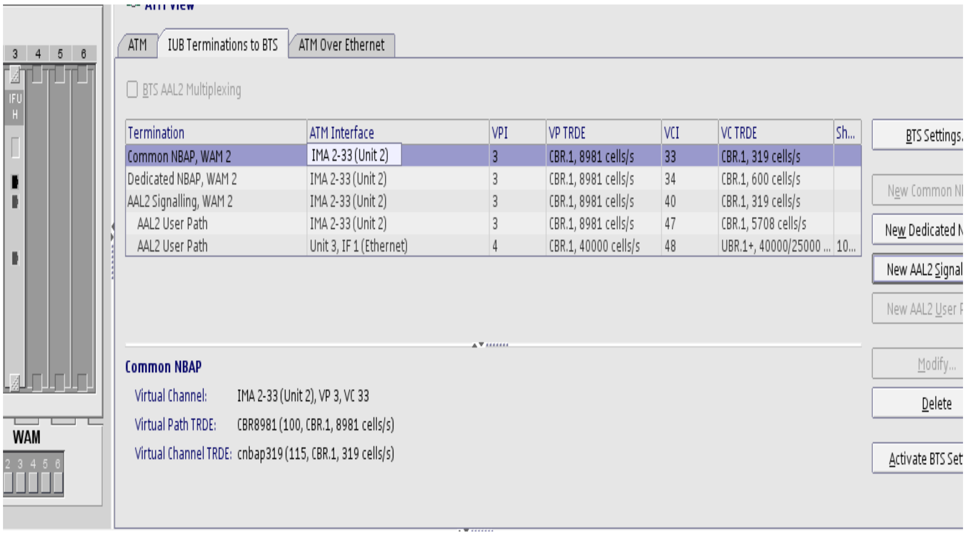


Figure 82. IuB terminations in UltraSite NODE B.

Finally, the tunnel configuration is done under ATM over Ethernet menu (see Figure 83).

The procedure is quite similar to the one in Flexi NODE B configuration. When creating the tunnel, the parameters requested are:

Tunnel definition

Local IP address: 192.168.213.246 (Tunnel start point address in BTS)

Netmask: 255.255.255.0 (/24)

Remote IP address: 192.168.213.249 (Tunnel far-end point in Tellabs 8630)

Next Router: 192.168.213.249 (No intermediate router is configured).

Active Interface: 1 (Fast Ethernet interface ID in IFUH card)

Once the tunnel has been configured in both ends (Node B and Tellabs 8630), the connectivity can be checked with the functionality *Check Tunnel Connectivity.*

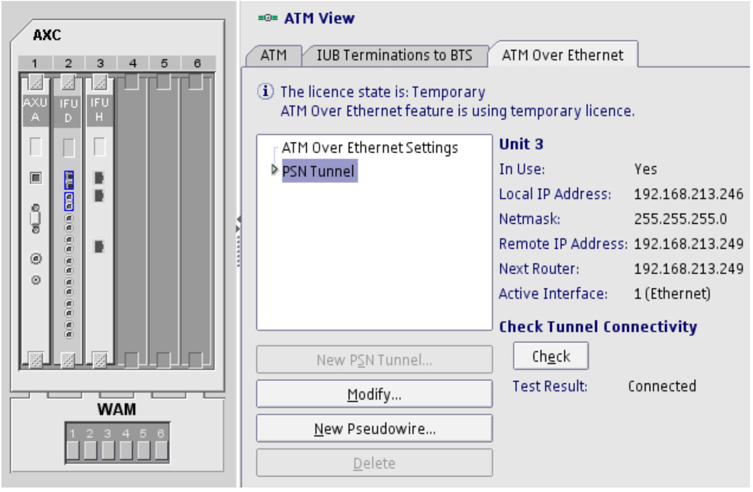


Figure 83. IuB ATM over Ethernet configuration. Definition of PWE3 tunnel. Note that the Tunnel Connectivity test result should be connected to indicate the correct E2E configuration.

Once the tunnel has been created, two pseudowires are defined with the option *New Pseudowire…*: one for HSDPA and the other for HSUPA traffic. The parameters introduced are:

Pseudowire parameter definition

MPLS Header Label TX: 163 (1st wire) **or 164** (2nd wire)

MPLS Header Label RX: 163 (1st wire) **or 164** (2nd wire)

Max. Cells per frame: 26

Per hop behavior: Best Effort

Packetization Timer: 4800 µs (In UltraSite NODE B the value 5000 µs cannot be configured. Using the immediate inferior one was proved not to introduce any impact on the results).

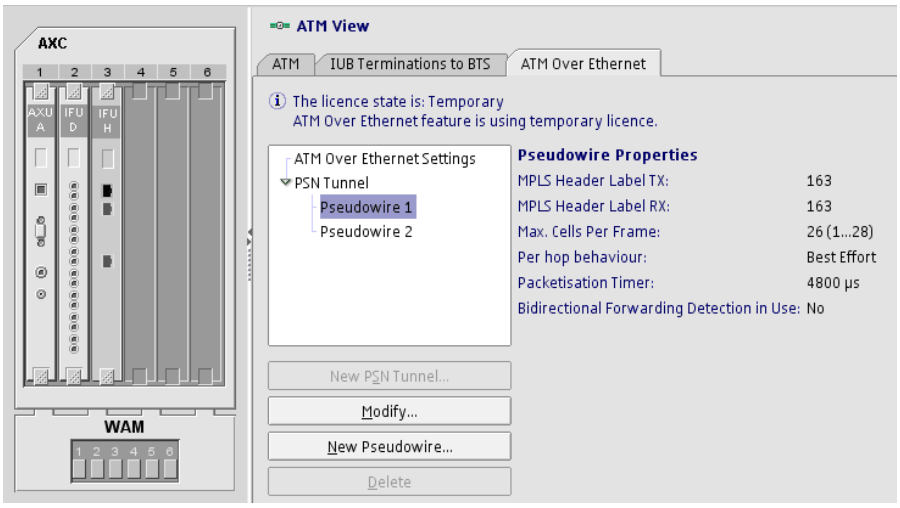


Figure 84. IuB ATM over Ethernet configuration. Pseudowire definition.

RNC transmission commissioning

The Radio Network Controller is the most complex network element in the Radio Access Network. In order to understand how the RNC handles the transport of ATM traffic it is worth to detail the physical and logical entities involved in the creation of the appropriate transmission solution in the IuB, from the mere physicals until the definition of the logical VP/VC circuits handling the transport of the higher IuB protocol layers (See Figure 85).

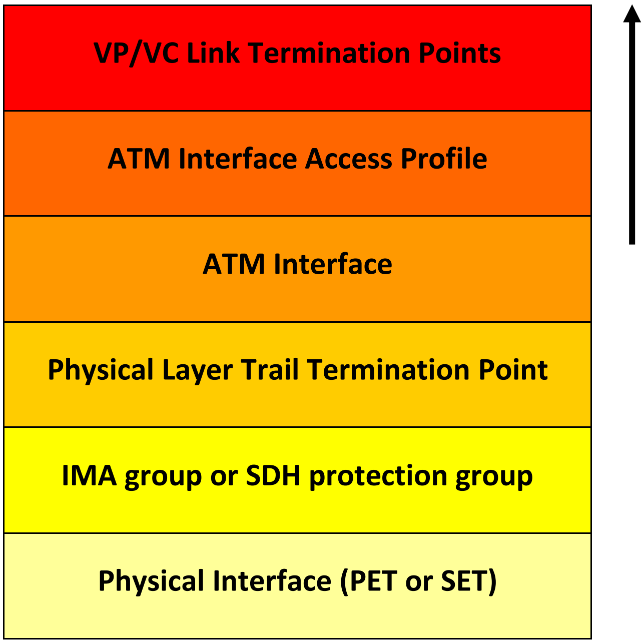


Figure 85. Bottom-Up stack to follow when defining ATM connections in RNC.

RNC Network Interface cards

The RNC has two different interface cards to handle PDH and SDH connections which are NIP and NIS board, respectively. These cards have a different number of connection points, called PET (PDH Exchange Terminal) or SET (SDH Exchange Terminal). These PETs and SETs can be used individually as a single connection or can be grouped in order to create an IMA group (PDH) or an SDH protection group (required when STM-1 redundancy mechanisms are in use).

Physical Layer Trail Termination Point (PhyTTP)

The PhyTTP is configured between the physical layer and the ATM layer. The idea is to provide the higher layers with a physical support to interface with disregarding the physical media used for that.

ATM Interface

The ATM interface is an external logical interface under which VP and VC connections are built. The ATM interface can work as User-Network Interface (UNI), for example in the IuB interface, or as Network-Node Interface (NNI), which is the case of the connections towards the Core Network. When the ATM Interface is created, it is linked to a PhyTTP. The system determines automatically the capacity of the ATM interface (in cps) according to the physical capacity of the PhyTTP.

ATM Interface Access Profile

The access profile created for an ATM interface defines the connection structure built under the interface. The access profile parameters to be defined are:

- maximum number of Virtual Path Identifier (VPI) bits
- maximum number of Virtual Channel Identifier (VCI) bits
- UPC/NPC (usage/network parameter control or also known as policing)

These parameters will modify the header in the ATM cells. Just for reference, maximum number of VPI bits defines the number of bits available for specifying the Virtual Path link termination points, which in turn, define how many VPs can be created under the ATM interface. Likewise, maximum number of VCI bits defines the amount of Virtual Channels that can be created inside each VP.

According to ITU-T Recommendation I.361, VCI values 1 to 31 are reserved for specific purposes; for example, VCI 3 and VCI 4 are reserved for Operations, Administration and Maintenance (OAM). Also, VCI value 0 is not allowed. For this reason, VCI number 32 or higher has to be used for an external VC connection.

Finally, UPC/NPC (Usage/Network Parameter Control) is defined as the set of actions taken by the network to monitor and control that the traffic contract is respected in terms of traffic offered and validity of the ATM connection, at the user access and the network access, respectively.

VP/VC link termination points

Link termination points are created both on VP level and VC level. They are the terminating ends of VP/VC links. Virtual Path Link termination points (VPLtps) must be created before creating any Virtual Channel Link termination points (VCLtps) under the VPLtp.

The interface configuration defines the limits of the total capacity available to the VPLtps. The number of VCLtps created under each VPLtp depends on the VPLtp capacity.

Termination points are reserved for:

- Signaling links on VC level (AAL2 Signaling, DNBAP and CNBAP).
- AAL type 2 paths (VCC endpoints), allowing the creation of AAL type 2 connections for user traffic.
- IP over ATM connections on VC level (used to setup the O&M connection between the RNC and the Node B).
- Semi-permanent cross-connections through the ATM network element on VP and VC level (these will be used as part of the monitoring solution developed).

MML Configuration

The RNC uses a mixture of Man-Machine Language (MML) commands and a Graphical User Interface. The steps shown provide the configuration for both a 2 E1 IMA group and 2 STM-1 links IuB based interface as per the top design in Figure 70.

From step 2 onwards only the creation of the 2 E1 link is followed, because once the PhyTTP is created both configurations maintain the same rationale and only differ in the parameters used in the commands:

1) Creation of 2 E1 IMA group 1 (PETs 1 & 2 of NIP1 interface card are used)

   ZYBC:1:PET:1&2:1; //1 refers to the minimum number of links without defects inside the IMA group in order not to report an IMA group failure.

2) Creation of SDH protection group 1 with MSP 1+1 mechanism – non-revertive (SET 0 in NIS1P-0 and SET 4 in NIS1P-1 are used. Note that each NIS1P card has 4 SETs and NIS1P-0 and NIS1P-1 act as a protected pair of SDH interfaces).

   ZYWC:1,,:0,4:; //”,” are used to leave default settings. In this case they refer to non-revertive protection and MSP 1+1 protocol variant.

3) Creation of PhyTTP 1 for IMA group 1:

   ZYDC:1:IMA=1;

4) Creation of ATM Interface 1 for PhyTTP 1:

   ZLAC:1:UNI,1,UNLOCKED; //UNLOCKED refers to the administrative state of the interface. It means “enabled”.

5) Creation of ATM Access Profile associated with ATM Interface 1, with a capacity for 16 (2^4) VPs and 128 (2^7) VCs:

   ZLAF:1:4:7:; //Policing is enabled by default.

6) Creation of O&M connection. Since O&M is usually not very interesting for monitoring purposes, the VP/VC structure is created directly on the ATM interface where the physical connections of the Node B are terminated. In this case, ATM interface 1.

   6.1) Creation of VP 0. The ATM service class for O&M is UBR with a PCR of 4528 cps. (Refer to Table 30).

   ZLCC:1:VP:0,,,U:U:4528:CPS:;

6.2) Creation of VC 32 inside VP 0. It has the same parameters as VP 0.

ZLCC:1:VC:0:32:U,,U:U,,U:4528,CPS:4528,CPS:;

Monitoring solution with Nethawk M5 protocol analyzer

Introduction

The existence of an integrated monitoring system for all the interfaces in the RNC is crucial for troubleshooting and investigating problems in the different network elements of the RAN and Core Network, in particular, for the validation of Hybrid Backhaul solution. If done inefficiently it can easily increase the cost of testing due to the high prices of software and licensing of this kind of tools.

The main objective of this monitoring solution is to trace IuB, IuCS and IuPS interfaces simultaneously for the same RNC irrespective of the amount of Node Bs connected to it by using only one protocol analyzer.

The reason why IuPS and IuCS monitoring are required together with the IuB is due to the ciphering method used between the UE and the Core Network. If the tracing tool is able to get hold of the ciphering keys for a given call it will then be able to decipher all the messages exchanged between the different protocols. Otherwise, the tool will only be able to display ciphered messages with no sense for the engineer.

This was a key step not only for this validation but also for the rest of validation projects managed in the lab environment.

This solution was designed for a single RNC, however, with enough number of monitoring interfaces, the solution can be easily replicated in different RNCs and a whole lab network can be traced from a centralized point.

Design

In order to implement this solution, the following is required:

- Internal ATM cross-connections in the RNC (This concept will be explained together with the monitoring layout).

- Optical Splitters with inputs/outputs of 100%/90% and 10% and LC/LC optical fibers.
- Computer equipped with Nethawk protocol analyzer or similar. The monitoring interface is usually a PCMCIA adaptor card which enables a direct connection of optical fiber to the PC.

The layout of the design is shown in Figure 86:

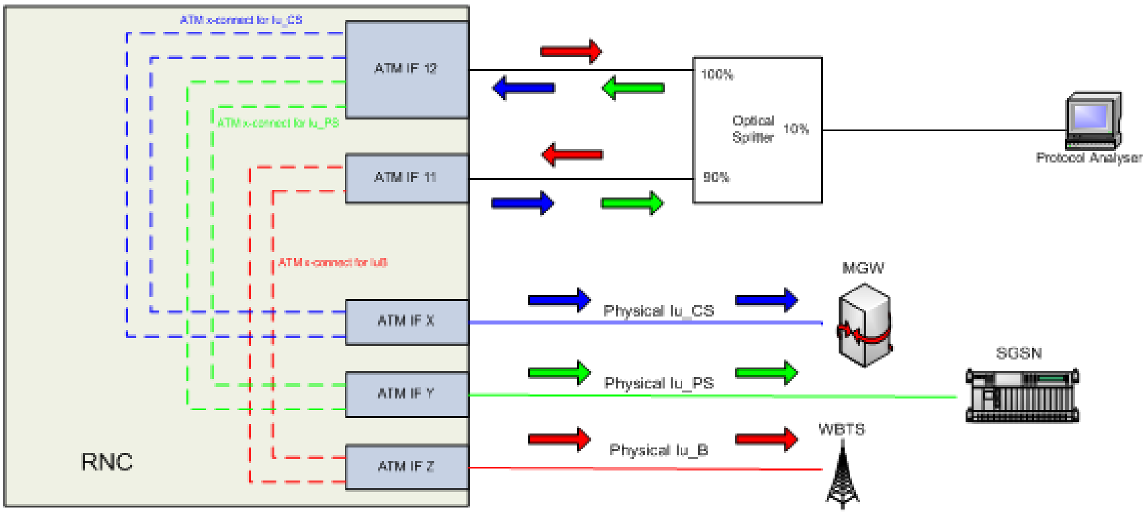


Figure 86. Monitoring System layout. The colored arrows show the path followed by the traffic on each one of the RAN interfaces (IuB, IuCS and IuPS) when it is directed from the RNC to the rest of network elements. In addition, ATM interfaces are shown in the RNC instead of physical connections (PETs and SETs) in order to simplify the sketch. All the physical connections are assumed to be STM-1 (with both TX and RX), apart from the IuB connection, which can also consist of E1s. IuR connections are not shown in the layout, but the same concept applies. Please note that IuCS is terminated in MGW, being this core network element a Signaling Transfer Point (STP) towards the MSS, responsible of handling the control plane.

In order to understand the role of the internal ATM cross-connections in the RNC the key is to differentiate the two possible functions that an ATM interface can have.

It has been explained previously that the ATM interface is a logical entity which establishes the physical connections between the processing units of the RNC and the external network elements. This is the main function: the ATM interface as an end-point of an external physical connection which communicates directly with the data processing units. However, this design uses another interesting property of the ATM interfaces: they can communicate with other ATM interfaces, being totally transparent for the traffic carried on them. This concept can be explained as “an extension of the physical connections inside the RNC”. These logical connections between ATM interfaces are known as ATM cross-connections. Cross-connections can be made at VP or VC level.

For example, referring back to Figure 85, it can be analyzed how the IuB traffic is routed across the system from the RNC to the Node (red arrow). In this case, ATM interface 12 is the end point/start point for the traffic coming/going from/to the Node B. It then goes via the Optical Splitter, where a 10% of the signal is extracted for analysis. The other 90% (the RNC SET sensitivity supports a 10% decrease in the signal power) is routed back to ATM interface 11. Since this is not the ATM interface where the Node B is connected physically, the traffic needs to be cross-connected from this interface to ATM interface Z, which is the one containing the physical connection of the Node B. Since both interface 11 and interface Z wants to remain transparent from the traffic carried inside the VCs, the cross-connection is made at VP-level. Once there, the traffic can reach to the Node B and the communication path is closed.

The same applies for IuCS and IuPS connections. In this case, ATM interface 11 is the traffic end point, and internal cross-connections are set from ATM interface 12 to X and Y, respectively.

Multiple logical ATM cross-connections can be applied to the same interface, so in the common case that more than one Node B is connected to the RNC, the only action required is to set up the required cross-connection between ATM interface 11 and the ATM interface where the physical connection of the Node B is set.

As an example, it is shown the necessary commands required to enable the IuB interface monitoring of the 2 E1 link (8981cps in ATM capacity) when the Node B is connected to ATM interface Z=1 (it is assumed that the ATM interface has been already set up and that the ATM end point, ATM interface 12, has been created in the RNC GUI as shown in section *RNC transmission commissioning*).

1) First of all, a VP with the same properties as the one created in ATM interface 12 (VP ID, peak cell rate and ATM service type) has to be created in interface 11. It will close the circuit IF 12 – Optical Splitter – IF 11. For the example it is used VP ID=6, PCR=8981 cps and service type=CBR:

   ZLCC:11,VP,6,,VP::C,,,C1,:C,,,C1::8981,CPS,:8981,CPS;

2) Creation of the cross-connection from interface 11 to interface 1. Usually the VP configured in NODE B has an ID=1. When creating a cross-connection there

is no need for the VP ID to match in both ends, so, in this case, ATM interface 1 is configured with VP_ID=1. Another advantage when creating cross-connections is that a VP will be created automatically in the other end, avoiding the repetition of step 1 in interface 1.

ZLBC: VP, PTP:11,6:1,1:;

Setting up Nethawk protocol analyzer

Once the physical connectivity is done and all the ATM traffic parameters have been defined correctly is time to set up the protocol analyzer. There are three basic steps to follow prior to start the interface analysis:

- Nethawk has a *Physical State View* window (Figure 87) to verify the status of the optical fiber connectors in the PCMCIA adaptor. If no errors are reported, such as LOS (Loss of Signal) or incorrect positioning of Tx/Rx, the status of the connection ports should be green.

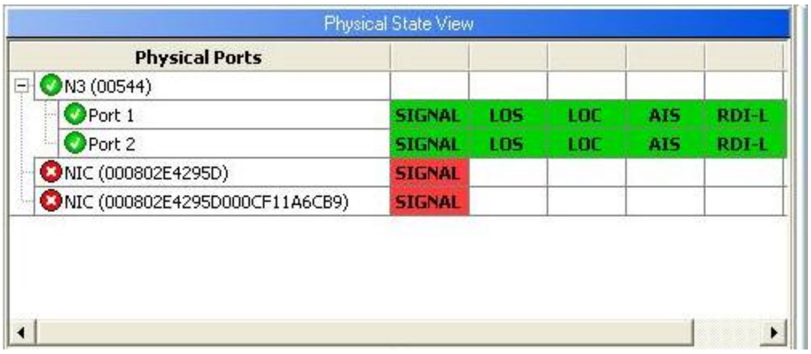


Figure 87. Physical State View in Nethawk M5. The optical fiber adaptor card is N3 and has two physical active connections: Port 1 (Tx) and Port 2 (Rx).

- Once the physical connections are set, is time to set up the ATM connections (VP/VC) to monitor. It is done in *Connection Configuration* (Figure 88). The quickest way to find the connections found by the protocol analyzer is to enable the *Scanner* option. Nethawk will display VP and VC information found as well as the radio network protocols transported on them. Since Nethawk is a generic protocol analyzer, protocol parameters should be reviewed to match with those compliant with the RAN equipment (3GPP Release, vendor specific messages, etc..) when setting up the ATM connections to monitor with the *Protocol Monitor*.

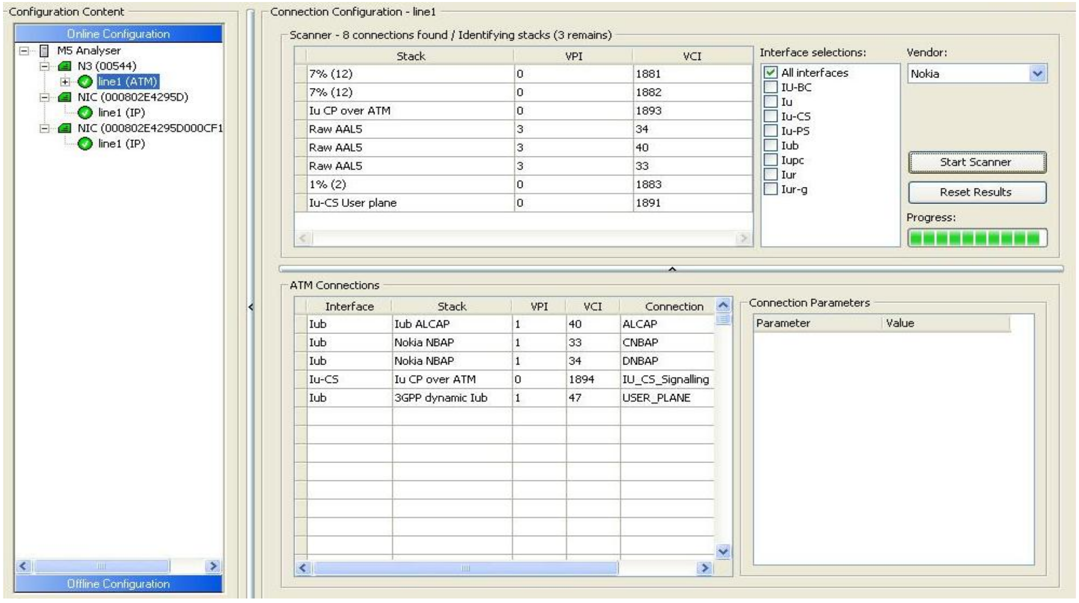


Figure 88. Connection Configuration in Nethawk M5. Note the Scanner view and the ATM connections view. In ATM connections the user can select which ones to monitor between all the ranges sniffed by the analyzer. VP and VC connection IDs must match the ones defined in the ATM interface end-point in the RNC.

