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Transport Resource Management within UMTS Radio Network Subsystem

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ABSTRACT OF MASTER'S THESIS

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At the moment the most challenging research and development in telecommunication industry is concentrated around the third generation mobile telecommunication systems, often referred to as 3G. The specifications of 3G systems have reached the first stable releases and their commercial deployment is on the way in Japan and Europe. The Universal Mobile Telecommunications System (UMTS) is one of the 3G systems.

This thesis gives an overview of the UMTS system and functionality of its network elements. The main attention is paid to the UMTS Terrestrial Radio Access Network (UTRAN) and more specifically to the Radio Network Subsystem (RNS) constituted by Radio Network Controller (RNC) and a set of Node Bs belonging to it. The RNC and Node Bs are connected via the open interface commonly referred to as an Iub interface. The Iub interface provides the RNC with the means to control Node B via exchanging signalling messages and enables the efficient and reliable transmission of user traffic within RNS. For that it owns the transport resources that must be thoroughly managed. The transport resource management over the Iub interface is the main topic of this thesis.

The transport network architecture is given and explained. Also the set of protocols as well as functional units running at the Iub interface and contributing to the transport resource management are presented and described in details. The main attention is paid to the application protocols both in Transport Network and Radio Network layers of the interface and interaction between them. These protocols are Node B Application Part (NBAP) and Access Link Control Application Part (ALCAP).

The implementation of the NBAP prototype and Node B Manager functional unit is presented as a practical part of this thesis

Keywords: UMTS, 3G, Iub interface, transport resource management, protocol, NBAP, Node B Manager, ALCAP

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Tällä hetkellä haastavin telekommunikaatioteollisuuden tutkimus – ja kehitystoiminta on keskittynyt kolmannen sukupolven matkapuhelinjärjestelmien ympärille. Järjestelmien standardointityössä on saatu aikaiseksi ensimmäiset vakaat spesifikaatioversiot ja kaupallista toimintaa ollaan parhaillaan aloittelemassa Japanissa ja Euroopassa. Eräs kolmannen sukupolven järjestelmistä on UMTS (Universal Mobile Telecommunications System).

Tämä diplomityö antaa yleiskuvan UMTS järjestelmästä ja sen eri verkkoelementtien toiminnallisuuksista. Päähuomio on kiinnitetty radioverkkojärjestelmään (UMTS Terrestrial Radio Access Network) ja erityisesti sen radioaliverkkojärjestelmään (Radio Network Subsystem), joka koostuu radioverkonohjaimesta (Radio Network Controller) ja joukosta siihen kuuluvia tukiasemia (Node B). Radioverkonohjain ja tukiasemat on yhdistetty avoimen rajapinnan kautta jota kutsutaan Iub -rajapinnaksi. Rajapinta tarjoaa radioverkonohjaimelle mahdollisuuden kontrolloida tukiasemia signalointiviestien avulla ja mahdollistaa tehokkaan ja luotettavan käyttäjätiedon siirron radioaliverkkojärjestelmän sisällä. Tämän diplomityön pääasiallinen sisältö on siirtoresurssien hallinta Iub -rajapinnan ylitse.

Työssä esitellään ja selitetään siirtoverkon arkkitehtuuri. Myös kaikki Iub:ssä sijaitsevat protokollat ja toiminnalliset yksiköt jotka vaikuttavat siirtoresurssien hallintaan esitellään ja kuvataan yksityiskohtaisesti. Päähuomio on kiinnitetty sovellusprotokolliin sekä rajapinnan siirtoverkko- että radioverkkokerroksella sekä näiden protokollien väliseen vuorovaikutukseen. Kyseiset protokollat ovat Node B Application Part (NBAP) ja Access Link Control Application Part (ALCAP).

Työn toteutusosassa käydään lävitse NBAP –protokollan prototyypin ja Node B Manager –toiminnallisen yksikön prototyypin implementaatio.

Avainsanat: UMTS, 3G, Iub interface, transport resource management, protocol, NBAP, Node B Manager, ALCAP

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Also thanks to my study colleagues for joyous and encouraging study in Lappeenranta.

Helsinki, 22nd of April, 2002

Andrei Zimenkov

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ABBREVIATIONS

2G	The Second Generation Mobile Communication Systems
3G	The Third Generation Mobile Communication Systems
3GPP	3rd Generation Partnership Project
AAL2	ATM Adaptation Layer 2
AAL5	ATM Adaptation Layer 5
AICH	Acquisition Indication Channel
ALCAP	Access Link Control Application Part
ARIB	Association for Radio Industry and Business
ANSI	American National Standards Institute
ASN.1	Abstract Syntax Notation One
ATM	Asynchronous Transfer Mode
AUC	Authentication Center
BCH	Broadcast Channel
BER	Bit Error Rate
BS	Base Station
BSS	Base Station Subsystem
CASE	Computer Aided Software Engineering
CASN	Compiler for ASN.1
CC	Call Control
CDMA	Code Division Multiple Access
CM	Connection Management
CN	Core Network
CPCH	Common Packet Channel
CRNC	Controlling RNC
CS	Circuit-Switched
CVOPS	C-based Virtual Operating System
DCH	Dedicated Channel
DRNC	Drift RNC
DL	Downlink
DPCCH	Dedicated Physical Control Channel
DPDCH	Dedicated Physical Data Channel
DS-CDMA	Direct Sequence Code Division Multiple Access
DSCH	Downlink Shared Channel
FACH	Forward Access Channel
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FER	Frame Error Rate
FH-CDMA	Frequency Hopping Code Division Multiple Access
FP	Frame Protocols
EIR	Equipment Identity Register
EP	Elementary procedure

ETSI	European Telecommunication Standards Institute
GGSN	Gateway GPRS Support Node
GMSC	Gateway Mobile Services Switching Center
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HLR	Home Location Register
ID	Identifier
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISO	International Standards Organisation
ITU	International Telecommunication Union
ITU-T	Telecommunication Standardisation Sector of ITU
MAC	Medium Access Control
MC-CDMA	Multi Carrie Code Division Multiple Access
ME	Mobile Equipment
MM	Mobility Management
MSC	Mobile Services Switching Center
MSC	Message Sequence Chart
NBAP	Node B Application Part
NSS	Network and Switching Subsystem
O&M	Operation and Maintenance
OSI	Open Systems Interconnection
PCCPCH	Primary Common Control Physical Channel
PCH	Paging Channel
PCPCH	Physical Common Packet Channel
PDU	Protocol Data Unit
PER	Packet Encoding Rules
PID	Process Identifier
PLMN	Public Land Mobile Network
PDSCH	Physical Downlink Shared Channel
PRACH	Physical Random Access Channel
PS	Packet-Switched
PSTN	Public Switched Telephone Network
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAB	Radio Access Bearer
RACH	Random Access Channel
RAN	Radio Access Network
RANAP	Radio Access Network Application Part
RF	Radio Frequency
RLC	Radio Link Control
RNC	Radio Network Controller
RNS	Radio Network Subsystem

RNSAP	Radio Network Subsystem Application Part
RRC	Radio Resource Control
RSM	Radio subsystem management
RTS	Run-time system
SCCP	Signalling Connection Control Part
SCCPCH	Secondary Common Control Physical Channel
SCH	Synchronisation Channel
SDL	Specification and Description Language
SDT	SDL Design Tool
SF	Spreading Factor
SGSN	Serving GPRS Support Node
SIR	Signal-to-Interference Ratio
SM	Session Management
SMS	Short Message Service
SRNC	Serving Radio Network Controller
SS7	Signalling System Number 7
SSCF	Service Specific Co-ordination Function
SSCOP	Service Specific Connection Oriented Protocol
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TRM	Transport Resource Management
TTP	Traffic Termination Point
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UNI	User Network Interface
USIM	UMTS Subscriber Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
WCDMA	Wideband Code Division Multiple Access

INTRODUCTION

During last two decades on the background of booming growth in telecommunication industry we have witnessed of fast development of cellular networks from introduction of 1st generation systems through deep penetration of 2nd generation systems in social life all over the world, towards their smooth evolution to the global 3rd generation systems bringing new range of services and bright shiny perspectives, from mobile telephony as a mean of communication between people to the "Information Society" concept where mobile communications in tight convergence with Internet and multimedia is viewed as an integral part of business and everyday life.

The 2nd generation mobile systems are those that are currently most widely used all over the world. One of their representative is the GSM (Global System for Mobile communications), which is nowadays deployed worldwide. But was originally standardized by the ETSI (European Telecommunications Standards Institute) only for European perspective. In some parts of the world the other standards specified by the local standardization bodies and therefore not compartible with GSM are also used. This became one of the shortcoming of the 2nd generation mobile systems that they cannot be used globally. Another demerit of the GSM-like systems is the inability to support high and variable data rates. Initially the 2nd generation systems were inteded to provide mainly low bit rate services such as voice transmissions. But current trends are such that there is a continuously growing need for convergence between Internet and multimedia technologies and mobile telephony. Current radio and transport technologies utilized in existing 2nd generation mobile sysems, and GSM in particular, cannot meet any longer rapidly growing requirements imposed on services to be provided. The intensive research in that area has led to creation of new family of standards referred to as a 3rd generation (3G) mobile telecommunication systems.

As the successors of the 2nd generation systems the 3G systems are intended to eliminate the shortcomings of their predecessors. First of all this means that the 3G is being developed as a global family of standards, meaning that its members are compatible between each other, and all together provide the global access to the mobile communication system worldwide.

Secondly, while the mobile telephony is expected to be the dominant application in wireless networks for many years, at the same time 3G cellular networks will offer multimedia and packet-switched services, Inernet and Intranet access, entertainment and value-added services. The data rate that can be supported in 3G varies, depending on the service category. Mobile wide-area service will be provided at 64Kbit/s, slower pedestrian mode at 384 Kbit/s and stationary office settings will be supported at 2Mbit/s. All this is becoming a reality due to the introduction of a number of new technologies, which enable high transfer rates on radio interface.

The Universal Mobile Telecommunication System (UMTS) will be the one element of the 3G global network. It will be deployed worldwide mostly as an evolutionary development of GSM-like systems and due to this it has some distinctive features enabling the backward compartibility with GSM systems on the first stages of evolution.

The air interface in UMTS is based on Wideband Code Division Multiple Access (WCDMA) technology. New technology employed on radio interface naturally imposes new requirements to the radio access networks. Obviously, the radio access network, called UMTS Terrestrial Radio Access Network (UTRAN), is the most revolutionary part of the UMTS architecture, since it supports new radio technology. In addition to introduction of new interface, the UTRAN employes new transport technology. The transport within the radio access system is very important and crusial point. It must provide the support from the RAN side for the most efficient utilisation of radio resources. In other words it shall not be a bottleneck between the radio interface and core network that provides services through the radio interface to the user.

At the moment ATM is being promoted as a current choice for the radio access network transport due to its ubiquitous nature for heterogeneous traffic types, quality of service (QoS) guarantee and its widespread deployment in public networks. In addition, the International Telecommunication Union (ITU) has recently approved a new ATM Adaptation Layer type 2 (AAL2) to be used on top of the ATM to transport low bit rate, real-time traffic within the UTRAN. Together with efficient transport resource management it provides the sufficient support for the maximum effective utilization of resources on the radio path.

In this work we describe what the transport resources are as such, what protocols are involved and what transport resource management tasks they perform on the example of single interface between two UTRAN elements, WCDMA base station (called Node B in UMTS) and Radio Network Controller (RNC).

The rest of the paper is organized as follows. It consists of two parts, theoretical and practical. In theoretical part Chapter 1 gives some background information about the 3G standardization and presents detailed overview of UMTS architecture and most of all UTRAN as its part. Chapter 2 presents the structure of Iub interface, the interface between Node B and RNC, and Chapter 3 gives an overview of the protocols running at the Iub interface, and their contribution to the transport resource management. The main attention at that point is paid to the NBAP protocol. Chapter 4 represents the practical part of this thesis work. It describes the example implementation of NBAP protocol and Node B Manager unit. Chapter 5 provides conclusion of the thesis and tells some words about the future of UTRAN transport.

1. UMTS SYSTEM

1.1 The role of UMTS in 3G standardization

3G systems have been under intense research, standardization and implementation from the middle of 90s, that resulted in currently performing commercial 3G network in Japan and test networks in Europe. From its beginning standardization process was conducted by the regional standardization bodies frequently having different visions of 3G. In effort to gather all the standardization activities under one "umbrella" and produce globally applicable Technical Specifications and Technical Reports for a 3rd Generation mobile system in December 1998 the unified standardization body named 3GPP was established. 3GPP stands for 3rd Generation Partnership Project. This collaboration agreement brings together a number of telecommunications standards bodies, which are known as "Organizational Partners". The current Organizational Partners are ARIB (Association of Radio Industries and Business, Japan), CWTS (China Wireless Telecommunication Standard, China), ETSI (European Telecommunication Standard Institute, Europe), T1 (Standards Committee T1 Telecommunications, USA), TTA (Telecommunication Technology Association, Korea), and TTC (Telecommunications Technology Committee, Japan).

As far as 3GPP represents unified international standardization body it has to take into account political, industrial and commercial pressures from all the regional bodies. Mainly because of that there are three main different viewpoints on the global cellular system, adopted by 3GPP. These viewpoint and their distinctive features are shown in Table 1.1.

Variant	Radio Access	Switching	2G Basis
3G (USA)	WCDMA, EDGE, cdma2000	IS-41	IS-95, GSM1900, TDMA
3G (Europe)	WCDMA, GSM, EDGE	Advanced GSM NSS and Packet Core	GSM900/1800
3G (Japan)	WCDMA	Advanced GSM NSS and Packet Core	PDC

Table 1.1. 3G Variants and Their Building Blocks [1]

The main idea behind the globality assumes that it's possible to take any of switching systems mentioned in the table and combine it with any of radio access part to get functioning 3rd generation cellular system.

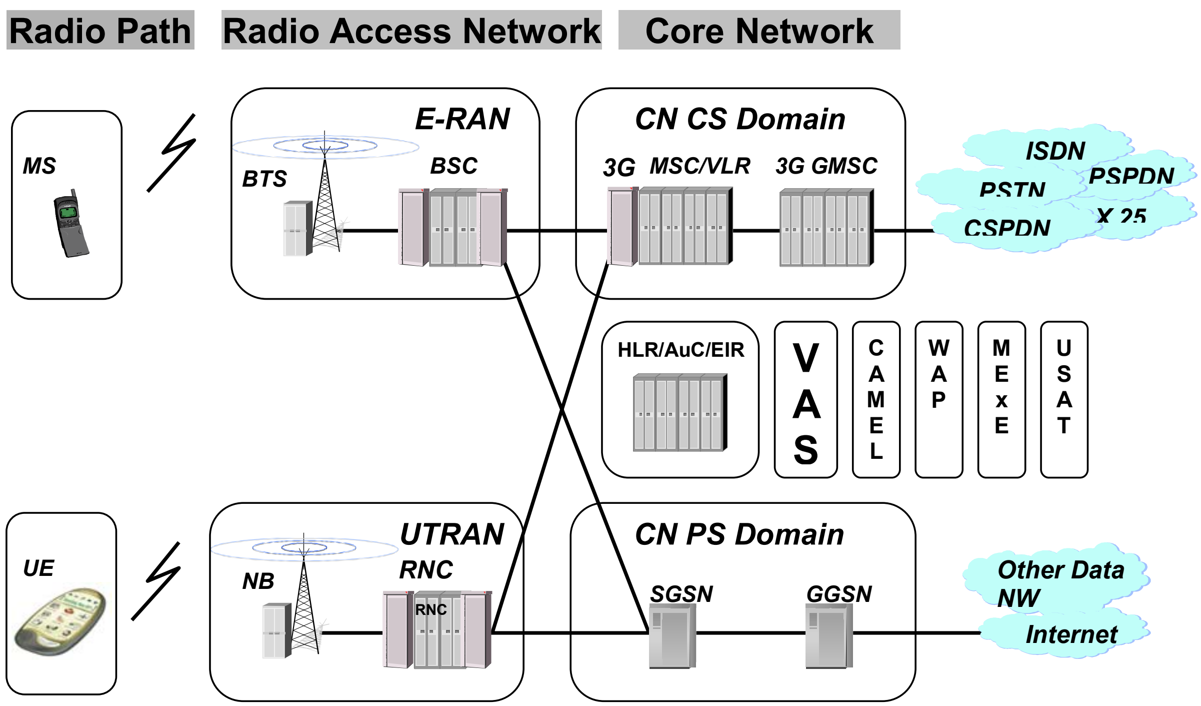
The second row in the table represents the European viewpoint on the 3G also called Universal Mobile Telecommunication System (UMTS) and this thesis concentrates mainly on that approach. Whereas the third row represents Japanese view commonly referred to as International Mobile Telecommunication – 2000 (IMT2000), it is also frequently used as a synonym for 3G [1].

The UMTS system architecture was agreed to be based on the harmonized radio interface scheme of ARIB's WCDMA proposal and ETSI's UTRA proposal. The core network at the same time was agreed to develop based on the GSM core network as evolution of GSM Network SubSustem (NSS). This point is very important for providing backward compatibility and interoperability between UMTS and old GSM networks. It allows GSM mobile operators insensibly proceed to UMTS cellular system by simply replacing Radio Access Networks (RAN) without significant changes in the core network architecture. That is why the first 3GPP release (R99) is well known as having relatively strong "GSM presence". The 3G scenario according to the 3GPP R99 is presented on the Figure 1.1.

There are basically three release phases on which the specification of 3G is divided. The release separation was done in order to provide smooth and seamless way of evolution from second-generation to third-generation systems. The first release is R99, also – to be consistent – sometimes called R3, the following two are described below.

In Release 99 (R99) 3GPP introduced new radio technology, WCDMA. WCDMA and its radio access equipment is not compatible with the GSM equipment thus it needs addition of new network elements namely Radio Network Controller and Node B. These two elements, as it will be shown later, have a wider spectrum of responsibilities and functions than their analogs in GSM. In such a way they are forming new radio access network called UMTS Terrestrial Radio Access Network (UTRAN). The transmission technology within newly formed radio access network raised a lot of discussions already during pre-standardization projects. As a final decision the ATM technology was taken as a transport technology on the top physical transmission media. This fact is worth to mention here since the essential part of the thesis will assume the ATM and its adaptation layers used as a transport layer within UTRAN.

The choice of ATM as a transport technology was caused by the certain reasons. First of all ATM has a relatively small cell size that decreases the need for information buffering. One should realize that buffering as such has a very negative impact on the QoS requirements, especially for real-time traffic, because it involves increasing of expected delays and creates static load in the buffering equipment.



Legend:

MS: Mobile Station
UE: User Equipment
BTS: Base Transceiver Station
NB: Node B
BSC: Base Station Controller
RNC: Radio Network Controller
SGSN: Serving GPRS Support Node
GGSN: Gateway GPRS Support Node
CS: Circuit Swiched

MSC: Mobile Switching Center
VLR: Visitor Location Register
HLR: Home Location Register
AuC: Authentication Center
EIR: Equipment Identity Register
E-RAN: EDGE Radio Access Network
UTRAN: UMTS Terrestrial Radio Access Network
GMSC Gateway MSC
PS: Packet Switched

Figure 1.1. 3G Network Scenario (3GPP R99) [1]

On the other hand IP was also considered as the alternative. But IPv4 has numerous disadvantages as compared to ATM, above all tied with limited addressing space and missing QoS. But that can be easily compensated for by ATM with its bit rate classes. All this has led to the solution where for packet traffic IP can be placed on the top of ATM and used for co-ordination with other networks whereas ATM takes care about QoS and routing. Due to IPv4 shortcomings IPv6 addressing was decided to be used within 3G network, but for adaptation to other networks which may not necessary use IPv6, IP backbone must have IPv4/IPv6 converters. Worth to note that in 3GPP R99 this IP penetration concerns only core network while UTRAN stays pure ATM based.

The next release was previously denoted as Release 00, but because of numerous changes it was split into two releases known as 3GPP Release 4 (R4) and 3GPP Release 5 (R5).

The main trends behind the development of Release 4 may be summarized as separation of connection, its control and service parts in CN Circuit Switched Domain and moving towards the network to be completely IP based. From the evolution of services point of view R4 makes provision for multimedia services to be provided by 3G system itself. This caused the emergence of new element in the core network, Multimedia Gateway (MGW). The 3G network scenario according to 3GPP Release 4 is presented on the Figure 1.2.

Release 4 phase is characterized by significant changes in the relationship between circuit and packet switched traffic. The user traffic is mainly packet switched, also some traditionally circuit switched services such as voice service for example, will be converted at least partially to packet switched using VoIP (Voice over IP). In order to provide methods for making VoIP calls new CN element called IMS (IP Multimedia System) is added. Additionally it will be used for IP based multimedia services.

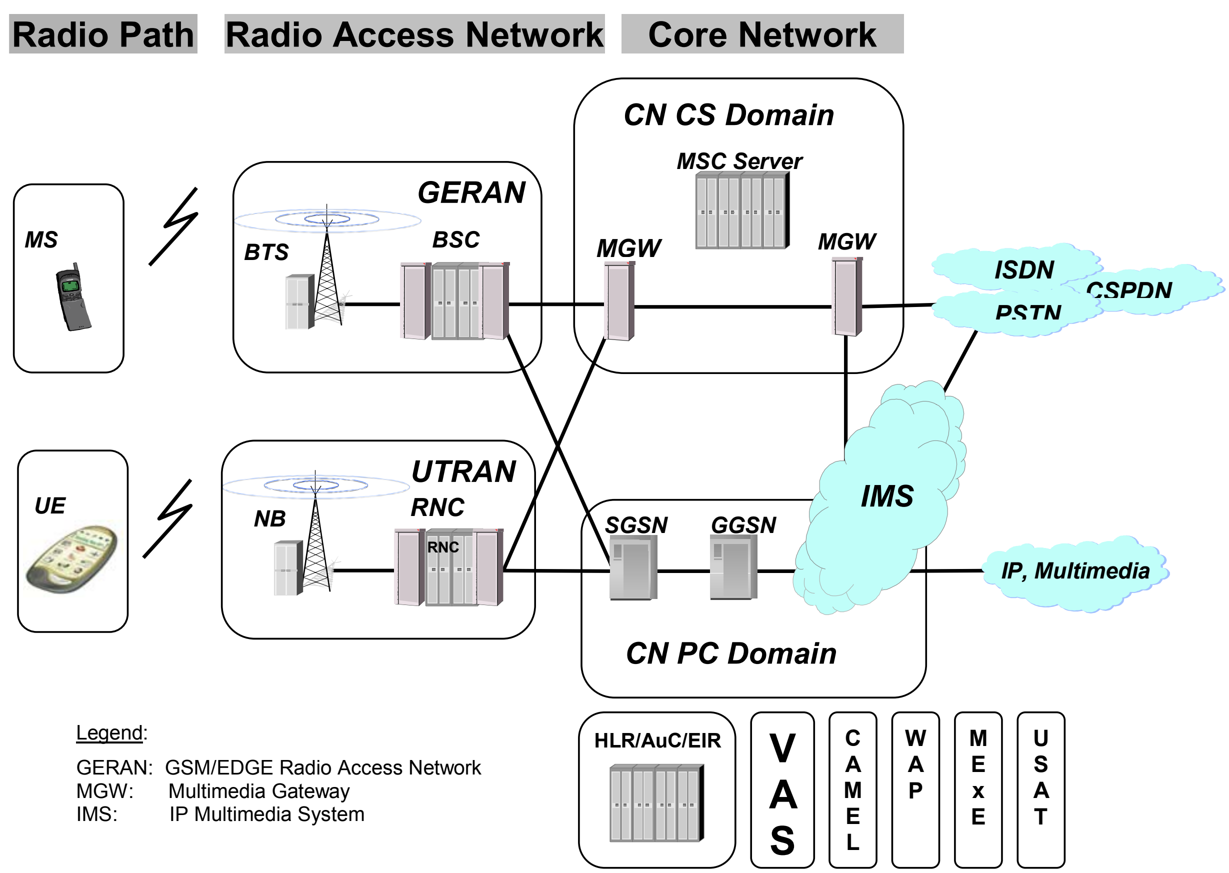


Figure 1.2. 3G Network Scenario (3GPP R4) [1]

Naturally Release 4 presuppose the using of IP within radio access network, but time schedules for IP based UTRAN are unclear, that is why specification process was extended to Release 5.

In 3GPP R5, as one can easily guess, all traffic coming from UTRAN supposed to be completely IP based, meaning that IP penetration has reached even UTRAN. Therefore there is no need for CS Domain in core network any longer and on the 3GPP R5 reference architecture, presented on Figure 1.3, it doesn't exist as such.

As a summary worth to note that from the UE point of view the network, which it communicates with, looks always the same for all development phases represented on figures 1.1, 1.2 and 1.3, whereas inside the network everything has changed. The major changes touch the transport technology as time goes by evolving from the ATM to IP. But for backward compatibility the operator reserves the opportunity to choose between the ATM, IP, or their combination. Nevertheless the current trends are such that as IP development goes by from IPv4 to IPv6, it's going to reach the ATM capabilities with lower costs and wider prevalence.

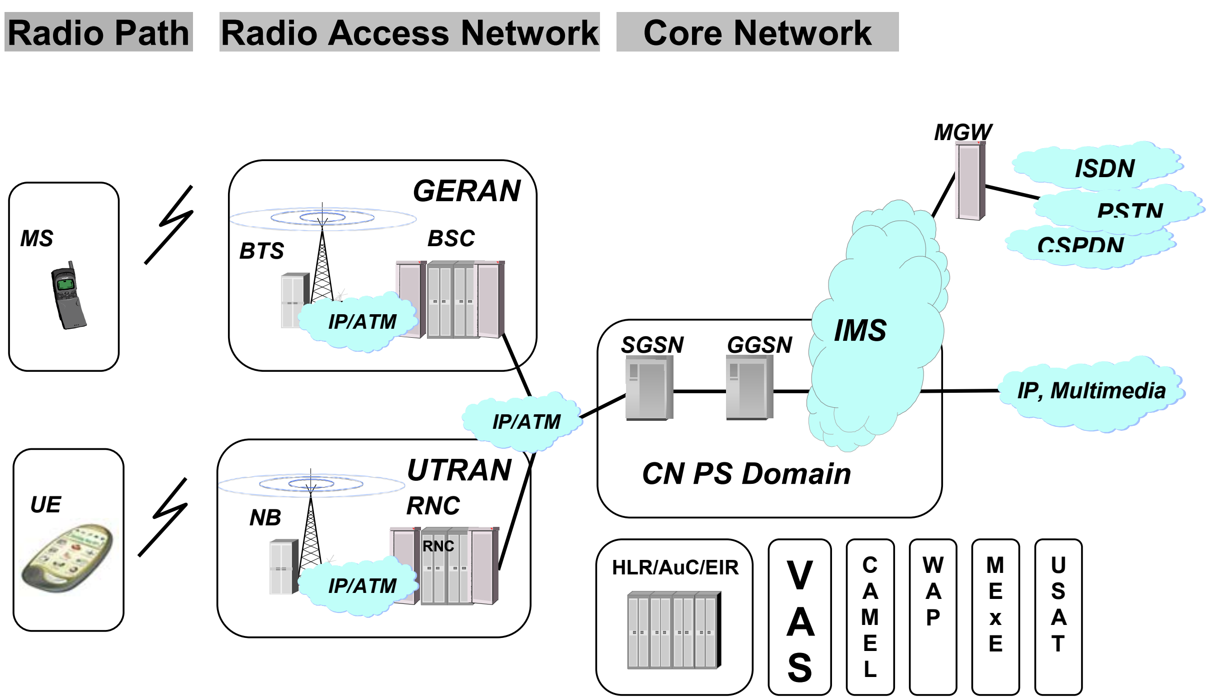


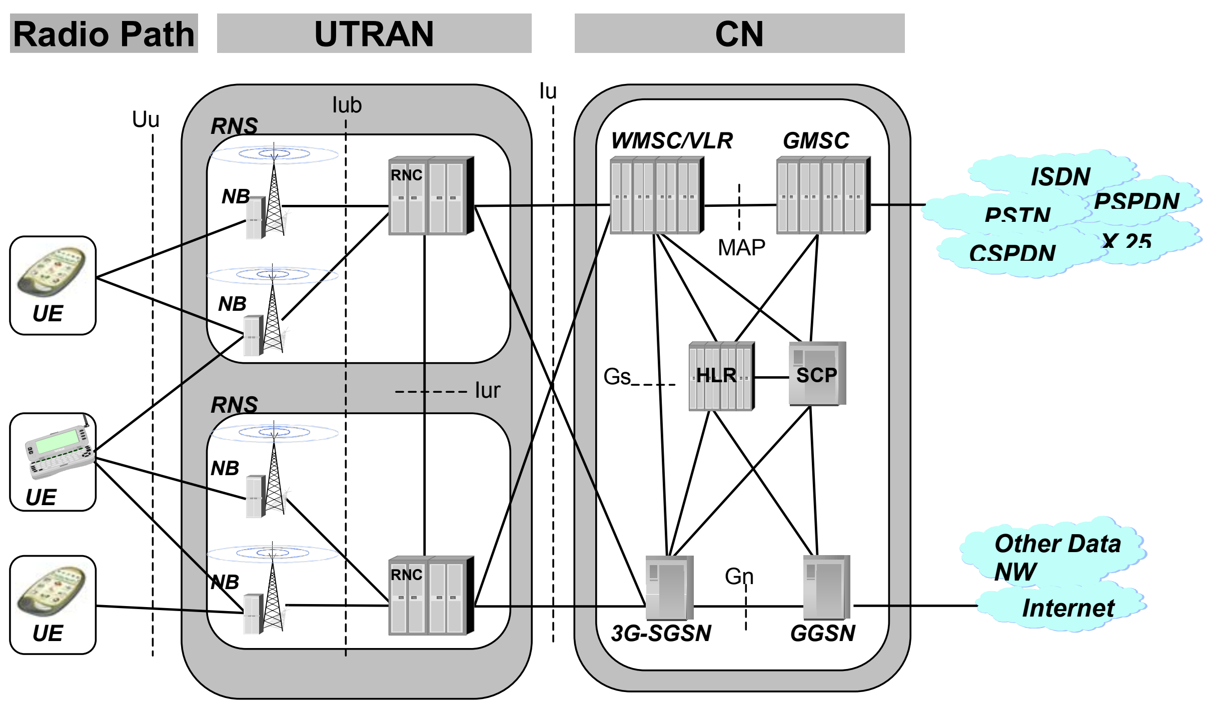
Figure 1.3. 3G Network Scenario (3GPP R5) [1]

The next chapters will concern mainly 3GPP Release 99 and partially Release 4 in part of UTRAN. The implementation part of the thesis was based on the assumption of ATM and

ATM Adaptation Layers being used as a transport technology within UTRAN, thus we will not concern IP issues, except Chapter 5 where as a conclusion the future of UTRAN transport will be discussed.