- Finally, once the ATM connections are set up, the analysis can be started in *Protocol Monitor (*Figure 89*)*. It offers a complete description of all the protocol messages apart from showing timestamps, VP/VCs,… and offering options such as extended message view or trace recording which are useful for troubleshooting.

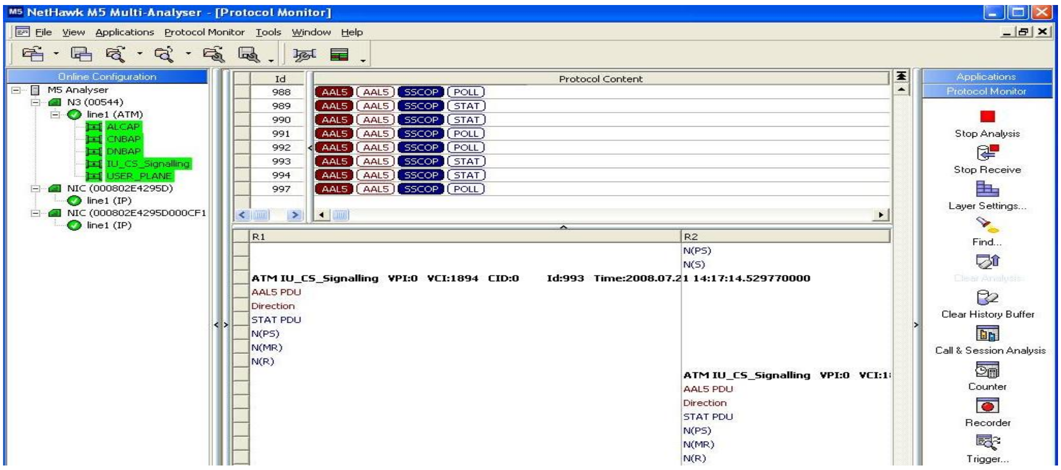


Figure 89. Protocol Monitor in Nethawk M5.

4.2.4 Test Results

Finally, this section will offer the results obtained during the testing campaign carried on the hybrid backhaul solution discussed in previous sections. Testing has been divided into several steps, each one with different objectives:

- **Basic Functionality:** The aim of this very first stage is to prove that hybrid backhaul is a seamless transport solution as far as the Radio Access Network is concerned. Real-time and Non-Real-time R99 traffic should not be affected since it is conveyed on legacy E1 links, whereas HSPA traffic should be correctly routed on the assigned pseudo wires. HSPA throughput is verified using *NetPerSec* PC application and the correct mapping of traffic to VCs in the RNC is checked with Nethawk M5 protocol analyzer. Testing on MSP 1+1 mechanism has been also included as part of this first step.

- **End to End campaign:** Since hybrid backhaul solution is not deployed in the live network at the time of writing the report, an "E2E simulation" is run the lab. The objective is to benchmark the results obtained against the validation campaign run with a non-hybrid backhaul solution and the Key Performance Indicators (KPIs) committed by the vendor. The results cannot be fairly compared (due to the lab being more similar to ideal conditions), so it is expected a slightly improvement in the ones obtained in the lab. Mobility scenarios have been also considered in this case, related with the nature of the IuB: from hybrid to hybrid configuration, from hybrid to non-hybrid and from non-hybrid to hybrid.

- **Fine-Tuning of Concatenation Factor and Packetization Timer in non-ideal conditions**: In the last stage of testing, an Ethernet impairment tool is inserted in the Fast Ethernet (FE) link of the hybrid backhaul. The objective is to investigate the impact on HSDPA throughput when controlled delay and packet loss are introduced to the FE link and which is the role of concatenation factor and packetization timer in order to mitigate throughput degradation.

Basic functionality results

Ranges of test (see Table 33) have been carried out in both Node Bs and both hybrid backhaul scenarios mentioned in Figure 70. These tests comprise the following and have been done under ideal radio conditions using RF isolation boxes:

	TEST	RESULT
R99 real time traffic (RT)	Mobile Originated AMR call	PASSED
	Mobile Terminated AMR call	PASSED
R99 Non-Real Time (NRT) traffic	FTP download	PASSED
	FTP upload	PASSED
Multi-RAB RT and NRT traffic	Multi-RAB	PASSED
HSDPA traffic	FTP download	PASSED
HSUPA traffic	FTP upload	PASSED

Table 33. Basic functionality test results summary.

- ***R99 real time traffic - Mobile Originated AMR call***: A 1 minute voice call is made from a cell under the NODE Bs concerned. Results witnessed showed correct establishment of the call, no voice degradation and correct ATM transport path usage (Flexi NODE B: VP_ID=1/VC_ID=47; UltraSite VP_ID=3/VC_ID=47).

- ***R99 real time traffic - Mobile Terminated AMR call:*** A 1 minute voice call is received in a cell under the NODE Bs concerned. Again, results were satisfactory, presenting the same outcome as the previous test.

- ***R99 non-real time traffic –FTP download:*** Using the UE as a dial-up connection and a server connected directly to the SGSN, an FTP download of a 20 MByte file, hosted in the before mentioned server, is done. Correct ATM path is witnessed (Flexi NODE B: VP_ID=1/VC_ID=47; UltraSite VP_ID=3/VC_ID=47) and no degradation in throughput is obtained during the entire download. The radio bearer established offers a constant bit rate of 384 Kbps as per the maximum bit rate allowed for non-real time traffic in downlink defined in the Admission Control functionality of the Node B.

- ***R99 non-real time traffic –FTP upload****:* The same as in the previous test case applies, but in this scenario the upload consist of a 5 MByte file. The results witnessed meet the expected ones (constant uplink bearer of 384 Kbps, no throughput degradation and correct ATM path is followed).

- ***Multi-RAB call (real-time Mobile Originated Call combined with non-real time traffic download/upload):*** The same steps as per the first test case are followed, but an FTP download (test case 3) is initiated without terminating the voice call. Once the download is finished, test proceeds with an FTP upload (test case 4). Once the upload is finished the voice call is terminated after few seconds. The expected results in terms of call establishment/termination, voice and packet transfer quality and correct ATM path usage are met. In this case, both downlink and uplink packet radio bearers reach the bit rate of 256 Kbps, which is the maximum bit rate allowed in a multi-RAB scenario by the RAN software at the time of testing.

- ***HSDPA FTP downloads:*** This test has been made with Huawei E270 (HSDPA CAT 8) dongle. The maximum speed achievable for this HSDPA category is 7.2 Mbps in physical layer, which represents a roughly 6.5 Mbps at RLC level (considering a 10% packet overhead on top of physical layer). This is the approximate speed that should be obtained with NetPerSec throughput monitoring tool. In this case, the file to download is a 50 Mbyte file, but the steps to follow are the same as per test case 3. Throughput obtained and correct ATM path usage (VP_ID=2 VC_ID=48) is shown in Figure 90 and Figure 91 respectively. These results really proof the concept of hybrid backhaul, since no throughput degradation is witnessed and the ATM path used is the one carried over the pseudowire. Successful results are obtained for both Flexi and UltraSite Node B.

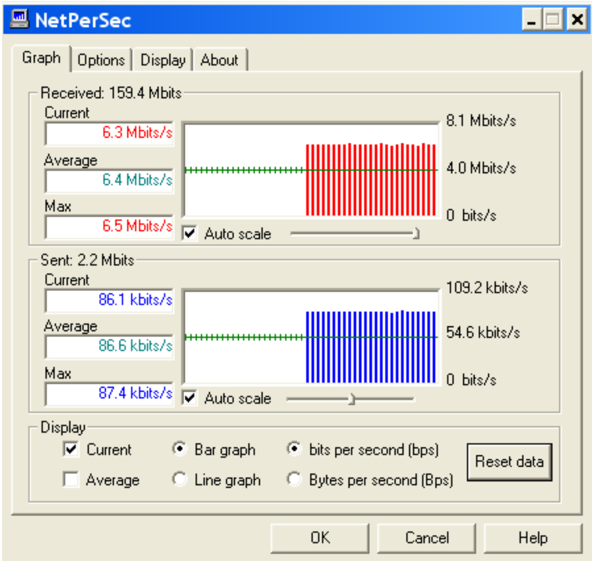


Figure 90. HSDPA throughput obtained with Huawei E270.

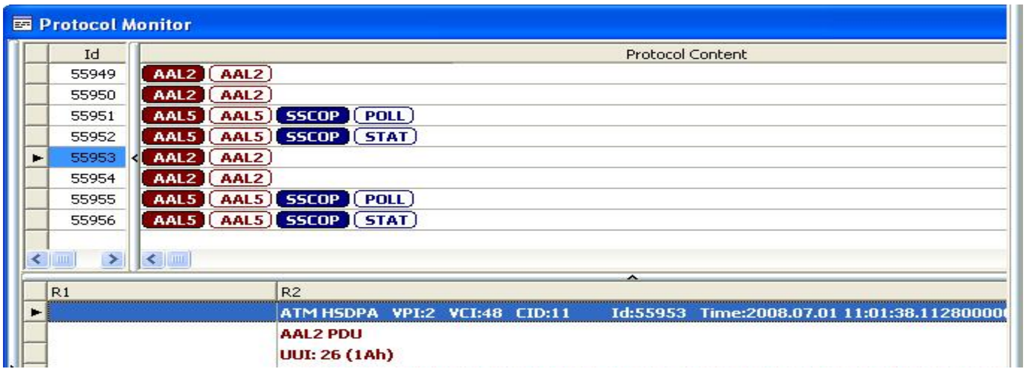


Figure 91. Nethawk M5 HSDPA trace. The ATM path displayed is VPI=2 / VCI=48 as expected for Flexi NODE B transport configuration.

- ***HSUPA FTP uploads***: This test has been made with the same Huawei E270 (HSUPA CAT 5) dongle. The maximum speed achievable for this HSUPA category is 2 Mbps in physical layer, which corresponds to 1.88 Mbps in RLC layer (similar results should be witnessed in NetPerSec). In this case, the file to upload to the server is a 20 Mbyte file, but the steps to follow are the same as per test case 4. Throughput obtained and correct ATM path usage (VP_ID=2 VC_ID=49) is shown in Figure 92 and Figure 93 respectively. Again, no throughput degradation is witnessed and the correct ATM path is in use.

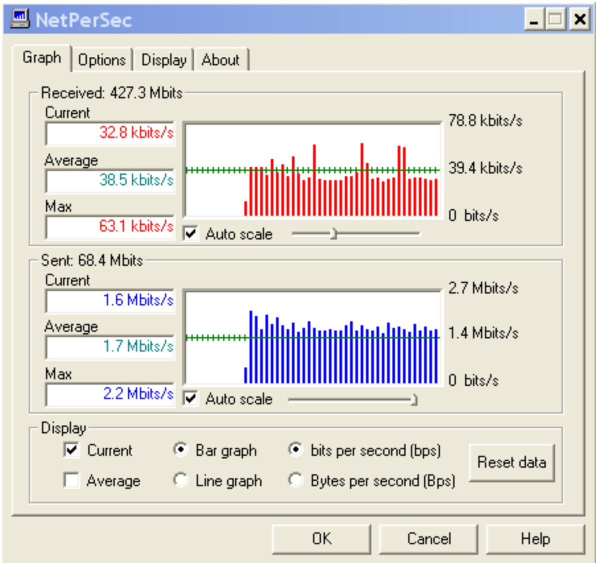


Figure 92. HSUPA throughput obtained with Huawei E270.

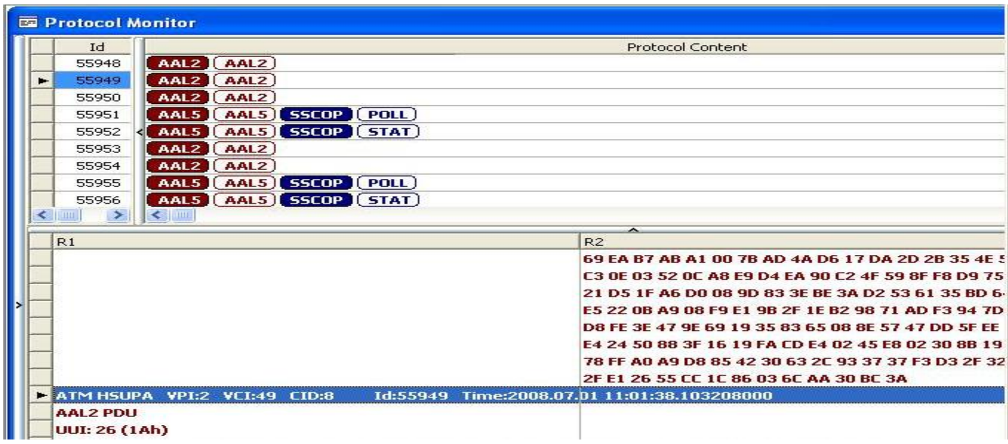


Figure 93. Nethawk M5 HSUPA trace. The ATM path displayed is VPI=2 / VCI=49 as expected for Flexi NODE B transport configuration.

Protection mechanism test

In this very first stage in which basic behavior is tested it is also included the testing performed on MSP 1+1 protection mechanism. It is worth to remember that this mechanism makes sense when both links of the protection are terminated in different hardware units. From Tellabs 8630 equipment point of view, it means that the protection has been defined between two different slots, whereas in the RNC, the links have to be configured in hardware units logically grouped into protected pairs. They work in a way that only one unit in the protection group works at a time and whenever a failure occurs in the working unit, a seamless switchover is performed towards the second unit.

During this study three different scenarios have been tested. Hardware unit failures have been simulated either by forcing switchovers between units or by setting virtual faulty flags via MML commands in the RNC. A forced switchover is simulated by changing the status of the unit to SE-NH (Separated – No Hardware), which indicates to the system that the unit cannot be used. A continuous HSDPA download is running during the execution of the test.

1. ***Forced hardware unit switchover in a non-revertive configuration***

Non-revertive implies that once the connection is set up in the protection link after a fault, traffic will not be returned to the working section even if recovered from the fault.

Result:

- First of all, a forced switchover is applied between the working and the protection hardware units, being harmless for the ongoing call.

- Once the status of the working unit is changed back to WO-EX (Working - Executed), the traffic still is carried over the protection unit, which is the expected behavior.

- Once in this situation, it was also interesting to see what could happen if the physical STM-1 link of the protection path was broken (removed from the interface). The outcome was that the call was diverted back to the working section without dropping the call. This behavior proved further robustness of the system since a lack of physical connectivity automatically triggered a switchover irrespectively of the non-revertive nature of the MSP 1+1 mechanism applied.

2. ***Link removal in a revertive configuration***

Revertive implies that once the working section of the protection system has recovered from a fault and once the *wait-until-restore* timer has expired, the data is automatically switched from the protection to the working path.

Result:

- Physical STM-1 link is removed manually from the working section and restored after few seconds. Traffic was then switched to the protection link and diverted back to the working section once the timer expired, being that the expected result. It has to be considered that the timer is defined in both ends of the communication, so the most restrictive timer from both equipments will define the time to switch the traffic back to the working section. During the test, a 30 s timer was defined in the RNC and a 200 s in the Tellabs 8630. The recovering time was 200 s as expected, since the highest value is the most restrictive in timers dedicated for redundancy assurance services.

3. ***Hardware unit failure forced in a revertive configuration***

Result:

- “FLTY” (faulty) flag was set to the working hardware unit. It forced the unit to perform an internal health check and the communication was switched to the protection unit and traffic remained undisrupted as expected. However, in the RNC GUI the connection towards the Node B appeared to be blocked. After the working hardware interface finished the internal testing and the timer expired, the traffic was switched back to the working unit and the RNC GUI showed again the connection as working. Even though the traffic was not disrupted at any time, the issue related with the RNC GUI was reported to the vendor and a fix was provided in the next software release.

End to End Campaign Results

Table 34 summarizes the tests executed for hybrid backhaul, together with the KPIs to meet in order to verify the correct behavior of the system. The test setup used during this test campaign is the second one presented in Figure 70. Static test have been run only in Flexi NODE B. UltraSite NODE B has been used for handover scenarios and its IuB backhaul has been changed to a non-hybrid solution with 4 x E1s when necessary.

All test cases have been done under an RF-controlled environment and the UEs used are Nokia N95 (HSDPA CAT6) and Huawei E270 (HSDPA CAT8 / HSUPA CAT5).

The process followed to obtain these results is gathered in extra tables detailing each of the tests individually. Note also that results obtained with a pure ATM backhaul are also attached for comparison purposes but how they were obtained is out of the scope of this project.

TEST	Pure ATM Backhaul	Hybrid Backhaul	Acceptance KPIs
SINGLE USER (Unloaded cell scenario)			
HSUPA Average Throughput	1153.9 Kbps	1164.15 Kbps	> 1150 Kbps
HSDPA Average Throughput	5849.18 Kbps	5916.33 Kbps	> 5800 Kbps
Small Ping DCH Average RTT	77.13 ms	59.29 ms	< 100 ms
Small Ping FACH Average RTT	192.6 ms	190.22 ms	< 200 ms
Big Ping DCH Average RTT	136.08 ms	118.97 ms	< 250 ms
Big Ping FACH Average RTT	1131.65 ms	1089.07 ms	< 1000 ms
Big Ping IDLE Average RTT	2625.85 ms	2261.64 ms	< 3000 ms
HSDPA Multi-RAB (1st data – 2nd voice)	2897.7 Kbps	3141.03 Kbps	> 3000 Kbps
HSDPA Multi-RAB (1st voice – 2nd data)	2884.1 Kbps	3105.02 Kbps	>3000 Kbps
MULTIUSER (Loaded cell scenario)			
HSDPA Average Throughput	2216.78 Kbps	2319.63 Kbps	> 2200 Kbps
Small Ping DCH Average RTT	82.32 ms	61.93 ms	< 100 ms

Small Ping FACH Average RTT	189.38 ms	192.11 ms	< 200 ms
Big Ping DCH Average RTT	152.16 ms	115.16 ms	< 250 ms
Big Ping FACH Average RTT	1079.13 ms	1026.31 ms	< 1000 ms
Big Ping IDLE Average RTT	2783.48 ms	2274.17 ms	< 3000 ms
MOBILITY (Hybrid to Hybrid scenario)			
Mean Interruption Time	762 ms	538 ms	< 1 s
Throughput	4472.8 Kbps	5129.79 Kbps	> 1050 Kbps
MOBILITY (Hybrid to non-Hybrid scenario)			
Mean Interruption Time	762 ms	357 ms	< 1 s
Throughput	4472.8 Kbps	3767.28 Kbps	>1050 Kbps

Table 34. E2E Campaign ATM vs. Hybrid Backhaul results summary. All the KPIs are met in all cases, improving the results obtained in a pure ATM IuB backhaul scenario.

Hybrid Backhaul Results

Table 35 specifically summarizes the results obtained for Hybrid Backhaul test campaign. The table is broken down into three different sections, being:

- ***Single User – Static Unloaded scenario***: it simulates the ideal situation in which only one HSPA user is located in the cell, in ideal RF conditions. The objective is to obtain the best results of the system in terms of throughput (*PS FTP Download/Upload)*, latency (*Round Trip Delays*) and multi-service (*Voice + HSDPA data*).

- ***Multi User – Static Loaded scenario***: the objective in this case is to test which is the impact in throughput and latency for an HSDPA user in ideal RF conditions when sharing Node B resources with three other users (cell load) in the same cell. Since HSDPA is a shared resource, throughput is expected to be shared amongst users, and hence a lower throughput value is met.

- ***Single User – Mobility Unloaded scenario***: HSDPA Serving Cell Change (SCC) testing is performed for a single user using two Node Bs in two different scenarios. In the first one, both Node Bs have a hybrid backhaul-based IuB and, in the second one, the IuB of one of them is changed back to a pure ATM backhaul. This test verifies whether there is any potential degradation in HSDPA SCC when using hybrid backhaul IuB and the mobility impact when different Node Bs uses different kind of transmission backhauls.