1.2 Basic concepts in UMTS

This chapter describes basic concepts and elements of UMTS. Following the Figure 1.4, where the general UMTS network architecture is presented, the UMTS system description in this chapter is subdivided into three sections: WCDMA as a radio technology, Radio Access Network and Core Network. WCDMA section gives the rough overview of the radio technology and its basic elements. The special attention is paid to the description of Radio Access Network as far as the rest of thesis is concentrated within this UMTS system part. And finally the third section in this chapter in several words describes functionality of CN and its elements.



Legend:

UE: User Equipment
NB: Node B
RNC: Radio Network Controller
3G-SGSN: 3G Serving GPRS Support Node
GGSN: Gateway GPRS Support Node
SCP: Service Control Point
WMSC: Wideband Mobile Switching Center
VLR: Visitor Location Register
HLR: Home Location Register
UTRAN: UMTS Terrestrial Radio Access Network
GMSC Gateway MSC
RNS: Radio Network Subsystem

Figure 1.4. UMTS system architecture

1.2.1 WCDMA Radio Interface

Radio interface technology has always been a subject of intensive research aiming to achieve the most efficient utilization of radio resources that are in one way or another limited. The choice of radio interface is the very crucial for overall functionality of the system since it determines the capacity of mobile radio network. The 3G systems impose high requirements on radio network capacity in order to serve greatly increased user traffic.

3GPP adopted several radio technologies for 3G mobile systems. In one way or another all the technologies support the possibility to adapt the bandwidth on demand and provide variable user data rates up to 2 Mbit/s. Some systems use Code Division Multiple Access (CDMA), whereas others are variations of Time Division Multiple Access (TDMA).

The UMTS system employs new radio technology considered as a "revolutionary" part of UMTS, Wideband Code Division Multiple Access (WCDMA). So why it is Code Division and why it is Wideband? These questions are setteled in this chapter.

For better understanding of the Code Division Multiple Access technology we should take a breif look at its alternatives, namely TDMA and FDMA (Frequency Division Multiple Access).

The idea behind the FDMA technology is rather simple. The radio spectrum is divided into fixed channels on different frequencies of a fixed bandwidth. Each user when making a call occupies its own frequency and utilises it as the sole user. Once the call is complete, the channel is released and could be given to the next user wishing to make a call. Figure 1.5 represents the channels allocation in FDMA. That kind of access control method was widely used in 1st generation systems.

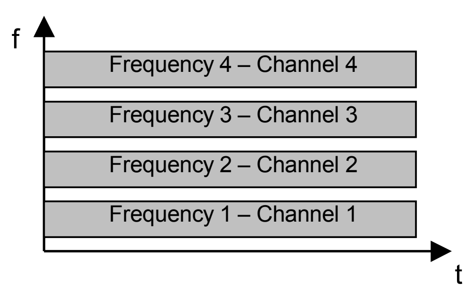


Figure 1.5. Channel allocation in FDMA

As evolution moved from 1st generation systems to 2nd, utilized radio technology changed. The systems like GSM started to use TDMA. Unlike in FDMA, TDMA allows one frequency to be used by a number of users. As depicted on Figure 1.6 each user on a frequency is separated by time, in other words each user occupies its own timeslot.

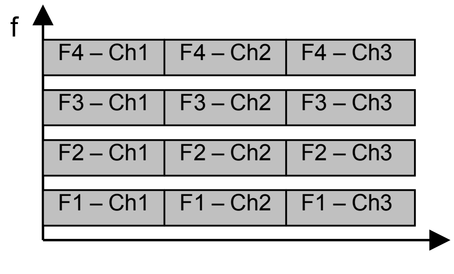


Figure 1.6. Channel allocation in TDMA&FDMA

As opposed to both FDMA and TDMA in the case of CDMA we have the solution where users share the same frequency and time, but are separated by codes. When a mobile terminal is listening to many base stations it can easily discriminate between them since each cell has its unique code. Similar, when a base station is listening to mobile stations, it can distinguish different subscribers using a unique code. In such a way applying certain code to the radio spectrum one can detect particular signal which is of interest while the rest of uninteresting signals will be considered as a background noise. Therefore each channel in WCDMA can carry several users having variable bandwidth separated by a code. This is depicted on the Figure 1.7.

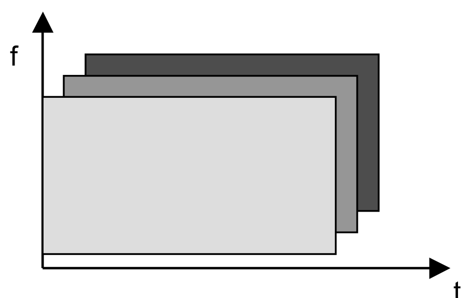


Figure 1.7 CDMA, channels occupy the same frequency and time.

The code used for separation purposes in CDMA is basically referred to as a *Spreading Code*. This code is allocated for each user based on the QoS requirements, since it implicitly determines the bit rate at which the actual user data will be transmitted. In fact the *Spreading Code* is constituted by the multiplication of two different codes, called *Channelisation Code* and *Scrambling Code*. Their use is presented in the following Table 1.2.

	Channelisation Code	Scrambling Code
Usage	**Uplink:** Separation of physical data and control channels from same terminal **Downlink**: Separation of downlink dedicated user channels	**Uplink:** Separation of terminals **Downlink:** Separation of sectors (cell)
Length	Variable (dependent on user allocation)	Fixed
Number of Codes	Depends on Spreading Factor	**Uplink:** Several million **Downlink:** 512

Table 1.2. Properties of Channelisation and Scrambling Codes [2]

The basic idea in WCDMA is that the user information bits (referred to as Symbols) are spread over the bandwidth by multiplying them with a higher bit rate pseudorandom bit stream. The bits in the pseudorandom bit steam usually referred to as *Chips* and their sequence represents *Spreading Code*. In that way in order to transmit information over the radio transmission path the sending side performs the *spreading* operation by multiplying these two signals and on the other side reciever performs the inverse operation called *despreading* by multiplying transmitted signal with the same code, as it's shown on Figure 1.8.

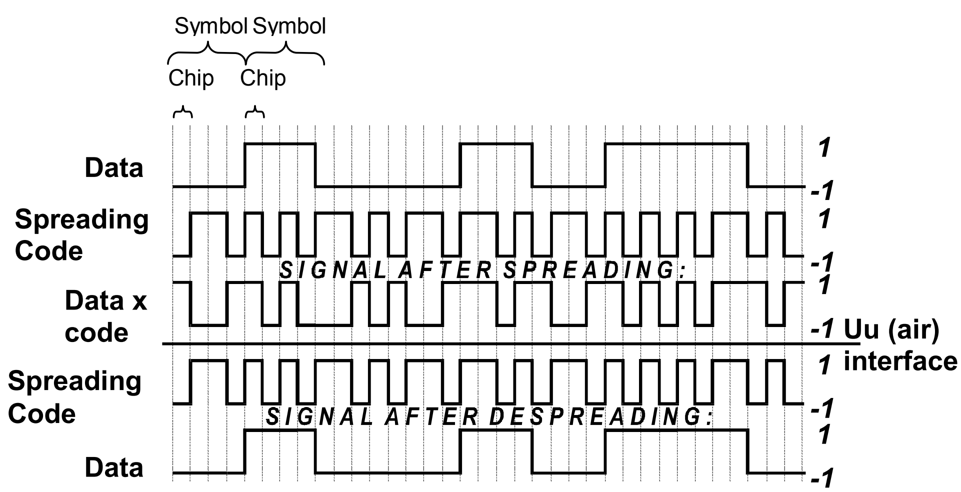


Figure 1.8. Symbols and Chips [2]

The multiplier characterising how information is spread along the chip rate is called *Spreading Factor.* In other words it defines how many chips are used per one symbol. Mathematically it can be expressed as follows:

$K = 2^k, where\, k = 0,1,2...8$

In WCDMA the code signal bit rate, i.e. chip rate, is fixed at 3.84 Mcps (million chips per second). Thus by adjusting the *Spreading Factor* we can achieve variable actual data bit rate. For example in Figure 1.8 *Spreading Factor* is equal to 4, hence the user data bit rate is 3.84/4 = 0.96 Msps (million symbols per second).

The number 3.84 besides the chip rate defines the effictive bandwidth for WCDMA (with guard bands the required bandwidth is 5 MHz). This explains why WCDMA has the prefix **Wide**. The **Wide** in **W**CDMA has derived from the fact that the European and Japanese 3G systems use a wider bandwidth than their American counterparts.

It is nesessary to note that WCDMA, specified by 3GPP, has two operational modes: FDD and TDD. They are defined as follows:

- Frequency Division Duplex (FDD): uplink (the transmission in direction from the mobile terminal towards the base station) and downlink (the transmission in direction from the base station towards the mobile terminal) use two different carriers located in a separated frequency bands.
- Time Division Duplex (TDD): uplink and downlink transmissions use the same carrier but occupy different timeslots. The information is transmitted in turn on the uplink or downlink.

All the information presented in the rest part of the thesis is based upon the UMTS-FDD implementation, as far as this is the first mode that will be implemented for UMTS, support for TDD will be added at a later stage.

There is also one issue to cover in this section that is essential for further reading in the next chapters, the introduction of UMTS channel concept. This is done in the folloing subsection.

1.2.1.1 WCDMA channels

When user wishes to make a connection to the radio access network or vice versa, WCDMA radio access allocates radio and transport resources for that connection. The allocated resources are handled by the term "channel". Channel can be viewed as a logical representation of the information flow between two communicating points. If we are talking about layered architecture of protocol software there can be different types of channels constituted by different layers with different levels of abstraction. In the case of UMTS, as it is shown on the Figure 1.9 there are three layers of channels.

The first type of channels is known as the ***logical channels***, they are located on the highest level and used for applications and signalling procedures to communicate with the network. Logical channels are not actually channels as such, rather they can be better interpreted as different tasks the network and the terminal should perform.

Once the data is in logical channel then it is mapped into the ***transport channels***, performing actual information transfer between the UE and access domain. Transport channels in their turn are mapped to the ***physical channels***. Physical channels are present only in the air interface, all information transfer within radio access network performed by transport channels. In that way transport channels can be understood as determining the sequence which the mapping of logical channels to physical channels must take.

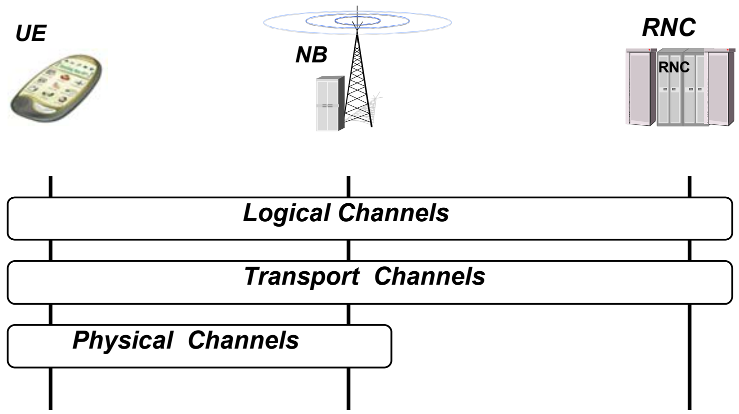


Figure 1.9. Channel types and their location in UTRAN [1]

As shown above logical channels can be mapped to the different physical channels, correspondingly through different transport channels, depending on the type of service required and which connections are alive. For example depending on whether the connection between UE and RAN exists or not (e.g. during initial access), signalling can use the same channel as for data or its own control channel. More information about mapping can be found in [3].

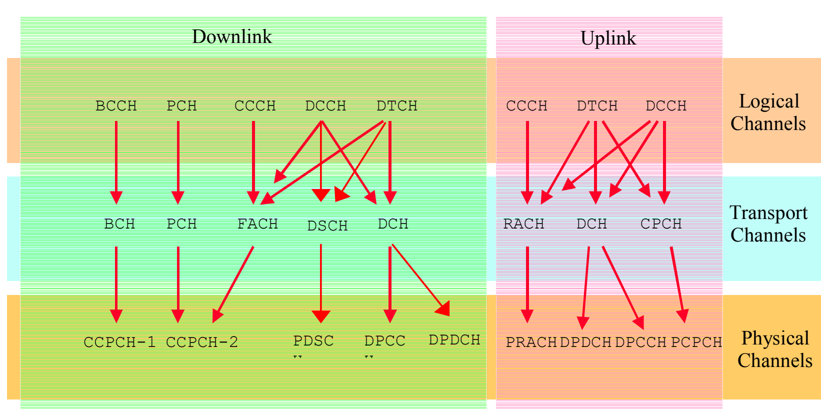


Figure 1.10. Channel mapping in the downlink and uplink

Further we will mainly concern transport channels since their management, allocation and deallocation is the subject of transport resource management. Following gives the rough overview of the transport channels existing in the UTRAN.

According to nature of transferred information the transport channels can be split into two groups: *common transport channels* shared by several terminals, and *dedicated transport channels* used for connection of one terminal with the network. Each group includes different channels in uplink and downlink directions.

The Transport Channels carrying the information flows in **downlink** direction are:

- **B**roadcast **Ch**annel (**BCH**). This common channel contains information about the radio environment, e.g. code values used in the current and neighboring cells, allowed power levels, etc.
- **P**aging **Ch**annel (**PCH**). This common channel is used by the network to find out the exact location of the particular UE for example when the network needs to setup a connection with that UE. All terminal continuously listen to the PCH to pick up the paging request for them.
- **F**orward **A**ccess **Ch**annel (**FACH**). This channel comprises Logical Common Control Channel, Dedicated Control Channel and Dedicated Traffic Channel, thus may carry common information for all UE residing in the cell as well as dedicated control and payload information.
- **D**ownlink **S**hared **Ch**annel (**DSCH**). This common channel encapsulates data coming from Logical DCCH and/or DTCH and is used for asymmetric connections where the amount of information in downlink is so small that there is no need for allocation of dedicated channel. It can be shared by the several users and quite similar to FACH.
- **D**edicated **Ch**annel (**DCH**). This is the only dedicated channel. It contains information coming from both Logical Dedicated Traffic Channels (DTCH) and Dedicated Control Channel (DCCH), i.e. the actual user traffic. Moreover it can carry the information from several DTCHs depending on the case. For instance user may have several connections for different services (e.g. voice and video call). Each service requires individual DTCH, however all of them use the same DCH. It should be noted that DCH is the dynamically allocated resource, it can be setup on demand for one user and then released, whereas common channels basically exist permanently.

The traffic in uplink direction is much smaller, thus it requires less transport and physical resources. There are only three Transport Channels available in uplink:

- **R**andom **A**ccess **Ch**annel (**RACH**). This channel used by the UE to send the initial access information when it wants to setup a connection with the network. Also mobile terminal responds to the paging request on this channel. Besides this, RACH can contain the small portion of dedicated information coming from Logical DTCH and DCCH instead of allocation new DCH.
- **D**edicated **Ch**annel (**DCH**). It carries the same information as a DCH in the downlink direction.
- **C**ommon **P**acket **Ch**annel (**CPCH**). It carries small amounts of user packets if the common resources are used for this purpose.

In conclusion it should be noted that some transport channels are optional (e.g. DSCH), whereas some are mandatory. Channels such as FACH, RACH and PCH play the essential role in the overall system functionality.

Now we are familiar enough with the basic radio and transport concepts of WCDMA and can proceed further towards the UMTS system element that manages all that resources, UMTS Terrestrial Radio Access Network (UTRAN).

1.2.2 UMTS Terrestrial Radio Access Network

As presented on the Figure 1.11 UTRAN has two main elements: Node B and Radio Network Controller (RNC). One RNC together with Node Bs belonged to it constitutes Radio Network Subsystem, the least structural element in UTRAN. Each RNC is responsible for the set of cells that can be covered by one NB or several NBs (one NB per cell).

There are two internal interfaces within the UTRAN:

- Iub interface located within RNS between RNC and NB.

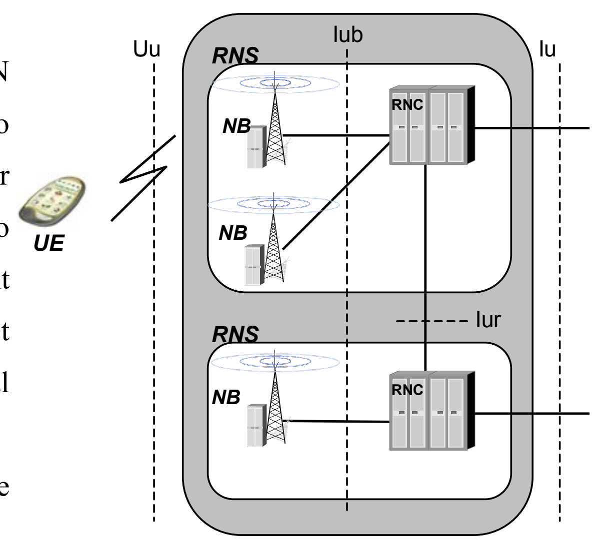


Figure 1.11. Radio Access Network

We will have a close look at Iub interface later on.

- Iur interface between two RNCs. This interface is completely new in UTRAN as compared to GSM, based on this interface UTRAN can completely handle Radio Resource Management itself, thus no interference from the Core Network in required. This interface is not mandatory; generally it exists but in some cases may not.

In addition UTRAN has two external interfaces towards the Core Network and towards UE.

- Iu establishes the interface from the RNC to the Core Network;
- Uu interfaces realizes the radio connection between the UE and Node B.

All these interfaces in 3GPP specification are open interfaces, this ensure the compatibility between equipment of different manufactures and allows multivendor scenarios in the network configuration.

Physically the interfaces are implemented as the protocol stacks running on the interface endpoints. Base Station (or officially Node B), for example, establishes the physical implementation of Uu interface and Iub interface. Realization of Uu interface means that Node B implements WCDMA physical channels and converts the information coming from transport channels to the physical channels under control of RNC. For Iub interface Node B performs the inverse functionality. It should be noted here that Node B owns only physical channels' resources whereas transport channels are completely managed by RNC.

Radio Network Controller (RNC) is the main controlling element in UTRAN, since it owns all logical resources of Radio Network Subsystem. It is responsible for controlling the use and integrity of all 3G radio resources by the means of performing Radio Resource Management (RRM) procedures. This includes functions such as Handover and Admission Control, Power Control and Code Allocation, Radio Resource Control (RRC) and Micro and Macro Diversity.

Macro Diversity and the term Soft Handover (SHO), tied with it, are completely new features in UMTS as compared to GSM systems. The statement saying that UTRAN supports Macro Diversity means that UE residing within the area controlling by UTRAN can have connections to several cells. The connection paths (or legs in SHO terminology) are combined either in Node B (if that cells belongs to one NB) or in RNC. These two cases correspond accordingly to Micro and Macro Diversity Combining. It should be noted that the decision of where to make a diversity combining is done by the RNC.

While the user is moving from one cell to another connection legs are added and deleted without breaking the connection. This is what is called Soft Handover. As far as SHO and

Macro Diversity are not limited within one RNS they would not be possible without addition of new interface between two RNCs, Iur interface.

Supporting Macro Diversity and SHO features over the Iur interface RNC may act in the three logical roles. The RNC having one Node B under its supervision acts as a Controlling RNC. In this role RNC is in charge of the load and congestion control in the cells belonging to that Node B and also fulfil configuration and fault management over the Iub interface. From UE point of view RNC may play two logical roles. First, when the UE initiates the connection, the RNC that first serve it becomes the Serving RNC (SRNC). Serving RNC owns all logical resources belonging to the user connection. Thus there can be only one SRNC per UE. As UE moves around the coverage area, due to the *multi-path propagation* property of radio signal, it may happen so that UE establishes the connection with several Node Bs belonging to different RNCs. That newly equipped RNCs are called Drifting RNCs. When all the branches go through one Drifting RNC UTRAN can perform the Serving RNC Relocation procedure. Serving RNC is the place where the Macro Diversity as such is executed.

1.2.2.1 Transport Technology in UTRAN

The transport technology in UTRAN has always been one of the hot topics in UMTS standardization. There are many requirements imposed on it. First of all it should support both circuit and packet switched traffic and on the other hand keep up the efficient utilization of the WCDMA radio channels, i.e. guarantee QoS and support for different bit rate classes.

The 3GPP has chosen the Asynchronous Transfer Mode (ATM) as the most closely corresponding to the imposed requirements transport technology. It combines benefits of both circuit switching (small and deterministic transmission delay, guaranteed transmission capacity) and packet switching (flexibility and efficiency for intermitten traffic). This is achieved by using the small, fixed packets, called cells, as transfer units. That is why ATM is called a cell switching technology. Each cell is of the length of 53 octets (bytes), containing 5-byte-long header (address information) and 48-byte-long payload (transmitted information).

ATM is known as a connection oriented protocol. Therefore before sending an information between two nodes one has to establish a connection (or Virtual Channel in ATM terminology). There can be two types of connection, Virtual Channel as such and Virtual Path (VP) which is the bundle of VCs. There can be thousands of VC within one VP, for instance in transmission of multimedia information, that requires several VCs simultaneously, one VC per each multimedia component. In more details ATM is described later on in the next chapters.

In theory ATM layer consists of simple transport media and is suitable for transmission purposes as such. But in practise the ATM layer must be adapted to the higher protocol layers in order to enable the most efficient utilisation of transport resources, regarding to the type of traffic produced by higher level protocols. UTRAN employes two types of ATM Adaptation Layers (AAL), namely AAL Type 2 (AAL2) and AAL Type 5 (AAL5). The AAL2 is used within the User Plane as the most appropriate for nature of traffic produced by Frame Protocols (e.g. voice and video). And AAL5 is used within the Control Plane as an underlaying transport layer for application protocols, i.e. for transmission of signalling data. The ATM Adaptation Layers will also be described in more datails in the later chapters.

1.2.3 Core Network

Core Network architecture is a very wide and complicated topic to describe since it comprises the essential logical and computational resources in the 3G system. It needs the separate study to expose all its functionality and structure. Since this thesis concentrated only within the Radio Access Network, the CN is out of our interest, therefore this section presents its very brief overview, merely in order to provide reader with the complete picture of UMTS system.

The Core Network performs all the functionality tied with switching (in Circuit Switched Domain) and routing (in Packet Switched Domain). In the other words it enables service provision to the UMTS subscribers.

UMTS supports both types of services, circuit- and packet-switched. This constitutes basic CN architecture logically divided into two parts, which are Circuit Switched Domain (CS Domain) and Packet Switched Domain (PS Domain). Its general view is represented on Figure 1.12.

CS Domain is used for handling circuit-switched connections, e.g. for voice and streaming video. Such kind of connections once being set up remain active during the whole communication time. They can provide constant data flow with deterministic variable bit rate, therefore enabling real-time traffic.

On the other hand PS Domain handles packet-switched traffic, requiring no constant link between end-points to be set up. The data in here is divided into packets, which are transferred through packet-switched network to the destination. Data flow in PS Domain has intermittent character and primary contains non-realtime data and services (but also can be real-time traffic), in such a way representing always-on type of connections that work on the background.

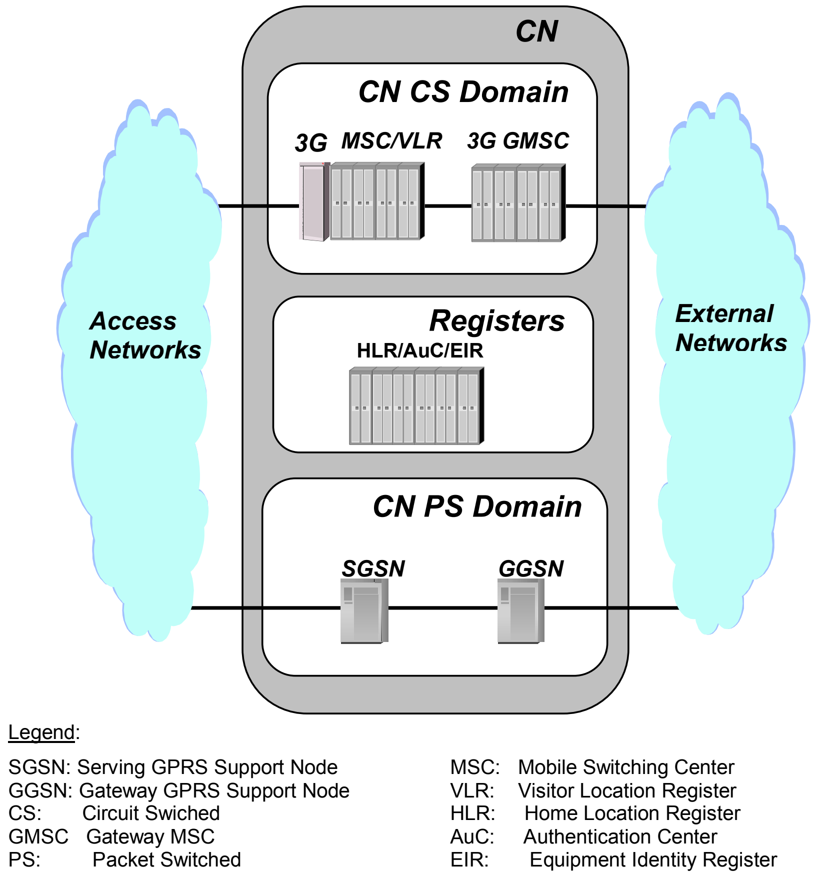


Figure 1.12. Generalized CN architecture (3GPP R99)

As it can be easily seen from the Figure 1.12, apart from CS and PS Domains the CN contains the set of register nodes – the databases storing subscribers' profiles, data needed for connection establishment and security activities.

The following is the brief description of the CN main elements.

Circuit Switched Domain

It has two basic elements, Mobile Switching Center (MSC) combined with Visitor Location Register (VLR) and Gateway Mobile Switching Center (GMSC). These two elements have different functionality but physically may be located in a one node.

- MSC: this element is responsible for call controlling activities, such as connection establishment, connection release and switching the established connections between two end users. It also performs activities related to mobility management of UE, such as location update, location registration, paging and security issues.

- GMSC: this node is in charge of all incoming and outgoing connections from and to other networks, such as PSTN, ISDN or other PLMN.

Packet Switched Domain

The PS Domain also contains two basic elements: Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN).

- SGSN: this node has almost the same responsibility as MSC in CS Domain, but in respect to packet-switched connections.
- GGSN: this element establishes and maintains the packet-switched connections towards other PS networks, such as Internet.

CN Registers

Registers are used by both PS and CS Domains, storing different kind of information about subscribers.

- Home Location Register (HLR): it is the most important database containing permanent subscribers' information. It stores subscriber's profile and information about its current location that is queried by GMSC or GGSN.
- Visitor Location Register (VLR): this database temporary stores information about the subscribers located in the service area of MSC. When subscriber roam into the service area of the MSC its information is copied from the HLR to the VLR associated with that MSC, so that MSC will have all necessary information needed for connection and mobility management of served user.
- Authentication Center (AuC): this database stores authentication and encryption information needed during connection set-up phase to verify user's identity and ensure the confidentiality of each call.
- Equipment Identity Register (EIR): EIR database handles security information related to the UE hardware. Such kind of information is needed for example to prevent calls from stolen or defective terminals.

CN may also include a number of value added service elements, for example Short Message Service Center (SMSC) and Voice Mail System (VMS). They are not included in CN general architecture description since it is implementation specific issue.

1.3 Generic model of UTRAN interfaces

In this section we will introduce the operational environment which is in concern of our problem domain, the general UTRAN protocol model.

There are four interfaces specified for UTRAN: Iu toward CN, Uu – radio interface, Iur – between two RNC and Iub – between RNC and Node B, which is of our prime interest. All the interfaces are open, meaning that 3GPP defines open specifications of the protocols that physically implement the interface. The set of protocols defined for each interface is organised in a stack and follows the general protocol model. Such model for UTRAN interfaces is depicted on the Figure 1.13.

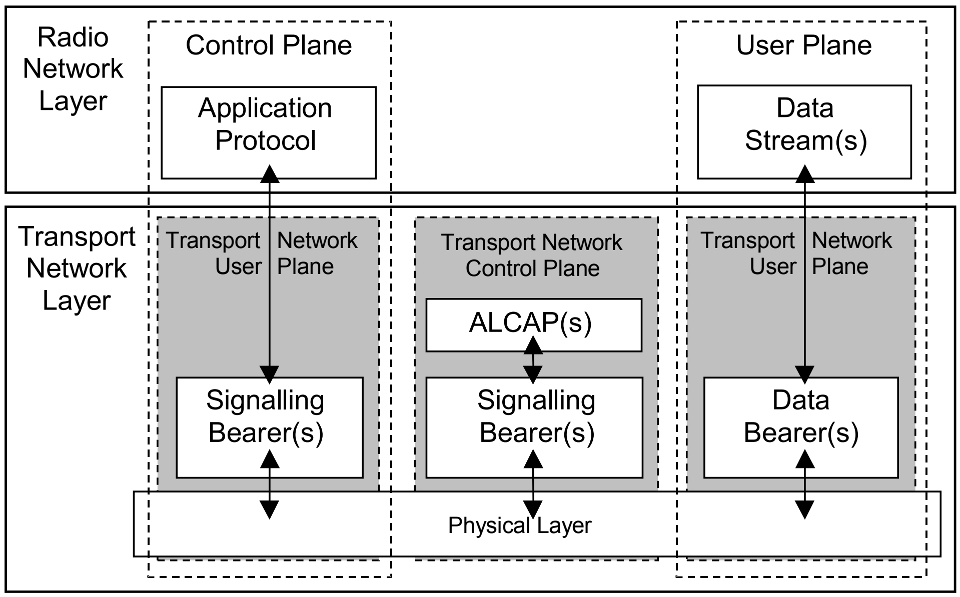


Figure 1.13 General Protocol Model for UTRAN interfaces [4]

The UTRAN protocol architecture follows the generic principles of OSI (Open System Interconnection) reference model. In OSI model each communicating node is subdivided into different functional layers. Each layer provides its services to the layer above and uses the services from the layer below. By the means of that on the logical level it can communicate with its peer entity via messages called Protocol Data Units (PDU). There are totally seven layers in the OSI model, but this doesn't mean that every protocol stack defined according to open standards must also have seven layers, rather it can be mapped in to the arbitrary number of OSI layers.

Following this principle the URTAN interface model is subdivided into two layers. Besides layers separation vertically it is divided into two planes. Each layer and plane is logically independent of each other, so that a protocol or a protocol stack can be changed without affecting the other layers or planes.

Horizontally the interface structure separates all the UTRAN related functionality from the terrestrial transport functionality into two layers: Radio Network Layer and Transport Network Layer respectively.

Radio Network Layer comprises the protocols that are specially designed for the UMTS system and the common task for them is to perform all the UTARN related functionality, independently from the underlying transport technology. This layer takes care about the management and use of radio access bearers across the set of UTRAN interfaces. In the terms of interaction between Radio Network Layer and Transport Network Layer it can be said that Radio Network Layer creates some information to be transported to the other node and passes this information to the Transport Network Layer which performs the actual information transferring over the physical media, regardless to the content of that information.

In that context ***Transport Network Layer*** can be viewed as a responsible for the management and use of transport bearers, which in particular serve as a part of Radio Access Bearer on the level of transport network in the UTRAN interface. This functionality includes the signalling, establishment, maintenance and release of transport bearers. The name Transport is used here in the same sense as its OSI meaning, i.e. to cover the set of protocols allowing distributed nodes to communicate with each other through heterogeneous internetwork. As distinct from Radio Network Layer, Transport Network Layer was designed with the assumption that it may include all those protocols, which were selected from existing protocol suits instead of having to design them specially for UMTS purposes.

For example, the current choice for the transport technology is ATM, whereas layered topology of interface model allows to easily change transport in future to IP based, or any other transport technology, by simply replacing the Transport Network Layer, while the Radio Network Layer will remain intact.

In this section we have used term Radio Access Bearer, that was not defined previously. In following paragraph the short definition of notion *bearer* in UMTS is given, since this term will be used in the further statements.

From the end-user point of view the UMTS system mainly acts as an infrastructure providing facilities, adequate bandwidth and quality of connection between end-users and their applications. When the one end-user establishes a connection with another terminal or service platform, this connection requires a lot of resources to be dedicated in order to transfer the information flows across the UMTS network. In general all resources involved can be of the different nature and belonging to different networks. Thus some accociation between that resources is needed. Here comes the notion *bearer* that represents all the resources involved in information transmission and association between them. Figure 1.14 shows the layered architecture of UMTS bearers.

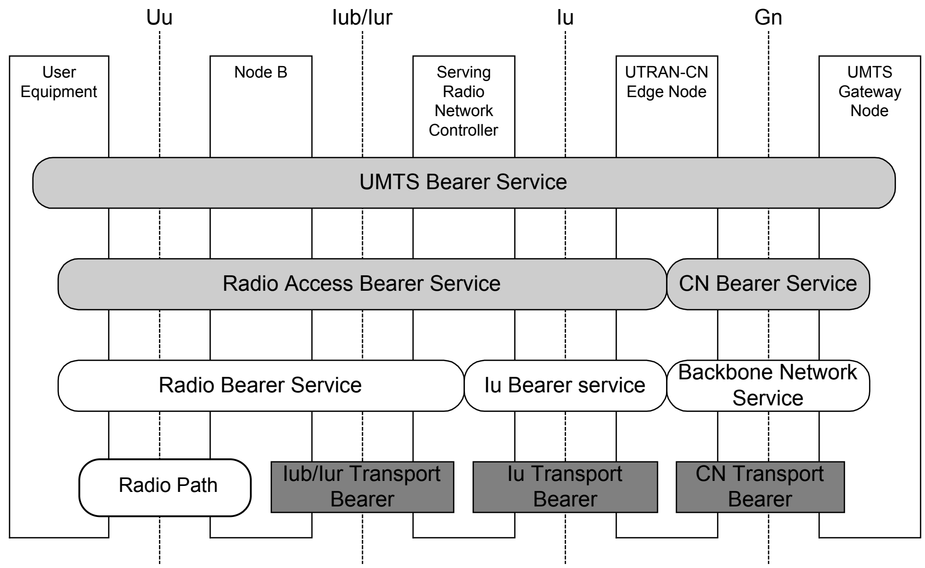


Figure 1.14. UMTS bearer service architecture

The overall resources involved in information exchange between two end-users constite the *end-to-end bearer*. As we go down across its layered architecture end-to-end bearer breaks down into several components belonging to different UMTS subsystems, which in turn consist of their constituent parts belonging to different interfaces. In such a way the *Radio Access Bearer (RAB)* is all the UTRAN resources, which are dedicated to transport user information for some particular user connection across itself, and it can be viewed as a service, which UTRAN provides to CN and UE.

Now lets get back to the examination of general protocol model for UTRAN interfaces. In addition to horizontal layerisation the architecture is divided into two planes: Control Plane and User Plane. This is based on the one of the main principles borrowed from SS7 networks, the clear separation of control (signalling) information and user traffic. One should realise that any bearer whether it is end-to-end bearer or RAB or transport bearer is not a static one, but rather it represents the dynamically allocated resources. Therefore in order to allocate that resources, in other words to setup bearer, a lot of control information need to be exchanged. Once being setup bearer may need to be reconfigurated and finally released, that also requires exchange of control information. In telecommunication terminology such kind of exchange of control information is called signalling. The signalling is conveyed by Application Protocols resided in the Control Plane, whereas all user traffic traverse through User Plane.

In such a way the ***Control Plane*** embrace both radio and transport network layers and consists of an Application Protocol and Signalling Bearers. The Application Protocols take care about all signalling functionality in the UTRAN required for setting up and maintaining Radio Access Bearers and Radio Links, which include setting up dedicated signalling and user connections and exchanging other UTRAN-specific control information They use generic bearer parameters to establish RABs. Since the signalling functions at each interface differ there are different Application Protocols specified for each interface. They are RANAP for Iu, RNSAP for Iur and NBAP for Iub interfaces. The latter will be described in more details in the next chapters.

For transporting the signalling information between two Application Protocol entities the Control Plane includes signalling bearers. They serve as permanent connections dedicated only for transporting the Application Protocol messages. The signalling bearers are always set up by Operation and Maintenance (O&M) actions during the installation or reconfiguration of the network.

The UTRAN Control Plane protocols implement the client-server principle. Regarding to Iub interface, which is of our prime interest, Node B takes the role of the server and RNC behaves as a client requesting to perform some actions. In such a client-server based protocol architecture the behavior of a server protocol entity is defined in terms of what kind of actions it should perform when receiving a service request from its client.

Whereas Control Plane performs all control functionality, the actual user traffic, such as coded voice or IP packets, is conveyed through the ***User Plane*.** The User Plane consists of the *Data Streams* and *Data Bearers*. Data Steams are formed on the Radio Network Layer by the frame protocols specified for each interface. The frame protocol is the common name for user plane protocols, since their common property is to be responsible for efficient transfer of user data frames. The Data Bearers perform the actual data transferring across the interface on the Transport Network Layer.

In order to ensure an efficient and reliable transmissoin over the signalling or data bearers they must be controlled and maintained on the level of Transport Network Layer. This requires the introduction of Transport Network Control and User Planes.

From the Transport Network Layer point of view there is no difference in what kind of information to transfer. As it was described earlier it does not somehow interpret the information formed on the Radio Network Layer, thus this information does not affect on the way it is transported. That is why the mapping between the control and user planes on the Transport Network Layer and those on the Radio Network Layer, is not one to one. In general the idea behind the user and control planes can be summarised as follows. The user plane represents the overall resources dedicated to actual traffic transferring and the functionality connected with it and the control plane represents the functionality tied with controlling and maintaining that dedicated resources. From this point both Signalling and Data bearers in the

UMTS Control and User Planes forms the user plane on the Transport Network Layer, called ***Transport Network User Plane***.

The Transport Network User Plane is not homogenous in its structure as the user plane on the Radio Network Layer, since it is assumed to carry two types of traffic conveyed by signalling and data bearers. Signalling bearers, as it was mentioned earlier, are statically allocated by O&M actions, thus they do not need any controlling elements. At the same time data bearers are dynamically allocated ones and should be set up for each dedicated connection. For that there is a Transport Network Control Plane located between Control Plane and User Plane.

The ***Transport Network Control Plane*** is responsible for transport bearer management, which includes the signalling, establishment, maintenance and release of transport bearers. It contains the Access Link Control Application Part (ALCAP) protocol and signalling bearers used to transport ALCAP's messages to its peer entity across the interface. Signalling bearers here may be of the same type as those used by Application Protocols on the Control Plane. ALCAP is the generic name for transport signalling protocols. It depends on the underlying transport technology and can be one of the already standardised signalling protocols, for example Q.2630.1 [5]. Above all ALCAP ensures the Radio Network Layer to be truly independent from the underlying transport. It means that when Application Protocol needs to set-up a bearer for User Plane, it provides the ALCAP with rather generic bearer parameters that are not tied to the transport technology. All this enables seamless changing of the transport technology if needed.

1.4 Protocol stack in UTRAN

In this thesis we concern both Radio Network and Transport Network Layers, since they both are involved in the functions of transport resource management. From the overall UMTS protocol interworking architecture perspective there is also the third layer called System Network Layer. The protocols in this layer extend from UE across the UTRAN until the transit network edge in the CN. Their responsibility is to ensure interworking on UMTS communication service related aspects. Such protocols as CM (Connection Management) and MM (Mobility Management) belong to that category, thus they left out of scope of this thesis, and not presented on the figures below (although in reality they exist on the UE and CN side).

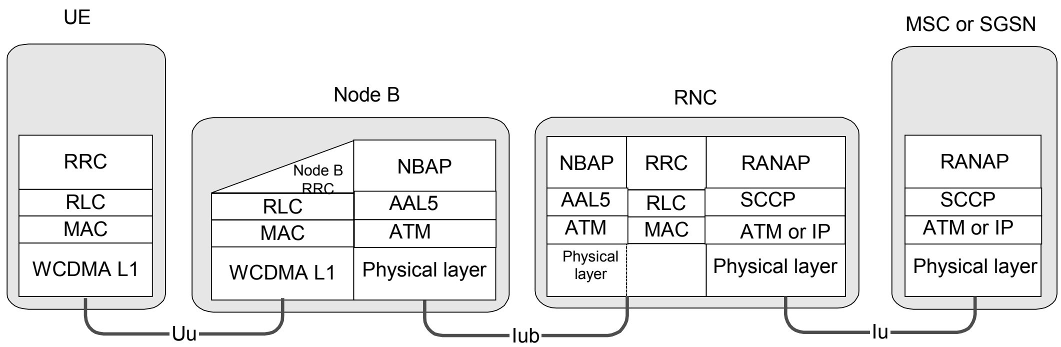


Figure 1.15. Control Plane protocol stack in UTRAN

Figure 1.15 represents the UTRAN protocol stack within the control plane, where Iu interface represents IP option for signalling transport, and Figure 1.16 shows protocol stack within the user plane. It should be noted that it's applicable only for packet-switched domain. For circuit-switch domain Radio Network Layer remains intact, the only difference is in Transport Network Layers used for Iu interface because of different nature of traffic in these domains.

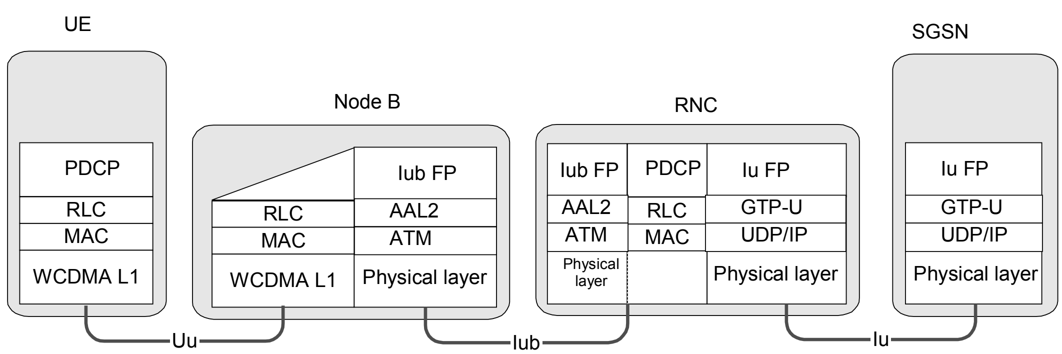


Figure 1.16. User Plane protocol stack in UTRAN (PS Domain only)

Futher on we will concentrate only on the Iub interface and protocols that physically implement it. Detaled description of those protocols used in Iub interface will be presented in the later chapters. Other interfaces and the protocols tied with them are out of scope of this thesis, and therefore only their short decription is given here.

Radio Resource Control (**RRC**) protocol is the essential protocol in performing radio resource management tasks. It is used to set-up, and maintain the dedicated Control and User Planes radio specific connections between UE and RNC, i.e. the radio bearers, transport and physical channels between UE and RNC. RRC protocol performs only on the control plane data transfer, whereas on the user plane the convergence sublayer is needed. That functionality performed by the **Packet Data Convergence Protocol (PDCP)** sublayer**.** It makes the UMTS radio interface applicable to carry IP data packets. Both RRC and PDCP protocols use the bearer service provided by the RLC sublayer to transport the signalling and data messages between their protocol entities.

Radio Link Control (RLC) protocol performs the regular data link layer functionality (according to OSI model). It is in charge of flow control procedures, segmentation and reassembly of higher-levels protocol messages and the reliable transmission of data. The operational environment of RLC depends on the plane discussed. In case of the user plane the RLC is used by the PDCP protocol, and in the case of control plane it's used by the RRC protocol.

Medium Access Control (MAC) protocol has the overall responsibility for controlling the communications over the WCDMA transport channels provided by the physical layer. As its service MAC provide a set of logical channels to the higher level protocol, i.e. RLC.

Node B Application Part (NBAP) protocol is used to maintain control plane signalling over the Iub interface, i.e providing RNC with the means for controlling over Node B. On the underlying transport network layer it uses ATM together with the AAL5 to transport signalling messages over the interface. This application protocol, as well as its transport, will be decribed in detail in later chapters.

Radio Network Subsystem Application Part (RNSAP) as well as NBAP is application protocol, but it performs its control over the Iur interface. Unlike the NBAP, RNSAP is a symmetric protocol, thus running by two RNCs, one of which takes the role of SRNC and another acts as DRNC.

Radio Access Network Application Part (RANAP) is the third application protocol in UTRAN. It runs on the top of Iu signalling transport layer. One of RANAP peer entity is resided at RNC while another at the MSC or SGSN. RANAP is used to set-up and maintain Control Plane and User Plane connections across Iu interface thus handling communication between UTRAN and CN.

On the transport network layer Iu interface employes two alternatives: **GPRS Tunneling Protocol (GTP-U)** and **Signalling Connection Control Part (SCCP)** correspondingly for User and Control Planes. GTP-U is a transport network protocol belonging to the packet switched domain in the UMTS. It provides the connectionless data transfer. At the same time SCCP is the connection-oriented protocol (but can be also in a connectionless mode) supporting control plane data transfer. Above all it is responsible for maintaning the harmonization between the IP and ATM transport options.

This section concludes the overall UTRAN description as a part of UMTS system. The rest of the thesis will be concentrated only on the Iub interface, as the sole interface located within the Radio Network Subsystem.

2. Iub INTERFACE

In this chapter we will have a closer look at the Iub interface, facilitating the inter-connection between the Radio Network Controller and the Node B.

The introduction of the Iub interface followed two main capabilities to be facilitated. The first is the *radio application related signalling*. This allows the RNC and the Node B to negotiate about the radio resources, for example to add or delete cells, controlled by Node B to support communication of the dedicated connection between the UE and Serving RNC. This cathegory also includes the information used to control the broadcast channel and the common information to be transported on this channel.

And the second is the *provision of the means for transport of uplink and downlink WCDMA transport channels' frames between RNC and Node B*. This is done by Iub Data Streams. Each of them conforms to the the data carried on the corresponding transport channel. The following is the set of Data Streams provided by the Iub interface: Iub DCH data stream, correponding to one bi-directional transport channel; Iub RACH data stream; Iub CPCH data stream [in FDD mode]; Iub FACH data stream; Iub DSCH data stream; Iub USCH data stream [in TDD mode]; Iub PCH data stream. For description of each transport channel, corresponding to Data Streams enumerated above, please refer to Section 1.2.1.1. Every one Iub Data Stream is carried on one transport bearer, resided within Transport Network Layer. Thus it is the responsibility of Iub signalling protocols to ensure the establishment of a transport bearer over Iub interface for each Iub Data Stream.

This responsibility is covered by one of the Iub functions called Management of Iub Transport Resources, which is the main problem domain in this thesis. The Iub Transport Resource Management is conducted by RNC and physically realized together by two siganalling protocols, NBAP in the Radio Network Layer and ALCAP in the Transport Network Layer. These two protocols will be decribed in details later on . In rough review the Transport Resource Management from the RNC point of view is concluded in assuring the set up, maintenance and release of the underlying transport resources. If we are talking about the ATM together with its Adaptaition Layers used as a transport technology, the transport resources to be controlled over Iub interface are represented by the AAL2 connections between RNC and Node B.

Besides the Transport Resouce Management Iub interface performs plenty of other functions such as [6]:

- Logical O&M of Node B. It comprises the signalling associated with the control of logical resources (channels, cells,…) owned by RNC but physically implemented in the Node B. This is mainly performed by the NBAP protocol procedures.
- System Information Management. Such kind of information can be provided by Controlling RNC in order to Node B update related system information. At the same time Node B can autonomously create and update certain Node B related system information on request from CRNC.
- Traffic Management of Common Channels. The common channels are controlled from the RNC. This is typically the control of RACH, CPCH and FACH channels, the information that is broadcast on the Broadcast Control Channel, and the control and request for sending information on the Paging Channels.
- Traffic Management of Dedicated Channels. This functions are related to the activation of logical resources (e.g. Radio Links, Iub ports), and the connection of these various resources together.
- Timing and Synchronisation Management. The processing of control and user plane information needs to be synchronized in different network elements. Iub interface supports the following synchronization types: Transport Channel (Frame) Synchronization, Node B – RNC node Synchronization and Inter Node B node Synchronization.

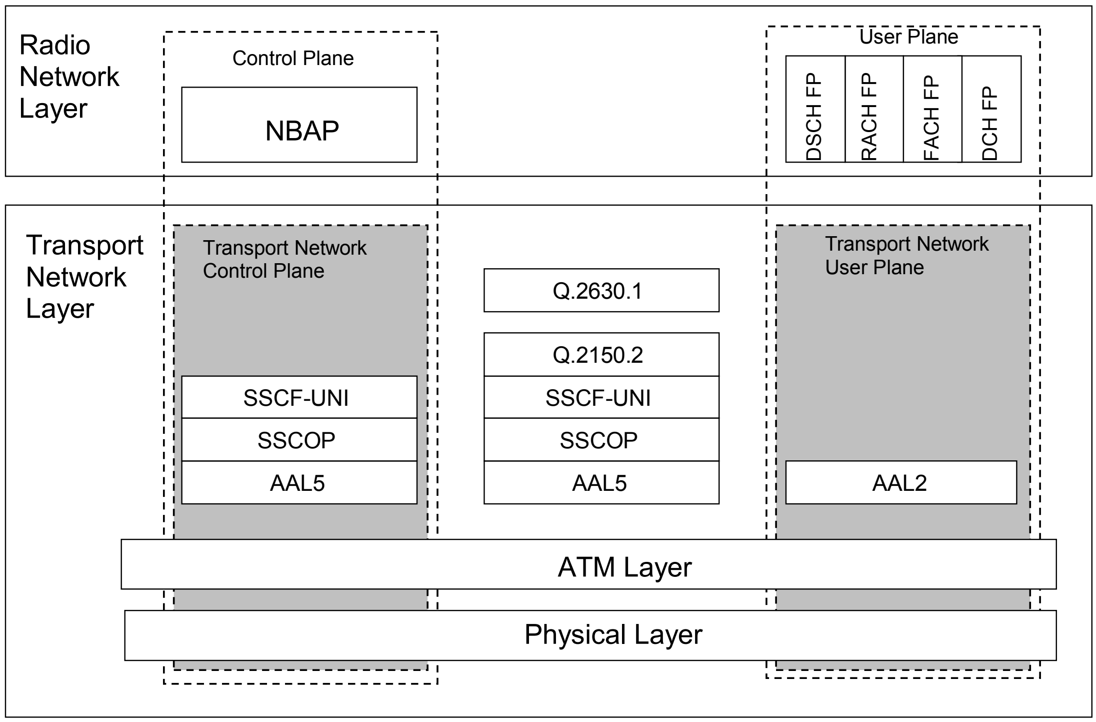
The enumerated functions include both signalling and user information transferring thus employ control plane protocols as well as protocols in the user plane. The following section gives the introduction of the protocol stack of the Iub interface.

2.1 Protocol stack of the Iub interface

The complete protocol structure of the Iub interface is shown, with the general triple plane notation, in Figure 2.1. The Radio Network Layer defines the procedures related to the operation of Node B and the Transport Network Layer defines the procedures for establishing and releasing physical connections between Node B and the RNC.

Radio Network Layer within the user plane consists of the set of Frame Protocols (FP) each for the corresponding transport channel. They define the structure of the frames and the basic inband control procedures for each type of transport channel such as the Dedicated Channel (DCH FP) and others. The structure of the Frame Protocols will be described in more details in later chapters.

As the data bearers in the transport network Frame Protocols use the AAL Type 2 connections resided on the top of ATM layer. ATM serves as a current choice for the transport technology within the UTRAN (and thus RNS) as it stated by 3GPP [4]. But since the ATM is suitable to carry traffic of the different nature it needs the adaptation layers for particular type of information flow. That is why the FPs use the AAL Type 2 as the most appropriate for their traffic.



Legend:

AAL: ATM Adaptation Layer
DCH: Dedicated Channel
DSCH: Dedicated Shared Channel
FACH: Forward Access Channel
RACH: Random Access Channel
NBAP: Node B Application Part
FP: Frame Protocol
SSCF: Service Specific Coordination Function
UNI: User-Network Interface
SSCOP: Service Specific Connection-Oriented Protocol

Figure 2.1 Protocol structure at the Iub interface [4]

Since the FPs are used to carry the user traffic that involves a lot of resources, the transport connections used to transfer that information across the interface must be of dynamic nature in terms of connection establishment and release. This is ensured by the ALCAP protocol in case of AAL2 specified as the AAL Type 2 signalling protocol defined by the International Telecommunication Union Telecommunication Sector (ITU-T) in recommendation Q.2630.1 [Capability Set 1] and recent enhancements in Q.2630.2

[Capability Set 2]. We will have a closer look at the transport network layer later on in this chapter.

The protocol of the Radio Network Control plane is the NBAP. It allows Node B and RNC to negotiate about the use of radio resources. This includes for example addition and deletion of cells, the management of soft and softer handover (by the means of radio link setup, addition and deletion), and the control of transmission power and addmission. Above all NBAP also commands the ALCAP to setup or release transport bearer when needed, thus participating in transport resource management. NBAP protocol will also be described separately in the next chapter.

From the Transport Network Layer point of view the radio network layer protocols are completely transparent, thus the NBAP signalling is just another type of user traffic than FP traffic that has to transported through Transport Network User Plane by using AAL Type 5, that seems to be the most appropriate for the signalling information.

The one of the general principles for the specification of the Iub interface, as stated by 3GPP [6], says that the Iub should be based on the logical model of Node B. Therefore in order to provide the reader with the complete insight to the Iub interface, and aslo for the further purposes, it is necessary to briefly introduce the logical model of the Node B. This issue is settled in the next section.

2.2 Logical model of the Node B

In order to ensure the independence from the physical Node B implementations of different manufacturers that can be in one way or another vendor specific, 3GPP defines the general logical model of Node B. Such a model represents the physical resources of Node B hidden behind the logical entities, that are only visible from the RNC side. Controlling RNC serves as a sole owner of the Node B's logical resources, and since they are generalized the RNC does not care about the physical architecture of Node B it communicates with, rather it deals with its logical entities. This guarantees that the RNC of one manufacturer is able to command the Node B of another.

The Figure 2.2 represents the logical model of Node B as it is seen from the Controlling RNC. All logical resources can be classified in two different ways.

First of all Node B consists of common and dedicated logical resources. The common logical resources can be used by all UEs resided in the service area of particular Node B, for example for initial access or in order to obtain the information about the radio environment in the particular cell. Such kind of logical resources are represented by ***Common Transport***

Channels with their attributes. They all have been described in the section 1.2.1.1. The configuration of each Common Transport Channel is performed on request from CRNC using common and logical O&M NBAP procedures. In the logical model Common Transport Channels are accociated with the corresponding data ports. This is valid for FACH, RACH, PCH, CPCH [FDD] and DSCH (which has also association with Node B Communication Context), but not applicable for BCH that is carried directly on the Common Control Port (Node B Control Port).

Each Common Transport Channel has the set of its attributes that basically includes the type of the channel, data port associated with it and physical parameters.

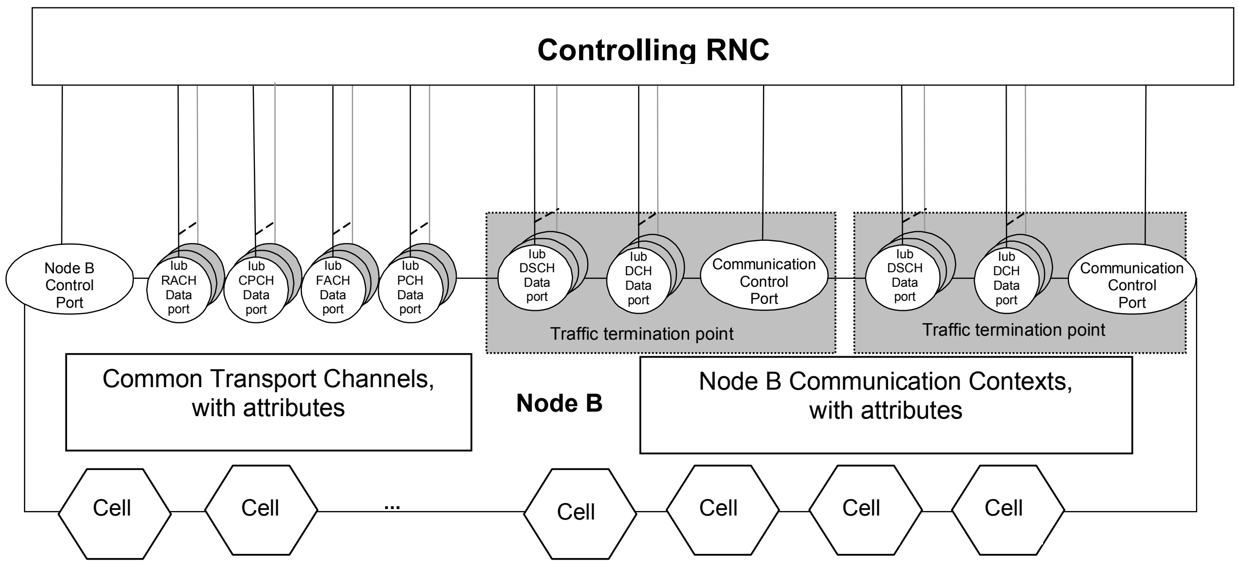


Figure 2.2 Logical model of Node B [6]

At the same time the dedicated resources are identified by the ***Node B Communication Contexts***. A Nobe B Communication Context corresponds to all the dedicated resources that are necessary for establishment and maintenance of user connection in dedicated mode using dedicated and/or shared channels as restricted to a given Node B.

Since one Node B supports numerous user connections, there are a number of Node B Communication Contexts inside a given Node B, one per connection. Each Node B Communication Context contains one or more DCHs and/or DSCHs that are accociated with their data ports. One given dedicated channel corresponds to one data port, except the case of coordinated DCHs that are multiplexed into the same DCH data port.

As well as Common Transport Channels the Node B Communication Contexts have their attributes basically consisting of:

- the list of Cells where dedicated resources are used;

- the list of DCHs and DSCHs with the associated data ports, which are mapped to the dedicated physical resources for that Node B Communication Context;
- the complete transport channel characteristics for each DCH and DSCH;
- physical layer parameters.

For controlling both dedicated and common resources Node B logical model provides for a common control port (common signalling link) and a set of dedicated control ports (dedicated signalling links) one per traffic termination point.

From the other hand, considering the Iub interface separation on the transport and network layers, the Node B logical model may be viewed as compising two types of logical resources: Radio Network Logical Resources and Transport Network Logical Resources. In two following subsections we will merely enumerate Radio Network Logical Resources and breafly review them, since they are not the subject of Transport Resource Management, and take a close look at the Transport Network Logical Resources that are of our prime interest.

2.2.1 Radio Network Logical Resources

To run the radio network the CRNC needs both common and dedicated resources in the Node B. The CRNC is the only one who manages radio network resources in the Node B, that is it can order the Node B to configure, reconfigure and delete these resources. However, if Node B cannot fully support the requested configuration because of lack of resources or broken equipment it can indicate the availability of common resources. Therefore each common resource has an operational state that can be one of the following: *enabled* (meaning that the resource can be used by RNC), *disabled* (meaning that the resource cannot be used by RNC) and *not existing* (meaning that the resource doesn't exist in Node B). The state transition is triggered by the NBAP common procedures.

The Node B Radio Network Resources controlled by CRNC are the Cell, common and dedicated physical and transport channels.

The *Cell* is the logical entity of the highest level of abstraction. It comprises all the logical radio resources within the given geographical area. All common transport and physical channels within given Cell belong to that Cell. The dedicated channels do not belong to any Cell as such since they do not exist permanently, rather they belong to the particular UE connection, however if any of Iub transport bearers for dedicated or common transport channels exist when the Cell is deleted, those channels must be also deleted (common channels triggered to the *not existing* state) and the Node B must initiate the release of those transport bearers.

In general one Node B may support one or more Cells to cover the specific area by using the directional beams.

One Cell can posses one or more common physical and transport channels, depending on those type, whereas all common physical and transport channel can belong only to one Cell.

2.2.2 Transport Network Logical Resources

As claimed by the principle of separation between Radio Network and Transport Network Layers the Transport Network resources are used as a transport of the traffic produced by the higher layer. From the Node B logical model perspective Transport Network Logical Resources are represented by the traffic ports. Each port is associated with one or more (in case of DCHs) transport channels and performs the actual mapping of the given channel (or set of channels) to the transport bearer. Traffic ports are subdivided on the control ports (signalling links), carrying signalling information and data ports (data links) for the actual data traffic.

Therefore the Transport Network Logical Resources are:

- Node B Control Port
- Communication Control Ports
- Traffic Termination Points
- Data ports corresponding to each type of transport channels

Following is the brief description of each logical entity.