SINGLE USER TEST RESULTS – STATIC UNLOADED SCENARIO				
Test Case	**KPI**	**Conditions**	**Nokia N95 (CAT6)**	**Huawei E270 (CAT8 / CAT5)**
PS FTP Download		**Cell Centre**		
FTP download success rate	98%		-	100.00 %
Average Throughput (Kbps)	> 5800 Kbps (CAT 8)		-	5916.33
Average CQI	N/A		-	23.93
PS FTP Upload		**Cell Centre**		
FTP download success rate	N/A		-	100.00 %
Average Throughput (Kbps)	> 1150 Kbps (CAT5)		-	1164.15
Average RSCP (dBm)	N/A		-	-57.50
Round Trip Delays – Ping (HSPA UE only)		**Cell Centre**		
Average Small DCH (ms)	< 80 ms / Success > 98%		-	59.29 / 100.00 %
Average Small FACH (ms)	< 200 ms / Success > 98%		-	190.22 / 100.00 %
Average Big DCH (ms)	< 160 ms / Success > 98%		-	118.97 / 100.00 %
Average Big FACH (ms)	< 1100 ms / Success > 98%		-	1089.07 / 100.00 %

Average Big IDLE (ms)	< 3000 ms / Success > 98%		-	2261.64 / 100.00 %
HSDPA Data + Voice		**Cell Centre**		
Average MTM Voice Call Setup Time			00:00:08.81	-
Average MTM Voice Call Setup Time: % samples < 11 s	< 11 s		100.00 %	-
Average Throughput (Kbps)	> 5800 Kbps (CAT 8)		3141.03	-
Success rate of multi-session	98%		100.00 %	-
Voice + HSDPA Data		**Cell Centre**		
Average MTM Voice Call Setup Time			00:00:00.00	-
Average MTM Voice Call Setup Time: % samples < 11 s	< 11 s		100.00 %	-
Average Throughput (Kbps)	> 5800 Kbps (CAT 8)		3105.02	-
Success rate of multi-session	98%		100.00 %	-
MULTI USER TEST RESULTS – STATIC LOADED SCENARIO				
Test Case	**KPI**	**Conditions**	**Nokia N95 (CAT6)**	**Huawei E270 (CAT8 / CAT5)**
PS FTP Download		**Cell Centre**		
FTP download success rate	98%		-	100.00 %
Average Throughput (Kbps)	> 2200 Kbps (CAT 8)		-	2319.63
Average CQI	N/A		-	23.57
Round Trip Delay – Ping (HSPA UE only)		**Cell Centre**		
Average Small DCH (ms)	< 90 ms / Success > 98%		-	61.93 / 100.00 %
Average Small FACH (ms)	< 200 ms / Success > 98%		-	192.11 / 100.00 %
Average Big DCH (ms)	< 180 ms / Success > 98%		-	115.16 / 100.00 %
Average Big FACH (ms)	< 1100 ms / Success > 98%		-	1026.31 / 100.00 %
Average Big IDLE (ms)	< 3000 ms / Success > 98%		-	2274.27 / 100.00 %
SINGLE USER TEST RESULTS – MOBILITY UNLOADED SCENARIO				
Test Case	**KPI**	**Conditions**	**Nokia N95 (CAT6)**	**Huawei E270 (CAT8 / CAT5)**

HSDPA Serving Cell Change: Hybrid_to_Hybrid		**Mobility**		
Handover Success Rate	> 95%		-	100.00 %
Mean Interruption Time (FTP break)	< 1 s		-	00:00:00.153
Average Throughput (Kbps)	1050		-	4744.73
HSDPA Serving Cell Change: Hybrid_to_non_Hybrid		**Mobility**		
Handover Success Rate	> 95%		-	100.00%
Mean Interruption Time (FTP break)	< 1 s		-	00:00:00.442
Average Throughput (Kbps)	1050		-	2351.28

Table 35. E2E Campaign Hybrid Backhaul results summary. Nokia N95 has only been used in multi-RAB testing, since it can support voice and HSDPA data simultaneously.

Each one of the tests conducted on each section is further detailed in the following tables, which show the amount of samples and the analysis extracted from the log files obtained with both NEMO Outdoor and Wireshark in order to arrive to the final results.

Sample	RRC Connection Request	PDP Context Activation Accept	PDP Context Deactivation Accept	DOS FTP DL Time (s)	File Size (Bytes)	FTP throughput (Kbytes/s)	FTP throughput (Kbits/s)	PS Call Success Rate	FTP DL Success Rate	Average CQI
1	14:07:55.427	14.08:01.736		70.28	51857224	737.87	5902.928	Y	Y	23.93
2				70.97	51857224	730.69	5845.537	Y	Y	
3				69.41	51857224	747.11	5976.917	Y	Y	
4				70.14	51857224	739.34	5914.71	Y	Y	
5				69.88	51857224	742.09	5936.717	Y	Y	
6				69.58	51857224	745.29	5962.314	Y	Y	

7				71.19	51857224	728.43	5827.473	Y	Y	
8				69.33	51857224	747.98	5983.814	Y	Y	
9				70.59	51857224	734.63	5877.005	Y	Y	
10			14:26:29.640	69.89	51857224	741.98	5935.668	Y	Y	
Average				**70.13**		**739.54**	**5916.33**	**100%**	**100%**	**23.93**
KPI							>5800	98%	98%	
PASS/FAIL							**PASS**	**PASS**	**PASS**	

Table 36. Single User – Static Unloaded Scenario. PS FTP Download. An average throughput performance with Huawei E270 dongle is done over 10 downloads within the same packet session (Only 1 PDP Context Activation/Deactivation). The average Channel Quality Indicator (CQI) of about 24 proofs the good radio conditions maintained during the entire test. All the KPIs are met in this case, so the overall test is PASSED.

Sample	**RRC Connection Request**	**PDP Context Activation Acce-pt**	**PDP Context Deactivation Accept**	**DOS FTP DL Time (s)**	**File Size (Bytes)**	**FTP throughput (Kbytes/s)**	**FTP throughput (Kbits/s)**	**PS Call Success Rate**	**FTP DL Success Rate**	**Average RSCP (dBm)**
1	10:53:18.140	10:53:19.654		144.81	20971520	144.82	1158.568	Y	Y	
2				143.58	20971520	146.06	1168.493	Y	Y	
3				143.47	20971520	146.17	1169.388	Y	Y	
4				145.77	20971520	143.87	1150.938	Y	Y	
5				143.91	20971520	145.73	1165.813	Y	Y	-57.50
6				143.63	20971520	146.01	1168.086	Y	Y	
7				143.63	20971520	146.01	1168.086	Y	Y	
8				143.52	20971520	146.12	1168.981	Y	Y	
9				143.42	20971520	146.22	1169.796	Y	Y	
10			11:23:29.990	145.47	20971520	144.16	1153.311	Y	Y	
Average				**144.12**		**145.42**	**1164.15**	**100%**	**100%**	**-57.50**
KPI							>1150	98%	98%	
PASS/FAIL							**PASS**	**PASS**	**PASS**	

Table 37 Single User – Static Unloaded Scenario. PS FTP Upload. An average throughput performance with Huawei E270 dongle is done over 10 uploads within the same packet session (Only 1 PDP Context Activation/Deactivation). In this case CPICH RSCP (Received Signal Code Power) value is given to verify the good radio conditions instead of a CQI, because the latter only applies for HSDPA connections. An RSCP value of -60 dBm is considered a cell centre scenario. All the KPIs are met again in this case, so the overall test is PASSED.

Sample	Small Ping DCH (ms)	Small Ping FACH (ms)	Big Ping DCH (ms)	Big Ping FACH (ms)	Big Ping IDLE (ms)
1	69.467	186.345	111.692	1097.408	2169.392
2	69.428	196.331	111.703	1107.361	2233.323
3	60.445	186.359	111.669	1081.435	2147.021
4	59.459	176.309	151.672	1014.042	2185.051
5	59.448	196.327	151.703	1104.773	2224.439
6	59.461	206.34	131.665	1086.673	2217.481
7	59.424	176.299	121.678	1095.225	2297.966
8	59.447	196.345	111.718	1096.135	2586.677
9	59.453	207.366	111.697	1089.627	2181.673
10	59.468	176.351	141.69	1066.762	2180.519
11	49.458	196.33	151.697	1080.312	2196.948
12	59.424	206.334	131.667	1091.92	2147.892
13	59.444	196.348	120.686	1109.462	2238.583
14	59.434	186.334	141.681	1104.76	2210.419
15	59.438	186.334	141.714	1087.069	2191.96

16	59.467	206.294	132.33	1033.163	2563.768
17	69.464	176.318	121.674	1127.426	2170
18	69.473	196.322	110.725	1058.065	2304.003
19	59.442	186.35	111.675	1029.191	2261.641
20	69.441	196.326	111.675	1086.662	2348.567
21	69.501	206.359	110.674	1144.989	2234.682
22	59.468	176.378	111.689	1120.485	2219.358
23	59.42	186.358	110.73	1129.598	2271.1
24	59.433	186.342	111.748	1147.998	2426.724
25	59.442	196.347	111.703	1101.35	2150.268
26	50.45	186.35	111.713	1111.737	2334.869
27	59.453	197.336	111.696	1127.249	2212.364
28	59.431	186.342	111.718	1128.994	2220.69
29	59.451	176.314	111.715	1117.645	2331.271
30	49.457	197.326	111.704	1017.779	2230.795
31	59.448	186.352	110.707	1031.54	2220.502
32	59.451	196.354	110.702	1088.629	2469.699
33	59.461	187.324	111.734	1092.309	2100.926
34	49.454	176.352	110.7	1136.93	2216.843
35	59.472	196.363	110.716	1026.632	2284.009

36	59.458	186.348	110.695	1106.083	2216.792
37	49.468	186.342	111.705	1035.134	2274.021
38	59.462	206.345	110.706	1121.989	2224.379
39	59.456	196.314	111.721	1098.208	2265.53
40	59.441	186.359	110.695	1020.752	2523.894
41	49.45	196.318	111.683	1105.383	2234.882
42	59.49	186.353	110.703	1111.326	2250.197
43	59.458	176.348	110.702	1012.977	2250.512
44	59.435	186.336	111.741	1111.68	2293.255
45	49.47	196.33	110.686	1099.984	2201.888
46	59.492	186.356	151.689	1095.571	2264.231
47	59.488	196.328	140.669	1099.477	2240.795
48	59.45	186.34	120.719	1086.514	2484.111
49	59.468	186.365	110.702	1100.397	2159.906
50	59.458	176.331	111.693	1076.601	2216.169
Average RTT	**59.294**	**190.219**	**118.971**	**1,089.068**	**2,261.640**
Success Rate	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**
KPI	80 ms	200 ms	160 ms	1100 ms	3000 ms
PASS/FAIL	PASS	PASS	PASS	PASS	PASS

Table 38. Single User – Static Unloaded Scenario. Round Trip Delays – Ping. The amount of samples required in this case is 50. The “Small ping” payload is of 0 Bytes, whereas the “Big ping” payload is of

1460 Bytes. Latency has to be tested in three different RRC Status: IDLE, FACH and DCH. When the UE is in IDLE mode it does not have any transport channel allocated, so in order to establish a ping, first of all it has to request for a connection. That is why we are expecting higher latency values whilst in this state. In order to collect the results in this state, a continuous ping is sent from IDLE mode and only the first sample of the series is taken. This process is repeated 50 times, and after each sample it is ensured that the UE returns to IDLE state. On the other hand, when the UE is in FACH or DCH mode, it has already setup a connection. The main difference is that whilst in FACH, the UE is using a Common Channel, rather than a dedicated channel (DCH), so the amount of data allowed to transmit will be lower and hence the higher value in latency compared to DCH. During the test it was noticed that when sending the 0 bytes ping, the UE will remain in FACH state, so all the 50 samples can be taken by running the command *ping <IP address> -n 50 –l 0*. However, when sending 1460 bytes the latency values where correct for the first sample of the series (higher value than the rest). This is because after the first ping the UE is allocated a dedicated channel (DCH) to speed up the data flow. So, in this case, instead of running a single command once, a script was created in order to record the relevant data. In order to record the samples in DCH, the only thing to do is to run a continuous ping and stop once the relevant samples are collected. All KPIs are accomplished, so the test is PASSED.

Call No.	CM Service Request	Alerting	Call Setup Time	Call Setup Success	RRC Connection Request	PDP Context Accept	PDP Deactivate Accept	DOS FTP DL Time (s)	File Size (Bytes)	FTP throughput (Kbytes/s)	FTP throughput (Kbit/s)	AMR + HSDPA Data Call Complete Success	File Download Success	Call End Time	Call Duration	Average CQI
1	16:12:51.984	16:13:00.781	00:00:08.797	Y	16:12:10.953	16:12:13.280		132.52	51857224	391.32	3130.53	Y	Y	16:17:22.601	00:04:21.820	24.5
2	16:18:03.923	16:18:12.694	00:00:08.771	Y	16:17:47.730			130.66	51857224	396.89	3175.09	Y	Y	16:22:55.176	00:04:42.482	
3	16:23:28.380	16:23:37.563	00:00:09.183	Y	16:23::18.133			132.41	51857224	391.64	3133.13	Y	Y	16:28:37.380	00:04:59.817	
4	16:29:01.404	16:29:09.432	00:00:08.028	Y	16:28:51.419			132.38	51857224	391.73	3133.84	Y	Y	16:34:06.187	00:04:56.755	
5	16:34:34.728	16:34:42.651	00:00:07.923	Y	16:34:23.965		16:40:01.906	133.97	51857224	387.08	3096.65	Y	Y	16:39:38.098	00:04:55.447	
6	10:24:43.588	10:24:53.601	00:00:10.013	Y	10:24:24.600	10:24:26.805		132.56	51857224	391.20	3129.59	Y	Y	10:26:56.095	00:02:02.494	24.4
7	10:27:29.406	10:27:37.791	00:00:08.385	Y	10:27:19.562			131.88	51857224	393.22	3145.72	Y	Y	10:29:46.000	00:02:08.209	
8	10:30:14.098	10:30:22.657	00:00:08.559	Y	10:30:04.330			133.52	51857224	388.39	3107.08	Y	Y	10:32:26.591	00:02:03.934	
9	10:32:59.254	10:33:08.011	00:00:08.757	Y	10:32:50.538			130.31	51857224	397.95	3183.62	Y	Y	10:35:10.441	00:02:02.430	

10	10:40:46.168	10:40:55.879	00:00:09.711	Y	10:40:33.312		10:43:17.202	130.66	51857224	396.89	3175.09	Y	Y	10:43:02.343	00:02:06.464	
Average			**00:00:08.813**	**100.00%**						**392.63**	**3141.03**	**100.00%**	**100.00%**			**24.45**
KPI			11 s								2800	90%				
PASS/FAIL			PASS								PASS	PASS				

Table 39. Single User – Static Unloaded Scenario. Multi-RAB HSDPA data + voice. The test consist of 10 simultaneous FTP downloads and voice call activations with Nokia N95. In this case, data calls are activated prior to voice. After the first 5 samples a new packet session (PDP Context Activation) is started. Voice calls are maintained during 2 minutes and disconnected before the end of the download. Voice quality is checked randomly during the execution of the test. All the KPIs are met, so the test is PASSED.

Call No.	Call Setup Success	RRC Connection Request	PDP Context Accept	PDP Deactivate Accept	DOS FTP DL Time (s)	File Size (Bytes)	FTP throughput (Kbytes/s)	FTP throughput (Kbits/s)	AMR + HSDPA Data Call Complete Success	File Download Success	Average CQI
1	Y	16:12:10.953	16:12:13.280		130.61	51857224	397.04	3176.31	Y	Y	
2	Y	16:17:47.730			132.47	51857224	391.46	3131.71	Y	Y	
3	Y	16:23:18.133			135.23	51857224	383.47	3067.79	Y	Y	24.5
4	Y	16:28:51.419			134.63	51857224	385.18	3081.47	Y	Y	
5	Y	16:34:23.965		16:37:38.474	135.23	51857224	383.47	3067.79	Y	Y	
Average	**100.00%**						**388.13**	**3105.02**	**100.00%**	**100.00%**	**24.5**
KPI								2800	90%		
PASS/FAIL								**PASS**	**PASS**		

Table 40. Single User – Static Unloaded Scenario. Multi-RAB voice + HSDPA data. In this case a voice call is initiated and maintained throughout the test. After that, a packet session is initiated consisting of 5 FTP downloads. Once the 5 downloads are finished, the voice call is released. Successful results are again obtained (PASSED).

Call No.	RRC Connection Request	PDP Context Accept	PDP Deactivate Accept	DOS FTP DL Time (s)	File Size (Bytes)	FTP throughput (Kbytes/s)	FTP throughput (Kbits/s)	PS Call Success Rate	FTP DL Success Rate	Average CQI
1	14:54:13.820	14:54:20.177		187.75	51857224	276.20	2209.63	Y	Y	23.57
2				181.83	51857224	285.20	2281.57	Y	Y	
3				181.14	51857224	286.28	2290.26	Y	Y	
4				172.42	51857224	300.76	2406.09	Y	Y	
5			15:26:17.595	173.83	51857224	298.32	2386.57	Y	Y	
6	15:32:03.971	15:32:10.302		184.81	51857224	280.60	2244.78	Y	Y	23.56
7				180.27	51857224	287.66	2301.31	Y	Y	
8				178.75	51857224	290.11	2320.88	Y	Y	
9				178.88	51857224	289.90	2319.20	Y	Y	

10			15:50:54.886	170.3	51857224	304.51	2436.04	Y	Y					
Average Main UE				**179.00**		**289.95**	**2319.63**	**100.00%**	**100.00%**	**23.57**				
KPI							2200	98%	98%					
PASS/FAIL							PASS	PASS	PASS					
Load UE 1				**Load UE 2**				**Load UE 3**						
File Size (Kbytes)	**DOS FTP DL Time (s)**	**FTP throughput (Kbytes/s)**	**FTP throughput (Kbits/s)**	**File Size (Kbytes)**	**DOS FTP DL Time (s)**	**FTP throughput (Kbytes/s)**	**FTP throughput (Kbits/s)**	**File Size (Kbytes)**	**DOS FTP DL Time (s)**	**FTP throughput (Kbytes/s)**	**FTP throughput (Kbits/s)**	**Max difference between samples**	**FTP throughput Std Devi (Kbps)**	**FTP throughput Average (Kbps)**
51857224	183.27	282.96	2263.64	51857224	190.09	272.80	2182.43	51857224	187.47	276.62	2212.93	81.21	41.02427847	2219.667
51857224	171.77	301.90	2415.19	51857224	189.89	273.09	2184.73	51857224	180.61	287.12	2296.98	230.47	115.2461446	2298.967
51857224	155.8	332.84	2662.76	51857224	180.34	287.55	2300.42	51857224	177.33	292.43	2339.47	49.21	198.8847398	2434.216
51857224	153.34	338.18	2705.48	51857224	173.8	298.37	2386.98	51857224	169.28	306.34	2450.72	299.39	168.5235577	2514.393
51857224	151.59	342.09	2736.71	51857224	172.88	299.96	2399.69	51857224	163.7	316.78	2534.26	350.14	169.647109	2556.884
51857224	186.34	278.29	2226.35	51857224	191.15	271.29	2170.33	51857224	184	281.83	2254.66	84.34	42.91999038	2217.112

51857224	189.77	273.26	2186.11	51857224	188.49	275.12	2200.95	51857224	179.59	288.75	2310.03	123.92	67.66740776	2232.363
51857224	183.52	282.57	2260.56	51857224	181.02	286.47	2291.78	51857224	176.36	294.04	2352.33	91.78	46.66287758	2301.558
51857224	177.99	291.35	2330.79	51857224	176.63	293.59	2348.74	51857224	171.88	301.71	2413.65	94.45	43.5893573	2364.393
51857224	173.52	298.85	2390.84	51857224	174.67	296.89	2375.09	51857224	158.28	327.63	2621.04	245.94	137.6761969	2462.323
	171.93	**304.01**	**2432.10**		**181.90**	**283.08**	**2264.66**		**177.29**	**292.99**	**2343.92**			

Table 41. Multi User – Static loaded Scenario. PS FTP downloads. In a multi-user scenario, 4 users (all of the same HSDPA category) are considered on the cell, 1 measuring the KPI and the other 3 performing FTP downloads (50 Mbyte file) in the same radio conditions as the one measuring the KPI. Procedure to measure the KPI is the same as the one applied for single user. In this case, though, KPI measurement shall start 30s after the beginning of FTP downloads.

Sample	Small Ping DCH (ms)	Small Ping FACH (ms)	Big Ping DCH (ms)	Big Ping FACH (ms)	Big Ping IDLE (ms)
1	60.392	181.344	101.455	1029.262	2259.607
2	60.39	200.32	111.462	975.781	2151.223
3	60.385	192.353	111.428	1016.675	2291.378
4	70.388	201.034	111.444	1004.403	2198.576
5	60.381	191.341	110.45	1016.73	2177.971
6	60.395	181.334	111.426	1023.933	2220.84
7	69.478	191.331	121.442	1023.193	2228.231
8	70.37	200.341	120.426	1020.754	2473.621
9	60.474	190.35	121.442	1041.306	2235.473
10	60.368	201.344	111.44	1027.041	2198.856
11	60.39	191.304	121.422	1048.099	2190.501
12	60.415	180.323	120.435	1030.202	2269.585
13	60.43	190.306	111.457	1026.516	2227.998
14	59.381	191.313	110.451	1027.87	2216.06
15	59.391	180.33	130.473	989.499	2230.735
16	60.391	190.342	121.231	1020.576	2522.371
17	60.404	201.342	121.459	1056.067	2208.946
18	59.408	190.342	110.454	1074.338	2359.445
19	60.401	201.329	121.444	1045.842	2164.165

20	59.508	190.33	121.435	1045.345	2319.516
21	59.462	180.352	110.466	1024.285	2262.43
22	60.42	190.31	111.43	991.145	2119.923
23	59.467	200.333	121.48	986.326	2307.199
24	60.374	190.346	121.434	999.906	2466.683
25	70.429	200.339	111.412	1040.21	2306.518
26	59.393	191.323	111.453	1045.417	2381.436
27	60.383	180.359	120.434	1038.042	2296.739
28	70.385	191.332	121.432	1018.173	2336.276
29	59.381	201.328	111.413	1038.083	2218.621
30	70.421	190.361	121.455	1055.778	2328.631
31	59.376	180.366	121.456	1034.518	2310.383
32	59.359	200.372	110.417	1047.107	2518.837
33	70.417	190.311	110.439	1027.913	2189.362
34	59.387	201.337	121.439	1015.242	2354.194
35	60.462	190.336	110.442	984.894	2311.134
36	59.392	181.333	110.418	1023.994	2185.993
37	69.463	190.313	110.463	1024.216	2147.795
38	59.457	200.342	120.472	1019.784	2143.708
39	59.462	190.329	110.429	1067.819	2267.438

40	60.376	180.308	110.445	1025.427	2434.561
41	69.394	200.324	110.434	1026.285	2227.84
42	59.436	190.334	110.432	1007.017	2166.103
43	60.396	190.355	120.456	1010.501	2301.803
44	59.466	200.366	111.431	1016.549	2182.06
45	59.367	190.349	110.443	992.846	2245.775
46	69.43	200.348	120.449	1053.945	2286.043
47	59.388	190.31	110.463	1040.002	2266.037
48	60.421	190.338	110.429	1040.395	2407.02
49	59.407	201.352	121.458	1041.143	2251.223
50	59.435	191.355	110.436	1035.283	2341.4
Average RTT	**61.931**	**192.110**	**115.159**	**1026.314**	**2274.165**
Success Rate	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**
KPI (ms)	90	200	180	1100	3000
PASS/FAIL	PASS	PASS	PASS	PASS	PASS

Table 42. Multi User – Static Unloaded Scenario. Same situation as in table 12 applies. The same procedure as per single user scenario is followed for the UE measuring the KPI, whereas the rest are just loading the cell with continuous FTP downloads.