The *Node B Control Port* (the same as Common Control Port) is used to exchange the NBAP signalling information for the logical O&M of Node B. Through this control port RNC commands Node B to create the Node B Communication Contexts for dedicated UE connections, to configure the common transport channels that Node B provides in a given cell. Also PCH and BCH control information between RNC and Node B is conveyed through Node B Control Port.

Each Node B has only one Node B Control Port, as well as one Node B Control Port can belong only to one Node B. In the transport network layer Node B Control port corresponds to one signalling bearer between the controlling RNC and the Node B. This signalling bearer is statically allocated by the O&M actions during the network setup or reconfiguration.

A *Communication Control Port* is used to control the Node B Communication Contexts. Therefore it is used to maintain the signalling for the dedicated UE connection. Each

Communication Control Port corresponds to one signalling bearer between RNC and Node B and belongs to one Traffic Termination Point. However there is no relation between the number of dedicated connections established over Iub interface and the number of Communication Control Ports, since one Communication Control Port can handle one and more UE connections. Therefore it can be used for managing the DCHs and DSCHs dedicated to different UEs. The selection of Communication Control Port is done according to the arbitrary (implementation specific) algorithm at the creation of Node B Communication Context. As it will be seen from the implementation part of the thesis, we used the "selection on load" algorithm, meaning that at the creation of new Node B Communication Context the Communication Control Port (and hence Traffic Termination Point) is selected as supporting the least number of UE connections.

The number of Communication Control Ports within one Node B is defined by the number of Traffic Termination Points supporting by the given Node B.

Traffic Termination Point represents DCH and DSCH data streams belonging to one or more Node B Communication Contexts (UE contexts), which are controlled via one Communication Control Port. The Traffic Termination Point is merely descriptive entity which neither is controlled over Iub nor by O&M. It can be rather seen as the logical representation of the ATM network interface cards supporting by Node B for connection to physical transport media. Thus the number of Traffic Termination Points is predefined on the Node B installation phase.

Transport Channel Data Ports are used to represent data bearers that carry corresponding transport channel data streams. They can be of the following type:

- Iub DCH Data Port, represents a user plane bearer carrying one DCH data stream between RNC and Node B. That transport bearer will carry only one DCH data stream except the set of coordinated DCHs that will be multiplexed and conveyed through the same user plane transport bearer.
- Iub RACH Data Port, represents a user plane data bearer carrying one Iub RACH data stream between the Node B and the RNC.
- Iub CPCH Data Port, represents a user plane bearer carrying one Iub CPCH data stream between the Node B and the RNC.
- Iub FACH Data Port, represents a user plane bearer carrying one Iub FACH data stream.
- Iub DSCH Data Port, represents a user plane bearer carrying one Iub DSCH data stream. If the DSCH is used by an individual UE, there is one Iub DSCH Data Port per Node B exclusively assigned to the Node B Communication Context of that UE.

- Iub PCH Data Port, represents an Iub PCH Data Stream between the Node B and the RNC.

All the logical entities of Node B logical model has their own identifiers (such as DCH-ID, DSCH-ID, etc.). They are used to address the particular entity need to be controlled.

2.3 The structure of Iub transport

In this section we get back to the protocol model of the Iub interface and take a close look at the Transport Network Layer of the model and the protocols it includes.

As it was defined by general model of Iub interface the Transport Network Layer is subdivided into two planes: Transport Network User Plane that performs the actual transporting of traffic generated by Radio Network Layer, and Transport Network Control Plane, providing the control mechanisms over the user plane transport bearers. It was also stated earlier that 3GPP Release 99 and partially Release 4 assume the ATM together with its adaptation layers to be used as a transport technology over the Iub interface. Therefore the Transport Network Layer herein is constituted by the ATM and AAL(n) protocol stack. Two types of AAL are present in the Iub Interface: AAL Type 2 for circuit switched user plane connections and AAL5 for control protocol exchange.

The AAL5 connections are statically allocated transport resources used to convey signalling traffic. They are set up and configured only once by the O&M actions during the network installation, thus they do not require any control network elements and are not the subject of the Transport Resource Management. All this is different for the AAL2 connections since they are used to carry the dedicated traffic and must be dynamically allocated and then after use deallocated. This is ensured by the Transport Network Control Plane and, in particular, by ALCAP protocol. As far as ALCAP is rather generic name for Transport Network Control Plane signalling protocols the 3GPP specification [7] gives the concrete definition saying that AAL2 signalling protocol (defined in the ITU-T Recommendation Q.2630.2) is to be used as the signalling protocol to control AAL2 connections on the Iub interface.

Now lets have a close look at both Transport Network Control Plane and Transport Network User Plane (in part of AAL2).

2.3.1 Transport Network Control Plane at the Iub interface

The simplified Transport Network Control Plane reference architecture is shown on the Figure 2.3. It represents the interconnection between two nodes that are negotiating about the establishment of AAL2 connection between them. As it is seen from this figure the control plane herein contains two types of AAL2 Signalling network elements: the AAL2 Service Endpoint that provides an access to the served user and intermediate AAL2 Switch that routes signalling messages.

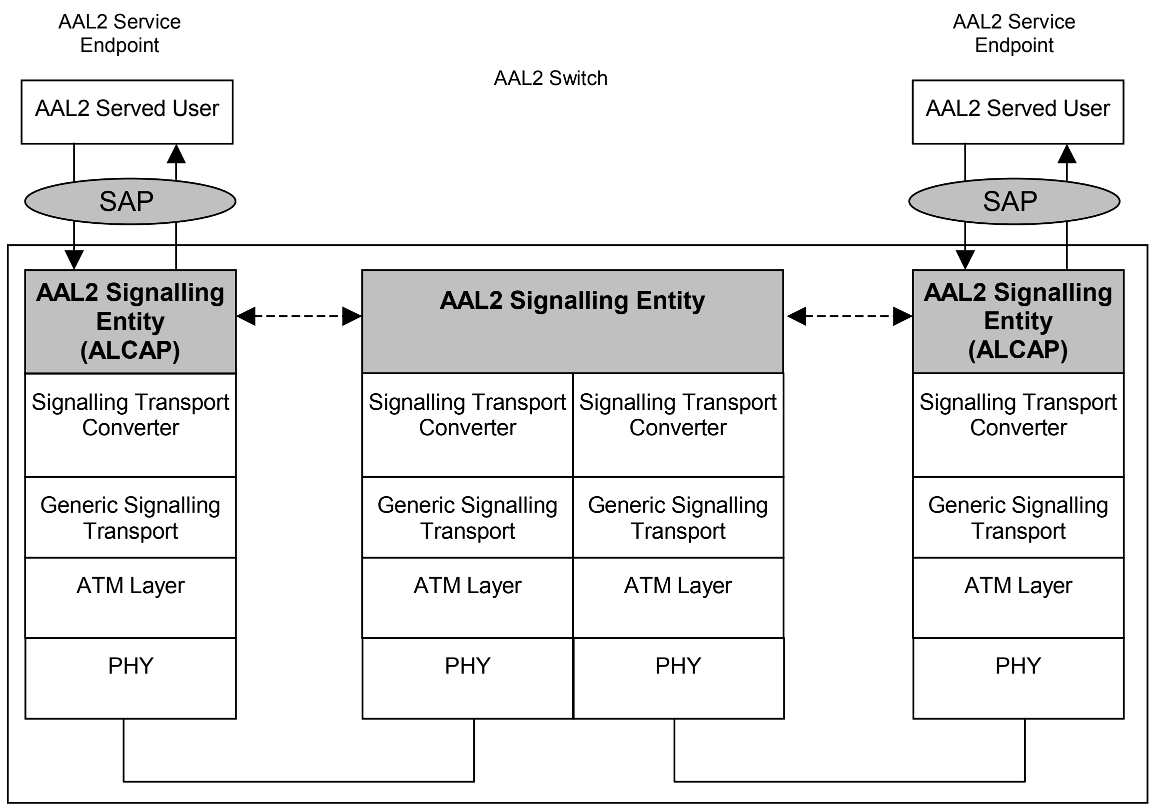


Figure 2.3. Control plane at the Iub interface [5]

For clear understanding the reader should realize that herein and further on the terms *AAL2 signaling protocol*, and *ALCAP* have the same meaning and basically within the context of Iub Transport Network Control Plane can be used as synonyms.

The term AAL2 Served User denotes the higher level protocol, to which AAL2 Signalling Protocol provides its services through the Service Access Point (SAP). The AAL2 Served User in the UMTS network is the radio resource management and handover control entity. It establishes/releases AAL2 connections when SHO legs are established/released.

The purpose of AAL2 Signalling Protocol is to establish the AAL2 connection between two AAL2 Service Endpoints. For that two adjacent AAL2 Signalling Entities exchange signalling messages or PDUs. To convey these messages between two nodes the AAL2 Signalling Entities rely on the Generic Signalling Transport service that provides assured data transport between them and service avialability indication. This services are accessible via the

Generic Signalling Transport Access Point. In more details the ALCAP and its representative at the Iub interface AAL2 Signalling protocol will be described in the next chapter.

In general the AAL2 is independent from the signalling transport, that's why on the Figure 2.3 the latter is reffered to as a *Generic* signalling transport. Although an assured data transport required with taking in to account massage size limits and etc. For that there is a Signalling Transport Converter (STC) used to adapt generic signalling transport service to a specific signalling transport service.

The *Generic Signalling Transport* consists of the Common Part of the AAL5 (Segmentation and Reassembly (SAR), Common Part Convergence Sublayer (CPCS)) and a Service Specific Convergence Sublayer (SSCS) providing different services to its users. SSCS on its top has the Service Specific Coordination Function, which directly provide the services to the STC via its service access point. These services include:

- *unacknowledged data transfer* – without guarantee from cell losses or insertions;
- *assured data transfer* of point-to-point connections, essential for transfer signalling information since it does relief its user from losses, corruption or disodering of data;
- *establish and release of signalling AAL connection* for services requiring assured data transfer [8].

As the second part of SSCS (after SSCF) the Service Specific Connection Oriented Protocol (SSCOP) supports the assured and unassured data transfer between its entities. It provides the *Sequence Integrity* preserving the order of service data units (SDU) to be transported, *Error Correction*, and *Flow Control* enabling the receiving entity to control the transfer rate.

The *Signalling Transport Converter* provides the transparent data transfer between STC served users (i.e. AAL2 Signalling Entities). In paticuar it supports the following services:

- *providing independence from the underlying transmission media* relieving then STC users from all concerns how the STC service is provided;
- *transparency of the information transfer*, meaning that SCT does not interpret somehow the information it transfers, thus the information content and coding have no affect on the way it is transported;
- *connection establishment and release* in order to provide a permanent connection service.

Such kind of transport architecture allows easily alter the transport technology to be utilised, for example between ATM and IP.

2.3.2 *Transport Network User Plane at the Iub interface*

The AAL2 connections that are established over the Iub interface, i.e. between the RNC and Node B has the point-to-point nature. But in the UTRAN basically there is no direct trunks between CRNC and each Node B belonging to it, furthermore all interconnections are organized in the form of transport network, i.e. with different routes from one node to another and switching elements that handle these routes.

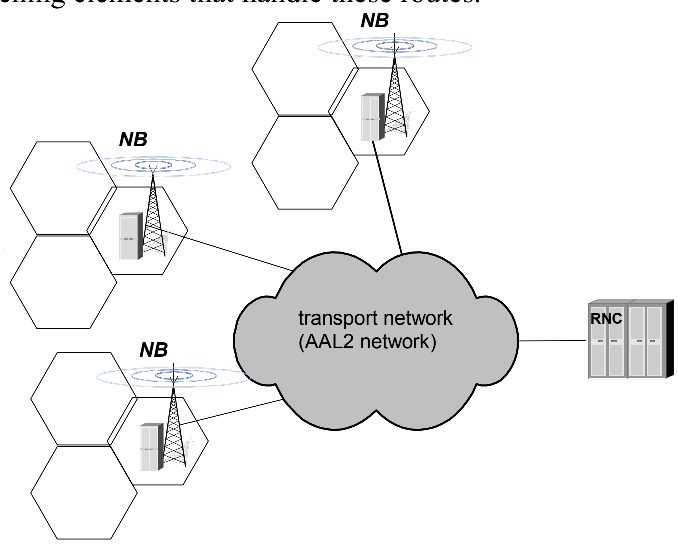


Figure 2.4. The network view on the RNS.

Therefore AAL2 network, as in case of AAL2 signalling network, has two types of elements: Service Endpoints and AAL2 Switch. Their protocol structure is shown on the figure 2.5.

The AAL2 User in the Iub User Plane is the Frame Protocol relying on the AAL2 network for transporting FP frames. It uses the services provided by the Service Specific Segmentation and Reassembly layer. The AAL2 layer provides different SAPs to its user in conjunction with different service specific layers. In case of Iub user plane the SSCS provides the segmentation and reassembly function and therefore called in this context as a Service Specific Segmentation and Reassembly (SSSAR) layer. The reason why the SSSAR was chosen as SSCS is that it allows the bandwidth efficient transmission of low-rate, short and variable length packets in delay sensitive applications such as telephony in UMTS networks.

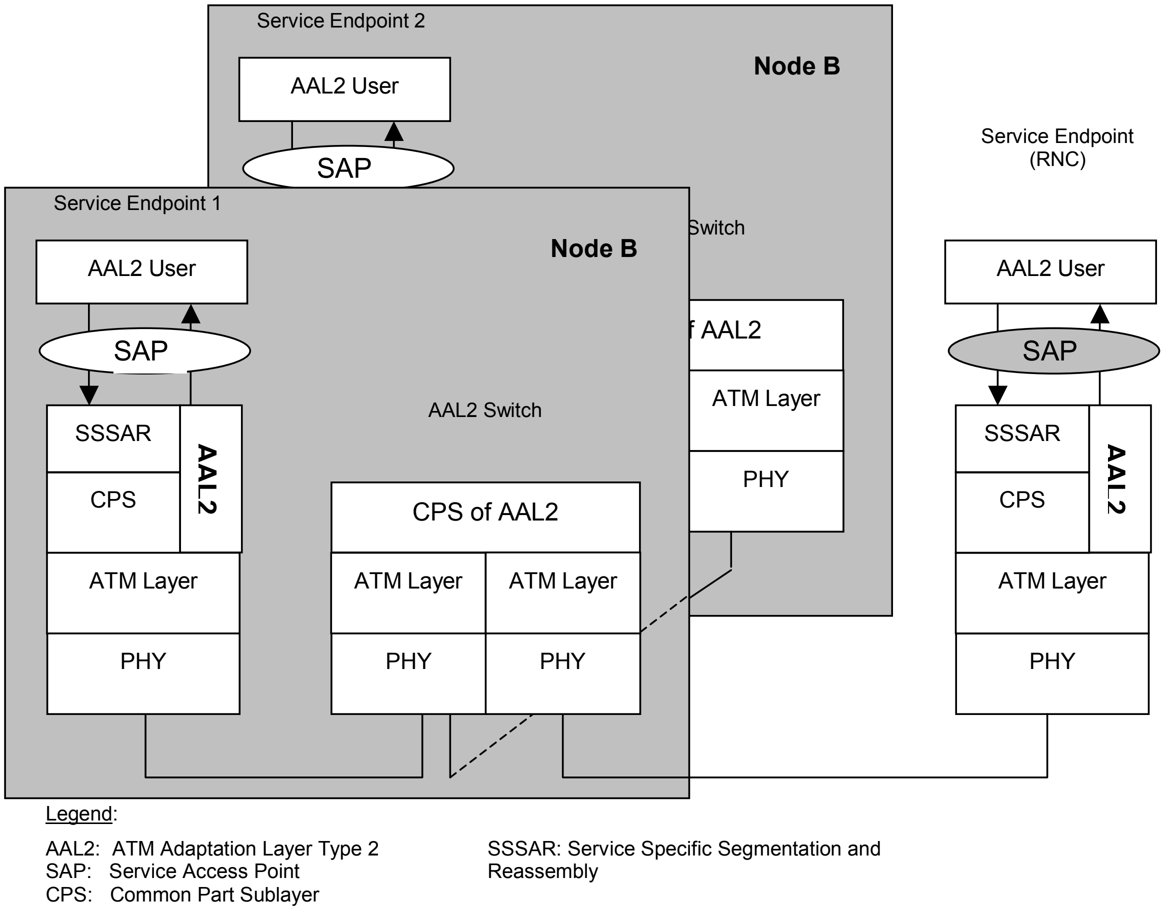


Figure 2.5. User Plane at the Iub interface

In the AAL2 switch the AAL2 connections are cross-connected in the Common Part Sublayer (CPS) with the help of Connection Identifier (CID) values that identify each AAL2 connection within an ATM Virtual Channel Connection (VCC).

In more details the AAL2 protocol stack and ALCAP as well as basic principles of ATM will be discussed in the next chapter. In that chapter we're coming closer to the immediate protocols playing direct or indirect role in the Transport Resource Management.

3. THE Iub PROTOCOLS INVOLVED INTO TRANSPORT RESOURCE MANAGEMENT

This chapter describes the main protocols that in the one way or another perform transport resource management tasks over Iub interface. The main attention will be paid to the NBAP protocol and Node B Manager (NBM) since they are in concern of the practical implementation part of the thesis. Above them the user plane protocols, transport protocols as well as some issues concerning the synchronization model and macro diversity combining will de discussed.

3.1 Frame Protocols and synchronization model

As depicted on the figure 3.1 the Frame Protocols (FP) are resided within the Iub User Plane. Their task is to deliver the actual traffic on the transport channels, i.e. user data and control information between the Node B and RNC. Therefore one peer entity of FP is located at the RNC side and another at the Node B.

In order to deliver FP PDU (Protocol Data Unit) between two peer entities Frame Protocols use the service provided by the transport layer in the form of *transport bearers* and *transport connections*. These two terms physically have the same meaning: the transport network resources allocated for the transport purposes on the particular transport channel. But logically they have two different applications. The term *transport bearer* represents the service provided by the transport layer and used by the DCH Frame Protocol for delivery of FP PDUs. The transport resources that are pooled by this term are quite dynamic in their nature, since they have to be allocated and deallocated each time when the dedicated UE connection is setup and released. From the Radio Network Layer this process is controlled by the NBAP protocol and from the Transport Network Layer – by the ALCAP. The *transport connections* on the contrary to the transport bearers are rather static, semi-permanent connections that serve the transport on the common transport channels such as FACH/ PCH, RACH, CPCH, and DSCH. Therefore the transport connections are used by the FP for those channels. Basically there is only one transport connection per common transport channel and it is connected with the corresponding transport channel data port, thus they are as many as the common transport channel data ports exist in the Node B. Transport connections does not require the exhaustive management performed by the ALCAP since they are setup only during the Cell setup procedures.

As it can be seen from the paragraph above, the idea of Frame Protocols is tightly tied with the concept of Transport Channels. Actually the Frame Protocol is the one, which is in charge of creating the content of the transport channel over Iub interface, i.e. the data stream to be transported over the given transport channel. Thus for each type of transport channel there is a certain sort of FP.

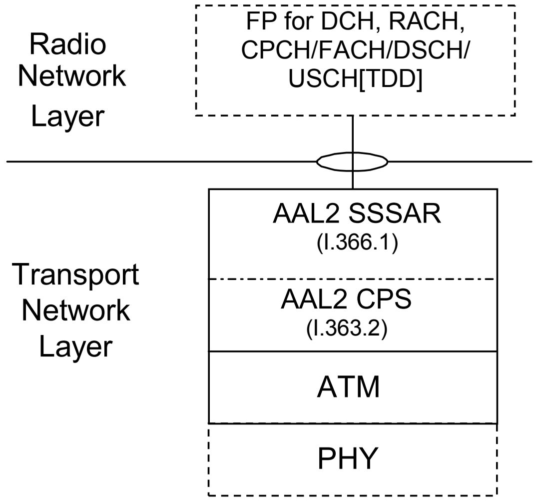


Figure 3.1. Protocol stack for DCH, RACH, CPCH, FACH and DSCH Iub data stream transport [9]

All the Frame Protocols are pretty similar in its structure, frame format and coding. They all provide basic service: the transport of TBS (Transport Block Set) between the Node B and CRNC, i.e. across the Iub interface. Herein we need to discover the terms Transport Block and Transport Block Set, since they are essential for the discussion about the Frame Protocols.

As stated in [10] the **Transport Block (TB)** is defined as the basic unit passed down to L1 from MAC, for L1 processing. (The L1 protocol represents the physical layer on the Uu interface.) An equivalent term for Transport Block is “MAC PDU”. If one takes a look at the figure 1.16 he/she could encounter the MAC protocol entities resided both at the RNC and Node B sides, but not presenting in the Iub interface protocol stack (figure 2.1). Actually, due to the UTRAN internal protocol structure and functional division, the MAC protocol is terminated at the RNC. Therefore there is no need to carry the MAC PDUs explicitly over the Iub interface. But that information must be somehow handed from the RNC to the Node B in order to pass it further towards the UE across the air interface. This is ensured by the Frame Protocols. As it will be shown in the next subsection describing frame structure and coding the Transport Blocks constitute the essential part of the frame's payload.

The **Transport Block Set (TBS)** in turn is defined as a set of *Transport Blocks* which is passed to L1 from MAC at the same time instance using the same *transport channel*. An equivalent term for Transport Block Set is “MAC PDU Set” [10].

Besides the transport of TBS across the Iub interface there is also some set of services that may be supported or may not be supported by the given FP depending on the Transport Channel it serves. That kind of services includes:

- Support of transport channel synchronization mechanism.
- Support of Node Synchronization
- Transport of outer loop power control information between the SRNC and the Node B.
- Transfer of DSCH Transport Format Indicator (TFI) from the SRNC and the Node B.
- Transfer of radio interface parameters from the SRNC and the Node B.
- Transfer of Rx timing deviation (for TDD mode only) from the Node B to the SRNC.

In fact all Frame Protocols are divided into two groups: FP for Dedicated Transport Channel data streams and FP for Common Transport Channels data streams. Since there is a single type of dedicated transport channels, DCH, there is only one FP representing that group, DCH FP. For common transport channel data streams following Frame Protocols exist: RACH FP, CPCH FP, FACH FP, and DSCH FP.

In order to provide the above mentioned services the FP performs the corresponding procedures. The following is the examples of protocol procedures in case of DCH FP, those are most relevant to the Transport Resource Management. The procedures are described in the same sequence as the corresponding services were enumerated above.

Data Transfer

This procedure is executed each time when there is some data to be transmitted. The data is organized in the form of frame with defined structure and transmitted every transmission time interval from the SRNC to Node B for downlink transfer, and from Node B to the SRNC for uplink transfer. Therefore data transfer is splitted into two procedures: Uplink Data Transfer and Downlink Data Transfer as shown on the Figures 3.2 and 3.3.

In this section we are not intending to describe each procedure in very details, for more information please refer to [11] and [12]. But from the transport management approach there should be noted couple of aspects.

Each transport channel has the set of characteristics defining the way in which the information is to be transferred on that given transport channel. This set is called **Transport Format,** it is defined in [10] as a format offered by L1 to MAC for the delivery of a *Transport Block Set* during a *Transmission Time Interval* on a *Transport Channel*. The combination of currently valid *Transport Formats* on all *Transport Channels* of an UE, i.e. containing one *Transport Format* from each *Transport Channel* is defined as a **Transport Format Combination (TFC)** that is identified by the Transport Format Combination Indicator.

The Transport Format has to be defined by the RNC for all transport channel when the transport bearer is setup and signaled to the Node B. As a part of the Transport Resource Management task this is ensured by the Application Protocols and namely NBAP at the Iub interface. For example there are two modes that can be used for the Uplink Data Transfer: *silent* and *normal mode*. The mode is selected by the SRNC and signaled to the Node B with the relevant NBAP procedure. Namely it is done by the Radio Link Setup or Radio Link Reconfiguration procedures. In details they will be described later on.

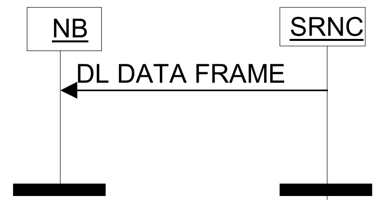


Figure 3.2 Uplink Data Transfer procedure Figure 3.3 Downlink Data Transfer procedure

Considering the Downlink Data Transfer procedure there is one aspect worth to note here not deepening into details, that in contrary to uplink transfer the downlink transfer requires the transport bearer synchronization. Before this synchronization has been achieved no data frame can be transmitted. The synchronization issues will be discovered later on in this section.

Timing Adjustment

The Timing Adjustment procedure is used to keep the synchronization of the DCH data stream in DL direction, i.e. to ensure that Node B receives DL frames in an appropriate time for the transmission of the data in the air interface. Actually the information is transmitted over the Uu (air) interface also in the form of frames (WCDMA frames) with the frame interval 10 ms. Thus in order to avoid buffering and hence improve efficiency the transport frames have to be synchronized in the downlink direction. This is the main purpose of the Timing Adjustment procedure.

In order to support Timing Adjustment there is an *arrival window* defined in the Node B. If a DL DATA FRAME arrives outside of that arrival window, the Node B sends the TIMING ADJUSTMENT control frame to the RNC containing the measured Time of Arrival (ToA) of that belated frame. Based on this RNC should adjust timing and send the next data frame so that it would arrive within the defined arrival window. In order to address the paticular frame each of them is assigned with the parameter called *Connection Frame Number*

(CFN). The **CFN** parameter is linked to the physical frame numbering and indicates at which time the user data should be transmitted over the radio interface or if it is a control frame at which time a specific event should be applied. Hence, the CFN provides the sequence integrity.

Herein there is a need to uncover the term **Time of Arrival (ToA)** as soon as we have mentioned it above. One could imagine this parameter as an absolute value representing the absolute time of the frame arrival. In reality it is not like this, ToA is rather relative parameter. It is defined as the time difference between the end point of the DL arrival window (ToAWE) and the actual arrival time of DL frame for specific CFN.

The ToAWE stands for the **Time of Arrival Window Endpoint**. It represents the time point by which the DL data or control frame shall arrive to the Node B from the Iub interface. In supplement to ToAWE there is another parameter called **Time of Arrival Window Startpoint (ToAWS).** As one may guess it represents the time after which the DL frame shall arrive to the Node B from Iub. These two parameters are set via the corresponding NBAP procedures (previously mentioned Radio Link Setup and Radio Link Reconfiguration) for each set of coordinated DCHs (and hence transport bearers) being setup.

DCH Synchronization

This procedure is used to achieve or restore the synchronization of the DCH data stream in Downlink direction. This is accomplished by the exchanging of the control frames between the RNC and the Node B.

The procedure is initiated by the SRNC sending a DL SYNCHRONIZATION control frame towards the Node B. Upon reception that Node B immediately responds with UL SYNCHRONIZATION contol frame inidicating the ToA for the DL SYNCHRONIZATION control frame and its CFN. Based on the received ToA the SRNC is able to adjust timing and upon that achieve synchronization.

Node Synchronization

Node Synchronization procedure is used by the SRNC to acquire information about the Node B timing. The idea herein is to compare the information about the time point at which RNC has sent the frame to the transport layer in effort to transfer it across the Iub interface and the time point at which the Node B has received that frame from the transport layer. And the same applied for the frame transfer in opposite direction. To resolve that task we need three parameters denoted as follows:

- T1: RNC specific frame number (RFN) that indicates the time when the RNC sends the control frame through the SAP (Service Access Point) provided by the transport layer.

- T2: Node B specific frame number (BFN) indicating the time when the Node B receives the correspondent control frame through the SAP from the transport layer.
- T3: Node B specific frame number (BFN) that indicates the time when the Node B sends the frame through the SAP to the transport layer.

The procedure is initiated by the SRNC sending a DL NODE SYNCHRONIZATION control frame to the Node B containing the T1 parameter. Upon reception of that frame the Node B immediately responds with UL NODE SYNCHRONIZATION control frame including the parameters T2 and T3 as well as the T1 indicating the initiating DL NODE SYNCHRONIZATION control frame.

For description of other procedures performed by the DCH FP such as *Outer Loop Power Control Information Transfer, Rx Timing Deviation Measurement, DSCH TFCI Signalling, Radio Interface Parameter Update* and *Timing advance* for TDD mode please refer to [11].

As it has already been mentioned the above presented procedure descriptions are valid only for the DCH FP, since it was taken as a descriptive example. In case of Common Transport Channel Frame Protocols the set of procedures (and thus data and control frames) remains the same, exept that some of control procedures may be or may not be supported by the given FP. The association between the transport bearer used by Common Transport Channel and the data/control frames it supports is presented on the Table 3.1.

In this table 'yes' indicates that the control frame is applicable to the transport bearer and 'no' indicates that the control frame is not applicable to the transport bearer.

Transport bearer used for	**Associated data frame**	**Associated control frames**						
		Timing Adjust-ment	**DL Transport Channels Synchroni-sation**	**Node Synchroni-sation**	**Dynamic PUSCH Assignment**	**Timing Advance**	**DSCH TFCI Signalling**	**Outer Loop PC Info Transfer**
RACH	RACH DATA FRAME	no	no	no	no	no	no	no
FACH	FACH DATA FRAME	yes	yes	yes	no	no	no	no
CPCH	CPCH DATA FRAME	no	no	no	no	No	no	no
PCH	PCH DATA FRAME	yes	yes	yes	no	no	no	no
DSCH	DSCH DATA FRAME	yes	yes	yes	no	no	no	no
USCH	USCH DATA FRAME	no	no	no	yes	yes	no	yes

Table 3.1. Association between transport bearer and data/control frame [11]

For detailed description of Common Transport Channel Frame Protocols please refer to [12].

As one may notice, in this section we used terms "*data frames*" and "*control frames*" defining the two types of frames that are traversing across the Iub interface. Their meaning is rather simple and conlcluded in their names. The purpose of the data frames is to transparently transport the transport blocks between the Node B and the SRNC. Data frames are used only in Data Transfer procedures and supported by each FP. All other procedures employ control frames as a transfer units. They are used to transport control information between SRNC and Node B. On the uplink these frames are not combined, they all are passed transparently from the Node B to the SRNC. On the downlink the same control frame is copied and sent transparently to all Node Bs belonging to the given SRNC.

The descrimination between the data and control types of the frame is defined by the frame structure discussed in the following subsection.

3.1.1 Frame structure

The general structure of FP frame consists of a header and a payload. Its general view is presented on the figure 3.4

Header	Payload

Figure 3.4 General structure of a Frame Protocol PDU

The header defines the frame type (data frame or control frame), above that it contains the CRC checksum and the frame type related information.