Call No.	RRC Connection Request	PDP Accept	Source Cell SC	Radio Bearer Reconfiguration	Radio Bearer Reconfiguration Complete	Target Cell SC	Reason	Last Packet before HO (Wireshark)	First Packet after HO (Wireshark)	TCP interruption Time	FTP End Time	DOS FTP DL Time	FTP throughput (Kbps)	Successful Data Resumption after SCC	HO Success
1	10:52:46.994	10:52:53.304	321	10:53:33.820	10:53:34.401	331	**SCC**	10:53:34.341	10:53:34.50	**00:00:00.160**				Y	Y
2			331	10:54:01.879	10:54:02.481	321	**SCC**	10:54:02.410	10:54:02.54	**00:00:00.131**	10:54:34.450	88.140	4706.72	Y	Y
3	10:54:58.347		321	10:55:23.929	10:55:24.498	331	**SCC**	10:55:24.439	10:55:24.61	**00:00:00.171**				Y	Y
4			331	10:55:54.929	10:55:55.514	321	**SCC**	10:55:55.453	10:55:55.59	**00:00:00.137**	10:56:32.680	87.920	4718.48	Y	Y
5			321	10:57:22.180	10:57:22.790	331	**SCC**	10:57:22.728	10:57:22.88	**00:00:00.160**				Y	Y
6			331	10:57:53.582	10:57:54.149	321	**SCC**	10:57:54.081	10:57:54.26	**00:00:00.188**	10:58:29.980	86.810	4778.80	Y	Y
7	10:58:58.469		321	10:59:19.303	10:59:19.938	331	**SCC**	10:59:19.877	10:59:20.03	**00:00:00.162**				Y	Y
8			331	10:59:50.777	10:59:51.378	321	**SCC**	10:59:51.308	10:59:51.47	**00:00:00.170**	11:00:27.780	87.420	4745.44	Y	Y
9			321	11:01:20.798	11:01:21.338	331	**SCC**	11:01:21.267	11:01:21.40	**00:00:00.141**				Y	Y
10			331	11:01:52.077	11:01:52.498	321	**SCC**	11:01:52.358	11:01:52.45	**00:00:00.101**	11:02:25.200	87.050	4765.92	Y	Y
11	11:03:07.981		321	11:03:32.262	11:03:32.910	331	**SCC**	11:03:32.788	11:03:32.95	**00:00:00.170**				Y	Y
12			331	11:04:03.339	11:04:03.930	321	**SCC**	11:04:03.870	11:04:04.01	**00:00:00.149**	11:04:35.950	87.280	4753.04	Y	Y
Average										**00:00:00.153**		**81.26**	**4744.73**	**100%**	**100%**
KPI										**< 1s**			**1050**		**95%**
PASS/FAIL										PASS			PASS		PASS

Table 43. Single User – Mobility Unloaded Scenario. HSDPA Serving Cell Change: Hybrid_to_Hybrid

Call No.	RRC Connection Request	PDP Accept	Source Cell SC	Radio Bearer Reconfiguration	Radio Bearer Reconfiguration Complete	Target Cell SC	Reason	Last Packet before HO (Wireshark)	First Packet after HO (Wireshark)	TCP interruption Time	FTP End Time	DOS FTP DL Time	FTP throughput (Kbps)	Successful Data Resumption after SCC	HO Success
1	15:55:24.643	15:55:31.051	321	15:56:25.370	15:56:25.956	331	**SCC**	15:56:25.875	15:56:26.016	**00:00:00.141**					
2			331	15:57:08.592	15:57:09.213	321	**SCC**	15:57:08.405	15:57:09.245	**00:00:00.840**					
3			321	15:58:04.873	15:58:05.494	331	**SCC**	15:58:05.434	15:58:05.615	**00:00:00.181**					
4			331	15:58:42.984	15:58:43.056	321	**SCC**	15:58:42.407	15:58:43.044	**00:00:00.637**	15:58:55.290	178.390	2325.52	Y	Y
5			321	15:59:54.094	15:59:55.000	331	**SCC**	15:59:54.591	15:59:54.752	**00:00:00.161**					
6			331	16:00:26.812	16:00:27.204	321	**SCC**	16:00:26.602	16:00:27.182	**00:00:00.580**					
7			321	16:01:04.216	16:01:04.847	331	**SCC**	16:01:04.803	16:01:04.963	**00:00:00.160**					
8			331	16:01:45.656	16:01:46.293	321	**SCC**	16:01:45.751	16:01:46.324	**00:00:00.573**	16:02:15.510	290.690	2461.60	Y	Y
9	16:22:32.314	16:22:38.645	321	16:23:16.332	16:23:16.971	331	**SCC**	16:23:17.242	16:23:17.399	**00:00:00.157**					
10			331	16:23:45.761	16:23:46.333	321	**SCC**	16:23:45.532	16:23:46.310	**00:00:00.778**					

11			321	16:24:26.379	16:24:27.005	331	**SCC**	16:24:26.958	16:24:27.167	**00:00:00.209**					
12			331	16:25:09.257	16:25:09.658	321	**SCC**	16:25:09.057	16:25:09.718	**00:00:00.661**	16:25:32.840	170.330	2435.60	Y	Y
13			321	16:26:36.221	16:26:36.778	331	**SCC**	16:26:36.728	16:26:36.917	**00:00:00.189**					
14			331	16:27:08.616	16:27:08.778	321	**SCC**	16:27:08.060	16:27:08.770	**00:00:00.710**					
15			321	16:27:56.298	16:27:56.918	331	**SCC**	16:27:56.875	16:27:57.136	**00:00:00.261**					
16			331	16:28:44.817	16:28:45.445	321	**SCC**	16:28:44.647	16:28:45.427	**00:00:00.780**	16:29:14.590	191.410	2167.44	Y	Y
17			321	16:30:14.128	16:30:14.768	331	**SCC**	16:30:14.697	16:30:14.907	**00:00:00.210**					
18			331	16:30:50.363	16:30:51.008	321	**SCC**	16:30:50.384	16:30:51.000	**00:00:00.616**					
19			321	16:31:40.569	16:31:41.209	331	**SCC**	16:31:41.126	16:31:41.317	**00:00:00.191**					
20			331	16:32:14.921	16:32:15.519	321	**SCC**	16:32:15.157	16:32:15.560	**00:00:00.403**	16:32:35.070	168.780	2457.92	Y	Y
21			321	16:33:34.968	16:33:35.601	331	**SCC**	16:33:35.537	16:33:35.737	**00:00:00.200**					
22			331	16:34:12.846	16:34:13.478	321	**SCC**	16:34:13.071	16:34:13.458	**00:00:00.387**					

23			321	16:34:52.899	16:34:53.531	331	**SCC**	16:34:53.466	16:34:53.597	**00:00:00.131**					
24			331	16:35:29.128	16:35:29.696	321	**SCC**	16:35:28.626	16:35:29.681	**00:00:01.055**	16:35:54.540	169.060	2453.84	Y	Y
25	16:36:24.311		321	16:36:55.957	16:36:56.503	331	**SCC**	16:36:55.745	16:36:56.476	**00:00:00.731**					
26			331	16:37:26.306	16:37:26.964	321	**SCC**	16:37:26.431	16:37:26.976	**00:00:00.545**					
27			321	16:38:10.861	16:38:11.497	331	**SCC**	16:38:11.435	16:38:11.655	**00:00:00.220**					
28			331	16:38:42.540	16:38:43.195	321	**SCC**	16:38:42.500	16:38:43.156	**00:00:00.656**	16:39:39.420	192.330	2157.04	Y	Y
Average										**00:00:00.442**		**194.43**	**2351.28**	**100%**	**100%**
KPI										**< 1s**			**1050**		**95%**
PASS/FAIL										PASS			PASS		PASS

Table 44. Single User – Mobility Unloaded Scenario. HSDPA Serving Cell Change: Hybrid_to_non_Hybrid

Fine-Tuning of Concatenation Factor and Packetization Timer in non-ideal conditions

This section is intended to show the results obtained during the study carried on how the parameters *concatenation factor* and *packetization timer* have an impact on the throughput when non-ideal conditions of the Ethernet link are met, such as delay and packet loss.

In order to control and measure delay and packet loss, Spirent Ethernet impairment tool was used, connected on the Fast Ethernet link of the IuB interface.

First of all, two preliminary tests are performed to assess the behavior of the platform under ideal conditions, which will help to setup the benchmark for the study.

Benchmark Test 1: Fixed packetization timer vs. variable concatenation factor

- **Test conditions:** Fixed packetization timer of 2000 µs is used. No Ethernet impairment tool used between Flexi Node B and Tellabs 8630 equipment.

CF	**1**	**5**	**10**	**15**	**20**	**26**
Throughput (Mbps)	6.5	6.3	6.5	6.5	6.4	6.5

Table 45. Downlink throughput obtained with FTP download per Concatenation Factor

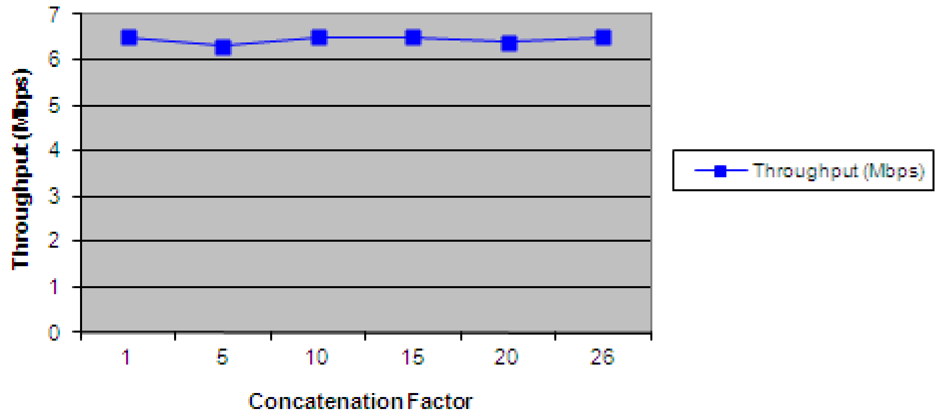


Figure 94. Downlink throughput obtained with FTP download per Concatenation Factor

No downlink throughput variation is found by using different CF values under ideal conditions, as expected.

Benchmark Test 2: Fixed concatenation factor vs. variable packetization timer

- **Test conditions:** Fixed concatenation factor of 26 is used. No Ethernet impairment tool used between Flexi Node B and Tellabs 8630 equipment.

PT (µs)	**2000**	**3000**	**4000**	**5000**
Throughput (Mbps)	6.5	6.3	6.5	6.5

Table 46. Downlink throughput obtained with FTP download per Packetization Timer

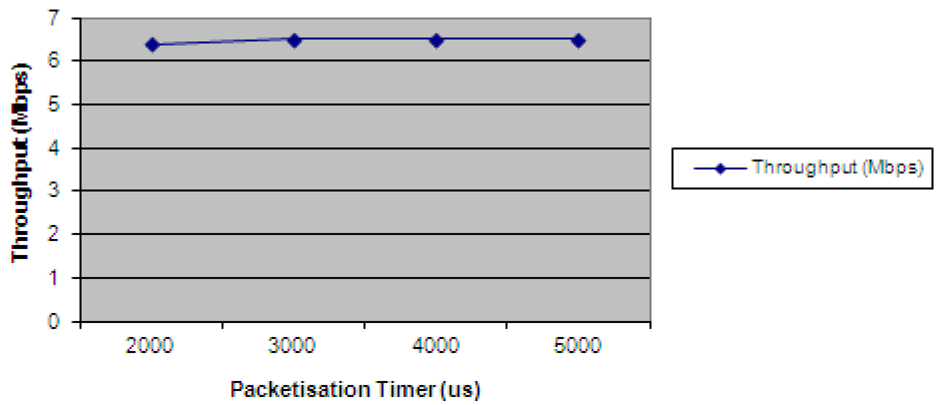


Figure 95. Downlink throughput obtained with FTP download per Packetization Timer

No throughput variation is found by using different PT values under ideal conditions, as expected.

In light of these results it can be concluded that, under ideal conditions, CF and PT parameters do not affect the behavior of the system and the expected downlink throughput will be around 6.5 Mbps.

Test 1: Fixed packetization timer and variable concatenation factor behavior depending on delay

Test conditions: Fixed packetization timer of 2000µs is used. Ethernet impairment tool used between Flexi NODE B and Tellabs 8630 equipment, introducing variable delay in downlink direction.

Throughput (Mbps)	**Concatenation Factor**					
Delay (ms)	**1**	**5**	**10**	**15**	**20**	**26**
50	6.5	6.5	6.4	6.4	6.5	6.5
100	5.8	6.1	6	6	6	6

150	5.1	5.1	5.1	5.1	5.1	5.1
200	4.3	4.4	4.3	4.4	4.4	4.3

Table 47. Downlink throughput obtained with FTP download per Concatenation Factor and Line Delay

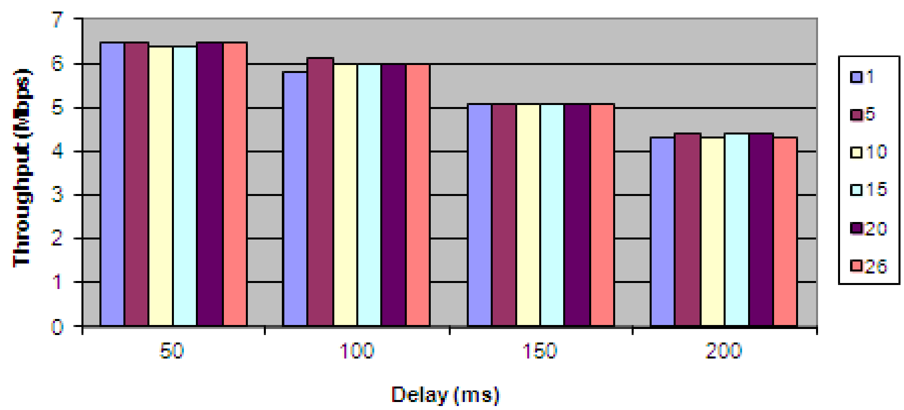


Figure 96. Downlink throughput obtained with FTP download per Concatenation Factor and Line Delay

This test reflects that, the higher the delay, the lower the throughput and it will decrease as expected irrespective of the concatenation factor used.

Test 2: Fixed concatenation factor and variable packetization timer behavior depending on delay

Test conditions: Fixed concatenation factor of 26 is used. Ethernet impairment tool used between Flexi Node B and Tellabs 8630 equipment, introducing variable delay in downlink direction.

Throughput (Mbps)	Packetization timer (μs)			
Delay (ms)	2000	3000	4000	5000
50	6.5	6.4	6.4	6.4
100	6	5.9	6	6
150	5.1	5.1	5.1	5.1
200	4.3	4.2	4.3	4.4

Table 48 Downlink throughput obtained with FTP download per Packetization Timer and Line Delay

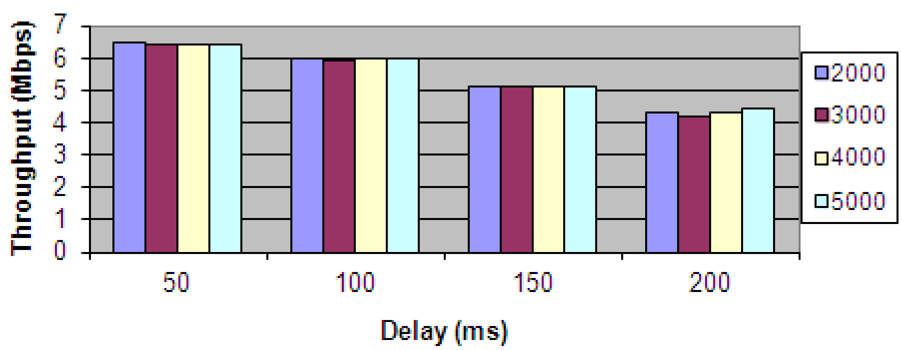


Figure 97 Downlink throughput obtained with FTP download per Packetization Timer and Line Delay

There is no major difference by changing the packetization timer for each delay condition. The behavior is quite similar to the one reached in Test 1, so it can be concluded that throughput figures under delay conditions cannot be improved with neither CF nor Packetization Timer parameters.

Test 3: Fixed packetization timer and variable concatenation factor behavior depending on packet loss

Test conditions: Fixed packetization timer of 2000 µs is used. Ethernet impairment tool used between Flexi Node B and Tellabs 8630 equipment, introducing variable packet loss rate in downlink direction.

Throughput (Mbps)	Concatenation Factor		
Packet Loss	**1**	**10**	**26**
1%	2.2	5.3	5.8
3%	2.3	5.3	5.7
5%	2.1	5.1	5.4
7%	1.9	4.9	5.3
10%	1.8	4.5	2.7

Table 49. Downlink throughput obtained with FTP download per Packetization Timer and Line Delay

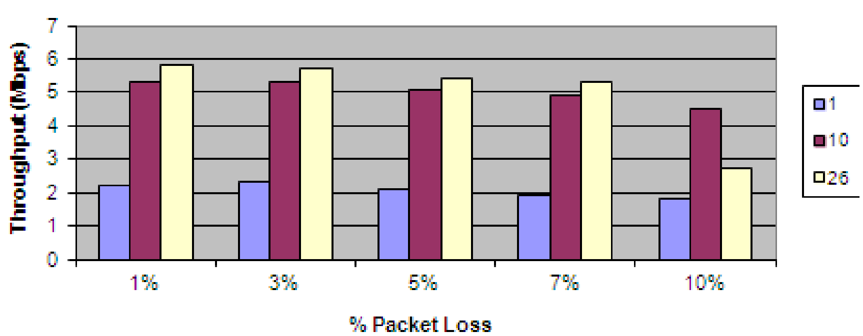


Figure 98. Downlink throughput obtained with FTP download per Packetization Timer and Line Delay

Under low packet loss conditions, concatenation factor does have an impact on the downlink throughput: a greater CF always offers better performance. That makes sense because the impact in throughput of losing 1% of packets carrying few ATM cells will be more negative than the impact caused by losing the same quantity of packets conveying more data (the average data sent will be always higher in the latter case). For higher packet loss rates (10%) the results are misleading. For the reader reference, typical packet loss rate in live network (apart from extremely abnormal situations) are 1%-3%.

Test 4: Fixed packetization timer and variable concatenation factor behavior depending on typical live network packet loss

Test conditions: Fixed packetization timer of 2000 µs is used. Ethernet impairment tool used between Flexi Node B and Tellabs 8630 equipment, introducing variable packet loss rate in downlink direction.

Throughput (Mbps)	Concatenation Factor	
Packet Loss	**1**	**26**
0.5%	5	5.9
0.8%	4.9	6
1.0%	4.9	6.1
1.2%	5.2	5.9
1.5%	4.3	5.6
1.8%	4.6	5.9

Table 50. Downlink throughput obtained with FTP download per Concatenation Factor and Packet Loss

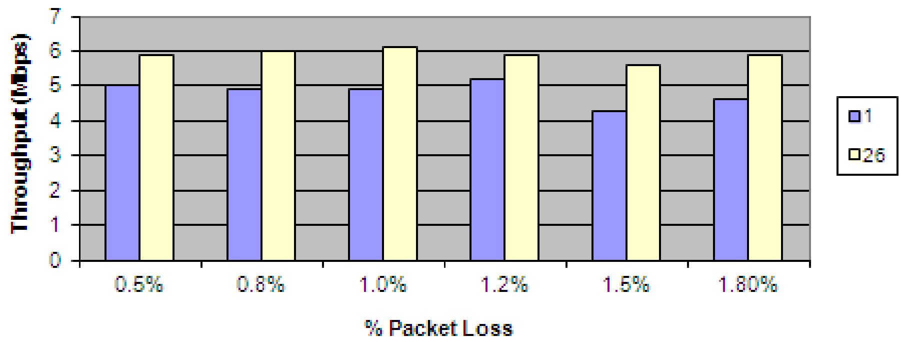


Figure 99. Downlink throughput obtained with FTP download per Concatenation Factor and Packet Loss

This test is a specific case of Test 3. The packet loss values managed in this test case are the ones that can be found in live network. The CF values shown simulate two extreme values. Under these conditions it can be highlighted the better throughput values offered by using a higher CF.

4.2.5 Test Conclusions

Validation tests for feature *Hybrid Backhaul* proved that:

- Basic network functionalities and end to end network KPIs are not affected by the introduction of a separated ATM service backhaul based on the traffic type, that is, Release 99 traffic (voice and data) is correctly routed through legacy E1-based IuB backhaul and HSPA data is simultaneously routed using ATM over Ethernet solution and no service affection is detected.

- Transmission network redundancy based on MSP 1+1 can be applied between the RNC and Tellabs equipment. In a lab network environment, it might make sense to apply protection mechanisms between boards of the same equipment; however, in live network scenarios it is more common that the transmission equipments conforming the Point of Convergence (PoC) between the Node Bs and the RNC are duplicated, applying not only equipment but also TX path redundancy as well, to improve system robustness.

- Seamless mobility can be executed between Node Bs with different TX solutions (non-hybrid to hybrid Node B and vice versa), ensuring a smooth deployment in live network.

- Under non-ideal conditions of packet loss in the TX media, ATM over Ethernet parameter *Concatenation Factor* can be tuned whilst leaving a *Fixed Packetization* timer to minimize the impact in throughput. It has also been proved that under heavy delay conditions, none of these parameters can help to avoid throughput degradation.

4.3 IuB over IP feature validation

Once the reader has understood the principles and results of a smooth migration from pure ATM transmission backhauls to Hybrid Backhaul scenarios, it is time to present the last step in the IuB interface evolution: the IP-based transmission design. During this section, the basics and principles of IuB over IP interface are explained, giving both the theoretical and practical point of view.

From testing activity point of view, the objective was to design the test environment to validate the new software features involved with IuB over IP. The following test cases will be discussed:

- **Layer 2 vs. Layer 3 design**. These solutions offer a different approach from the transmission design point of view. In case of live network deployments, it is common to define a layer 2 solution which separates the IP addressing for signaling and data services from maintenance services on a per VLAN basis. That allows the configuration of different QoS policies per service, for instance.

- **IuB over IP maintenance:** Bidirectional Forwarding Detection (BFD) configuration is introduced as a monitoring mechanism of packet data networks. In this case, it will allow the maintenance of IuB over IP solution.

- **IuB QoS Transport:** this feature allows QoS differentiation over IuB interface in an All-IP network. Differentiated Service Code Point (DSCP) concept will be introduced.

4.3.1 Feature Description

IP packet backhaul

Packet Backhaul refers to the last step in the substitution of E1 links by a packet-switched network based on full IP protocol stack. Transporting all the IuB traffic over packets implies tighter requirements:

- **Hard Quality of Service (QoS):** DCH real time traffic requirements should be accomplished.

- **Minimum restoration time:** if the packet network is disrupted, the service has to be re-started within the same restoration time of a current E1 link.

- **Synchronization:** maintaining synchronization with former E1 links, synchronous Ethernet solutions, IP clock mechanism or GPS are the alternative for synchronization.

- **Security:** As control plane and maintenance traffic is not sufficiently encrypted, this requirement is one of the most important.

- **QoS Awareness:** Prioritization might be used between the different traffic types in order to achieve the desired QoS.

Introduction to IuB over IP

Starting with 3GPP Release 6, WCDMA allows the use of IP as universal transport protocol in the UMTS Radio Access Network.

The main driver to support IP transport is the reduction in OPEX:

- Operators that already have an IP backbone network connection for core network elements can use the same infrastructure to provide UTRAN transport services.

- IP transport enables smooth deployment and upgrade of UTRAN transport over existing and coming packet switched networks, like metropolitan area networks and Ethernet Leased Lines.