The payload is obviously different for the data and control frames. The payload of the data frames may include radio interface user data, quality information for the transport blocks and for the radio interface physical channel during the transmission time interval (for UL only), and an optional CRC field. The control frames in turn contains commands and measurement reports related to transport bearer and the radio interface physical channel.

The specific frame format employed by different Frame Protocols as well as by procedures related to one FP differ from each other, but they all obey to the general notation defined on the Figure 3.5

When transmitting information over the Iub interface such kind of structure is aligned into a bit stream and the frame is transmitted starting from the lowest numbered byte. Within each byte, the bits are sent according to decreasing bit position (bit number 7 first).

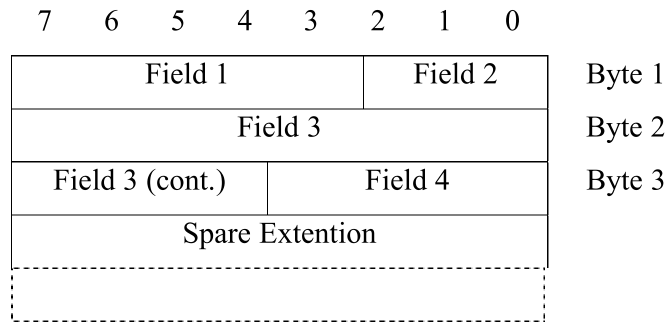
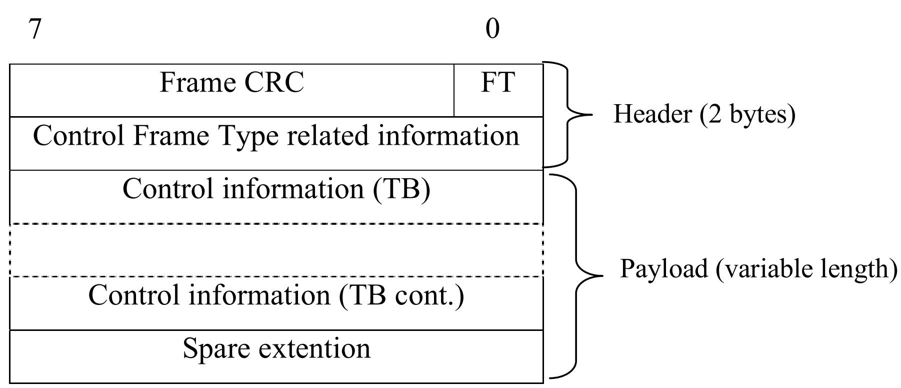


Figure 3.5. Example of notation used for definition of the frame structure [11]

As it was noted all the data and control frames belonging to different Frame Protocols are different. The precise information about them can be found in [11] and [12]. The following two figures give the generalized view at the data and control frames.

In the frame structures presented on these two figures the manadatory bit FT (Frame Type) is the one, which discriminate between the two frame types. The FT set to '0' defines the data frame type, otherwise set to '1' represents control frame type.



Fugure 3.6. General structure of the control frame

The Frame type related information in both control and data frames may include such parameters as CFN, Transport Format Identification (TFI) – a label for a specific *Transport Format* within a *Transport Format Set*. Above all TFI defines the size and the number of Transport Blocks in the frame. The QE stands for Quality Estimate. This parameter is derived from the Transport channel BER (Bit Error Rate). It is mandatory for data frames, control frames may also use it.

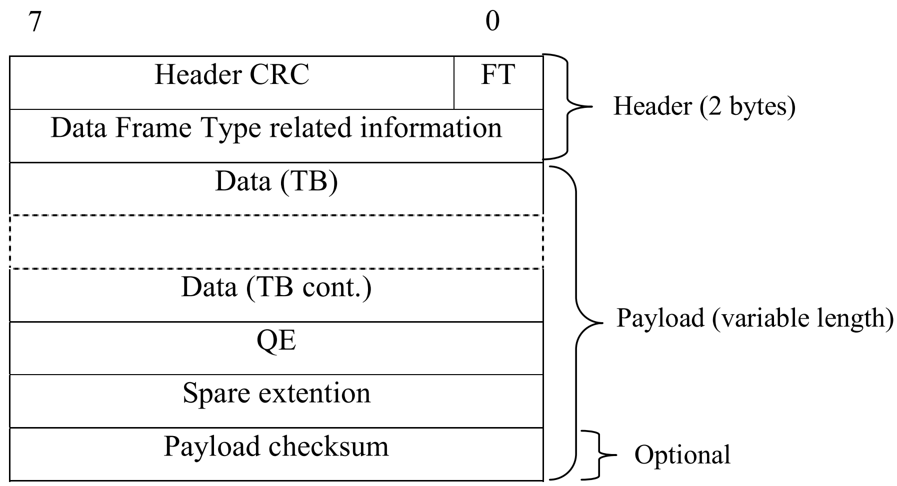


Figure 3.7. General structure of the data frame

The above presented subsection was aimed to give the reader merely rough overview about the way how the user information is handled on the Radio Network Layer. Further on it is passed to the transport network and transmitted across the Iub interface. Since the transport technology is of the arbitrary choice, due to the generic UTRAN interface model concepts, from the Radio Network Layer point of view the transport technology as such does not affect on the transport resource management tasks, these tasks have rather generic character. This phenomena is guaranteed, as it was also mentioned previously, by the Transport Network Control Plane and in particular ALCAP protocol. On that level the transport resource management tasks have more specific nature and conducted in accordance with the transport technology employed. Thus there are different levels of transport resource management functionality embracing all layers from Network to Physical layer. In such a way the decribing them all is a rather huge study and does not have a sense in case of rapidly changing and evolving view on the transport technology in UTRAN. Therefore in this thesis we try to discover rather general principles and components of the Transport Resource Management over the Iub interface mostly from the Radio Network point of view. But at the same time we cannot avoid issues tied with the currently adopted transport technology (meaning ATM with AAL(n)), thus must present at least general overview of the interaction nature and basic mechanisms within the Transport Network Layer in the aggregate with the Iub interface as a whole. Actually this is the one of the objectives being pursued in this section and the chapter as well.

3.1.2 Synchronization model in the UTRAN

As it has been already mentioned in the above presented subsection in effort to achieve the efficient utulization of transport and as a consequence WCDMA radio resources the processing of control and user plane information needs to be synchronized in different network elements.

Synchronization is used to minimize the required buffers in the network elements and the resulting queuing delays that are in a direct relation to the overall resource utilization efficiency and delay perceived by the user of a service.

The [13] identifies the different UTRAN synchronization issues:

- Network Synchronization;
- Node Synchronization;
- Transport Channel Synchronization;
- Radio Interface Synchronization;
- Time Alignment Handling.

The nodes involved in the above mentioned synchronisation interactions are shown by the synchronisation issues model on the figure 3.8.

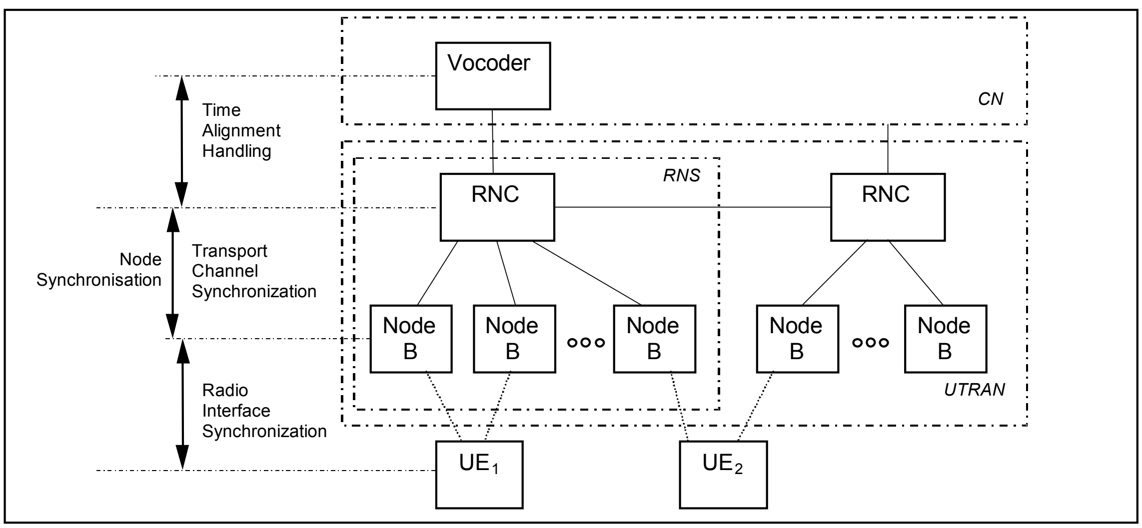


Figure 3.8. UTRAN Synchronization model [13]

As it's seen from the picture the RNS, and thus the Iub interface, directly involved in two synchronization issues, the Transport Channel Synchronization, or as it is often referred to as a Frame Synchronization and Node Synchronization. Therefore the transport resource management tasks over Iub interface are responsible only for that kinds of synchronization.

The Transport Channel Synchronization is achieved by performing the DCH FP *DCH Synchronization* procedure (or *DL Transport Channel Synchronization* in case of common transport channel FPs), and Node Synchronization correspondingly by the FP *Node Synchronization* procedure. These procedures were discovered previously in this section.

Following is the brief description of the synchronization issues in the UTRAN.

Time Alignment Handling synchronizes the transfer of information between the diversity handover unit in RNC and vocoders or interworking functions in CN. It adapts to the used data framing, and minimizes the delay in between by sending and receiving frames just in time for processing.

The Radio Interface Synchronization relates to the timing of the radio frame transmission. In FDD mode it is necessary to assure that the UE receives radio frames synchronously from the different cells, in order to minimize UE buffers. This especially relates to the macro-diversity case when there is a need to buffer out the transport delay difference of the branches. The Frame Protocol frame indicates the start of the radio interface transmission time by the Connection Frame Number (CFN) for each transport channel frame, and this indication is executed per transport channel frame. The radio interface transmission time is defined as a Cell System Frame Number (SFN). Then the mission of the Node B is to determine the mapping between CFN of a FP frame and SFN of a radio frame.

The Node Synchronization relates to the estimation and compensation of timing differences among UTRAN nodes. The Iub interface implies the "RNC-Node B" synchronization. It allows to get knowledge of the timing differences between the RNC and its Node Bs. Its use is mainly for determining good DL and UL offset values for transport channel synchronization between RNC and their Node B's. Knowledge of timing relationships between these nodes is based on a measurement procedure called *Node Synchronization* procedure. The procedure is defined in the user plane for Iub DCH FP, DSCH FP, and FACH FP. For information about this procedure see above.

The Transport Channel Synchronization mechanism defines synchronization of the frame transport between RNC and Node B, considering radio interface timing. It ensures that the same Transport Blocks are sent from the involved Node Bs towards one UE in the downlink direction, and the same blocks sent by one UE and received by different Node Bs are combined in RNC in the uplink direction. It is implemented via Frame Protocol's *DCH Synchronization* procedures over Iub interface. The Frame Protocols are also used to minimize the delay between the optimal arrival time of a Transport Block (Set) and the actual measured arrival time in the Node B in the downlink direction. The actual arrival time can be adjusted by either advancing or delaying the sending time of the frame from RNC. The optimal arrival time is the radio interface transmission time reduced by a processing time of the block in Node B. The Serving RNC controls the timing adjustment for both dedicated and common transport channels. For the information about the realization of Transport Channel Synchronization see above, the description of the FP procedures.

The presented material is rather brief overview of the UTRAN synchronization model, for more information about all the synchronization issues in the UTRAN please refer to [13].

3.2 Macro Diversity Combining

In the previous section we discussed a lot about the splitting and combining of transport frames during the Macro Diversity handling. From the Transport Resource Management point of view it would be interesting to take a close look at the way how it is done on the ATM transport level. This objective is pursued by this section.

Here we assume that the reader is familiar with the basic Macro Diversity principles, since they have been discussed in the Section 1.2.2. In fact the Macro Diversity feature as such relates to the Radio Resource Management, which is the subject of the separate study. Therefore the aim of this section is to discover what kind of interactions on the transport level is required for performing the Macro Diversity combining.

The Macro Diversity Combining is executed during the WCDMA soft handovers. It means that the separate radio channels (legs) are combined to one transport channel in the network in uplink direction and in the UE in downlink direction in effort to produce the maximum obtainable quality. The status of particular radio frame is indicated to the Macro Diversity Combining (MDC) entity (i.e. good or bad frame) and the MDC chooses the frame with the best quality or take the sum of all frames (with the equal SFN) to be processed further. These status (control) frames are transferred via inband signalling (i.e. within the FP control frames). The MDC operation is rather simple from the processing perspective, but may require quite large amount of memory in case the frames are long and/or bit rates are high. Figure 3.9 shows the principle of the MDC.

As it was mentioned above in macro diversity depending on quality of signals received from different legs they will be processed by some form of combining algorithm. The algorithm may be based on selection of the signal from the leg with the best quality measure (e.g. signal to noise ratio) or may add the signals from all legs weighed by the quality measure on each leg. In fact, depending on how a UE roams, it may remain in the macro diversity mode for an arbitrary period of time. During that time the signal quality measured on each leg could be continuously changing.

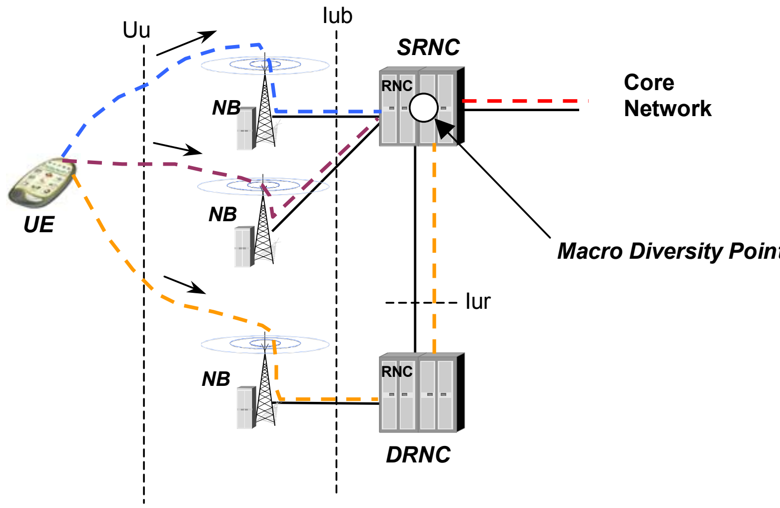


Figure 3.9. Macro Diversity Combining in RNC [1]

For physical realisation of combining algorithm at the macro diversity point there should be an separate physical unit basically reffered to as a *MD Combiner* (in fact the same is applied for the MD Splitter). The simplified architecture is presented on the figure below.

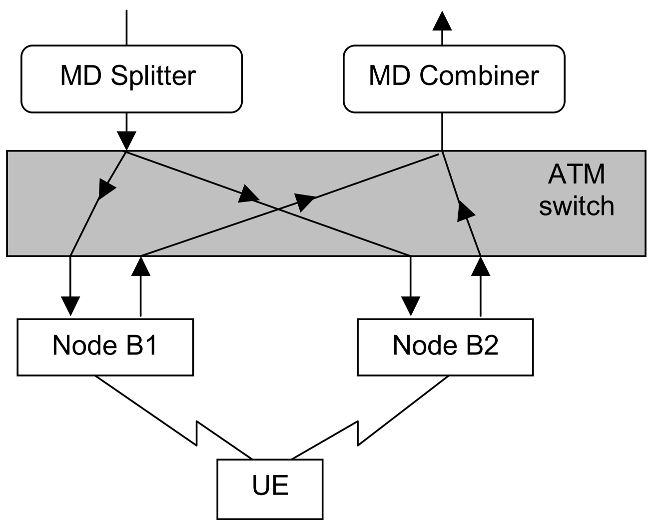


Figure 3.10. ATM Switch support of Macro Diversity

The role of MD Splitter depicted on the figure is to multicast data in downlink direction over separate ATM virtual channels or use multicast facilities within the ATM switch. In that case the ATM cell header might be different for each Node B. Identical radio frames must be extracted and aligned to arrive at the UE at the same time. In order to guarantee this the frame synchronization is used (see the Transport Channel Synchronization above).

Now lets take a closer look at the MD combining process on the example of possible ATM switching architecture in the RNC. Such kind of RNC structure is presented on the figure 3.11.

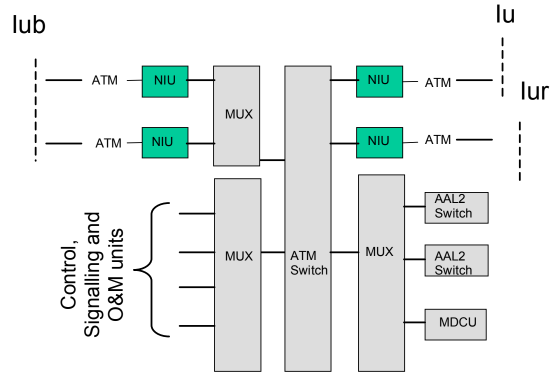


Figure 3.11 ATM/AAL2 switching architecture of the RNC

The presented picture employes the following main switching and processing units:

- Network Interface Unit (NIU), performs the physical layer processing, Inverse Multiplexing for ATM and ATM layer processing;
- Multiplexer (MUX), participates in ATM layer processing and Traffic management;
- ATM Switch, the backbone switching element, directly performing the ATM cell switching;
- AAL2 Switch, performes the AAL2 termination and switching;
- Macro Diversity Combining Unit (MDCU), responsible for Macro Diversity combining, ciphering, Power Control and Frame Protocols.

Now lets simulate the macrodiversity case when the RNC receives the copy of the same signal via three different legs, as depicted on the figure 3.9. The process of macrodiversity combining is divided into four steps:

1. switching of UE originated data flow over Iub and Iur,
2. establishment of internal connection to the dedicated Macro Diversity Combining (MDC) unit,
3. Macro Diversity Combining,
4. establishment of egress connection over Iu.

UE originated data flow over Iub and Iur interfaces

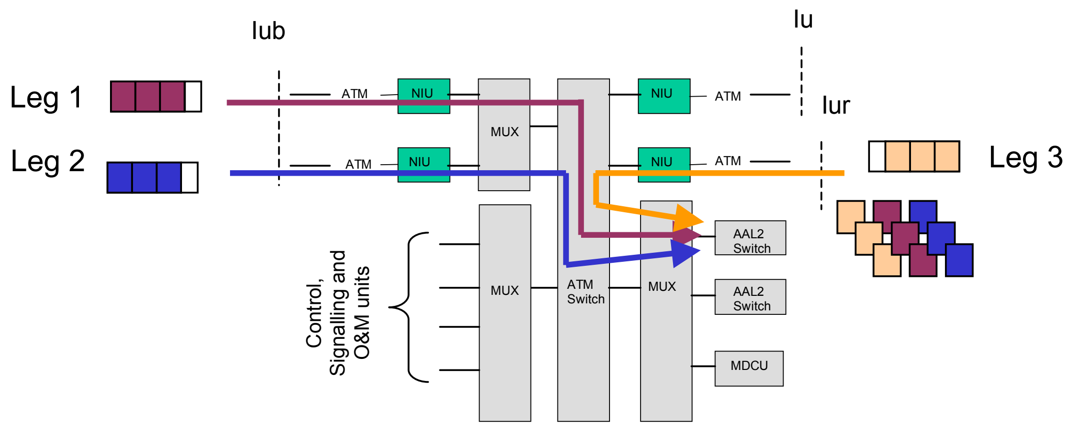


Figure 3.11.1. Switching of UE originated data flow over Iub and Iur

The RNC receives three copies of frame via three legs. For transmission the ATM/AAL2 connection are used. The received ATM cells are always switched through MUX and ATM Switch to a dedicated AAL2 unit (AAL2 Switch) on a cell-by-cell basis without any changes in the ATM payload.

Internal connection to the dedicated MDC unit

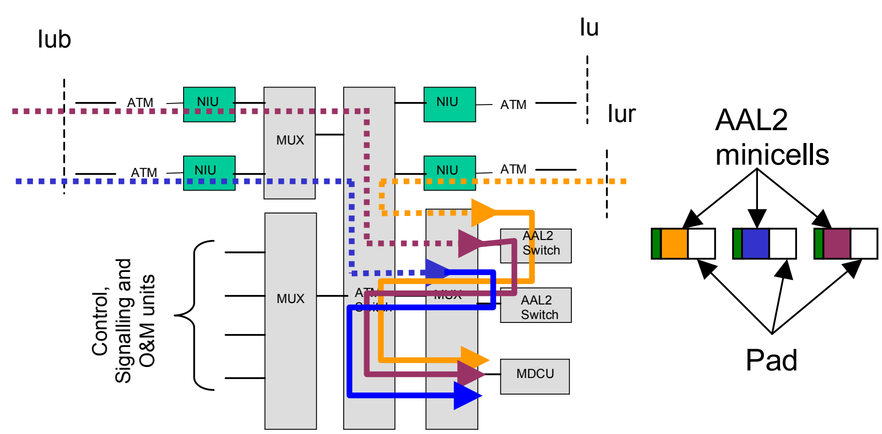


Figure 3.11.2. Establishment of internal connection to the dedicated MDC unit

Then the AAL2 packets (minicells) are demultiplexed in the AAL2 Switch. Each minicell is packed into one or several ATM cells and transmitted over internal connections towards the dedicated macrodiversity combining unit (MDCU). It should be noted that the AAL2 switching is done only in the AAL2 Switch functional unit, all other elements perform switching at the ATM level.

Macro Diversity Combining

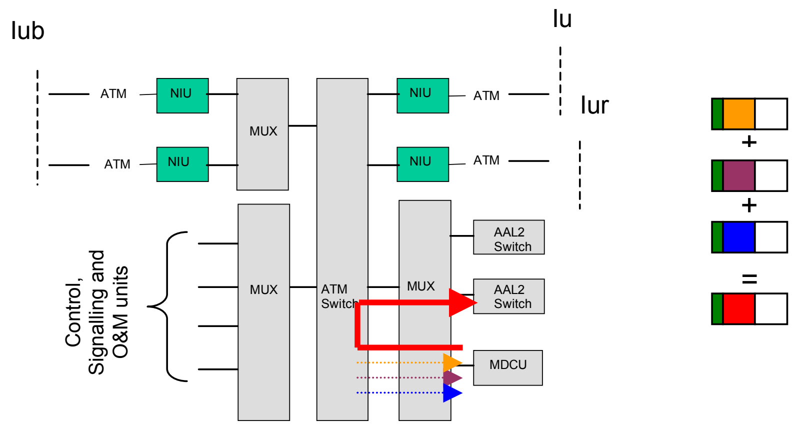


Figure 3.11.3. Macro Diversity Combining

Macro Diversity Combining is performed in the MDCU. In practice the signals carried in the AAL0/5 cells – each carrying a single AAL2 minicell – are combined according to the specific algorithm. After signal combining, a single AAL0/5 cell is transmitted to one of the AAL2 Switching units for external transmission towards the core network.

Establishment of egress connection over Iu

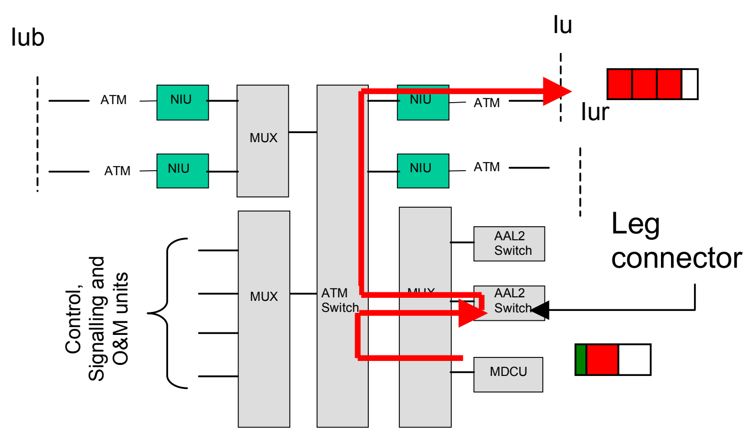


Figure 3.11.4 Establishment of egress connection over Iu

Now the outgoing leg is established from NUI to AAL2 Switch. The AAL2 Switching unit takes care of AAL2 multiplexing to ensure that the external transmission resources are utilised as efficiently as possible. A leg connector maps the internal connection from the MDCU to the outgoing leg. Now the combined frame is ready to traverse further, towards the core network.

Note: the RNC architecture is highly vendor depending solution, thus the ATM/AAL(n) switching and concrete MDC unit implementation might be realised in different ways. Here the merely demonstrative example of RNC is presented in order to show the basic principles of macrodiversity combining within RNC.

Through the whole discussion about the Transport Resourse Management we have been talking a lot about the the ATM technology and its place in the UTRAN interfaces. But in order to clearly understand what the transport resources are as such regarding to the employed technology one has to be aware of its basic principles and mechanisms. The next section is aimed to give the reader some overview of the ATM together with its AALs as transport technology.

3.3 ATM stack and adaptation layers

3.3.1 Basic concepts of ATM

ATM is a cell switched, connection-oriented networking technology that provides dedicated, high-speed connections to virtually an unlimited number of users. It operates on a cell-based fast-packet communication method that supports transfer rates from 1.544 Mbps to 10 Gbps. Dedicated media connections running in parallel allow an ATM switch to simultaneously support multiple conversations, eliminating the bandwidth contention and data bottlenecks found on shared-media networks such as Ethernet, Token Ring and FDDI.

Because of its asynchronous nature, ATM is more efficient than synchronous technologies, such as *time-division multiplexing (TDM)*. With TDM each user is assigned to a time slot, and no other one can send in that time slot. If a station has much data to send, it can send only when its time slot comes up, even if all other time slots are empty. However if a station has nothing to transmit when its time slot comes up, the time slot is sent empty and wasted. Because ATM in contrary to TDM is asynchronous, there is no strict assignment between users and time slots, rather the time slots are available on demand with information identifying the source of the transmission contained in the header of each ATM cell.

What is the ATM cell? The cell in ATM is the fixed-size packet, which serves as a information transfer unit over ATM networks. Each cell consists of 53 octets (or bytes) shared between 5-byte-long header and remaining 48-byte-long payload. Why 53 bytes? A large payload is advantageous since more data can be sent with fewer overheads wasted on unneeded headers. Also payloads are traditionally sized in powers of 2. The original proposed sizes for the ATM payload were 32 and 64 bytes. Keeping a small payload increases speed and is ideal for delay sensitive data such as voice communications. Having a large 64 byte payload is better for transferring large amounts of data, but in voice communications problems with echo occurred. So 48 bytes was decided as a compromise, this with a 5 byte header (which contains address and other pertinent information) makes for the magic number 53. The structure of ATM cell is presented on the Figure 3.12.

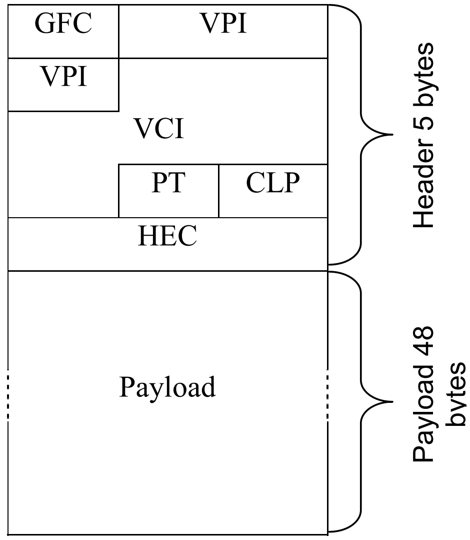


Figure 3.12 ATM cell structure

The most important information that the header contains is the VPI and VCI. They both in conjunction define the next destination of a cell as it passes through a series of ATM switches on the way to its destination.

VCI and VPI identify two basic types of ATM connections: *virtual paths* and *virtual channels*. Their meaning is concluded in the definition of the ATM as a fundamentally connection-oriented technology, which means that a virtual channel (VC) must be set up across the ATM network prior to any data transfer. Therefore the ATM may be viewed as providing the service to the user in the form of Virtual Channel connection. In practice there are two types of such kind of ATM service exist: *Permanent Virtual Circuits (PVC)* and *Switched Virtual Circuits (SVC)*. The difference between them is that PVC is setup manually and allows the direct connectivity between sites, in this way a PVC is similar to a leased line. A SVC in contrary is rather dynamic connection. It's established and released automatically and remains in use only as long as data is being transferred. In this sense it is similar to telephone call.

In such a way the ATM connections are organized in the forms of virtual paths and virtual channels. (A virtual channel is roughly equivalent to a virtual circuit.)

A virtual path is a bundle of virtual channels, all of which are switched transparently across the ATM network based on the common VPI. All VPIs and VCIs, however, have only local significance across a particular link and are remapped, as appropriate, at each switch. In that way the VPs are incorporates in VCs that in their turn are pooled in a transmission path, representing the physical media. The process of concatenation is shown on the Figure 3.13.

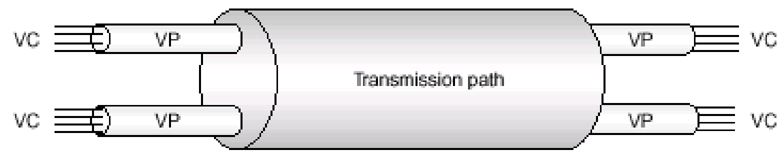


Figure 3.13 VCs concatenate to create VPs [33]

The ATM was developed by the ITU-T as an open strandard. In this role it uses the logical model to describe the supporting functionality that conforms to the OSI reference model. This model and its mapping to the OSI architecture is presented on the figure 3.14.

The model consists of three planes which span all layers:

- *Control* – This plane is responsible for generating and managing signalling requests.
- *User* – This plane is responsible for managing the transfer of data.
- *Management* – this plane manages the layer specific functions as well as coordination functions related to the complete sysyem.