Due to the layered structure of the UTRAN protocol architecture, ATM to IP migration has a minimum impact on the Radio Network Layer (RNL). However, there is a deep change in the architecture of the Transport Network Layer (TNL). IP transport technology requires a different approach compared to ATM. Issues like network technology, topology, addressing, quality of service and routing have to be designed according to different criteria. Control Plane and User Plane evolution and configuration guidelines considered during testing are presented herein:

IP based IuB User Plane

IuB use plane is based on the IP protocol suite, according to the 3GPP IP transport option shown in Figure 100:

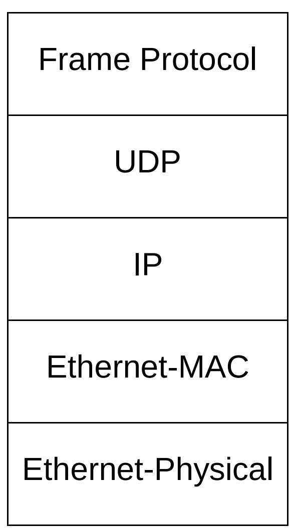


Figure 100. IP based User Plane protocol stack

User Datagram Protocol (UDP) is used for transport of data in the User Plane. The RNC and BTS use multiple local UDP ports, one per transport bearer. UDP ports for traceroute [33434-33933] and Bidirectional Forwarding Detection (BFD) single-hop and multi-hop [3784, 49152-65535] functionalities are reserved. Both network elements use the UDP port received via control signaling (NBAP) as destination port for the egress traffic, whereas the source port for the ingress traffic is locally selected in the network element.

On IuB, the RNC interface supports an IP layer MTU size not greater than 1500 bytes and it can be configured individually for each IP interface. The maximum, though, is defined by port limitation in BTS. Since MTU path discovery is not supported in downlink direction, HSDPA frames might exceed the configured interface MTU and, eventually, the configured BTS MTU size for User Plane (1468 bytes in test scenario). In these cases, the Frame Protocol (FP) layer in RNC will adjust the FP frame size so that none of the above limitations are exceeded, hence not requiring IP fragmentation for downlink user plane. However, IP fragmentation is used in uplink direction if the resulting IP packet size is bigger than 1500 bytes in the BTS. This can commonly happen with HSUPA PDUs. For this scenario, the BTS performs IP fragmentation and the RNC IP reassembling.

IP based IuB Control Plane

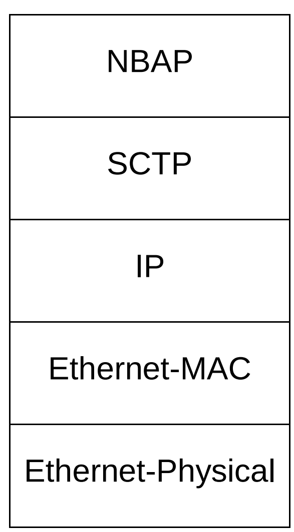


Figure 101 Control Plane protocol stack

The control plane is based on the 3GPP IP transport option shown in Figure 101.

Note that in control and user plane, ARP protocol will allow resolving the MAC address associated with a specific IPv4 address. The mapping table of IP addresses to MAC addresses is created during system start-up and updated after network reconfiguration. Both RNC and BTS are able to create ARP requests in order to update the mapping table.

Stream Control Transmission Protocol (SCTP) is included in IuB over IP protocol stack. Each signaling bearer is carried over a separate SCTP association. All association endpoints for a single BTS have the same IP address and a different SCTP port. The RNC should be configured to use different SCTP ports for each BTS, and each BTS should use the same ports configured in the RNC for a particular BTS. Each signaling bearer is mapped to a SCTP stream and each SCTP association carries only one stream.

The port number of the CNBAP association is indicated by *MinSCTPPort* parameter in the BTS and the *MinSCTPPortIuB* parameter in the RNC. Port numbers for DNBAP associations are assigned according to the rule *MinSCTPPort* + 1 for Flexi type Node B and to *MinSCTPPort* + *ControlPortID* for UltraSite type Node B, where *ControlPortID* identifies the WAM unit inside the Node B. *MinSCTPPort* in Node B and *MinSCTPPortIuB* in RNC must be equal.

In terms of configuration, Flexi Node B and UltraSite Node B (equipped with AXC board) require a single CNBAP and a single DNBAP SCTP association. However, if the UltraSite is equipped with IFUH board, it requires multiple DNBAP SCTP associations.

SCTP fragmentation and reassembly is supported in both DL and UL directions. It is used to carry NBAP messages exceeding the supported IP MTU size. Provisioning of fragmentation and reassembly mechanisms at SCTP layer instead of IP layer allows increasing the performance of control plane. MTU size in control plane is limited to 1472 bytes.

In addition, SCTP also supports path and endpoint fault detection. If the peer endpoint is considered unreachable, the fault is properly reported to the upper layer for further recovery actions.

BFD

BFD (Bidirectional Forwarding Detection) is defined by IETF as a mechanism to monitor the connectivity in packet networks, BFD can be used to monitor the status of the IP paths between the Node and the RNC (IuB) or between RNCs (Iur). In this case it is only shown the behavior in IuB interface.

At IuB, BFD control packets are encapsulated over UDP/IPv4/Ethernet, the same as the user plane. VLAN tagging is applied if selected for the rest of the traffic.

Limitation of this feature is that only one IP address in the RNC can be used for BFD, irrespective of VLAN ID.

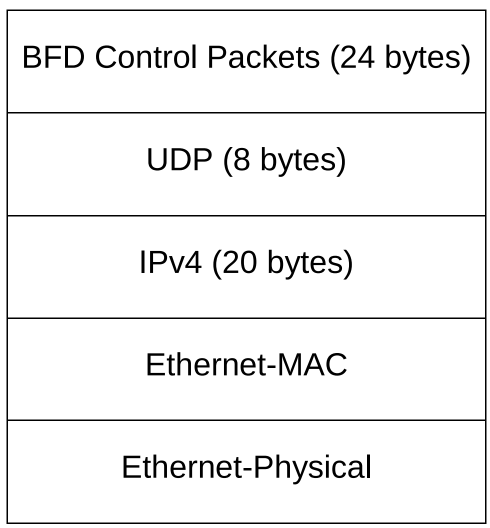


Figure 102. Encapsulation of BFD in IuB/Iur

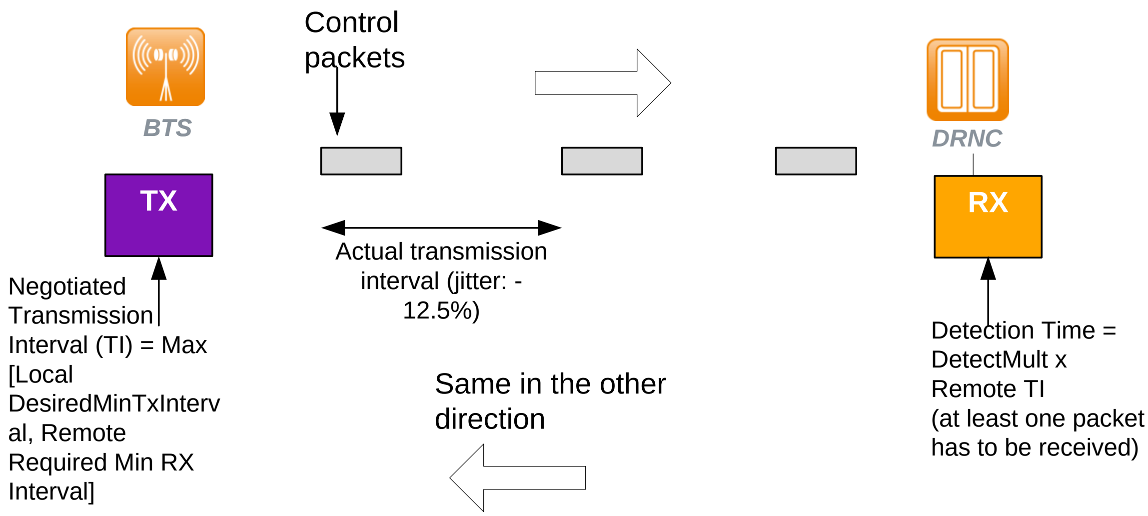


Figure 103. BFD Mechanism. Detection time = DetectMult (received from the peer) x MAX (RequiredMinRXInterval, DesiredMinRXInterval (received from the peer)).

BFD functionality is implemented in asynchronous mode, which is already supported by Node B. In this case, once a BFD session has been established, each end of the path generates a continuous sequence of packets independently of the sequence in the other direction.

Main design constraints found during BFD configuration:

- Both RNC and Node B support an active role.
- There is only *1 BFD session* per Node B.
- Addressing:
    - Node B uses the user plane address.
    - RNC supports only one single IP address per port to support BFD.
    - Source UDP port will be fixed (port 4784) and common to all BFD sessions. This port is in the same UDP port space as the user plane, but it cannot be used for user plane connection, even in BFD is not in use.

- Session Activation:
    - A decision has to be made for which destinations the BFD sessions are going to be established. IP addresses are not configured automatically based on the user plane addresses, but they are configured separately.
    - Transmission interval parameters are configured.
    - Each session can individually be activated.

4.3.2 Testbed configuration and settings

In addition to the before mentioned RAN network elements (RNC and Node B), the whole end-to-end scenario including UEs, laptops, Core Network elements, interfaces, additional routers, switches and servers should support the preferred new features in terms of configuration, licenses and available bandwidth. The following subsections list all the designs implemented during this validation phase.

Scenario 1: Layer 3 transport design overview

From the implementation point of view, IP addressing plan and network element configuration can be divided into two main steps: external configuration (including RNC external IP interface, layer 3 router and NODE B) and internal configuration (including connectivity with ICSUs – which are the control plane interface processing board in the RNC- and OMU – which handles the operation and maintenance traffic of the Node B).

External Configuration

Figure 104 shows the elements involved concerning RNC external configuration. This scenario emulates a situation in which the RNC - Node B connectivity is divided in different IP subnets:

- ***IP Subnet 1*****:** dedicated for the link between the RNC and the traffic aggregation equipment. In this case, NPGE-1 is the Ethernet interface board of the RNC where the IuB link is terminated. A Gigabit Ethernet port, IFGE-0, will be used. On the other hand, Tellabs 8630 will be used as the layer 3 router and the physical connection will be terminated in a Gigabit Ethernet interface board.

- ***IP Subnet 2*****:** dedicated for the link between the traffic aggregation equipment and the transmission interface board of the Node B. In this case a Fast Ethernet port will be used in both sides, replicating what would be a real implementation scenario, where many Node Bs using Fast Ethernet connections are aggregated into a Gigabit Ethernet trunk towards the RNC. The reader can already foresee the scalability of this solution (where many Node Bs can be connected to a Fast Ethernet interface of the traffic aggregation equipment by connection other transmission equipments in cascade). However, from an IP addressing planning point of view, a point to point dedicated subnet per Node B is inefficient. For that reason, point to multi-point IP addressing combined with Layer 2 design is most commonly used in live network deployments (1 IP address in the traffic aggregation equipment, 1 IP address per Node B and many layer 2 transmission equipments, usually packet microwave nodes, defining a star or ring topology). Lately in this chapter, it will be shown how this transmission design can be reused for current 4G network deployments and which are the most common topologies involved

- ***IP Subnet 3*****:** dedicated for the Node B O&M domain. It is internally defined within the Node B.

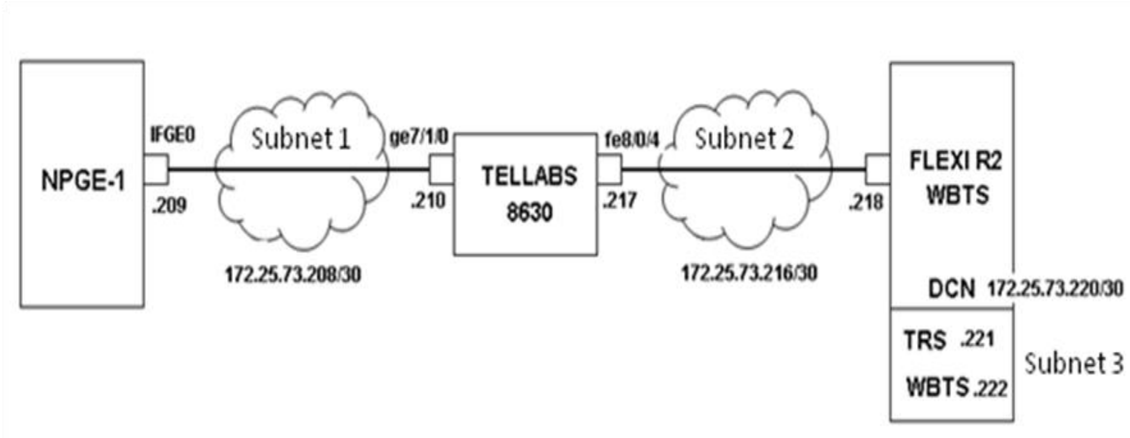


Figure 104. Layout and IP addressing used for Layer 3 External Configuration in lab environment.

In this case, 3 different /30 IP subnets are allocated in order to provide connection in the RNC-Router-NODE B layout and for the NODE B management configuration:

- 172.25.73.208/30 for RNC-Tellabs8630 segment (Subnet 1)
- 172.25.73.216/30 for Tellabs8630-NODE B segment (Subnet 2)
- 172.25.73.220/30 for NODE B O&M domain (Subnet 3)

RNC	
Interface	**IP address**
IFGE0	172.25.73.209
Tellabs 8630	
Interface	**IP address**

Ge7/1/0	172.25.73.210
Fe8/0/4	172.25.73.217
NODE B	
Interface	**IP address**
Transport Ethernet	172.25.73.218
TRS	172.25.73.221
NODE B	172.25.73.222

Table 51. IP addressing reference

RNC configuration

- Configuration of IP Optical Gigabit Ethernet interface in NPGE-1:

  ZQRN:NPGE,1:IFGE0:172.25.73.209,30:;

- Configuration of static route in order to communicate NPGE-1 board with the Node B for Control Plane and User Plane with Tellabs 8630 as the next hop:

  ZQKC:NPGE,1:172.25.73.216,30:172.25.73.210:;

- Configuration of static route in order to communicate the NPGE-1 board with the Node B O&M network:

  ZQKC:NPGE,1:172.25.73.220,30:172.25.73.210:;

- Assign DSPM profile to the IP interface in NPGE-1, which allows the definition of QoS policies over the IP connections on the selected Ethernet interface. This will be used in the validation step dedicated to QoS.

  ZQ8S:NPGE,1:IFGE0:ENA:;

Tellabs 8630 Configuration

- Configuration of Fast Ethernet interface (Tellabs 8630 – Node B segment)

  Tellabs(config)# interface fe8/0/4

  Tellabs(cfg-if[fe8/0/4])# ip address 172.25.73.217/30

  Tellabs(cfg-if[fe8/0/4])# no shutdown

  Tellabs(cfg-if[fe8/0/4])# exit

- Configuration of Gigabit Ethernet interface (Tellabs – RNC)

  Tellabs(config)# interface ge7/1/0

  Tellabs(cfg-if[fe8/0/2])# ip address 172.25.73.210/30

  Tellabs(cfg-if[fe8/0/2])# no shutdown

  Tellabs(cfg-if[fe8/0/2])# exit

- Addition of necessary static routes. In the command it is indicated both the destination IP subnet and the next hop IP to reach that subnet.

  Tellabs(config)# ip route 172.25.73.220/30 172.25.73.218 // To enable the communication towards subnet 3 via Node B transmission interface.

  Tellabs(config)# ip route 172.25.73.203/32 172.25.73.209 //To enable the Node B to communicate with the Operation and Management System within the RNC. Please refer to Figure 38.

Tellabs(config)# ip route 172.25.73.200/32 172.25.73.209 //To enable the Node B to communicate with the Operation and Management Unit in the RNC.

Tellabs(config)# ip route 172.25.102.0/24 172.25.83.209 //To allow communication between the Node B and NetAct network for O&M purposes.

Tellabs(config)# ip route 10.16.76.64/26 172.25.73.209 //To allow communication between the Node B and the RNC internal SCTP subnet (see internal configuration) for signaling control purposes. Note that user plane is directly handled by NPGE logical instance.

Configuration of Node B and RNC Object Browser is explained after the internal configuration is explained.

Internal Configuration

Figure 105 explains the RNC internal logical and physical architecture involved in the definition of an IuB over IP in the hardware under test.

Considering the evolution of the external interface with regards the implementation of a full IP protocol stack, it is expected beforehand an internal architecture evolution at logical level, so the legacy hardware units can be reused and only few extra boards are required to make a cost-effective evolution for the operator.

Hardware Units

- **NPGE/N2PGE**: new interface board, supporting FE/GE interfaces and processing IuB over IP user plane data.

- **ICSU**: legacy signaling control units in charge of terminating SCTP connections for control plane data processing.

- **OMS:** operation and maintenance system board, in charge of software version maintenance.

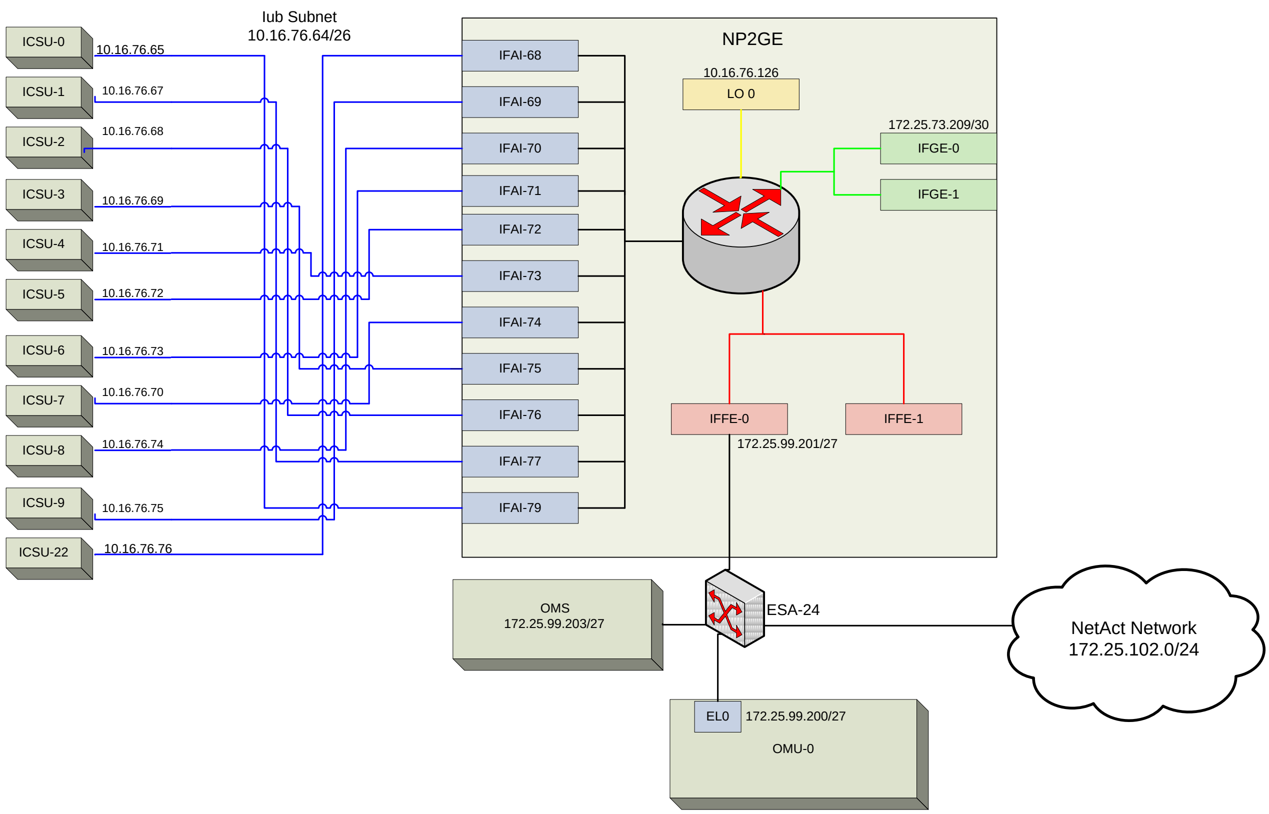


Figure 105. Layout and IP addressing used for Layer 3 Internal Configuration in lab environment.

- **OMU:** operation and maintenance unit board, in charge of terminating Node B O&M connections

- **ESA-24:** RNC switch board, connecting with external operation and maintenance platform, herein called NetAct. In live network, the operator uses this platform to manage all RAN elements.

Logical interfaces:

- **IFAI:** IP over ATM interface logical instance to be created on NPGE board to allow inter-board communication. IP over ATM connections were used in the legacy RNC inter-board communication (physically established through the backplane). For that reason, IFAI logical interface is created to offer a backwards compatible solution. Note that IFAI interfaces involved in the ICSU communication subnet are automatically defined as soon as the subnet is configured; however, manual instances might be required as an option to allow O&M Node B connectivity. This process is explained further down.

- **IFFE**: logical instance emulating inter-board Fast Ethernet connectivity between NPGE and ESA-24 switch board.

RNC Configuration

- Configuration of IuB Control Plane subnet for ICSU boards:

  ZQMN:1:10.16.76.64,26:;

- IuB over IP profile definition for user and control plane. This configuration reflects a 100 Mbps pipe, with 90 Mbps committed bandwidth for user plane, 50 Kbps committed bandwidth for control plane and 1Mbps committed bandwidth for O&M traffic.

  ZQRU:ADD:1,"IUBNODE B40":100000:90000:50:1000:;

- IuB over IP profile is assigned to the selected NPGE IP interface.

  ZQRC:NPGE,1:IFGE0:IPV4=172.25.73.209:ID=1:;

- O&M network definition

  - Creation of IFFE0 interface to communicate N2PGE unit with ESA-24, OMU and OMS:

ZQRN:NPGE,1:IFFE0:172.25.99.201,P:27:;

- Creation of static route from OMU pointing towards DCN subnet in NODE B, with NPGE (IFFE0 interface) configured as next hop:

  ZQKC:OMU,0&&1:172.25.73.220,30:172.25.99.201:LOG;

- Note that a static route from N2PGE unit towards NODE B DCN subnet has already been defined in step 3 of section External Configuration.

- Since Node B/AXC Element Manager needs to be executed from NetAct, a static route is necessary from N2PGE to NetAct network. OMU is already connected with NetAct via ESA-24, so it has to be defined as the next hop of the route.

  ZQKC:NPGE,1:172.25.102.0,24:172.25.99.200:;

This configuration has shown successful results in terms of connectivity, alarm reporting and Element Manager stability. Correct Node B IP address and DCN status is correctly displayed in RNC object browser.

In addition, an alternative non-standard configuration has been tested during the validation, following the logic hidden behind internal IPoATM connectivity within RNC functional units. Despite the successful connectivity results achieved, this design has shown different DCN-related issues like alarm reporting from Node B and incorrect DCN status displayed both in RNC object browser and Node B. The following steps were followed to implement this configuration:

DCN configuration using internal IPoATM connections:

- Manual creation of IPoATM interface (IFAI10) to enable connectivity between NPGE-1 and OMU. It will allow the access of NPGE-1 to NetAct network. In the same command it is created a one-way IPoATM connection, pointing to OMU.

ZQRN:NPGE,1:IFAI10,:172.25.99.201,:32:172.25.99.200:;

- Manual creation of IPoATM interface (AA508) in OMU. In the same command it is created a one-way IPoATM path pointing to NPGE-1, so bi-directional connectivity is enabled between both elements.

ZQRN:OMU,0&&1:AA508,:172.25.99.202,L:32:172.25.99.201:;

- Configuration of static route from OMU towards NODE B DCN network. Next hop of this route is NPGE IPoATM interface IFAI10:

ZQKC:OMU,0&&1:172.25.73.220,30:172.25.99.201:LOG;

- Configuration of static route from NPGE-1 to OMS, with OMU as next hop:

ZQKC:NPGE,1:172.25.99.203,32:172.25.99.200;

- Configuration of static route from NPGE-1 to NetAct network with OMU as next hop:

ZQKC:NPGE,1:172.25.102.0,24:172.25.99.200;

Note: the required static route between ICSU and Node B is automatically created once the IPNB instance is associated to the corresponding Node B in the RNC object browser.

RNC Object Browser Configuration

- **Creation of IPNB Object:** IPNB Object is the entity responsible to configure the control plane management for Node Bs with IP based connections. Once a Node B is associated to an IPNB object, its relationship with ATM needs to be deleted unless Dual IuB protocol stack is used. This step was required during the validation because the Node B under test was previously configured over ATM. Once the *Control Plane Destination Address IuB* is setup, a static route between the ICSU controlling the Node B is automatically setup, as shown in the following MML command extract:

```
MAIN LEVEL COMMAND <___>

< ZQKB: ICSU,9;

LOADING PROGRAM VERSION 2.13-0

RNC       RNC02                     2009-11-11  10:22:22

INTERROGATED STATIC ROUTES

                                                ROUTE

UNIT      DESTINATION        GATEWAY ADDRESS    TYPE  PREFERENCE NBR

--------- ------------------ ------------------ ----- ---------- ----

ICSU-9    172.19.131.209/32  172.19.131.177     LOG   0          5

ICSU-9    172.25.73.218/32   10.16.76.126       LOG   0          6

ICSU-9    172.19.131.214/32  172.19.131.181     LOG   0          16
```

Note the SCTP port assignments for CNBAP and DNBAP protocols. It automatically follows the rule: DNBAP SCTP port = CNBAP SCTP port + 1. In case of UltraSite NODE B, the number of SCTP addresses to be reserved for DNBAP connections is directly proportional to the number of WAMA units configured in that Node B.

However, it may be interesting to dimension the SCTP addresses needed for UltraSite considering the maximum number of WAMA units that can be installed in that Node B.

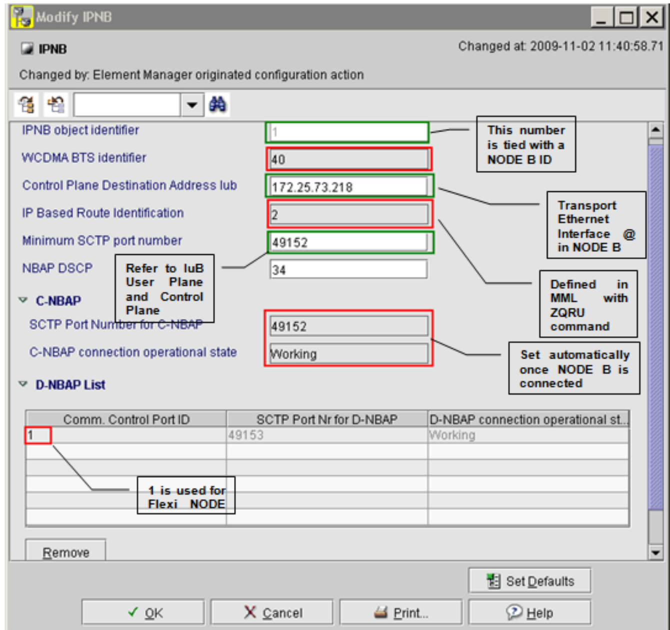


Figure 106. IPNB object configuration in RNC object browser.

Configuration of Node B Object

The following points have to be taking into account when configuring the Node B object:

- IuB Transport Media Selection parameter has to be setup as IP IuB only.
- ATM Based IuB Control Plane fields have to be empty.
- Correct IPNB Object ID has to be configured.
- The only non default value to fill in under IP Based IuB user plane is the IP Based Route id IuB which has to match with the one configured with the MML command ZQRU:

```
MAIN LEVEL COMMAND <___>

< ZQRL;

CONFIGURED IP BASED ROUTE

                          ROUTE BW COMMITTED COMMITTED COMMITTED
                                       BW       SIG BW    DCN BW
 SEQ  ID   NAME              (KBPS)    (KBPS)     (KBPS)    (KBPS)   IFC
 ---- ---- ---------------- --------- --------- --------- --------- ---
    1    1 SGSNG40            1000000         0         0         0 OFF
    2    2 IUBNODE B40         100000     90000        50      1000 OFF
    3    3 IUBNODE B37         100000     90000        50      1000 OFF
```

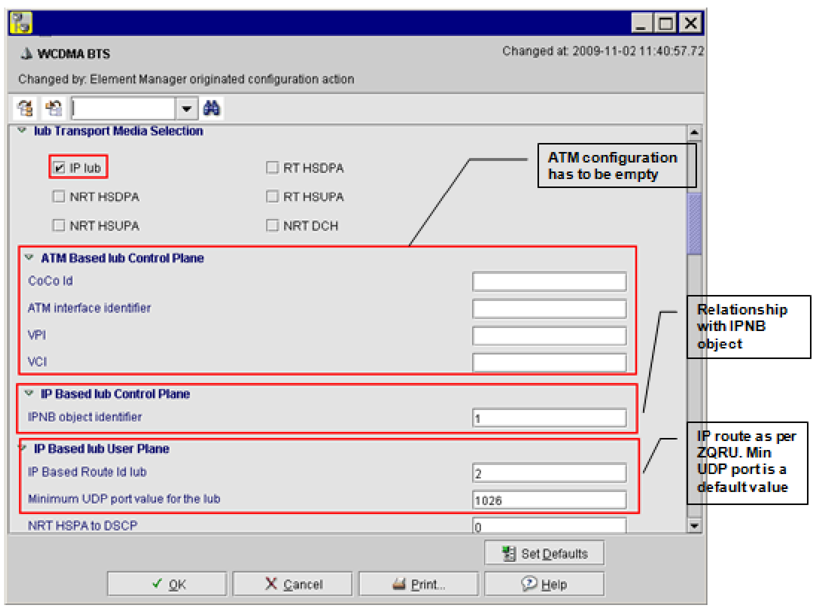


Figure 107 Node B object configuration

Node B Configuration

Following screenshots show the configuration done in Node B under test. This configuration is implemented via the Node B manager (Transmission Resource System), following the different steps hereunder explained:

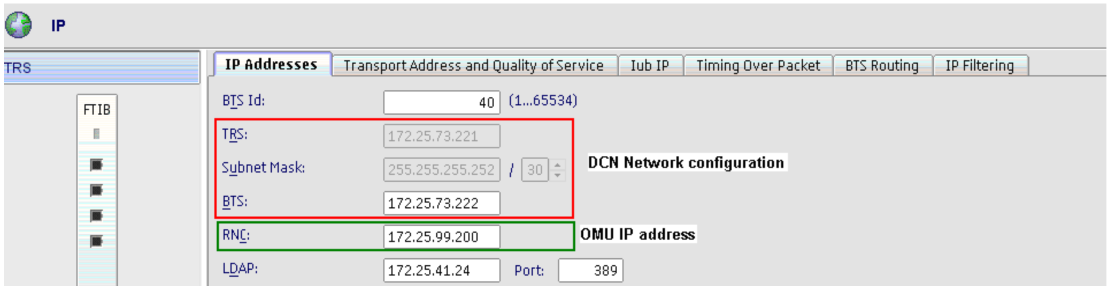


Figure 108. IP addresses configuration for DCN

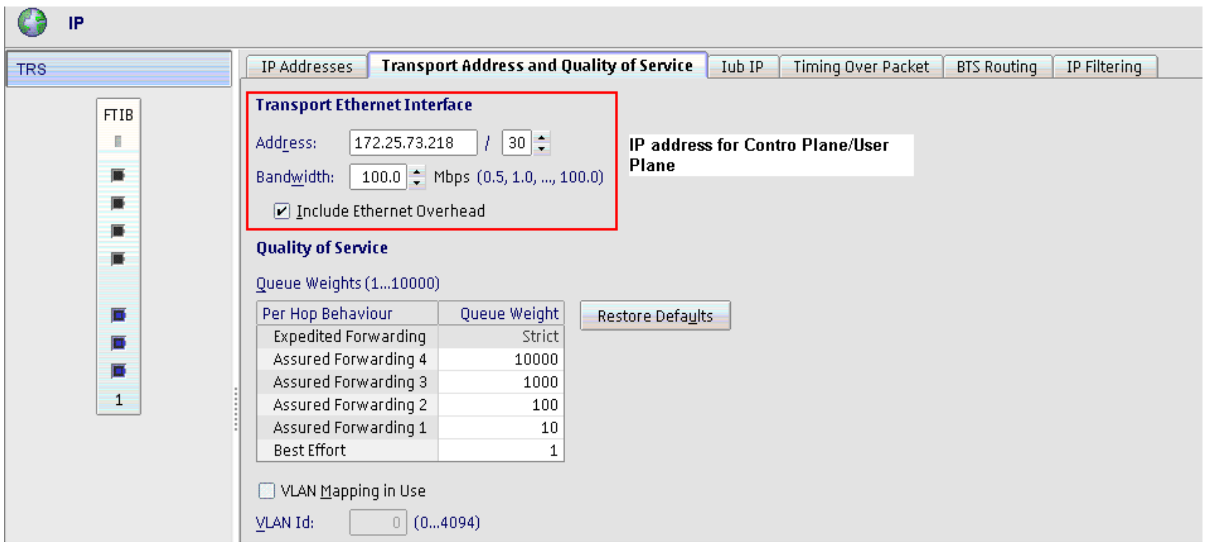


Figure 109. IP address for Control/User Plane. Note also that within this menu it can be also defined the different QoS policies (weights depending on the PHB) and a VLAN ID in case a Layer 2 design is followed.

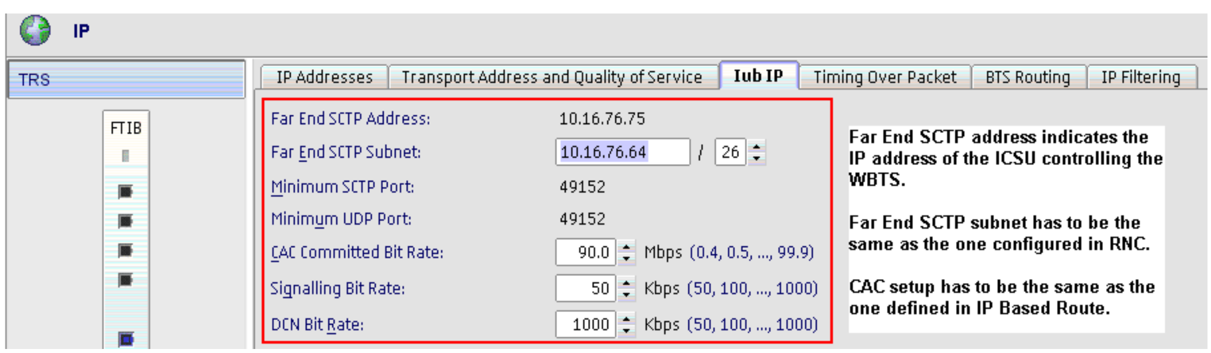


Figure 110. Control Plane and User Plane configuration

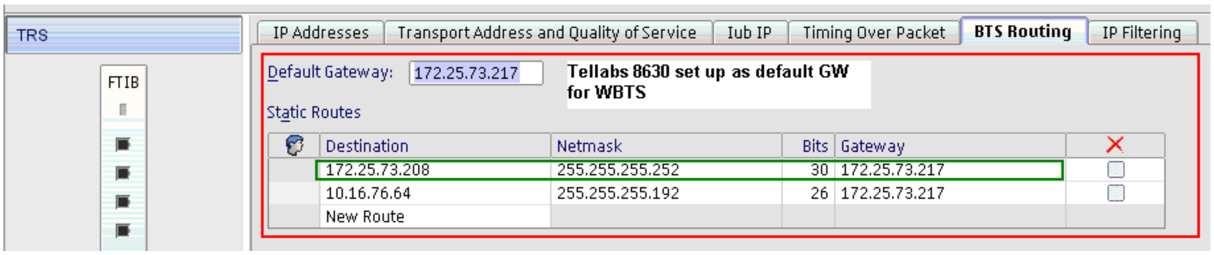


Figure 111. Routing configuration in Node B

At this stage, synchronization was taken from legacy TDM E1 connection, already present in the layout. Current IuB over IP synchronization solution is based on synchronization over Ethernet, so the legacy E1 connection can be removed. This feature must be supported by the TX equipment, which must be connected to a referenced clock source.

Scenario 2: Layer 2 Transport design overview

Once Layer 3 transport solution has been explained, in this section it is presented the implementation of Layer 2 design. It has to be highlighted that Cisco 4948 multilayer switch has been used instead of Tellabs 8630, because the latter does not support Layer 2 switching.

Internal configuration is common to Layer 3 transport so only external configuration (NPGE interface card, Cisco 4948 and AXC) is shown.

Connectivity between NP2GE interface card and Cisco 4948 has been done using Gigabit Ethernet Cat 5 copper connection. By doing that, it was also verified the performance of NP2GE card when having both optical and electrical connections used simultaneously (IFGE0 supporting Layer 3 design based on optical Ethernet and IFGE1 supporting Layer 2 design based on electrical Ethernet).

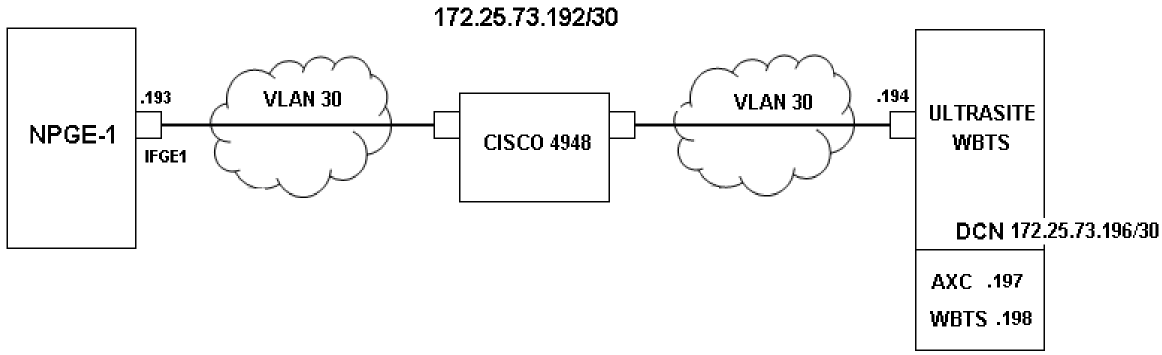


Figure 112. Layout and IP addressing used for Layer 2 External Configuration in lab environment

In this case, only 2 different /30 IP subnets need to be allocated in order to provide connection in the RNC-Node B chain and the Node B DCN configuration: 172.25.73.192/30 for RNC-Node B and 172.25.73.196/30 for Node B DCN.

RNC	
Interface	IP address
IFGE1	172.25.73.193
NODE B	
Interface	IP address
Transport Ethernet	172.25.73.194
AXC	172.25.73.197
NODE B	172.25.73.198

Table 52. IP addressing reference

RNC Configuration

- Configuration of IP Electrical Gigabit Ethernet interface in NPGE-1. VLAN will be used in this interface so only interface activation is needed.

  ZQRN:NPGE,1:IFGE1:;

- Configuration of VLAN 30 for this interface:

  ZQRM:NPGE,1:VL30:30:IFGE1;

- Assignment of IP address to VLAN 30 in IFGE1 interface:

  ZQRN:NPGE,1:VL30:172.25.73.193,P:30:

- Configuration of static route in order to communicate the NPGE with the Node B DCN network, with network transport interface in Node B as next hop.

  ZQKC:NPGE,1:172.25.73.196,30:172.25.73.194:;

NODE B Configuration

From UltraSite type Node B point of view, configuration is only needed in AXC in order to enable IFUH for Layer 2 solution:

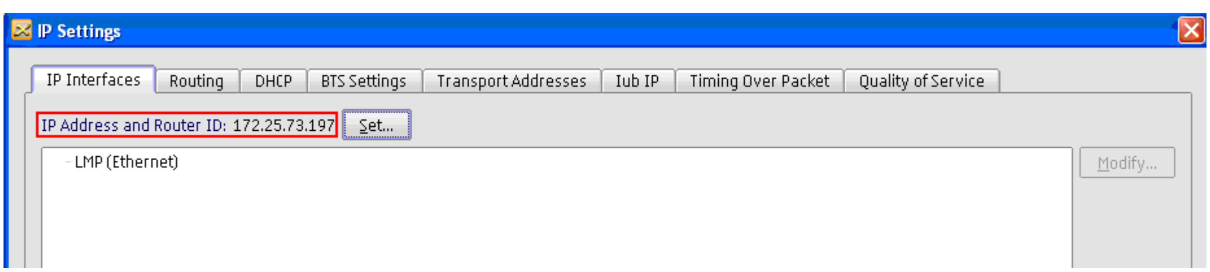


Figure 113. Setting AXC IP address for TX interface management

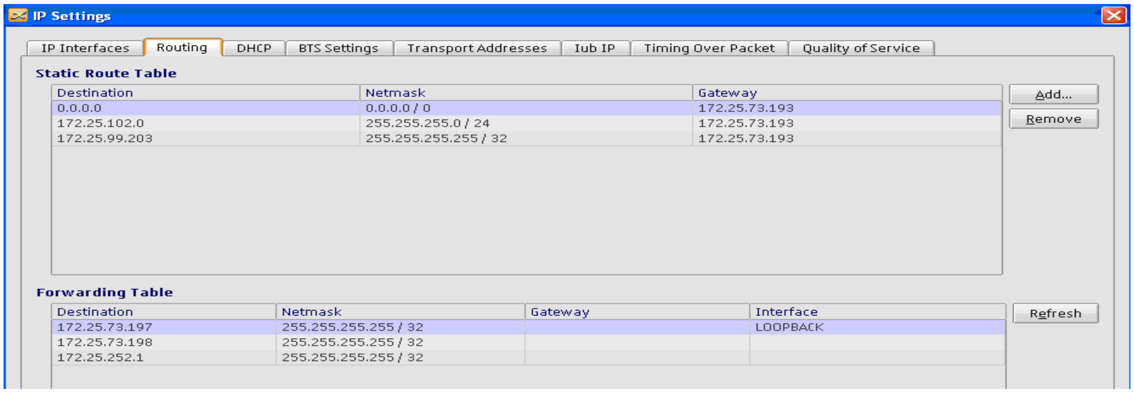


Figure 114. AXC routing table. Routes towards NetAct network and OMS have been set. Gateway is set as per the next hop, which is IFGE1 interface in NP2GE.

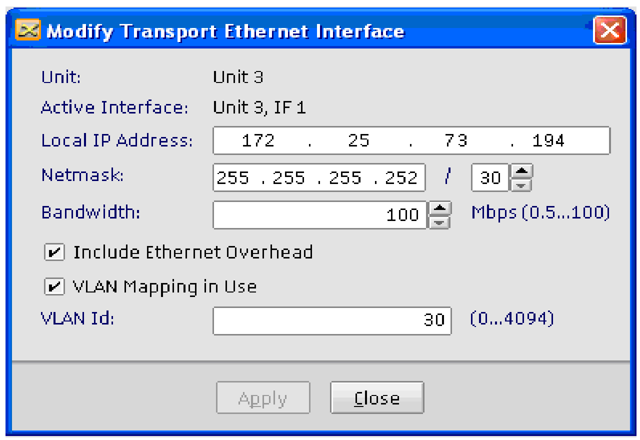


Figure 115. Configuration of Transport Ethernet Interface.

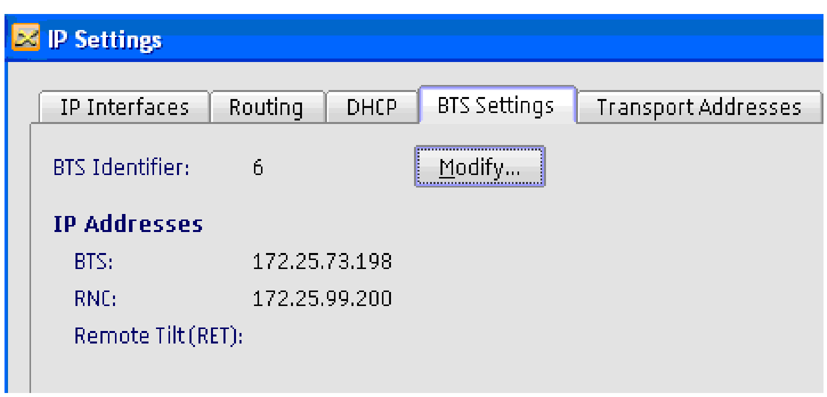


Figure 116. BTS IP settings for DCN

Hardware, Software and Features requirements

Within this section, it is listed the hardware, software and feature requirement in order to test IuB over IP solution under the conditions previously described:

Hardware Requirements

- Flexi type Node B with FTIB transmission board.
- UltraSite type Node B with IFUH transmission board.
- NP2GE Gigabit Ethernet interface unit in RNC.

Software Requirements

3G RAN	
RNC	RN4.0 CD1.05
OMS	R_OMS1_4.43.release_oms.corr46
WBTS	WN5.0 12.4-188
AXC	C5.5 BL6.0

Table 53. Software Requirements

Feature Requirements

Following features need to be enabled in the RNC and Node B:

3G RAN	
RNC	IP Based IuB Flexi WBTS
RNC	IP Based IuB UltraSite WBTS
WBTS	ATM over Ethernet for BTS

Table 54. Feature Requirements

4.3.3 Test results

Regression testing

The following regression testing has been carried out during lab validation phase for IuB over IP Layer 3 solution (only basic functionality testing was executed with Layer 2 solution – AMR voice call, PS R99 data call and PS HSPA call. Successful results were met in all these scenarios). In the following table it is described the test scenario, the RAN equipment used, UE type, test status and comments to further describe the result achieved or other factors affecting the test campaign.