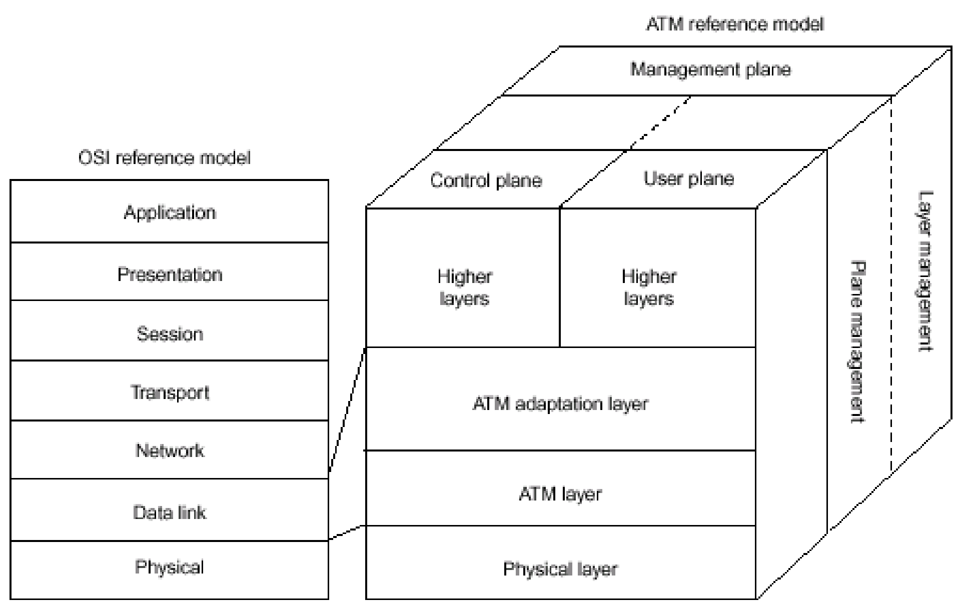


Figure 3.14 ATM reference model mapped to OSI model [14].

In the other dimention the ATM reference model is splitted on the following layers:

- **Physical layer** – Similarly to the physical layer of the OSI model, the ATM physical layer manages the medium-dependent transmission.
- **ATM layer** – It's responsible for the simultaneous sharing of virtual circuits over a physical link (cell multiplexing) and passing cells through the ATM network (cell

relay). To do this it uses the VPI and VCI information from the header of each ATM cell.

- **ATM Adaptation Layer (AAL) –** The AAL is responsible for isolating higher-layer protocols from the details of the ATM processes. The adaptation layer prepares user data for conversion into cells and segments the data into 48-byte cell payloads.
- **Higher layers –** Accept user data, arrange it into packets and hand it to AAL.

The ATM layer as such consists of fairly simple transport media and is just used for transmission purposes as such. Thus it will not be described within this theses. Much more interest represent the ATM adaptation layers providing the immediate transport services to the user and control plane protocols (in our case to the Radio Network Layer protocols).

3.3.2 ATM Adaptation Layers

The ATM adaptation layer (AAL) segments upper-layer user information into ATM cells at the transmitting end of a virtual connection and reassembles the cells into a user-compatible format at the receiving end of the connection. In such a way the AAL plays the role of adapter between higher layer protocols and the ATM layer. In this role the AAL can be regarded as the single most important element of the ATM architecture. It is the AAL that provides the means to handle different types of traffic, ranging from the continuous voice traffic to the highly bursty packet traffic.

How AAL processes are carried out depends on the type of traffic to be transmitted. Different types of AALs handle different types of traffic, but all traffic is ultimately packaged by the AAL into 48-byte segments for placement into ATM cell payloads. The ITU-T has defined what are called ATM service classes with AAL. Its basic idea is to specify service classes each to be provided by one AAL. The following Table 3.2 represents the traffic classes corresponding to different AALs.

The AAL performs two main functions in service specific sublayers of the AAL:

- A convergence function in the convergence sublayer (CS)
- A cell segmentation and reassembly function in the segmentation and reassembly sublayer (SAR).

Traffic Class	Source & Destination	Connection	Bit Rate	Typical Use
Class A (AAL1)	Synchronised	Connection-oriented	Constant	Fixed Connection
Class B (AAL2)	Synchronised	Connection-oriented	Variable	Audio & Video
Class C (AAL3/4)	Not Synchronised	Connection-oriented	Variable	Frame Relay
Class D (AAL5)	Not Synchronised	Connectionless	Variable	Packet-switched services

Table 3.2 ATM traffic classes supported by AAL

The purpose of these two sublayers is to convert user data into 48-byte cell payloads at the same time maintaining the integrity and identity of the user data. They are briefly described below:

Convergence sublayer (CS). The CS provides appropriate traffic services to higher layer protocols.

Once connection is established between communicating ATM entities with an appropriate quality of service (QoS), the CS accept higher level traffic for transmission through the network. Depending on the traffic type certain header and/or trailer fields are added to the user data payload and formed into information packets called convergence sublayer protocol data units (CS-PDUs). These packets are passed further to the segmentation and reassembly sublayer (SAR) of the AAL for further processing.

Segmentation and Reassembly (SAR) sublayer. The SAR segments each CS-PDU received from the CS into smaller units and adds a header and/or trailer field, depending on the traffic type, to form 48-byte payloads called segmentation and reassembly sublayer protocol data units (SAR-PDUs). The generalized processes through which the user data stream is transformed into appropriate ATM data units are illustrated in figure 3.15.

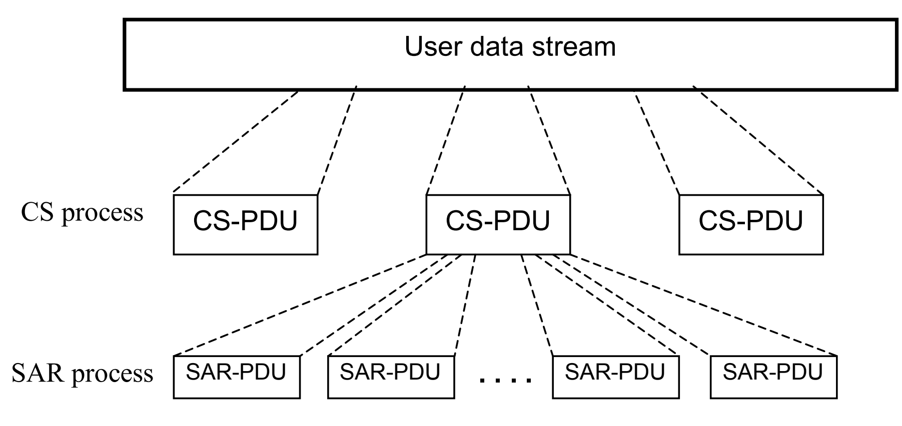


Figure 3.15. Data processing relationships in AAL

Once the user data is arranged into SAR-PDUs by the AAL layer, they are passed to the ATM layer which packages the data into 53-byte ATM cells, making them suitable for transport as outgoing ATM cells by the physical layer, as indicated in figure 3.16.

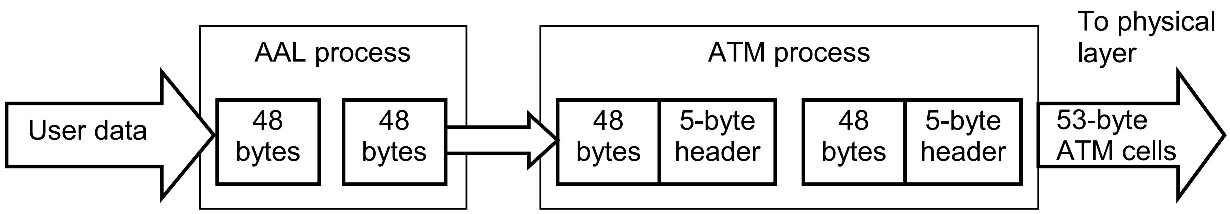


Figure 3.16. Arranging ATM data for transport by physical layer

Conversely upon receiving of incoming ATM cells from the physical layer, the AAL removes any AAL specific information from each cell payload and reassembles the packet for providing to higher layer protocols in the form expected by the user application.

As it was stated, for different types of traffic the different AALs are used, see table 3.2. In practice, the ATM together with particular AAL can be used in different network applications. It was naturally specified as a high-speed transfer technology for voice, video and data over the public and private networks (e.g. LANs and WANs). But in this thesis we concern ATM/AAL technology only from the telecommunication use perspective, particularly its use within the UTRAN. Therefore it's worth to concentrate on the two types of AAL employed by the Iub interface as a part of UTRAN, AAL2 and AAL5.

3.3.2.1 ATM Adaptation Layer 2

The ATM Adaptation Layer 2, AAL2, has recently been defined in the ITU-T. It provides both high efficiency and low delay in the use of bandwidth resources, keeping the low complexity. User application packets of variable length can be transported in an AAL2 connection and it is ideal for carrying compressed voice and low bit rate data. Importantly, AAL2 provides the capability to multiplex application packets from different user connections over the same ATM connection.

The AAL2 is subdivided into two layers, the **Common Part Sublayer (CPS)** and **the Service Specific Convergence Sublayer (SSCS)**, please refer to figure 3.17. The general division into Convergence Sublayer (CS) and the Segmentation and Reassembly (SAR) functionality is not visible in AAL2 architecture, rather the standard merged the SAR and Common Part Convergence Sublayer (CPCS), being the part of CS, to the CPS.

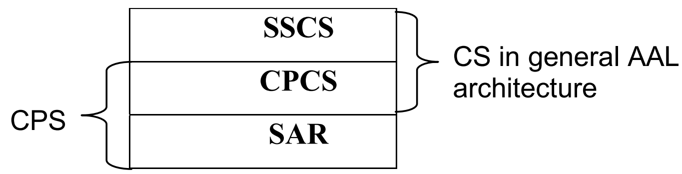


Figure 3.17. AAL2 protocol stack

The Common Part Sublayer of AAL2 (AAL2-CPS) was proposed to adapt the powerful capabilities of ATM to the traffic requirements of low and variable bit rate applications such as compressed voice used in cellular environments. AAL2-CPS achieves both low packetization delay and high bandwidth efficiency by:

a) allowing variable packet length, from 1 octet to 45 octets.
b) multiplexing several AAL2 connections in an ATM virtual channel connection (VCC).

Point a) allows easy control of the packetization delay by letting the application choose the most convenient maximum packet size for its delay requirements. The lower the size the lower the delay. Point b) allows efficient use of bandwidth resources. Instead of having user data partially filling an ATM cell, AAL2-CPS will fill the cell with AAL2 packets from several active AAL2 connections.

There are two different message formats in AAL2 that have to be distinguished, the CPS packet and the CPS Protocol Data Unit (PDU), which is then mapped to an ATM Service Data Unit (SDU). The AAL2-CPS packet format is shown in figure 3.17.

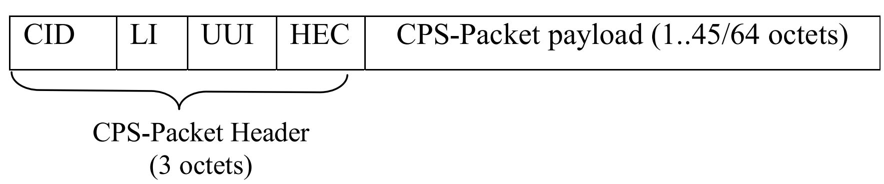


Figure 3.18. AAL2-CPS packet format

The CPS packet consists of 3 octets header and up to 45 octets payload. The actual length of the payload is indicated in the "length indicator" (LI) field. A "user-to-user information" (UUI) field has been included for upper layers (users) to transparently convey information (e.g. some SSCS use it to convey a sequence number and/or the type of voice-codec used). An 8 bits "connection identifier" (CID) identifies individual AAL2 connections inside an AAL2 link (ATM VCC set up for transport of AAL2 traffic). Finally, the 5 bits CRC field protects the AAL2-CPS packet header from transmission errors (the payload is not protected).

The CID provides for multiplexing up to 248 AAL2 connections in a single ATM VCC. This is done at the CPS, which multiplexes CPS packets from several AAL2 connections inside the payload of the ATM cell of the AAL2 link. Each ATM cell is filled with packets from one or more user, such as voice packets and/or data packets. In order to avoid unnecessary padding and thereby maximizing the efficiency, the AAL2 packet can be split over two ATM cells. The basic principle is shown in the figure below.

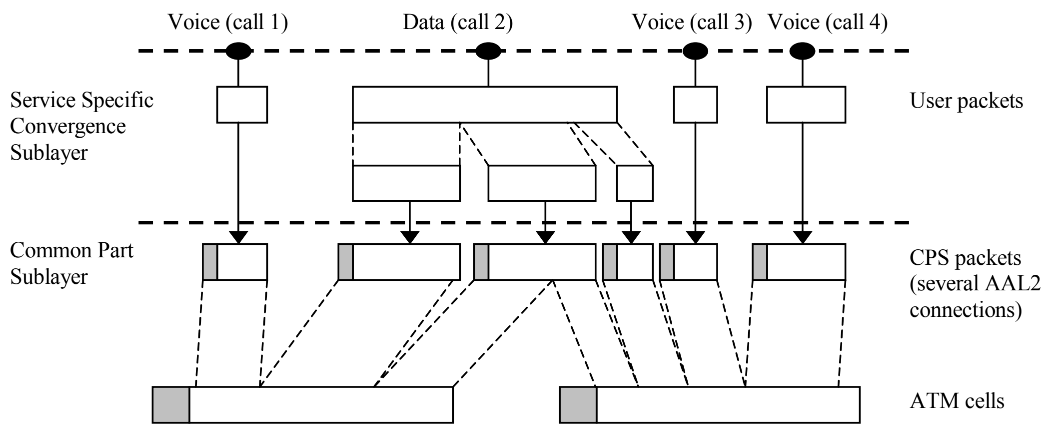


Figure 3.19. AAL2-CPS multiplexing

Delineation of AAL2-CPS packets inside an ATM cell is done by the CPS PDU "start field" (SF) and the LI of CPS packets. The process is shown in figure 3.20. The SF is one octet long and is like the header of a CPS PDU (although it is not referred as that in the standards). AAL2-CPS PDUs are all 48 octets long, so they fit perfectly inside the ATM cell payload. The SF contains the offset to the starting point of the first AAL2-CPS packet that starts transmission inside the current AAL2-CPS PDU (ATM cell). A one bit sequence number (SN) and a parity bit (P) provide basic mechanisms for identifying cell loss and errors in the SF field respectively.

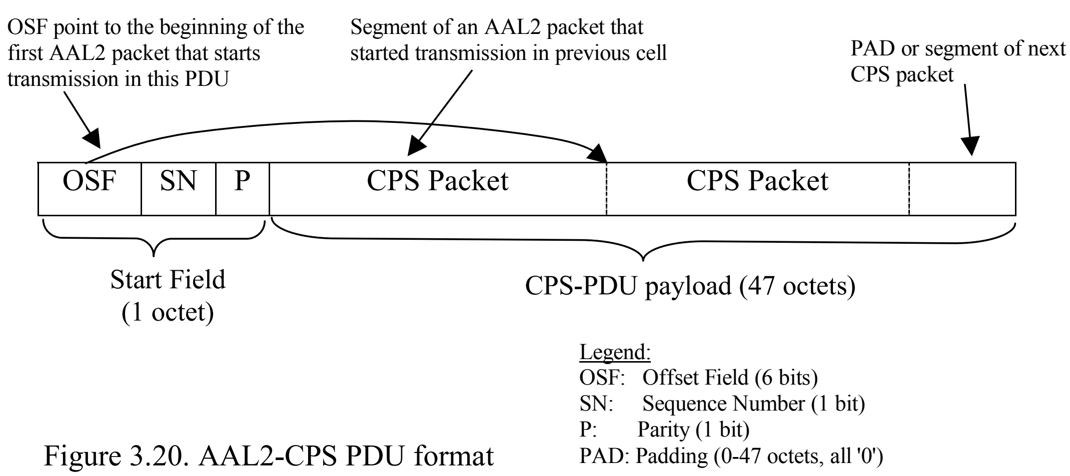


Figure 3.20. AAL2-CPS PDU format

The AAL2 can be used by many low bit rate and VBR (variable bit rate) applications without the assistance of an SSCS if they generate data in a way that can be directly inserted inside AAL2-CPS packets. However, many applications either generate data in a way that AAL2-CPS can not be directly used (i.e. packets longer than 45 octets) or require services not provided by the AAL2-CPS (like error protected payload or protection against packet loss). In these cases an SSCS is needed as interface between the user of the AAL2 and the AAL2-CPS.

3.3.2.2 ATM Adaptation Layer 5

In previous subsection it was shown that the AAL2 provides good mechanism for achieving high bandwidth efficiency for low bit rate and VBR applications. But its efficiency is restricted by a user packet's length. I.e. for transmitting long packets (longer than 45 octets) the user may choose either AAL2 (through its segmentation SSCS) or AAL5, which was explicitly specified for long packet data. It is known that for small packets (up to a few hundred octets) AAL2 is more efficient than AAL5 while for long packets AAL5 is definitely recommended. Regarding to our problem domain, the reader will make certain that the Application Protocols PDUs, being exchanged between the control plane protocols over Iub interface, might by of a relatively large size (up to hundreds of Kbytes). Therefore the AAL5 was chosen by the 3GPP as an Iub signalling transport.

Originally AAL5 was intended to be used for broadband data services over ATM. Its protocol stack is of rather generic nature (as defined for common AAL structure). I.e. it consists of Convergence Sublayer (CS), subdivided into SSCS and CPCS, and the Segmentation and Reassembly (SAR) sublayer. Basically they play the similar role as in case of AAL2.

Although AAL5 is simple, it does not support multiplexing and thus AAL5 PDUs must be padded so as to be aligned to an integer number of ATM cells, as illustrated in the figure below.

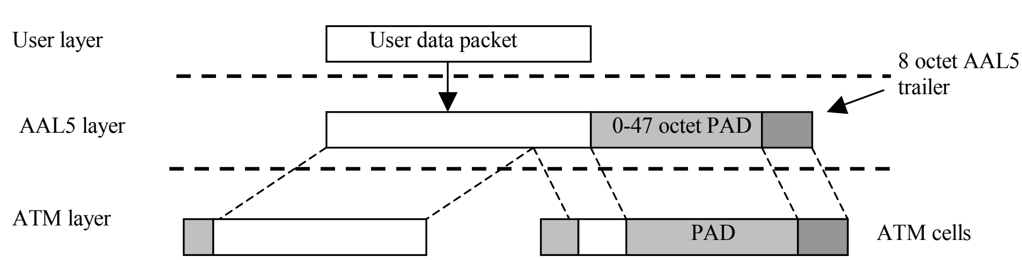


Figure 3.21. AAL5 cell assembly

From the point of view of performing transport resource management tasks over the Iub interface the AAL5 connections used as a signalling transport for application protocols are rather static and permanent ones, thus they do not require the continuous management. Therefore AAL5 is not described in very details herein and will not be concerned further in this thesis.

On the other side, the AAL2 connections employed by the user plane protocols are very dynamic transport resources and therefore require continuous management. Since the AAL2 connection is dedicated to the particular UE connection, it must be allocated when the UE initiates the connection with the URAN and then released when the connection is terminated. This caused the need for Transport Network Control Plane, as it was described earlier, and the ALCAP protocol, responsible for controlling setup, reconfiguration and release of AAL2 transport bearers. The next chapter is aimed to give an overview of the ALCAP protocol.

3.4 ALCAP protocol

The ALCAP stands for the Access Link Control Application Part, and its a rather generic name denoting the certain signalling protocol to be used on the top of Transport Network Control Plane. In case of Iub interface the role of ALCAP is played by the AAL2 Signalling Protocol specified in the ITU-T Recommendation Q.2630.1, please refer to the figure 2.1.

The Q.2630.1 Recommendation [5] describes the AAL2 signalling protocol that supports the dynamic establishment and release of individual AAL2 point-to-point connections. It also describes the maintenance procedures, the protocol framework and interaction between the entities of AAL2 signalling functional architecture. Such kind of architecture is illustrated in the figure 3.23.

The functional architecture basically consists of two signaling nodes representing the endpoints of AAL2 connection to be established. To accomplish that these two AAL2 service endpoints exchange AAL2 signalling messages. In fact there is no direct point-to point connection between two given endpoint, rather they are part of one ATM network, as illustrated in figure 2.4. This fact implies the need for the switching element, AAL2 switch that routes the signalling messages to the destination endpoint.

According to the OSI reference model the protocol architecture at each AAL2 service endpoint (or switch) is organized in the form of stack. In order to ensure the logical peer-to-peer communication two sublayers exchange the primitives. There are four types of primitives that can be exchanged, as described in figure below.

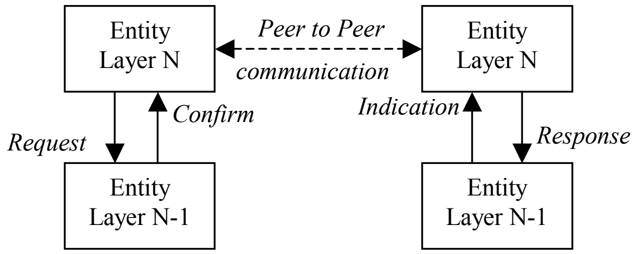
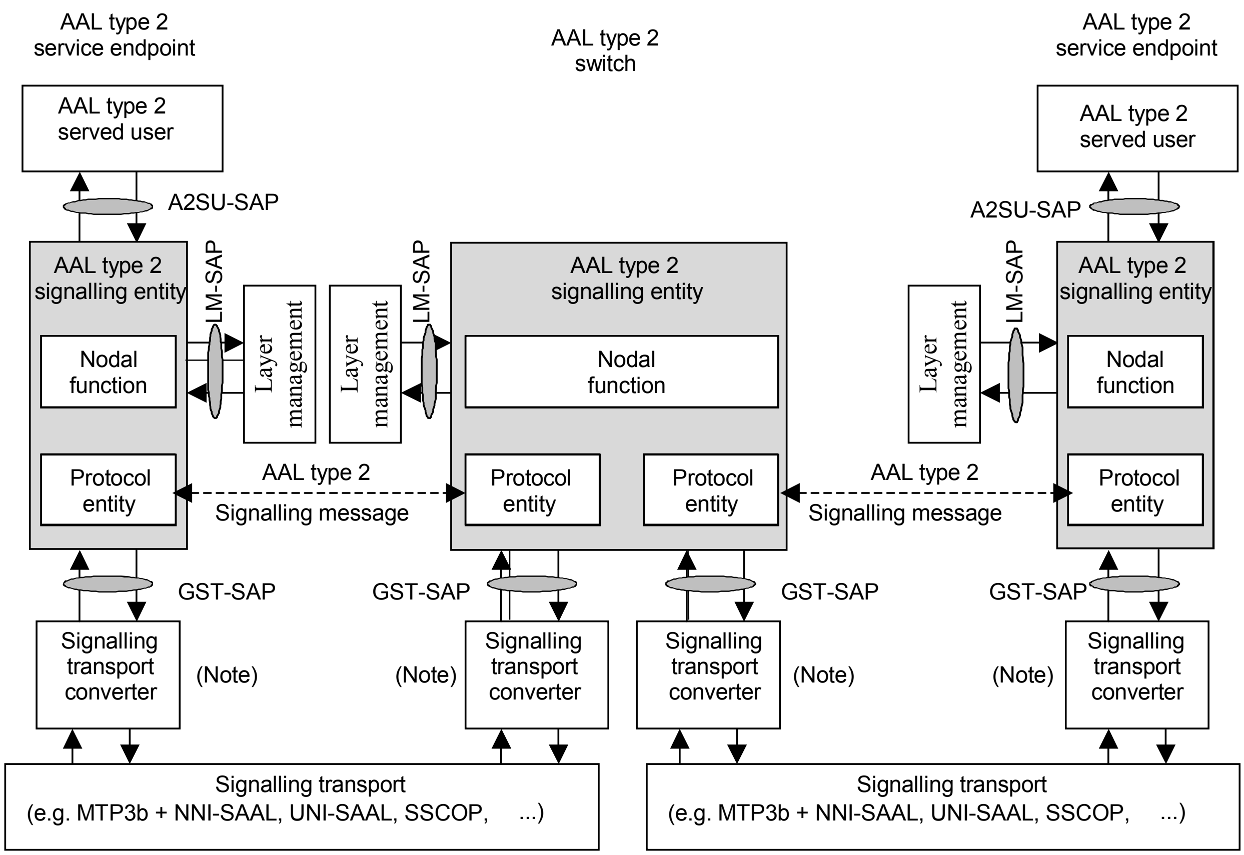


Figure 3.22 Primitive exchange in the OSI model

The N-Layer entity may request a service from the N-1 entity. On the receiving side (peer) the Indication message from the N-1 Layer acknowledges to the upper N-Layer that the N-1 entity is ready. The Response is the reaction of the N Layer to the Indication message of the layer below in order to be replied to the peer as an acknowledge. The Confirmation message is sent by the N-1 layer to acknowledge that the service required is completed.



NOTE – In every AAL type 2 node, a signalling transport converter instance is associated with each AAL type 2 signalling transport

Figure 3.23 AAL Type 2 signalling protocol reference architecture [5]

The scope of Recommendation Q.2630.1 is limited within the definition of AAL2 signalling entity and its interfaces to other layers through Service Access Points (SAP). Thus the signalling transport and signalling transport converters that provide assured data transfer between AAL2 signalling entities are beyond the scope of ALCAP specification. For information about the ALCAP underlying protocol stack at the Iub interface, please refer to figure 2.1.

The AAL2 signalling entity consists of two parts, the protocol entity and the nodal function. The protocol entity is the one, which performs all the signalling, and maintenance related functionality. The protocol entities are absolutely the same at AAL2 service endpoints as well as at AAL2 switches. This fact makes the AAL2 signalling protocol to be considered as a symmetric. The protocol entity is subdivided into several procedures: outgoing protocol procedures, incoming protocol procedures and maintenance protocol procedures.

The outgoing protocol procedures provide the mechanism to initiate an AAL type 2 connection request. The incoming protocol procedures are applied when a request for an AAL type 2 connection is received from a peer entity. Both of these procedures provide for the orderly release of an AAL type 2 connection. The maintenance protocol procedures provide the mechanisms to align the status of the AAL type 2 resources (available/not available, blocked/unblocked) at the two adjacent AAL type 2 nodes and the procedures to block and unblock an AAL type 2 path.

The nodal function provides the bridge between incoming and outgoing protocol entities, performs the routing functionality, and keeps track of the AAL type 2 path resources.

As illustrated in the figure 3.23, the AAL2 signalling entity has three interfaces with other layers and thus three SAPs:

- through A2SU-SAP - the interface between AAL2 signalling entity and the AAL2 served user – the interface to a higher layer protocol,
- through GST-SAP - the interface between AAL2 signalling entity and the generic signalling transport – the interface to a lower layer protocol,
- through LM-SAP - the interface between AAL2 signalling entity and layer management – the internal interface to the network management system.

Since the main objective of this thesis is to study the transport resource management mainly from the Radio Network Layer point of view, the interface with the AAL2 served user, resided at the Radio Network Layer and the one which directly commands ALCAP to establish or release transport (AAL2) connection, is of the most interest for us. The other interfaces are not described herein, for detailed information about them, please refer to [5].

The AAL type 2 signalling entity provides the following services to the AAL type 2 served user across the A2SU-SAP:

- establishment of AAL type 2 connections; and
- release of AAL type 2 connections.

Note: the Recommendation Q.2630.2 (Capability Set 2) adds the modification of AAL2 connection resources service, please refer to [15]. This capability is not described here.

For provisioning these services the A2SU-SAP implies the following primitives to be exchanged between the AAL2 signalling entity and its served user (here in and further on the reader may also read: between ALCAP and Radio Network Layer Control Plane protocol): ESTABLISH.request/indication/confirm, RELAESE/request/indication/confirm.

Theses primitives are used by the originating served user to initiate AAL2 connection establishment (ESTABLISH.request) and by the originating and destination served users to initiate the release of the connection (RELEASE.request); and by the AAL2 signalling entities to indicate an incoming connection (ESTABLISH.indication/confirm) to the destination served user, and notifying either the originating or destination served user of the release of a connection (RELEASE.indication/confirm). In fact these primitives have rather descriptive character, in practice their use is implementation dependent. However the general framework has to be kept, meaning that the specific implementation must rely on the generic primitive structure containing basic parameters to be carried by the given primitive.

The primitive's parameters represent the information, passed by either served user or ALCAP. The most important parameters needed for transport bearer (AAL2 connection) establishment are:

- **AAL2 Service Endpoint Address** – this parameter carries the endpoint address of the destination. In practice it defines the exact location of the endpoint within the transport network and directly used in routing the signalling message to its destination. That's why in Radio Network Layer application protocol terminology the A2EA is also referred to as a *Transport Layer Address*, the reader will face it later.
- **Served User Generated Reference** – this parameter carries a reference provided by the originating AAL2 served user. It's used by the APs to ensure the binding mechanism between the Transport and Radio Network Layer addresses. At the Radio Network Layer this parameter is referred to as a Binding ID. This will be described later in the section devoted to NBAP.
- **Service Specific Information (SSCS Information)** – this parameter identifies the type and capabilities of AAL2 SSCS layer (for more information about SSCS, please refer to section 3.3.2.1).
- **Link Characteristics** – this parameter gives an indication of the resources required for the AAL2 connection and is used only for AAL2 path selection and connection admission control.

Once the AAL2 connection is established, the ALCAP responds to its served user with the primitive containing the reference parameter uniquely identifying the particular established connection. That parameter is used in each primitive to address the certain AAL2 connection instance (for example during AAL2 connection release). This reference parameter is not specified by the Q.2630.1 and considered to be an implementation detail. Therefore it won't be mentioned any more in this section, but will be seen in the next chapter describing NBAP implementation issues.

In effort to achieve the better understanding of the nature of processes running within the ALCAP let us present the following descriptive example of AAL2 connection establishment.

Lets start from the very beginning. When the UE (or CN) initiates the establishment of dedicated connection the UTRAN must provide, as its service, the Radio Access Bearer for that connection. The Iub interface, in particular, has to provide the transport bearer between the RNC and Node B, as a part of RAB. For that the Iub Radio Network Layer protocol (NBAP for example) commands the ALCAP to establish transport bearer by sending ESTABLISH.request primitive with the appropriate parameters.

When the nodal function receives an ESTABLISH.request primitive from the AAL2 served user, it analyses the routing information and selects a route with sufficient AAL2 path resources to the succeeding AAL2 node. It then selects an AAL2 path from within that route which is able to accommodate the new connection. The routing is typically based on addressing information, link characteristic and other information (such as SSCS information) passed in the primitive.

AAL2 node internal resources are allocated to establish an AAL2 node internal path for the new connection from the originating AAL2 served user to the outgoing AAL2 path. On the selected outgoing AAL2 path, the Connection Identifier (CID) and other resources (e.g. indicated by link characteristic or SSCS information) are allocated for the outgoing AAL2 link. Once the resources have been allocated an outgoing protocol entity instance is invoked and the following parameters are passed to it: the AAL2 service endpoint address, the AAL2 path identifier, and a CID value. After that it sends the establishment request message to the peer AAL2 signalling entity, by the means of conveying it via the primitive to the general signalling transport.