Test case title	RNC/Node B	UE	State	Comment
Intra-Frequency, intra-RNC				
Multi-RAB soft or softer HO	RNC 1 - Flexi Node B 1 (IP configuration) & Flexi Node B 2 (ATM configuration)	Samsung Z630	Pass	DL Throughput 1.6Mbps
Video call soft or softer HO			Not Tested	CN Config Issue
HSUPA Soft Handovers		Huawei E-270	Pass	UL Throughput 2 Mbps
PS/HSDPA call soft or softer HO		Huawei E-270	Pass	Data rate 384Kbps/6.4Mbps
Service Cell Change (SSC) with 384k associated Uplink Channel		Huawei E-270	Pass	Cell 1 (NB 1) HSDPA enabled Cell 3 (NB 2) HSDPA disabled. UL data rate 384k in both Cells
Inter-Frequency, intra-RNC				
AMR 12.2 soft or softer HO	RNC 1 - Flexi	Samsung Z630	Pass	

Multi-RAB soft or softer HO	Node B 1 (IP) & Flexi Node B 2 (ATM)	Samsung Z630	Pass	Data rate 384K
PS call soft or softer HO		Samsung Z630	Pass	Data rate 6.4 Mbps on both Cell1 and 3
HSDPA with Multi-RAB		Samsung Z630	Pass	Data Rate 1.6 Mbps
Intra-Frequency Inter-RNC				
Multi-RAB IuR Handover	RNC 2 Flexi Node B 3 (ATM) to RNC1 Flexi Node B 1 (IP)	Samsung Z630	Pass	
Voice Call IuR Handover		Samsung Z630	Pass	
PS data call soft HO (SSC)		Samsung Z630	Pass	
HDSPA data call soft HO		Samsung Z630	Pass	
Others				
Throughput Based Optimisation	RNC1 Flexi Node B 1	Samsung Z630	Pass	
Multi RAB call with Setup Release of PS		Samsung Z630	Pass	3-4 Attempts of HSDPA calls along with AMR
HSUPA 1.44Mbps		Huawei E-270	Pass	
Dynamic link optimization 384 -> 128 -> 64		Huawei E-270	Pass	
Soak test		Samsung Z630	Pass	10 voice calls followed by 10 HSDPA calls
IuB Link Failure		Samsung Z630	Pass	1.6 Mbps

Table 55. Layer 3 transport solution regression results

Throughput testing

Considering the available bandwidth offered by IuB over IP solution, it was also tested the feature *RAN1305 14.4 Mbps per cell*. In order to reach this DL throughput, special HSDPA CAT9 (Nokia 6700) and CAT10 (Icera 505 dongle) UEs were tested.

Just for reference, the different HSDPA categories are outlined in the table below. From this it can be seen that the overall raw data rate and hence the category is determined by a number of elements including the maximum number of HS-DSCH codes, TTI, block size, etc.

HS-DSCH CATEGORY	MAX NO OF HS-DSCH CODES	MIN INTER-TTI INTERVAL	HSDPA DATA RATE (MBPS)	TRANSPORT BLOCK SIZE	MAX NO SOFT BITS	SUPPORTED MOD SCHEMES
1	5	3	3.6	7298	19200	16QAM, QPSK
2	5	3	3.6	7298	28800	16QAM, QPSK
3	5	2	3.6	7298	28800	16QAM, QPSK
4	5	2	3.6	7298	38400	16QAM, QPSK
5	5	1	3.6	7298	57600	16QAM, QPSK
6	5	1	3.6	7298	67200	16QAM, QPSK
7	10	1	7.2	14411	115200	16QAM, QPSK
8	10	1	7.2	14411	134400	16QAM, QPSK
9	15	1	10.1	20251	172800	16QAM, QPSK

HS-DSCH CATEGORY	MAX NO OF HS-DSCH CODES	MIN INTER-TTI INTERVAL	HSDPA DATA RATE (MBPS)	TRANSPORT BLOCK SIZE	MAX NO SOFT BITS	SUPPORTED MOD SCHEMES
10	15	1	14	27952	172800	16QAM, QPSK
11	5	2	1.8	3630	14400	QPSK
12	5	1	1.8	3630	28800	QPSK

Table 56. UE Radio Access Capabilities according to 3GPP TS 25.306. As it can be see the maximum data rate under ideal conditions for CAT9 UE will be 10.1 Mbps and 14 Mbps for CAT10 UE. Maximum Number of HS-DSCH codes refers to the number of multiplexed codes on the high-speed physical downlink shared channel (HS-PDSCH) that receive data / Minimum Transmission Time Interval (TTI) is the time interval allocated to the mobile terminal for receiving data. There is a balance between short TTI for providing adaptation while keeping the overhead to a minimum / The maximum buffer size for hybrid automatic repeat request (HARQ) is the maximum number of bits in the receive buffer after demodulation / Categories 1-10 support 16QAM as well as QPSK. Categories 11-12 only support QPSK.

Additionally, two scenarios have been tested for each UE category: HSUPA enabled/disabled. The aim is to verify whether a 384 Kbps UL return channel provides the sufficient bandwidth to support a HSDPA throughput over 10 Mbps.

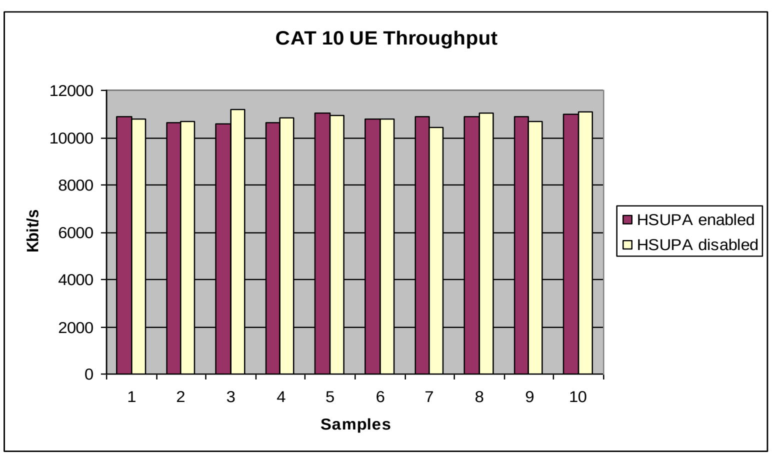


Figure 117. HSDPA CAT 10 UE throughput results in Layer 3 transport solution

CAT 10 UE Throughput (Kbit/s)		
Sample	**HSUPA Enabled**	**HSUPA Disabled**
1	10868.08	10779.76
2	10650.24	10693.04
3	10578.24	11179.44
4	10641.76	10832.64
5	11039.92	10957.68
6	10784.24	10801.92
7	10881.52	10432.72
8	10868.08	11021.44
9	10881.52	10658.96
10	11012.4	11104.64
Average	**10820.6**	**10846.2**

Table 57. HSDPA CAT10 UE throughput results achieved with 14.4 Mbps feature enabled in Layer 3 transport solution. There is no impact in enabling / disabling HSUPA for ICERA dongle. Even though the test was performed under ideal radio conditions, chipset limitations lead to lower performance than expected. In addition, protocol overheads should be considered since 14.4 Mbps refer to the maximum theoretical throughput achieved in the physical layer.

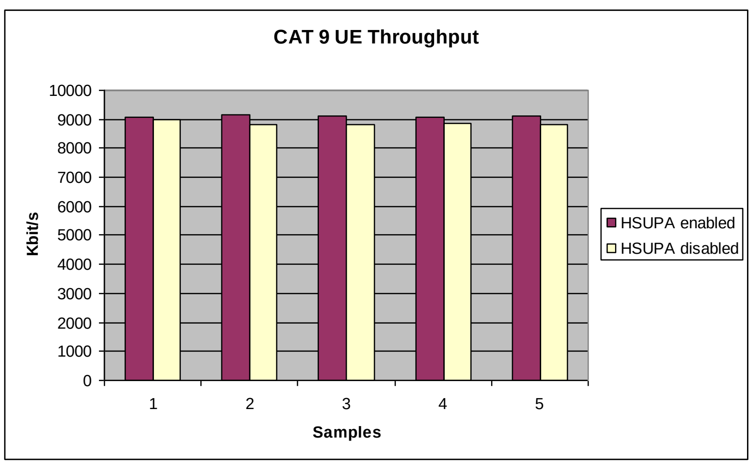


Figure 118 HSDPA CAT 9 UE throughput results in Layer 3 transport solution

CAT 9 UE Throughput (Kbit/s)		
Sample	**HSUPA Enabled**	**HSUPA Disabled**
1	9089,44	8988,8
2	9174	8839,04
3	9115,44	8833,36
4	9091,36	8842,88
5	9097,36	8818,32
Average	**9114**	**8.864**

Table 58. HSDPA CAT9 UE throughput results achieved with 14.4 Mbps feature enabled in Layer 3 transport solution. In this case there was a slight impact when HSUPA was enabled (implying higher bandwidth for the UL return channel during HSDPA download)

Additional testing: BFD mechanism and IuB Transport QoS

Once it has been tested the performance achieved with IuB over IP solution, it is also interesting to verify the implementation and behavior of two new system robustness oriented mechanisms which come along with the All IP solution. These are:

- ***Bidirectional Forwarding Detection*** feature, already introduced at the beginning of this chapter.
- ***IuB Transport QoS feature***, oriented to prioritize different kinds of traffic, considering Differentiated Services Code Point (DSCP) functionality associated with IP protocol, in the event of TX congestion.

4.3.4 BFD Testing

RNC configuration

- Configuration of BFD profile 1. (Transmit and Received intervals are set to 1000 ms and the detection multiplier to 5. The idea is to define the same values in the Node B, so BFD will trigger an alarm if no BFD control packet is received within 5 x 1000 ms = 5000 ms on either the RNC or Node B side).

  ZYGR:C:PROF=1,RXINT=1000,TXINT=1000,DMULT=5;

- Configuration of BFD session between NP2GE card (IFGE0) and Node B transport interface:

  ZYGS:C:NPGE,1,172.25.73.209,172.25.73.218:PROF=1,ALARM=ON;

```
   LOCAL IP    -    REMOTE IP   -  PROFILE_ID - ALARM - BFD STATE - SESSION ID
-------------------------------------------------------------------------------
  172.25.73.209   172.25.73.218     1           ON       ENABLE           1
```

- Setting BFD Administrative state to up: (MODE=0 removes ADMIN-DOWN mode)

  ZYGS:S:NPGE,1,1:PROF=1,ALARM=ON,MODE=0;

NODE B configuration

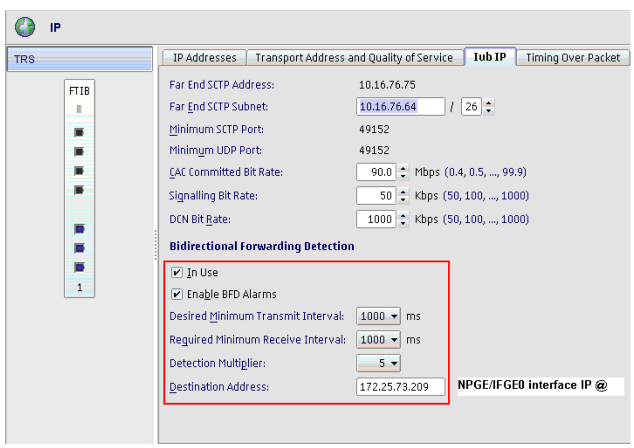


Figure 119. BFD settings in Node B. Note that the same BFD protocol parameters used on RNC side have been defined here.

Test Results

Firs to all, it is verified the correct behavior of the BFD session according to our test settings. In the following Nethawk analyzer capture of the IuB under test, it can be seen that BFD control packets are sent over UDP protocol as expected and the packet transmission cadence is 1000 ms.

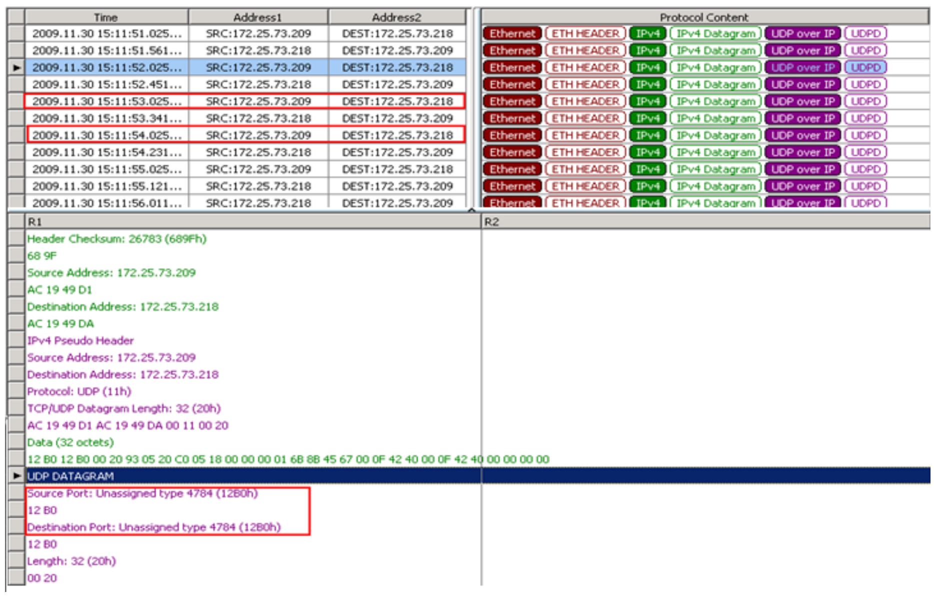


Figure 120. BFD is sent from/to RNC/NODE B every 1000 ms. BFD is sent on top of UDP and the source/destination port assigned is 4784, as expected.

Additionally, the following screenshot show the alarms triggered by an IuB link failure in Node B (which can be triggered by physically removing the Ethernet cable from the TX board):

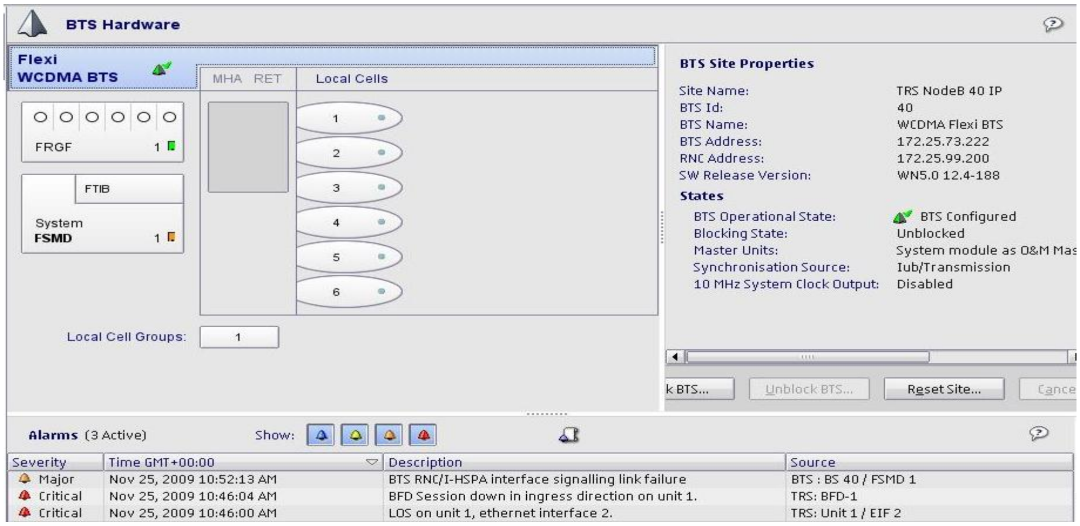


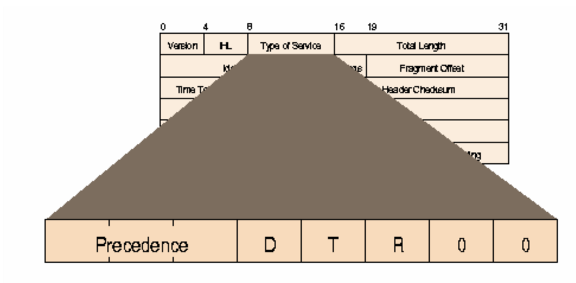
Figure 121. "BFD Session down in ingress direction on unit 1"alarm is triggered together with "LOS on unit 1, Ethernet interface 2". These alarms are cleared within 10 seconds after IuB link recovery.

The alarm can be also witnessed in RNC side by using ZAAP MML command. It shows the correlated alarm in NPGE card:

```
(24705) RNC02           1A004-00-15     EQUIPM       2009-11-25 10:46:04.53

        *   ALARM   NPGE-1

            2878    BFD LINK FAILURE

            09B0H   NPGE-1

            01 NPGE 1d 172.25.73.218 172.25.73.209 00 00 00000001 6B8B4567
```

4.3.5 IuB Transport QoS testing

With the arrival of full IP based protocol stack in the transport side, further QoS mechanisms can be implemented in the RAN in order to ensure system robustness under TX congested scenarios. IP QoS differentiation is based on the information contained in Type of Service field of an IPv4 packet header. Traffic classification will be made according a three-way trade off between low delay, high reliability and high throughput.



Bits	Content
0 to 2	Precedence
3	0 = Normal Delay, 1 = Low Delay
4	0 = Normal Throughput, 1 = High Throughput.
5	0 = Normal Reliability, 1 = High Reliability
6 and 7	Reserved for Future Use

Precedence Field			
Bits	Meaning	Bits	Meaning
111	Network Control	011	Flash
110	Internet Work Control	010	Immediate
101	CRITIC / ECP	001	Priority
100	Flash Override	000	Routine

Figure 122. Type of Service field on IPv4 protocol header.

The use of the Delay, Throughput and Reliability indications may increase the cost of the service. In many networks better performance for one of these parameters is coupled with worse performance of another. Except for very unusual cases, at most two of these three indicators should be set.

The Network Control precedence designation is intended to be used within a network only. The actual use and control of that designation is up to each network. The Internetwork Control designation is intended for use by gateway control originators only. If the actual use of these precedence designations is of concern to a particular network, it is the responsibility of that network to control the access to, and use of, those precedence designations.

Prior to the verification of results, the following table shows the mapping between DSCP decimal and Type of Service (ToS) hexadecimal values. In fact, network traces obtained with Nethawk analyzer will show ToS values, whereas DSCP values are used to configure QoS tables in the Node B.

ToS to DSCP mapping

ToS (dec)	ToS (hex)	ToS (bin)	ToS Precedence (bin)	ToS Precedence (dec)	ToS Precedence Name	ToS Delay Flag	ToS Throghput Flag	ToS Reliability FLag	DSCP (bin)	DSCP (hex)	DSCP (dec)	DSCP Class
0	0x00	00000000	000	0	Routine	0	0	0	000000	0x00	0	none
32	0x20	00100000	001	1	Priority	0	0	0	001000	0x08	8	cs1
40	0x28	00101000	001	1	Priority	0	1	0	001010	0x0A	10	af11
48	0x30	00110000	001	1	Priority	1	0	0	001100	0x0C	12	af12
56	0x38	00111000	001	1	Priority	1	1	0	001110	0x0E	14	af13
64	0x40	01000000	010	2	Immidiate	0	0	0	010000	0x10	16	cs2
72	0x48	01001000	010	2	Immidiate	0	1	0	010010	0x12	18	af21
80	0x50	01010000	010	2	Immidiate	1	0	0	010100	0x14	20	af22
88	0x58	01011000	010	2	Immidiate	1	1	0	010110	0x16	22	af23
96	0x60	01100000	011	3	Flash	0	0	0	011000	0x18	24	cs3
104	0x68	01101000	011	3	Flash	0	1	0	011010	0x1A	26	af31
112	0x70	01110000	011	3	Flash	1	0	0	011100	0x1C	28	af32
120	0x78	01111000	011	3	Flash	1	1	0	011110	0x1E	30	af33
128	0x80	10000000	100	4	FlashOverride	0	0	0	100000	0x20	32	cs4
136	0x88	10001000	100	4	FlashOverride	0	1	0	100010	0x22	34	af41
144	0x90	10010000	100	4	FlashOverride	1	0	0	100100	0x34	36	af42
152	0x98	10011000	100	4	FlashOverride	1	1	0	100110	0x26	38	af43
160	0xA0	10100000	101	5	Critical	0	0	0	101000	0x28	40	cs5
184	0xB8	10111000	101	5	Critical	1	1	0	101110	0x2E	46	ef
192	0xC0	11000000	110	6	InterNetworkControl	0	0	0	110000	0x30	48	cs6
224	0xE0	11100000	111	7	NetworkControl	0	0	0	111000	0x38	56	cs7

Table 59. ToS to DSCP mapping. Ordered from lower to higher priority: DSCP = 0 (Best Effort) / DSCP = 10..14 (Assured Forwarding 1) / DSCP = 18…22 (Assured Forwarding 2) / DSCP = 26…30 (Assured Forwarding 3) / DSCP = 34…38 (Assured Forwarding 4) / DSCP = 46 (Expedited Forwarding).

The validation executed for this feature is only related with the object configuration and traffic DSCP mapping verification. At the time of the test there was no equipment available to reproduce congestion in a 100 Mbps dedicated TX path.

Different traffic profiles will be tested herein: AMR voice call, non-RT R99 data call, HSDPA call with/without HSUPA enabled and HSUPA call.

RNC configuration

- Creation of a Traffic Queue Management entity (TQM id =1) object in RNC object browser with the following QoS priority mappings. Note that the higher the criticality of the traffic, the higher the DSCP mapping. Usually, signaling and voice is mapped to EF (DSCP=46), whereas low priority HSPA traffic is mapped to BE (DSCP = 0).

QosPriToDSCP	DSCP
CSTrafficToDSCP	46
PchFachRachToDSCP	46
SRBToDSCP	46
DCHQoSPri15…Pri14ToDSCP	46
DCHQoSPri13…Pri0ToDSCP	34
HSPAQoSPri15…14ToDSCP	46
HSPAQoSPri13ToDSCP	26
HSPAQoSPri12ToDSCP	18
HSPAQoSPri11…5ToDSCP	10
HSPAQoSPri4…Pri0ToDSCP	0

Table 60. QoS priority mapping for DSCP.

- Association of configured TQM object with Node B under test.

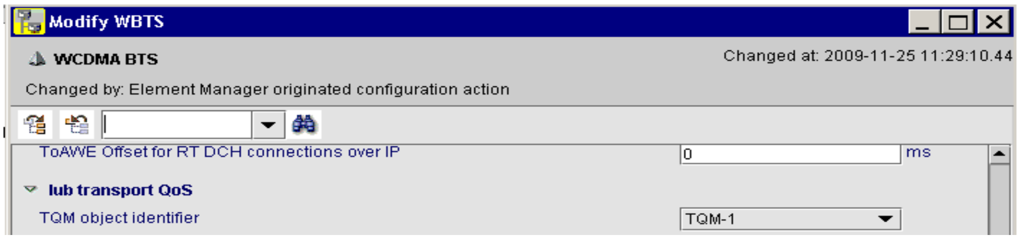


Figure 123. Node B parameter "TQM object identifier".