On the destination peer side upon receiving an indication from an incoming protocol entity instance requesting a new connection, the nodal function checks the availability of the CID value and other resources, e.g. indicated by link characteristic or SSCS information, in the incoming AAL2 path. If the CID and the other resources are available for the new connection, they are allocated to the new connection and then the AAL2 service endpoint address is examined. The nodal function determines that the destination AAL2 service endpoint has been reached.

Then the AAL2 node internal resources are allocated to establish an AAL2 node internal path for the new connection from the incoming AAL2 path to the destination AAL2 served user. The nodal function acknowledges the successful AAL2 connection establishment towards the incoming protocol entity instance that sends the establishment response message back the originating AAL2 signalling entity. After that an ESTABLISH.indication primitive is sent to the AAL2 served user to inform it of the successfully established new connection.

On the originating side the establishment procedure is accomplished by receiving an indication of the successful AAL2 connection setup from the signalling transport, after which an ESTABLISH.confirm primitive is sent to the AAL2 served user.

This is the basic scheme of the ALCAP message exchange during the transport connection establishment. The connection release is conducted in a quite similar way, except that it is initiated by the RELEASE primitives carrying the reference parameter associated with the given AAL2 connection instance and the *Cause* value.

This is perhaps all what is necessary to know about the ALCAP from the transport resource management point of view and for understanding some implementation details described in the next chapter. For more information about ALCAP please refer to [7] and [5].

3.5 NBAP as a control plane protocol over the Iub interface

NBAP is a Radio Network Layer protocol maintaining control plane signalling across the Iub interface, please refer to figure 2.1. Since it's only the protocol representing the control plane at the Iub interface the NBAP is the one which is responsible for control of all its resources.

In fact the Iub interface as such provides the means for communication between the RNC and the Node B. These "means" are physically realized by the set of protocols organized in the form of stack at the Iub interface. Each protocol performs the certain task in RNC-Node B intercommunication process. As a one of such tasks the NBAP allows the RNC to conduct the control over the logical resources at the Node B.

In such a way the NBAP defines the certain intercommunication scenario played by two actors: the RNC and the Node B. Therefore the one peer entity of NBAP protocol resides in the Node B and the other entity resides in the Controlling RNC. The correlation between the NBAP entities resided in the Node B and those resided in the RNC are one-to-one and one-to-many correspondingly. Meaning that for each NBAP entity in the Node B there is only one peer resided in the RNC and for each NBAP entity in the RNC there are as many peers in the Node Bs as a number of Node Bs belonging to the given RNC (one NBAP entity per Node B). The figure 3.24 illustrates the operational environment for the pair of intercommunicating NBAP entities.

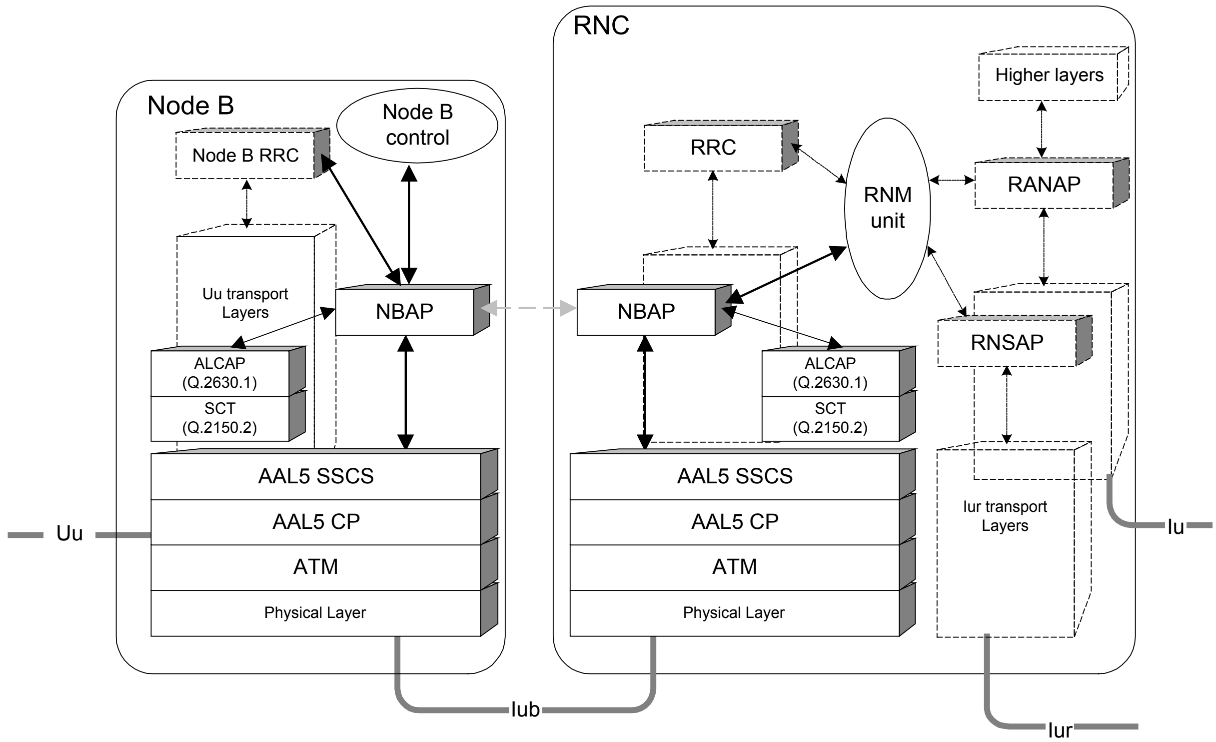


Figure 3.24. Operational environment of NBAP

The Node B is merely passive element of the UTRAN architecture, meaning that it doesn't make any decisions of its own. It can be rather seen as an accumulation of physical resources that have to be controlled by the RNC. Basically all the tasks concerning Transport Resource Management either Radio Resource Management or RAB management are initiated by the RNC, it remotely commands the Node B to perform one or another functionality. And that's what the NBAP protocol ensures.

In such a way the NBAP represents the client-server architecture, where Node B takes the role of the server and RNC behaves as a client requesting to perform some actions. Such kind of architecture constitutes the asymmetric nature of NBAP protocol. This means that the peer protocol entities resided in the RNC and the Node B have different functionality and different interfaces through which they communicate with other protocols. This can be easily seen in the figure 3.24 that illustrates the NBAP interfaces designated by the bold arrows. It should be noted that the interfaces of NBAP to another Radio Network Layer protocols, as well as Transport Network Control Plane protocols, are not clearly specified in the 3GPP specification [16] defining the NBAP signalling. They can be rather seen as an implementation specific. For instance the figure 3.24 is created upon a particular NBAP implementation that has been done within the framework of this thesis, and described in the next chapter. The only guaranteed interface, i.e. specified by the 3GPP in [17], is the interface with the transport layer protocols.

The NBAP resides on the top of the Iub transport layers and uses the provided services in order to transfer its signalling messages across the Iub interface. The 3GPP R99 and R4 choice of underlying transport technology used to carry NBAP messages over the Iub interface is ATM. It is known from the above presented description of ATM that regarding to the traffic to be transported the ATM is used together with its AAL. In case of NBAP the AAL5 is used as the most suitable for the nature of NBAP generated traffic. The ATM/AAL5 protocol stack forms the signalling bearer for NBAP, as stated in 3GPP technical specification [17]. The signalling bearers for NBAP represent the semi-permanent point-to-point connections that are setup and released by the O&M actions (basically during the network installation). In fact the NBAP relies on the quarantined reliable transmission on the signalling bearer. This means that NBAP assumes that all messages sent across the Iub interface will reach the NBAP peer entity without any errors. Such approach relieves the NBAP protocol of the need for error handling mechanisms.

The exchange of signalling messages constitutes the logical interaction between two NBAP peer entities. It is shown in the figure 3.24 as a gray dashed arrow. In the protocol software engineering field the messages logically exchanged between two peer entities are called Protocol Data Units (PDUs). In practice the horizontal interconnection between layers is ensured by the lower layer protocols, in our case by the ATM/AAL5 stack in the transport layer. For that the PDU to be transported to the peer entity is passed down to the underlying protocol in the form of so called SDU (Service Data Unit) message, that basically consists of PDU and some sort of header usually containing routing information. The transformation from the PDU to SDU basically includes also the information encoding at the sending side and decoding at the receiving side. For NBAP protocol the 3GPP specification [16] defines the Packet Encoding Rules (PER) encoding to be used as transfer syntax. For information about the PER encoding principles please refer to [18].

3.5.1 NBAP services

The functionality of any protocol is defined in the terms of services it provides. The service in this case is a some sort of action that is undertaken upon the request from the protocol operational environment. This is pretty much conforms to the basic client-server architecture principles. In protocol engineering such kind of action is called *Elementary Procedure (EP),* and in protocol specifications it's defined as a set of PDUs to be exchanged in the certain order. For NBAP the set of elementary procedures is defined by the 3GPP in technical specification TS.25.433 [16].

All NBAP services can be roughly subdivided into two groups: Logical Operation and Maintenance (O&M) of Node B and transport resource management tasks aimed to initiate the setup and release of dedicated transport connections across the Iub interface. In fact the procedures corresponding to both types of services are not executed in stand alone manner, rather their use intersects in such sense that for example the execution of transport bearer setup related procedures is impossible before some O&M actions is undertaken.

All the resources physically implemented in Node B logically belong to and controlled by RNC. For that there is a Logical Model of Node B defined, refer to section 2.2. It represents the way in which the Node B physical resources are seen and interpreted from the Controlling RNC. This RNC performs the control on the level of logical resources, while the physical implementation of resources and control procedures in Node B is left unspecified. Physical procedures performed in the Node B change the states of the logical resources owned by the RNC and this requires some information exchange between RNC and the Node B to keep RNC aware of the changes. Such kind of information exchange is referred to as a Logical O&M of the Node B. Logical O&M constitutes the integral part of NBAP signalling.

The second group of NBAP services relates to the NBAP responsibility to establish and maintain a control plane connection over the Iub interface, to initiate setup and release the dedicated user plane connections across the Iub interface and command the Node B to activate resources for new radio links over the Uu interface.

All NBAP signalling functions are divided into common elementary procedures and dedicated elementary procedures. The common procedures are not related to any particular UE, but rather used to manage common logical resources of Node B. Hence the great part of common procedures is constituted by signalling related to Logical O&M. It includes procedures for configuration management of logical resources, procedures allowing the RNC to initiate specific measurements in the Node B and the latter to report the results of the measurements. Above all the common procedures are also used to initiate creation of a new

Node B Communication Context for some specific UE in the Node B by setting up first radio link for that UE. For ensuring the common NBAP signalling over the Iub interface there is always one permanently existing signalling link, which terminates at Node B Control Port (please refer to figure 2.2).

The dedicated procedures are always related to some specific UE, for which the Node B Communication Context has already been created during the common procedure. Thus the dedicated procedures are applied to control dedicated logical resources at the Node B. They include procedures for managing and supervision of existing radio links, i.e. for establishing and releasing of some radio links belonging to existing Node B Communication Context and reporting failures or restorations of transmission on some radio links. These procedures also include radio link reconfiguration management and corresponding power control activities, which allow the RNC to adjust downlink power level on the radio links. Dedicated NBAP signalling is carried via one of the Communication Control Port belonging to a particular Traffic Termination Point, which is assigned to UE at the creation of Node B Communication Context. The Communication Control Port terminates the dedicated signalling link at the Node B side.

The complete specification of NBAP common and dedicated procedures can be found in the 3GPP specification TS.25.433 [16]. The following table is merely brief overview of all NBAP procedures regarding to the service provided.

Function	**Description**	**Elementary Procedure(s)**	**Common/ Dedicated**
Cell Configuration Management	Gives the CRNC the possibility to manage the cell configuration information in Node B	a) Cell Setup b) Cell Reconfiguration c) Cell Deletion	Common
Common Transport Channel Management	Gives the CRNC the possibility to manage the configuration of Common Transport Channel in a Node B	a) Common Transport Channel Setup b) Common Transport Channel Reconfiguration c) Common Transport Channel Deletion	Common
System Information Management	Gives the CRNC the possibility to manage the scheduling of System Information to be broadcast in a cell	System Information Update	Common
Resource Event Management	Allows the Node B to inform the CRNC about the status of Node B resources	a) Block Resource b) Unblock Resource c) Resource Status Indication	
Configuration Alignment	Gives the CRNC and Node B the possibility to verify and enforce that both nodes have the same information about the radio resources.	a) Audit Required b) Audit c) Reset	Common
Measurements on Common Resources	Allows the CRNC to initiate measurements in the Node B and the Node B to report the result of the	a) Common Measurement Initiation b) Common Measurement	Common

	measurements.	Reporting c) Common Measurement Termination d) Common Measurement Failure	
Radio Link Management	Allows the CRNC to manage radio links using dedicated resources in a Node B	a) Radio Link Setup	Common
		b) Radio Link Addition c) Radio Link Deletion d) Unsynchronized Radio Link Reconfiguration e) Synchronized Radio Link Reconfiguration Preparation f) Synchronized Radio Link Reconfiguration Commit g) Synchronized Radio Link Reconfiguration Cancellation h) Radio Link Pre-emption	Dedicated
Radio Link Supervision	Allows the CRNC to report failures and restorations of a Radio Link.	a) Radio Link Failure b) Radio Link Restoration	Dedicated
Measurements on Dedicated Resources	Allows the CRNC to initiate measurements on dedicated resources in the Node B and the Node B to report the result of the measurements.	a) Dedicated Measurement Initiation b) Dedicated Measurement Reporting c) Dedicated Measurement Termination d) Dedicated Measurement Failure	Dedicated
DL Power Drifting Correction	Allows the CRNC to adjust the DL power level of one or more Radio Links in order to avoid DL power drifting between the Radio Links.	Downlink Power Control	Dedicated
Reporting of General Error Situations	Allows reporting of general error situations, for which function specific error messages have not been defined.	Error Indication	Common / Dedicated

Table 3.3. Mapping between NBAP functions and elementary procedures

The Transport Resource Management in not explicitly mentioned in this table but its tasks indirectly present in some procedures, e.g. in Radio Link Setup procedure which is described in the following subsection.

3.5.2 Example of signalling procedure

As it was stated above the functionality of NBAP and its services are defined in terms of elementary procedures. It can be said that the elementary procedure is defined as a unit of interaction between two NBAP peer entities.

All procedures are executed in the following manner. Each procedure is triggered by the message sent from the radio network management unit of the RNC or control unit of Node B. Upon receiving trigger message the initiating peer entity forms the initiating PDU, encodes it and pass it down to the transport layers to be transferred across the Iub interface. Receiving peer entity decodes PDU, analyses its content and based on it generates and forward some request to the corresponding interfacing unit. At this point if the given procedure consists only of initiating message without response it is considered completed. Otherwise the receiving NBAP entity awaits for a response from the interfacing unit, based on which it generates corresponding PDU, encodes and forwards across the Iub interface back to the initiating entity. The initiating entity decodes response PDU and forwards the confirmation message to the unit, which triggered the given elementary procedure.

From the point of problem domain studied in this thesis the best way to illustrate the contribution of NBAP protocol in performing the Transport Resource Management over Iub interface is to examine the signalling involved in the dedicated user plane connection establishment to a UE. Such kind of signalling procedure involves a lot of interaction between different network elements and signalling protocols. For simplicity the example is limited within the Iub Radio Network and Transport Network control planes, the other interfaces are left out of scope.

For describing the interaction between protocols the Message Sequence Charts (MSCs) notation is used. Following this notation the interacting protocols are shown as ellipses on the each side of the interface. The messages traversing across the interface are depicted as the named arrows. It should be noted that in MSC the messages are sent and received in the sequential order. Meaning that at any given moment of time only one message in transferred between two peer entities in order defined in the MSC, from top to down.

Besides the Iub interface protocols the presented example includes the RRC signalling. This is done in effort to present more or less clear picture about who and why from the operational environment triggers Iub control plane protocols to setup dedicated connection over Iub. The RRC is the protocol, which carries out the communication between RNC and UE. This protocol is used by the UE to inform RNC that it needs a dedicated connection (when making a call for example) and deliver the parameters of the required connection (transparently to Node B). When the connection has been established, the RNC in turn use the RRC protocol to inform the UE about the characteristics of allocated dedicated channel.

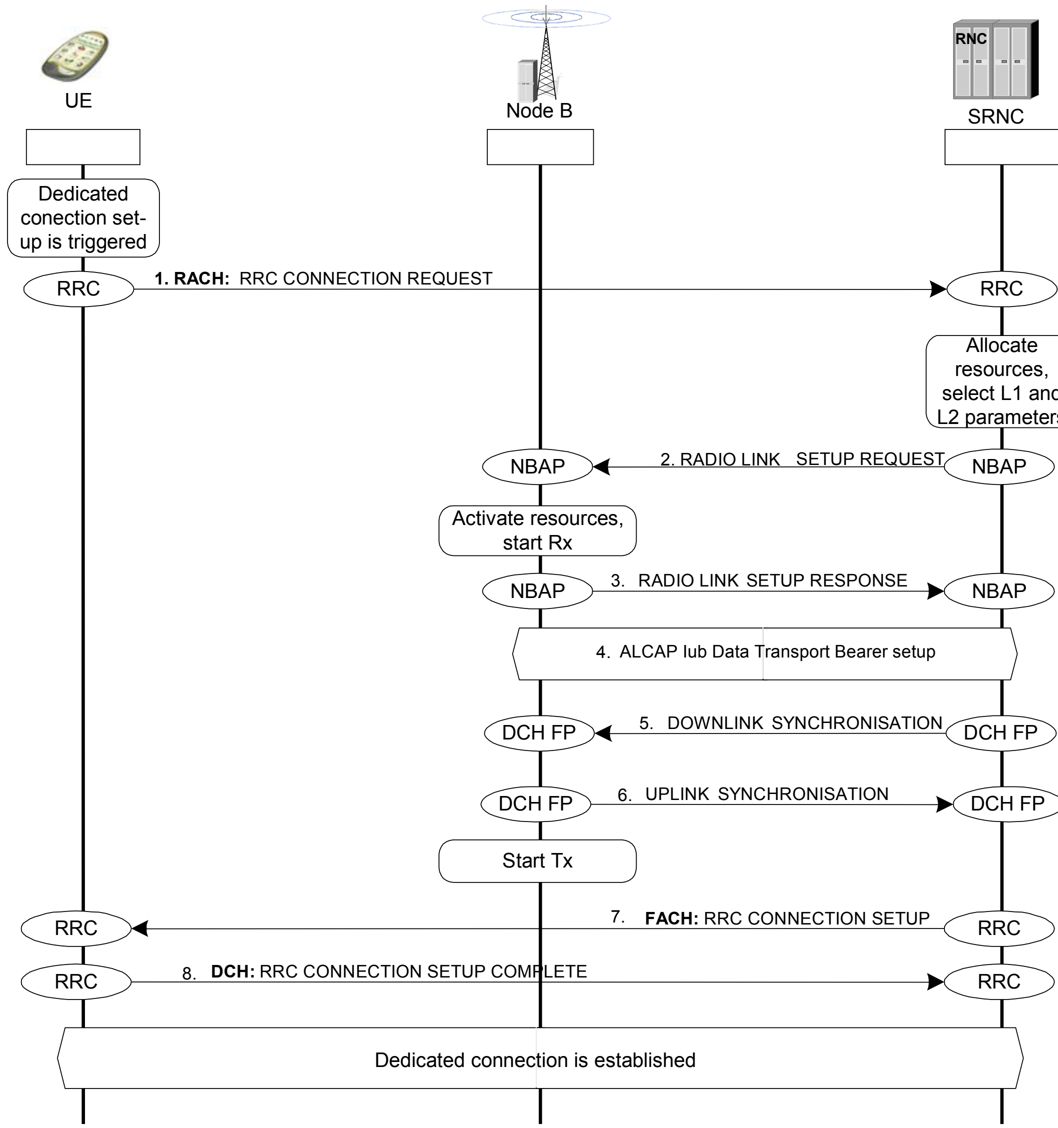


Figure 3.25 Dedicated connection establishment

Now lets discuss the dedicated connection establishment step by step, see figure 3.25.

1. Lets assume that the UE initiates the setup of telephone call. For that the upper layer protocols in the UE stack triggers the RRC protocol entity to send the RRC CONNECTION REQUEST message (so called establish an RRC connection). Since at this moment UE does not have a dedicated channel to the UTRAN it uses the Common Control Channel to convey its messages. In this case the RACH transport channel is used.
2. Upon reception of RRC request message the SRNC decides to use a DCH for this RRC connection, allocates the RNTI (Radio Network Temporary Identity), uniquely identifying the particular UE during the dedicated connection lifetime, and prepare

the radio resources to be allocated. When everything is ready to setup a DCH, SRNC sends an NBAP message RADIO LINK SETUP REQUEST to the Node B. As the parameters this message carries the Cell ID, Transport Format Set for DCH to be allocated, ToAWE, ToAWS, frequency, uplink scrambling code and power information.

3. Node B allocates resources, starts the reception on the radio channel and responses with NBAP RADIO LINK SETUP RESPONSE message. This message carries the parameters, which are essential for the setup of data transport bearer over Iub interface, AAL2 address and AAL2 Binding Identity.
4. The SRNC triggers the ALCAP protocol to setup Iub data transport bearer. For that it sends the establishment request carrying as the parameters the AAL2 Transport Layer Address and Binding Identity received by the NBAP entity and used to bind the Iub data transport bearer to the DCH. The request for setup of transport bearer is acknowledged by the Node B. This process will be discussed separately later.

5./6. The SRNC and Node B achieve the synchronization for the Iub data transport bearer by the means of exchanging of appropriate DCH Frame Protocol frames, DOWNLINK SYNCHRONISATION and UPLINK SYNCHRONISATION. Once synchronization is accomplished the Node B starts downlink transmission.

7. After all procedures related to the allocation of Iub resources are completed the RNC sends the RRC CONNECTION SETUP message to the UE still using the common transport channel (FACH).
8. The UE switches to the allocated dedicated channel and responds to the SRNC with the RRC CONNECTION SETUP message indicating that connection has been successfully setup.

Now lets take a close look at the item four from the above presented description in order to discover the process of transport resources allocation at the Iub interface. If we work out the corresponding part of figure 3.25 in detail we will see that the establishment of transport bearer involves the interaction between two peer entities of ALCAP (AAL2 Signalling) protocol one resides in the Node B and another in CRNC, as it is illustrated in the figure below.

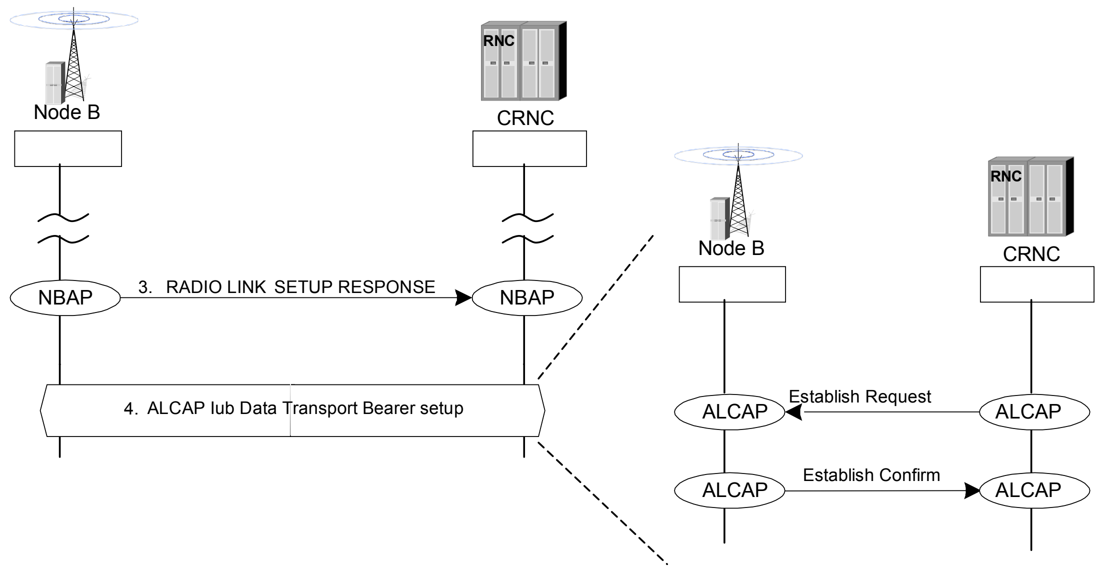


Figure 3.26. Mapping of Transport Network Control Plane signalling to NBAP signalling.

The ALCAP Establishment procedure is triggered by the Radio Network signalling protocol, in our case the NBAP, and what is important only at the CRNC side. Therefore the CRNC serves as the sole owner of the Iub transport resources. The requests for establishment, release or reconfiguration of Iub transport resources (bearers) are always initiated by the CRNC.

The independence of Control Plane and User Plane assumes that ALCAP signalling transaction takes place. But it should be noted that ALCAP might not be used for all types of data transport bearers. If there is no ALCAP signalling transaction, the Transport Network Control Plane is not needed at all. This is the case when pre-configured data bearers are used.

Before we take a look at the picture describing the signalling interaction between the NBAP and ALCAP protocol entities some parameters being used between them must be introduced.

Radio Network Control Plane identifiers

Each addressable object in each reference point has an Application Part level identifier. This identifier is allocated autonomously by the entity responsible for initiation of the setup of the object. This Application Part identifier will be used as a reference to the object that is setup. Both ends of the reference point keep the AP identifier memorized during the lifetime of the object. Application Part identifier can be related to a specific ALCAP identifier and that relationship is also memorized by both ends. At the Iub interface basic AP level identifiers are *DCH-ID* for Dedicated Transport Channel and *DSCH-ID* for Downlink Shared Channel.

Transport Network Control Plane identifiers

ALCAP identifier is used only in Transport Network Control plane (ALCAP) and may be used in User Plane in the actual data transmission using the transport link. ALCAP identifier identifies the transport link according to the naming conventions defined for the transport link type in question. Both ends of the reference point of the ALCAP keeps the ALCAP identifier memorized during the lifetime of the transport link. Each ALCAP identifier can be binded to an Application Part identifier. The example of ALCAP identifier for the AAL2 transmission link is AAL2 Path ID together with CID.

Binding identifier

Binding Identifier (Binding ID) is used to initialize the linkage between ALCAP and Application Part (NBAP) identifiers. Binding identifier can be used both in Radio Network Control plane Application Part protocols and in Transport Network Control Plane ALCAP protocol.

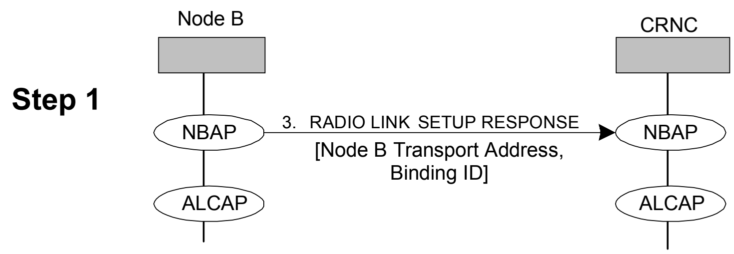
Binding ID binds the Radio and Transport Network Control plane identifiers together. To ensure maximal independence of those two planes, the binding ID is used only when necessary, i.e. only in Radio Network Control plane Application Part messages in which a new association between the planes is created and in ALCAP messages creating new transport bearers.

It should be noted that Binding ID for each transport bearer is allocated before the setup of that transport bearer, i.e. before the ALCAP signalling transaction takes place. In case of Iub interface the Binding ID is allocated at the Node B and sent on one direction using the NBAP protocol (in response message) and is returned in the other direction by the ALCAP protocol. So that the Binding ID has already been assigned and tied to a radio application procedure when the first ALCAP message is received in a node.

The association between the connection Id in the Application Part (NBAP) protocol (e.g. identifying a RAB) and the corresponding connection Id in the ALCAP protocol (e.g. identifying the AAL2 channel for that RAB) that was created with the help of Binding ID is memorized by both peers of each reference point and kept for the lifetime of the corresponding transport bearer.

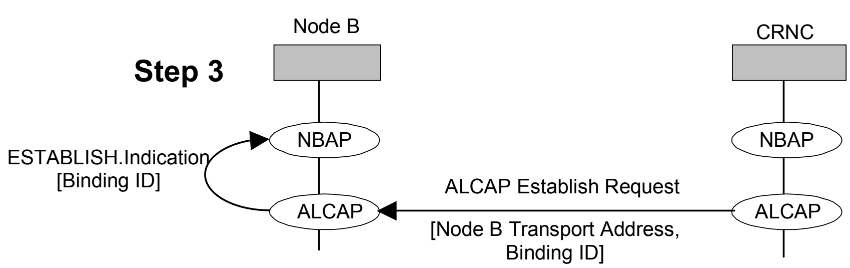
The Binding ID may be released and re-used as soon as both the NBAP procedure and the ALCAP procedure that used it are completed in both peers of the reference point.

The following figures illustrate how the NBAP and ALCAP instances are linked together via the Binding Identifier in the data transport bearer setup phase.



1. Node B allocates the Binding Identifier assigns it to the NBAP setup response message and sends it to the RNC. Above other parameters NBAP message contains the originating node Transport Layer Address (e.g. AAL2 Service Endpoint Address, please refer to section 3.4) and the allocated Binding ID.

2. Among reception of NBAP setup response the NBAP peer entity in the CRNC requests its ALCAP to establish a transport bearer. The Binding ID is passed to ALCAP.



3. CRNC sends an ALCAP Establish Request to the ALCAP peer entity in the Node B. The Node B Transport Layer Address here is used to route the ALCAP message to the destination Node B. The Binding ID carried as a parameter correlates the incoming transport connection with the NBAP transaction in step 1. In fact the after that the Node B ALCAP responds with the Establish Response message which is then confirmed to NBAP.

In such a way the dedicated connection establishment from the Iub perspective is always initiated by the RNC starting with the NBAP setup request message and completed upon receiving the ALCAP establish response message also at the RNC.

In addition the above presented example shows how the NBAP Radio Link Setup procedure contributes to the Transport Resource Management tasks, particularly to the transport bearer setup. Another example can be the NBAP Radio Link Reconfiguration procedure that assures the transport bearer replacement. This activity takes place, for example during handling the Softer Handover case, when the user moves to another cell belonging to the same Node B and there is a need to establish a new connection through that new cell.