- Creation of QoS profile in RNC:

  - Verification of DSCP to Per Hop Behavior (PHB) mapping profile (Profile ID = 0). During the test, only DSCP=0 services will be used for Best Effort traffic, so it is not required to modify the mapping in the RNC.

ZQ8L;

```
LOADING PROGRAM VERSION 2.24-0

INTERROGATING DSCP to PHB MAPPING PROFILE(S)

PROFILE ID = 0 ,PROFILE NAME = DEFAULT;

EF  = 46 ;

AF1 = 10 , 12 , 14 ;

AF2 = 18 , 20 , 22 ;

AF3 = 26 , 28 , 30 ;

AF4 = 34 , 36 , 38 ;

BE  =  00 , 01 , 02 , 03 , 04 , 05 , 06 , 07 , 08 , 09 , 11

        13 , 15 , 16 , 17 , 19 , 21 , 23 , 24 , 25 , 27 , 29

        31 , 32 , 33 , 35 , 37 , 39 , 40 , 41 , 42 , 43 , 44

        45 , 47 , 48 , 49 , 50 , 51 , 52 , 53 , 54 , 55 , 56

        57 , 58 , 59 , 60 , 61 , 62 , 63 ;
```

- Enabling QoS profile to interface IFGE0. Note that profile ID=0 is used.

ZQ8S:NPGE,1:IFGE0:ENA:ID1=0::;

```
CONFIGURED IP INTERFACE QOS CONFIGURATION

                  DSPM DSPM                     PHB  PHB
          IF      PROF PROF                     PROF PROF                     QOS
UNIT      NAME    ID   NAME                     ID   NAME                     STATE
--------- ---------- ---- -------------------- ---- -------------------- -----
NPGE-1    IFGE0   0    DEFAULT                  0    DEFAULT                  ENA

COMMAND EXECUTED
```

Tellabs 8630 configuration

- End to End QoS parameterization must be consistent; hence all the transmission equipment configured in the RAN must have implemented the same QoS policy mapping. In the scenario under test, the following CLI printout shows that the same policies are applied both in the ingress and egress TX ports:

TELLABS#show qos defaults

Ingress Queue	Egress Queue
qos mapping ingress ip-dscp 56 qos cs7	qos mapping egress qos cs7 ip-dscp 56
qos mapping ingress ip-dscp 46 qos ef	qos mapping egress qos ef ip-dscp 46
qos mapping ingress ip-dscp 38 qos af4 drop-precedence high	qos mapping egress qos af4 drop-precedence high ip-dscp 38
qos mapping ingress ip-dscp 36 qos af4 drop-precedence medium	qos mapping egress qos af4 drop-precedence medium ip-dscp 36
qos mapping ingress ip-dscp 34 qos af4 drop-precedence low	qos mapping egress qos af4 drop-precedence low ip-dscp 34
qos mapping ingress ip-dscp 30 qos af3 drop-precedence high	qos mapping egress qos af3 drop-precedence high ip-dscp 30
qos mapping ingress ip-dscp 28 qos af3 drop-precedence medium	qos mapping egress qos af3 drop-precedence medium ip-dscp 28
qos mapping ingress ip-dscp 26 qos af3 drop-precedence low	qos mapping egress qos af3 drop-precedence low ip-dscp 26
qos mapping ingress ip-dscp 22 qos af2 drop-precedence high	qos mapping egress qos af2 drop-precedence high ip-dscp 22
qos mapping ingress ip-dscp 20 qos af2 drop-precedence medium	qos mapping egress qos af2 drop-precedence medium ip-dscp 20
qos mapping ingress ip-dscp 18 qos af2 drop-precedence low	qos mapping egress qos af2 drop-precedence low ip-dscp 18
qos mapping ingress ip-dscp 14 qos af1 drop-precedence high	qos mapping egress qos af1 drop-precedence high ip-dscp 14
qos mapping ingress ip-dscp 12 qos af1 drop-precedence medium	qos mapping egress qos af1 drop-precedence medium ip-dscp 12
qos mapping ingress ip-dscp 10 qos af1 drop-precedence low	qos mapping egress qos af1 drop-precedence low ip-dscp 10
qos mapping ingress ip-dscp 0 qos be	qos mapping egress qos be ip-dscp 0

Test Results

As mentioned before, the objective of this test is to ensure that different kind of traffic is correctly mapped to its corresponding QoS policy, according to the configuration implemented in RAN equipments as per the previous section. The following traffic types were generated ranging from more to less critical in terms of delay and packet loss: *Signaling traffic, AMR voice traffic, downlink Non-real time R99 data traffic, downlink HSDPA data traffic with UL DCH return channel, downlink HSDPA data traffic with HSUPA enabled* and *uplink HSUPA data traffic.*

The following network analyzer captures from IuB interface help to verify the correctness of QoS mapping. In order to do that, the IPv4 datagram header containing the traffic under study is analyzed: ToS field is extracted and ToS to DSCP mapping table is used to check the corresponding DSCP value.

Note that no captures are attached for the scenarios *HSDPA data traffic with HSUPA enabled* and *HSUPA data traffic* because the same QoS mapping than downlink HSDPA traffic applies.

Test case 1: Signaling traffic

For this scenario, ToS included in IPv4 datagram containing *RRC Connection Request* signaling message is verified:

```
Type of Service (B8)

    -   Precedence: CRITIC/ECP
    -   Low Delay (1)
    -   High Throughput (1)
    -   Normal Reliability (0)
```

With this information, ToS to DSCP mapping table indicates that the corresponding DSCP value is 46, matching with *Expedited Forwarding (EF)* Per Hop Behavior (PHB, noted in the table as DSCP class). This is the highest priority QoS policy configured for the test, matching with the importance of signaling traffic.

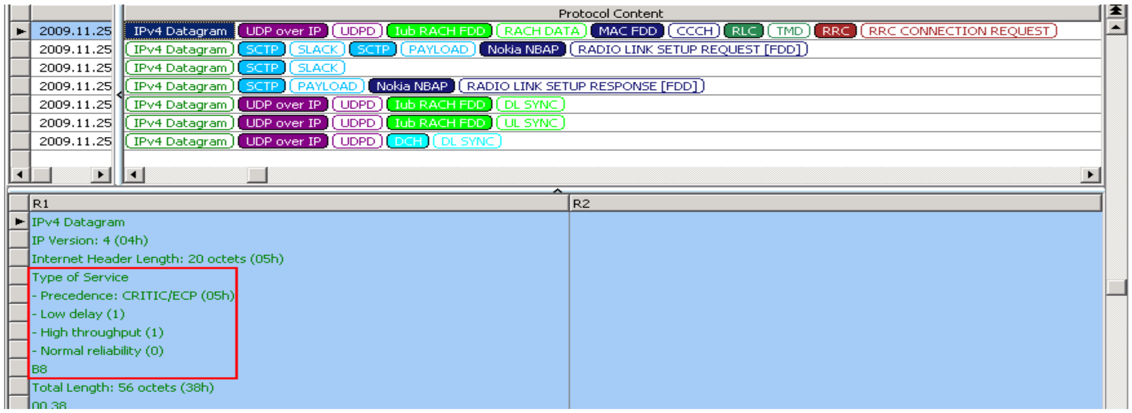


Figure 124. IPv4 datagram encapsulating RRC CONNECTION REQUEST. ToS hexadecimal value is B8 (DSCP=46 →DSCP class = EF) because UE signaling is a critical service.

Test case 2: AMR voice traffic

For this scenario, ToS included in IPv4 datagram containing *AMR voice traffic* is verified:

```
Type of Service (B8)

    -   Precedence: CRITIC/ECP
    -   Low Delay (1)
    -   High Throughput (1)
    -   Normal Reliability (0)
```

With this information, ToS to DSCP mapping table indicates that the corresponding DSCP value is 46, matching with *Expedited Forwarding (EF)* Per Hop Behavior (PHB, noted in the table as DSCP class). This is the highest priority QoS policy configured for the test, matching again with the low tolerance of voice traffic to delay and packet loss.

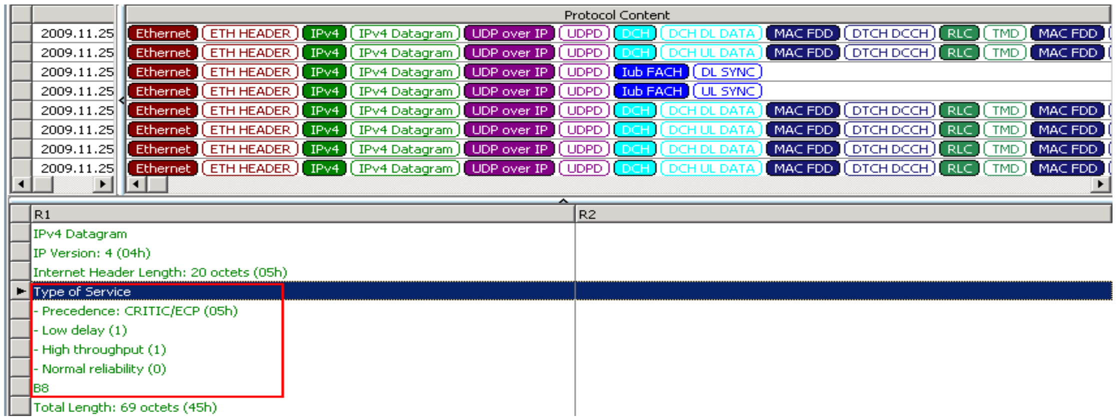


Figure 125. IPv4 datagram sent during AMR voice call containing data. ToS hexadecimal value is B8 and the precedence CRITIC/ECP. The correspondent mapping to DSCP decimal value is 46, which maps to Expedited Forwarding (EF) DSCP class.

Test case 3: Downlink Non-real time R99 data traffic

For this scenario, ToS included in IPv4 datagram containing *DL Non-Real time R99 data* is verified:

```
Type of Service (88)

    -   Precedence: Flash Override
    -   Normal Delay (minimize delay)(1)
    -   High Throughput (1)
    -   Normal Reliability (0)
```

With this information, ToS to DSCP mapping table indicates that the corresponding DSCP value is 34, matching with *Assured Forwarding 41 (AF41)* Per Hop Behavior (PHB, noted in the table as DSCP class). This is the QoS policy which was configured in the RAN for DCH traffic in this test, lower than the QoS defined for signaling and voice traffic, but higher than non-real time HSPA traffic. At the time of the test, preserving R99 data over HSPA data traffic was a common trend within operators at a first stage, where non all the users were allowed to enjoy HSPA data rates across the whole network (basically due to the early deployment stage of HSPA features and because the TX infrastructure, mostly based on legacy E1s, was not yet fit for purpose and congestion scenarios could be frequently met).

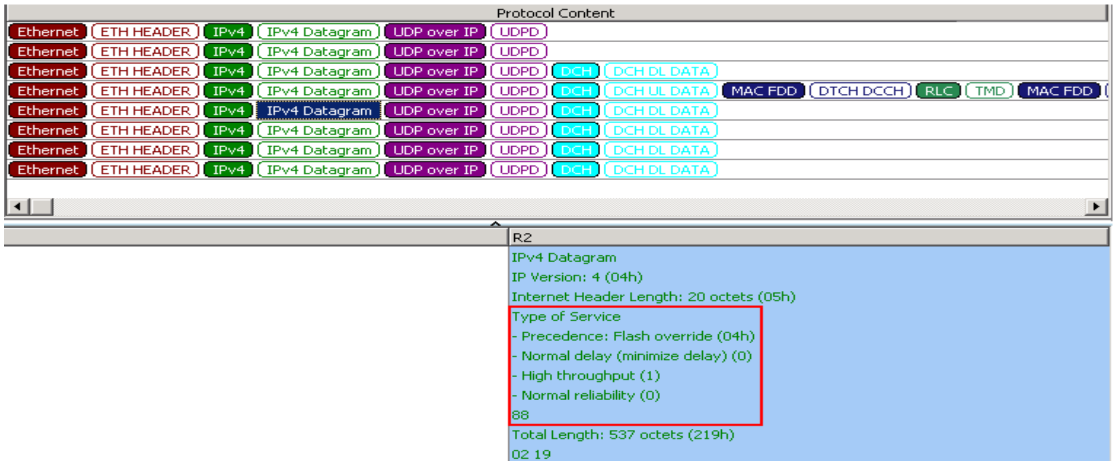


Figure 126. IPv4 datagram encapsulating non-real time R99 data. ToS hexadecimal value is 88 and the precedence is "Flash override". This value maps to DSCP decimal number 34, which corresponds to Assured Forwarding 41 (AF41) DSCP class.

Test case 4: Downlink Non-real time HSDPA data traffic with UL DCH return channel

For this scenario, first of all, ToS included in IPv4 datagram containing *DL Non-Real time HSDPA data* is verified:

```
Type of Service (00)

    -   Precedence: Flash Override
    -   Normal Delay (minimize delay)(0)
    -   High Throughput (0)
    -   Normal Reliability (0)
```

With this information, ToS to DSCP mapping table indicates that the corresponding DSCP value is 0, matching with *Best Effort (BE or none)* Per Hop Behavior (PHB, noted in the table as DSCP class). This is the QoS policy which was configured in the RAN for non-real time HSPA traffic in this test, the lowest QoS among all services.

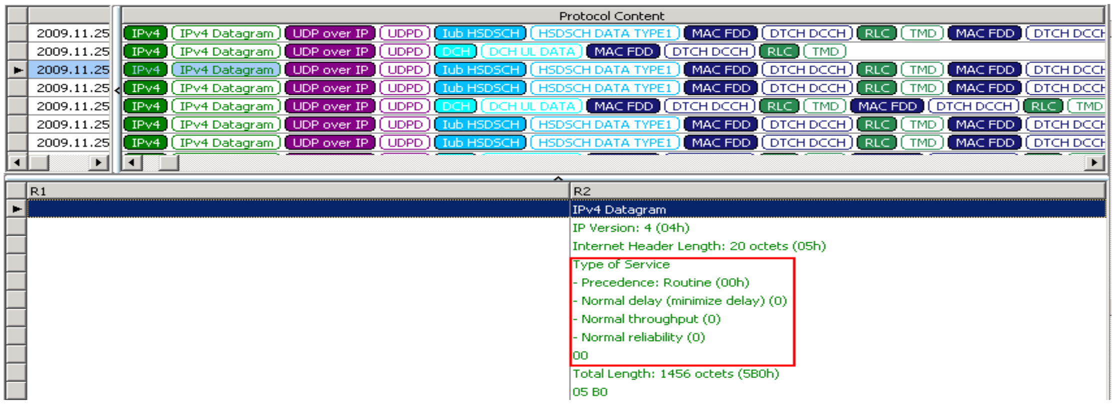


Figure 127. IPv4 datagram encapsulating HSDPA data. ToS hexadecimal value is 00 and the precedence is "Routine". This value maps to DSCP decimal number 0, which corresponds to Best Effort (BE) DSCP class.

It is verified, additionally, that the UL DCH return channel traffic (mainly containing ACKs from DL TCP communication) is mapped to the same QoS policy than DCH services in test case 3:

```
Type of Service (88)

    -   Precedence: Flash Override
    -   Normal Delay (minimize delay)(1)
    -   High Throughput (1)
    -   Normal Reliability (0)
```

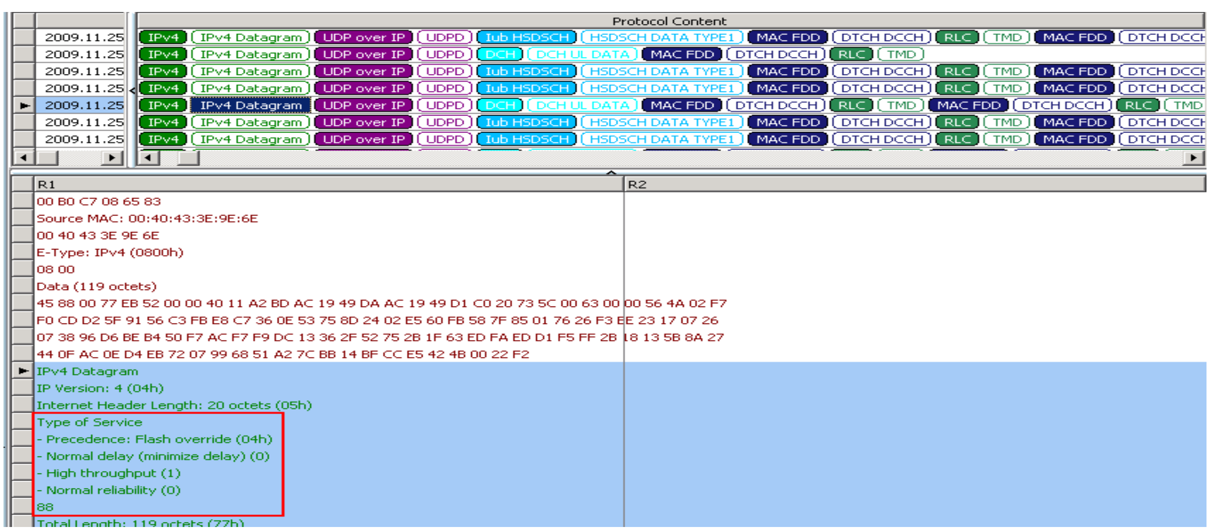


Figure 128. IPv4 datagram encapsulating HSDPA return channel (UL DCH). ToS hexadecimal value is 88 as expected (AF41 DSCP class).

Test cases 5 and 6: Downlink Non-real time HSDPA data traffic with HSUPA enabled and Uplink non-real time HSUPA data traffic

In both cases, HSxPA services were mapped to *best effort* QoS as expected. Similar observations than in test case 4 were obtained.

4.4 Test Conclusions

Validation of *IuB over IP* solution has proved that:

- Both Layer 3 and Layer 2 designs can be used to implement an IuB over IP solution in live network. Nevertheless, considering the scalability and complexity of the solution, Layer 2 will be more indicated to be used for live network deployment. Additionally, deployment of Layer 3 Point-to-point connections will lead to an inefficient use of network IP addressing. In fact, current network deployments are mainly based on Layer 2 packet microwave transmission technology (introduced in Figure 64 as part of the Long Term solution for TX backhaul), where usually a /27 IP subnet is enough to manage up to 29 Node Bs connected to the same packet microwave ring topology.

- Expected downlink throughput figures for CAT9 and CAT10 UEs can be achieved. At the time of the test, HSDPA throughput features supporting up to 14.4 Mbps where available in the software release under test. However, this solution is also future-proof to test further downlink throughput evolutions brought by the introduction of higher capacity modulations such as 64 QAM (up to 21 Mbps), new TX/RX systems like MIMO (up to 28 Mbps) and Dual Carrier HSDPA (up to 42 Mbps), which can receive simultaneous downlink data served by two different HSDPA cells.

- BFD feature can be used as the new link monitoring mechanism.

- Different network traffic (signaling, voice and data) can be applied a different QoS class by using the information in Type of Service field within the IP protocol header.

5 Conclusions and future work

5.1 Conclusions

The test methodology studied during this thesis, has highlighted the importance for the operator to implement lab validation campaigns prior to live network deployment, but also should be considered as a mandatory experience required for all engineers involved in transmission dimensioning, radio network planning and radio network optimization.

In particular, the mobility test cases herein described have provided solutions to mitigate specific 2G/3G inter-RAT mobility pitfalls, by testing features oriented to reduce cell reselection time for Release 5 and Release 6 UEs and by including the possibility of cancellation for an ongoing inter-RAT handover from 3G to 2G, preserving a better user experience as a result. On the other hand, it has also been reached the objective to successfully test a feature oriented to provide better HSDPA throughput to a given premium user in a multi-user scenario. It has been checked that if the end to end quality of service parameterization is consistent, starting from the core network and finishing by the RAN, the Node B scheduling priority could be useful for this purpose. Finally, it has been tested the evolution of IuB interface in two steps: firstly, successful results have been achieved with the implementation of Hybrid Backhaul feature. In this section, it has been introduced the concept of ATM over Ethernet, involving two major parameters, which are the concatenation factor and the packetization timer. This solution has also been tested under non-ideal conditions in terms of delay and packet loss in the IuB interface, and it can be concluded that none of the before mentioned parameters can improve the downlink throughput figures under high delay conditions, but it has been proved that a higher ATM cell concatenation factor can contribute to a better performance in the event of packet loss. Secondly, it has been presented the required steps to configure and test the evolution towards a Full IP IuB interface. The increase in transmission capacity brought by this solution scenario has allowed the downlink throughput test for 3GPP Cat 9 and Cat 10 UE and sets the pace for future high throughput demanding features.

5.2 Future work

Network system verification and performance testing is a continuous process. As new software and hardware are implemented to the 3G network, not only the new features need to be tested but also existing features and functionalities need to be verified. But the future work should be mainly focused on LTE. Even though legacy 3G and 2G networks are still being developed, it can be expected that the development of LTE technology will continue for years to come. In the field of mobility, the important areas to work will include more complex scenarios in terms of inter-RAT mobility between 2G/3G/4G, since the operators will focus on keeping the users in the coverage layer offering the best service. One interesting topic is the implementation of voice services in a network which is conceived for data. In a first stage, Circuit Switch Fallback, which leans on legacy 2G/3G networks to carry voice services, will be the first feature to test. Afterwards, it is expected to appear the first implementations of VoIP in LTE networks, the so called Voice over LTE (VoLTE). After the introduction of this feature, the main challenge will be to maintain seamless user experience whilst moving across the different RATs, since voice services are critical for the operator KPI. For that reason, performance of Single Radio Voice Call Continuity (SRVCC), which is an inter-RAT handover of an existing voice call in LTE to legacy 2G/3G networks, becomes an important issue and should be intensively tested in lab environment. In parallel, mobility towards non-3GPP standard networks, such as WLAN, will then remain as one of the major areas of investigation. This will create the so called Heterogeneous Networks (HetNets) environment, involving a mix of radio technologies and cell types working together seamlessly. Definitely, it will play an important role in creating the optimal customer experience, especially in crowded areas.

Concerning data rates which can be transmitted over a capacity expansion of the evolved backhauls studies during this thesis, future 3GPP releases, such as Release 10, introduce the called LTE-Advanced, providing user data rates of up to Gigabits per second. These challenges will imply the testing of enhanced MIMO techniques of up to 8 TX antennas in downlink and 4 TX antennas in uplink. Cell with transmission bandwidth of up to 100 MHz could be deployed by aggregating up to 5 LTE Release 8 20 MHz bandwidths.

All in all, new challenges can be expected as yet another radio access technology with increased performance demands is to come: 5G standard is expected to be included in 3GPP Release 14 and Release 15, in preparation for a commercial deployment in 2020.

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