In this case the transport bearer replacement can be achieved by using the Synchronized Radio Link Reconfiguration Preparation procedure in combination with the Synchronized Radio Link Reconfiguration Commit procedure, or by using the Unsynchronized Radio Link Reconfiguration procedure. In both cases the following steps can be discerned:

1) The new transport bearer is established (using the same ALCAP transactions as presented above) after which two transport bearers exist in parallel.
2) The transport channel(s) is/are switched to the new transport bearer.
3) The old transport bearer is released.

In step 1), communication on the old transport bearer continues as normal. In addition, the Node B conducts the Synchronization procedure on the new bearer. This enables the SRNC to determine the timing on the new transport bearer.

Regarding step 2), the moment of switching is determined differently in the synchronized and unsynchronized case:

When using the combination of the Synchronized Radio Link Reconfiguration Preparation procedure and the Synchronized Radio Link Reconfiguration Commit procedure, the UL/DL data frames are transported on the new transport bearer from the CFN (Connection Frame Number) indicated in the RL RECONFIGURATION COMMIT message.

When using the Unsynchronized Radio Link Reconfiguration procedure, the Node-B starts using the new transport bearer for the transport of UL data frames from the CFN at which the new transport bearer is considered synchronized.

In both cases, starting from this CFN the Node B executes all applicable DCH frame protocol procedures on the new transport bearer.

And finally in step 3), the old transport bearer is released (using ALCAP Release procedure).

4. IMPLEMENTATION OF NBAP AND NODE B MANAGER

In this chapter we describe the practical part of the thesis. That is how the NBAP protocol and NBM (Node B Manager) functional unit were implemented as a part of ongoing Nokia Research Center project. The discussion includes the general background information about the project and overview of the NBAP and NBM implementation. Since the implementation involves a lot of tools and techniques their descriptions are also presented in this chapter.

As a practical part of the thesis the NBAP protocol and NBM were newly implemented according to open 3GPP technical specification 25.433 release 4.1. However a lot of experience was borrowed from the NBAP and NBM implementations that were done according to Nokia internal specifications within the framework of the same Nokia Research Center project. Above all the addition functionality were added to the NBAP as well as NBM implementations aimed to provide with the Transport Resource Management services.

4.1 General information and development stages

Implementation of NBAP and NBM discussed in this chapter is used in the software package that models the whole stack of UMTS signalling protocols. This software package consists of executable SDL models organized in the executable library called 3G SDL Library. The main objective of this library is to provide other ongoing Nokia projects with the up-to-date implemented protocols, so that they can be reused as a ready components in the projects that they deal with, for example, testing of different UMTS network elements. For instance the described NBAP implementation is used in the Node B testing project, as well as in the RNC tester. Since new versions of 3GPP specifications are released quite frequently, as they moving from the R99 towards R5, (basically once in 4 months) another important responsibility of the 3G SDL project is to keep all protocol implementations up-to-date. This constitutes the continuous character of the project. On the other hand the 3G SDL project influence on the standardization process itself. This is because there are still not many implementations of the 3G systems realized in practice (one commercial network is deployed in Tokyo and another test network is running on the island Mann). Therefore nobody can guarantee that the standardized protocols are really feasible. And this is what is also examined in our project, whether the specifications really work or not. The feedback provided by the project is considered in the following releases.

In fact the 3G SDL project is running as a general software development project, since the protocol development is the particular case of the software engineering process. The software engineering is such a discipline that integrates process, methods and tools for the developing of the computer software. This discipline defines different models of software developing process. Therefore the implementation of 3G SDL Library as a whole and NBAP/NBM protocols in particular should conform one of these proposed models.

From that point the 3S SDL Library development model can be considered as a spiral model [19]. Such kind of model couples the iterative nature with the controlled and systematic aspects of linear sequential model. It is divided into a number of framework activities as shown in the figure 3.27.

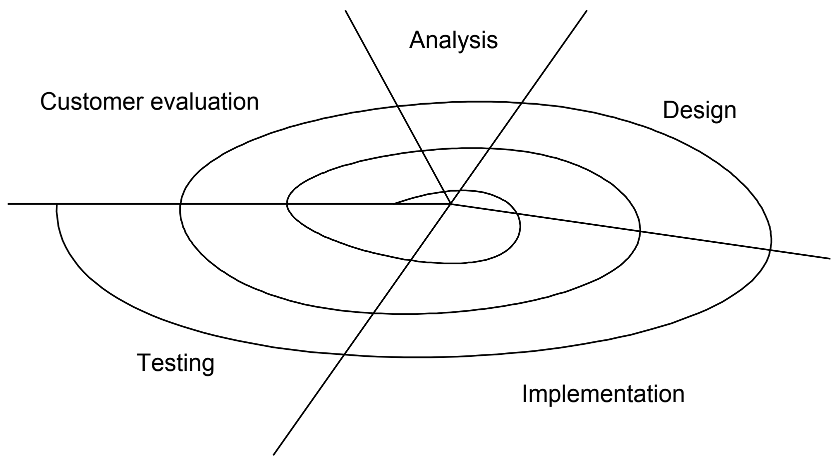


Figure 3.27. Development process model

As the protocol development starts it moves around the spiral in a clockwise direction beginning at the core. Basically the development life cycle goes around three circles starting from the beginning: New Protocol Development, Protocol Integration and Protocol Maintenance. At the each phase the set of framework activities is applied.

The analysis is aimed to discover behavior of the protocol and its place in the whole system. This activity involves a lot of efforts to analyze the protocol specifications, since they are written in such a way that the description of the protocol is given in a stand alone fashion, and almost nothing is said about its operational environment. Thus the interfaces to other protocols as well as set of messages exchanged in between should be identified at the analysis stage. Only after that the development process can proceed to the design stage.

The strict requirements are imposed on the protocol models included into the library. First of all each protocol model should provide the maximum modularity of the system as a whole on the one hand, and independence from the underlying protocol models on another. The latter concerns above all the application protocols, and NBAP in particular, that stated to be independent from the transport protocols. This requires the unified design principles implied throughout the whole library. Such kind of principles is defined in the 3G SDL

Library Style Guide that is strictly followed during the design and implementation stages for all protocols in the library. Besides this the protocol model should be designed in such a way that is would allow easy updating to the new specifications by simply adding new functionality without extensive revision of its architecture.

In fact the protocol design can be seen as splitted into two parts: definition of the external interfaces towards the protocol operational environment, and constructing the internal protocol architecture. Then the implementation task is merely to fill the skeleton created at the design stage with the appropriate logic and signalling procedures. Since the protocols are event driven systems, meaning that most of their actions are triggered by the external events, the definition of external interfaces is the most important and crucial aspect of the design stage.

Today, it is widely accepted that a key to success of a system lies in a thorough and rigorous specification and design. This requires the use of formal description techniques allowing the system to be specified at different abstraction levels, beginning from an overview and going on to very specific details. As one of these methods the *Specification and Description Language (SDL)* is used in the project. This language is widely used in the developing of communication systems, real-time and complex distributed systems. Though originally the SDL was seen as a language for the system design, at the implementation stage it can be easily converted into code in a particular programming language, such of C or C++. Several tools that offer such translation features are available today. One of them, the Telelogic SDL Design Tool, is being used in our project.

Besides that the implementation of the protocols is usually done regardless to the executable environment in which they will perform. This is due to the basic principle of protocol software serving as a mean for communication between different systems, which in general may be of different, heterogeneous nature. For example each intercommunicating node (network) may have data representation its own. In order to avoid network data representation and design problems the design of application data or PDUs, which are transmitted through the network should be done at *abstract data type level*. The solution here is to use the high-level specification language for expressing the abstract syntax of application data. In our project one of such data specification languages, *Abstract Syntax Notation One (ASN.1)* is used.

The NBAP as well as other protocol models in the library are implemented in SDL using the Telelogic Tau SDL Design Tool (SDT) as a development environment. The SDT is a commercial product provided by the Swedish company Telelogic [87] and widely used within the telecommunication companies worldwide. It provides the means for writing SDL code, generation the C code and finally building the executable model.

While the SDL language is used to define the dynamic behavior of the system, the data structures used in protocol model are defined using the ASN.1 language. There is a number of so called CASN-tools employed in the project. Their task is to provide bridge between ASN.1 definitions and SDT, allowing the use of ASN.1 data types in SDL code. CASN-tools are developed in the Nokia Research Center and thus are property of NRC.

After the SDL model is created and analyzed against the errors the executable model is then built. For that some part of hand written C code allowing encoding/decoding of PDUs must be added at the compilation phase.

In fact the implementation phase is done in the iterative manner alternating with the testing. It means that during the implementation as new feature is added the model is built tested and validated. Such kind of approach allows to uncover possible bugs at the point while the system is not yet huge, and can be tested easier.

Once the complete system is finally built and thoroughly tested is it integrated into the library and the integration testing is performed. The integration means that all the protocols are connected together forming the UMTS protocol stack. As soon as the integration phase is passed successfully the whole library or it is particular protocols are delivered to the customers. At this point the role of the customers in software engineering process is to provide a feedback based on the product evaluation. The customer feedback is vary valuable for the project, since it allows developers better adjust protocol models to the customer's requirements for the further releases.

4.2 Development environment

SDL

The Specification and Description Language (SDL) is a standard formal language developed by the International Telecommunication Union – Telecommunications (ITU-T) to specify and describe distributed and event driven real-time systems. Originally it was intended mainly for specification purposes but as time went by the new features like object-oriented support and combined use of SDL with ASN.1 were added and now it is widely used like any other high-level programming language.

The SDL covers all areas of system developing from the static system architecture to its dynamic behavior. This is achieved by different levels of abstraction provided by SDL. The system under specification is decomposed into four main hierarchical levels: system, block, process and procedure. The system is the topmost level. It consists of one or several blocks, which in turn incorporate one or several processes. In such a way the system and block hierarchy represent the static description of the SDL system and processes constitutes its dynamic behavior.

The SDL process is defined in terms of Extended Finite State Machine. It consists of a set of states and transitions between them. The transition between two states are triggered by the reception of a signal. The signals serve as a mean for communication between processes in SDL. The signals are carried on the signal routes that connect processes together. On the system level the signal routes are multiplexed into the signal channels connecting different blocks.

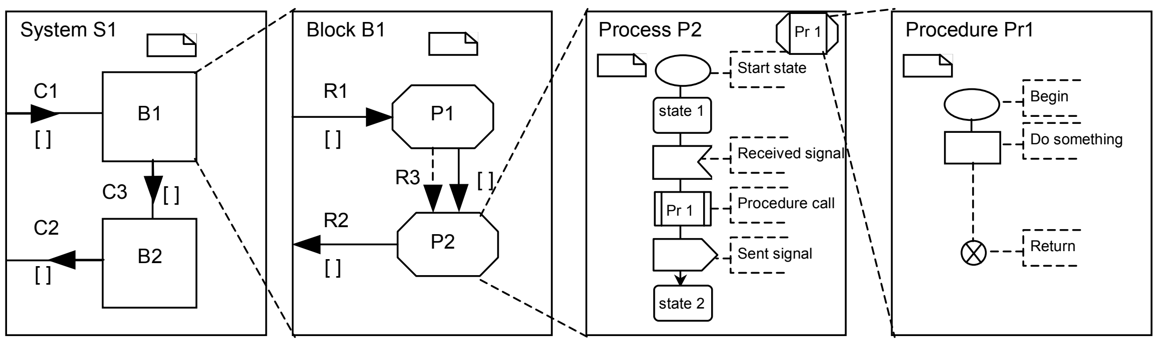


Figure 4.1. Mapping between the system, block, process and procedure

As it was mentioned above the SDL supports the abstract data types and object-oriented features. This allows development of reusable components.

The SDL language has two representation notations, textual (SDL-PR) and graphical (SDL-GR). Graphical notation is easier to read and understand therefore it is commonly used. The textual representation is also standardised, however it is seldom used.

While the SDL-PR can be written using any textual editor, the graphical representation requires the special CASE tool for creating and analysing the SDL code. As such a tool the Telelogic SDL Design Tool can be used. It allows comprehensive means for writing specifing and design of SDL systems, as well as for its analysis, code-generation, simulation and validation. Thus the SDT embrases three stages of protocol model development, design, implementation and testing.

ASN.1

The Abstract Syntax Notation One (ASN.1) is a high-level specification language for defining the data types and values. It is widly used within the telecommunication field mainly for specification the data exchanged between the protocol entities. It has been standardised by the ITU-T in Recommendation X.680 [20].

The main idea behind the ASN.1 is to represent information independently from the transfer syntax, i.e. the way how the information is represented on a particular platform. Therefore the ASN.1 operates with the abstract syntaxes saying nothing about their local representation. For example if the ASN.1 defines some type of INTEGER. In fact it imposes no restriction on the value the instance of this type may have. Such kind of restriction are platform dependent and hence shall not affect on the abstract syntax. In other aspects the ASN.1 is similar to any other modern definition language.

ASN.1 has tree main language constructs, types, values and modules. The type notation is defined as follows: *typereference ::= notation for the type*, where the *notation for the type* can be the one of the built-in type (such as INTEGER) or the type constructor for defining more complex types. The value notation represents the instantiation of the existing type. The example relation between type and value notation is shown in the following figure.

ASN.1 type definition

```
NbapNbAuditResponse ::= SEQUENCE {
  end-Of-Audit-Sequence-Indicator
                              End-Of-Audit-Sequence-ndicator  ,
  cell-InformationList-AuditRsp    Cell-Information-AuditRsp  ,
  transactionID                    INTEGER
}-
```

ASN.1 value definition

```
NbapNbAuditResponse : {
 end-Of-Audit-Sequence-Indicator  not-end-of-audit-sequence,
 cell-InformationList-AuditRsp {
  {
   c-ID 3,
   configurationGenerationID 1,
   resourceOperationalState disabled,
   availabilityStatus in-test,
   local-Cell-ID 3
  }
 },
 transactionID  4
}
```

Figure 4.2 The example of ASN.1 value definition

For convertion of ASN.1 values to the transfer format there is the encoding rules accosiated with ASN.1. They perform the exact translation of universal ASN.1 value to the particular transfer syntax, which will be then transferred over the communication medium. As one of such encoding rules the Packet Encoding Rules (PER) is used in the project. PER is standardized by the ITU-T in recommendation X.691 [18].

On the sending side the encoding functions based on PER codec accept as input the ASN.1 value of some type, for example like presented above, and returns as output the frame represented by a bit string. Such operation is called encoding. In the form of bit string the information is suitable for segmentation on the transport level and transferring over the communication media. On the receiving side the inverse operation is performed. The assembled at transport layer frame is decoded using the PER decoding functions and receiving protocol entity gets the original ASN.1 value.

As in case of SDL the ASN.1 has support of wide range of tools providing the functionality from the syntax and semantic check of ASN.1 definitions to the SDL and C code generation. As such kind of tools the *Nokia in-house ASN.1 tools* were used in the project. Their brief description is given below.

CASN

CASN stands for Compiler for ASN.1. It serves as a common front-end for all other ASN.1 tools. It checks the ASN.1 definitions for errors and if none generates an internal binary representation in the form of syntax tree for the back-ends.

ASN2C

ASN2C is a one of back-ends for the CASN compiler. It generates C type definitions from the ASN.1 data types and C constants for simple values, named numbers and bits. Optionally it may also provide the support for BER codec by generating BER encoding/decoding functions. BER stands for Basic Encoding Rules, they can be used as an alternative to PER. Besides ASN2C can also generate the test functions for asking and printing values. As input the tool accept the syntax tree file from CASN and as output it produces a number of C files. For example for ASN.1 module NBAP_PDUs the following files may be generated: C types definitions <nbap_pdus.typ>, C constants and macros <nbap_pdus.def>, C test functions prototypes <nbap_pdustst.ext> C test functions definitions <nbap_pdustst.c>.

ASN2PER

ASN2PER is another back-end for the CASN compiler. It generates the PER encoding/decoding functions for the ASN2C generated C types. They are used for coding of NBAP PDUs as it was described earlier. In addition to ASN2C compilation result the ASN2PER generates three more files: PER C encoding/decoding function prototypes <nbap_pdusper.ext>, PER C encoding functions definitions <nbap_pduspec.c> and PER C decoding functions definitions <nbap_pduspdc.c>.

ASN4SDT

ASN4SDT is the third back-end for CASN compiler that was used in the project. It generates the SDL sorts from the ASN.1 type definitions, so that they can be used in the SDL model. Besides this it generates a C glue-code combining the C code generated by previous ASN.1 tools and by Telelogic SDT. As compilation results we get: the SDL type definitions <nbap_pdus.sdl>, glue-code supporting functions prototypes <nbap_pdussdt.h> and glue-code supporting functions definitions <nbap_pdussdt.c>.

In such a way after running all ASN.1 tools for each ASN.1 module (defined in the file <module>.asn) the one receives about ten different files (in fact the number of generated files depends on the tool configuration) containing the C code that can be further compiled in linked into the executable model. The overall process of making the executable protocol model is shown in the figure 4.3. But before it will be presented there is a need to introduce one more indispensable element in the code generation flow.

CVOPS

CVOPS stands for C-based Virtual Operating System. It is widely used protocol development environment based on the C language. In the project only the part of CVOPS environment has been used, its run-time system library (CVOPS RTS). It provides basic functions working with dynamic memory allocation, frame buffer handling, I/O control and process termination.

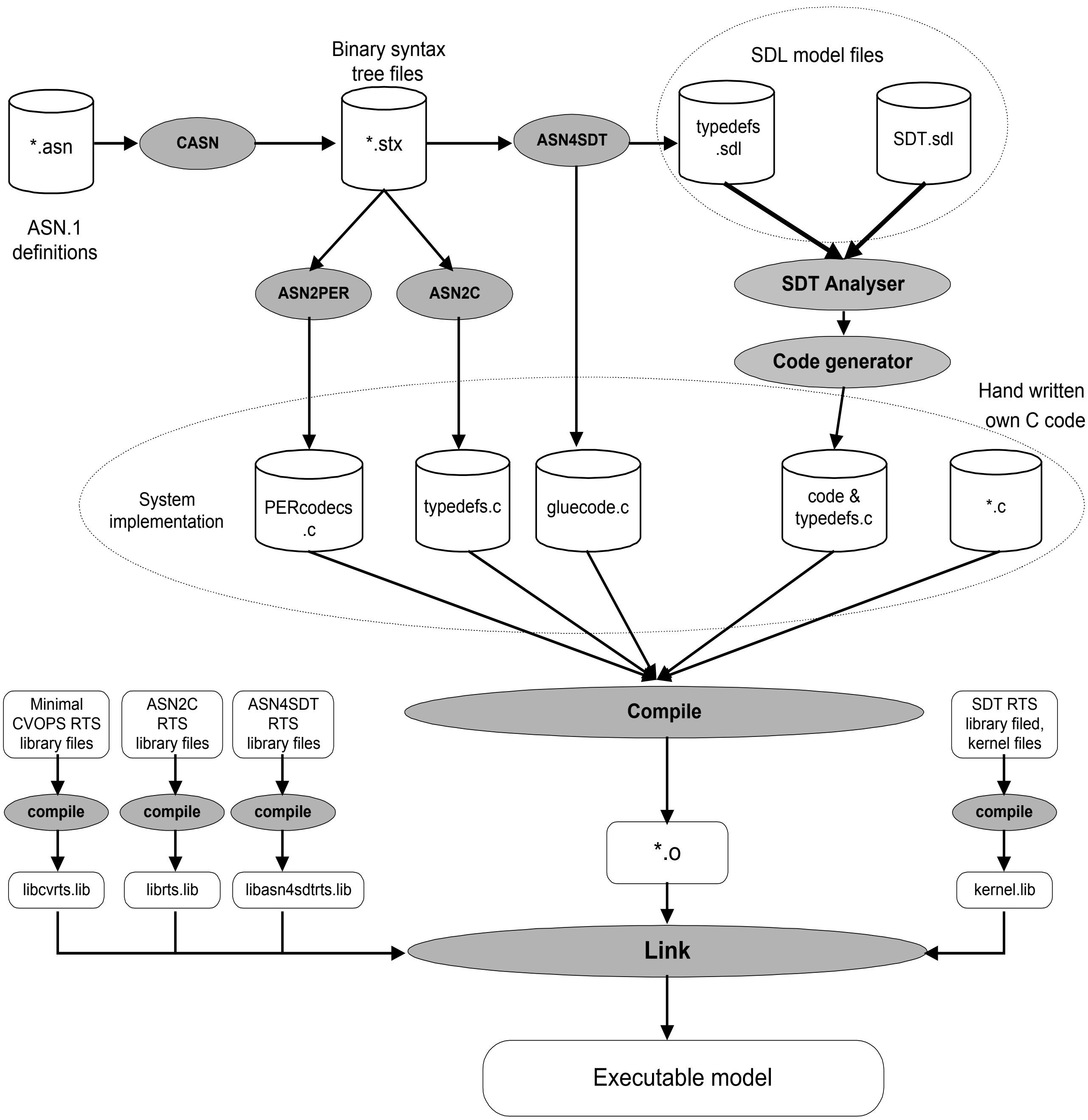


Figure 4.3 Code generation flow [41]

4.3 NBAP SDL implementation

The SDL implementation of NBAP has been made in accordance to the 3GPP Technical Specification 25.433 version 4.1 [16]. The implementation embraces the essential part of the specification including the most important procedures required by the customers. However some of minor procedures and messages are left out of implementation since they don't have a significant impact on the functionality of the system as a whole.

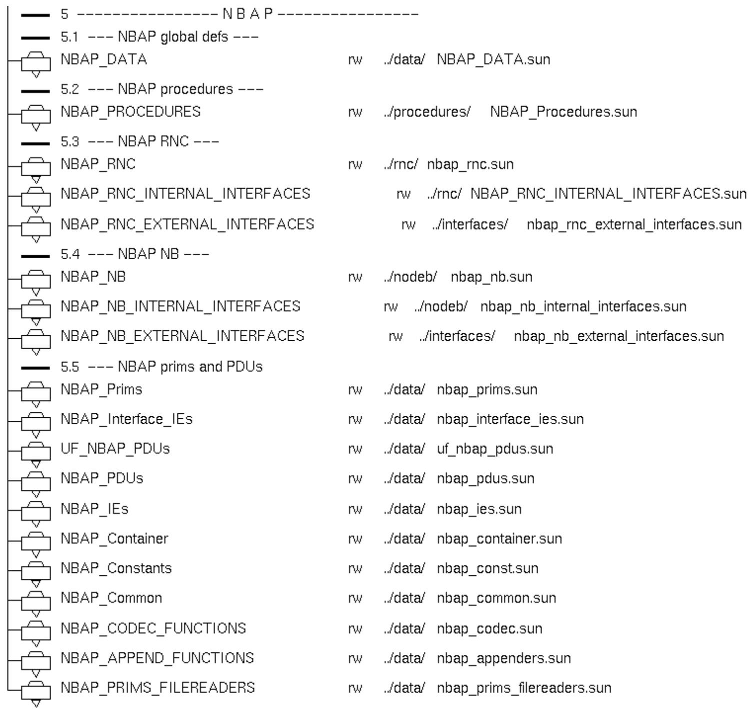
From the other hand some additional features that are not described in the specification were included. These features concern the transport resource management issues and interaction between NBAP and ALCAP.

As it was discussed in the previous chapter the NBAP is an asymmetric protocol. This means that the NBAP protocol entities reside in Node B and RNC has different functionality and thus require different implementations. It was accomplished by implementing them as two different block types. In SDL the block type realizes the object-oriented principle, it's what in OOP is called class. Therefore once being defined the block type can be then instantiated. In current implementations all blocks and processes are defined as block and process types.

In effort to achieve high modularity of the system and reusability of its components the whole software package consists of a number of SDL packages. The SDL package is some sort of library containing reusable component defined as type. In such a way the NBAP implementation as such is organized in the form of packages. The package may contain the block type with possible declarations and constants required for this block, or definitions of block interfaces (either external or internal) i.e. the signals and signal lists, or set of data types to provide different levels of their visibility, or at the end some set of procedures. For example the following is the package containing the NBAP_RNC block type. The similar package contains the NBAP_NB block type.

Once being created the package may be included in any other packages or SDL systems by the ***use*** clause (ex.: USE NBAP_RNC;). This is very important for the creating the test system. The implementation of NBAP as such does not require any packages from other protocol models and can realized in dozen of them, as shown in the figure 4.4. But to test it there is a need to construct a system modeling almost the whole control plane of Iub interface.

This is required to see how the NBAP messages traverse from one side of interface to another. To ensure this the test system may require the modeling of the whole NBAP operational environment, that results in using about forty additional packages from other protocols.



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Such kind of test system is depicted in the figure 4.5. From the highest level of abstraction it consists of two blocks *NodeB* and *RNC* representing corresponding UTRAN elements. The system is called NBAP_NBM_ALCAP. It means that these three protocol models are connected within the system and all other protocols lay beyond. The interaction with them is carried through the system's external interfaces. These interfaces are: towards Radio Network Management unit at the RNC side, to the physical layer and towards the RRC protocol at the Node B side.

The subsequent decomposition of the *NodeB* and *RNC* blocks uncover the following structure (see figure 4.5). Both blocks contain the NBAP protocol entities as such, signalling transport protocol emulators (FCL) and ALCAP protocol entities. Beside this the *NodeB* block contains the Node B Manager unit (NBM) which is described in the next section. All protocol entities are implemented as block types, and instantiated in the *NodeB* and *RNC* blocks.

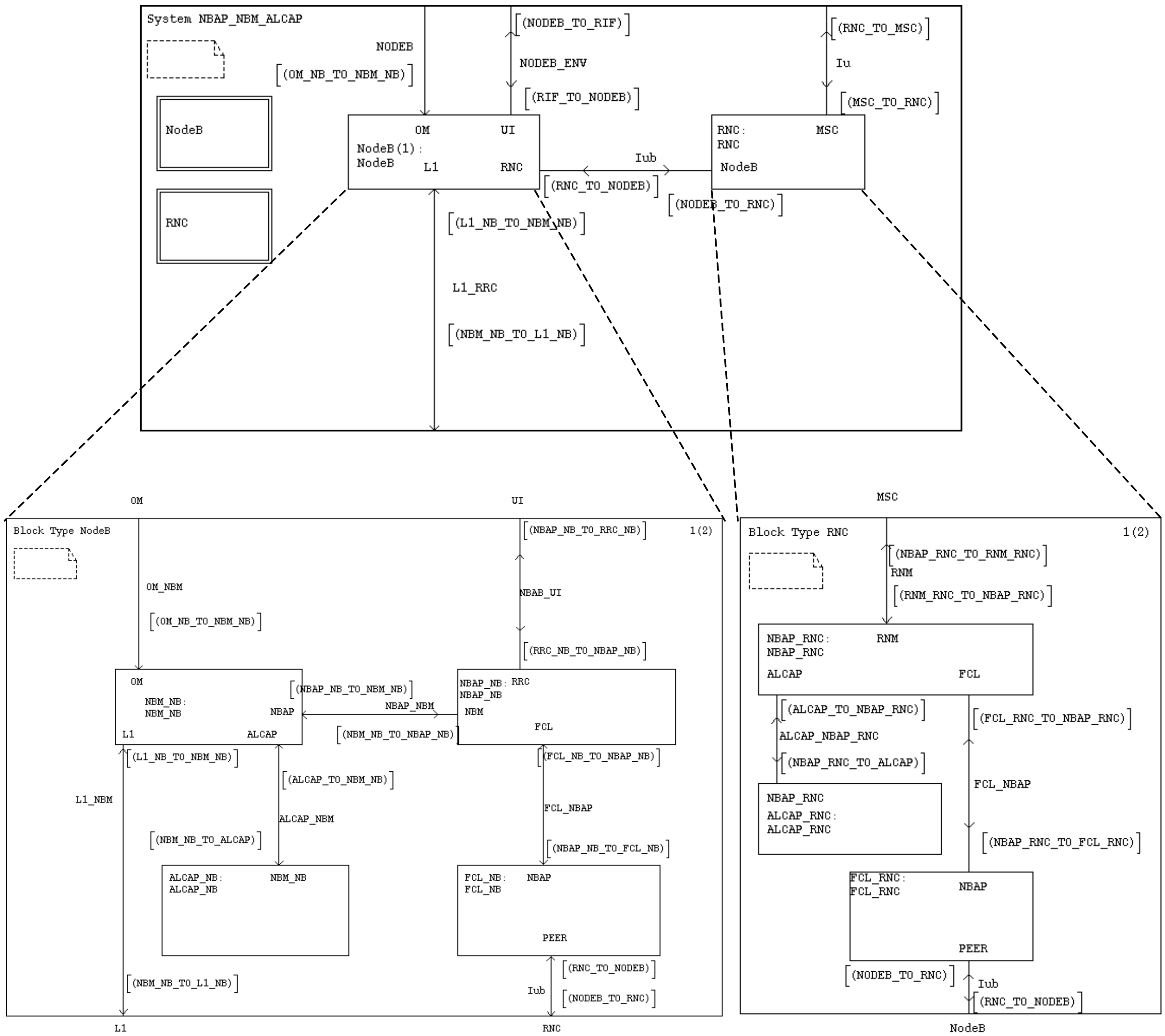

Figure 4.5. NBAP test system

The ALCAP and FCL protocols were designed as in some extent dummy protocols. Their main task is to simulate the interface towards NBAP so that from the NBAP point of view they can be seemed as a real transport layer. In such a way they can be alternated to any other real or dummy transport protocols without modifications to NBAP implementation.

Now lets take a closer look directly at the NBAP internal implementation on the example of NBAP_RNC block type. It is presented on the figure 4.6. Worth to note that the due to the common design principles the structure of NBAP_NB block is almost the same.

The internal structure of NBAP protocol entity is cased by the logical reflections. First of all the NBAP procedures are subdivided on the common and dedicated. In practice some of dedicated and common procedures may be executed at the same time. From this point there is a sense to implement Common and Dedicated NBAP as two different process types, so that their instances may run simultaneously. In such a way corresponding NBAP_RNC_COMMON and NBAP_RNC_UEC processes emerge. In addition the division into process types pretty much conforms to the way how the RNS is seen from the CRNC, when there are several Node Bs belonging to it, each represented by a NBAP_RNC_COMMON process, and a number of UE connections established through the given CRNC, each connection is represented by NBAP_RNC_UEC process. It is obvious that there can be multiple UE connections need to be controlled at the same time. This results in the solution where NBAP_RNC_UEC may have several instances dynamically created for each UE connection. At this point appears the need for the routing between different process instances and for managing their dynamic creation and destroying. For this purposes the third process type was defined, the NBAP_RNC_RED.

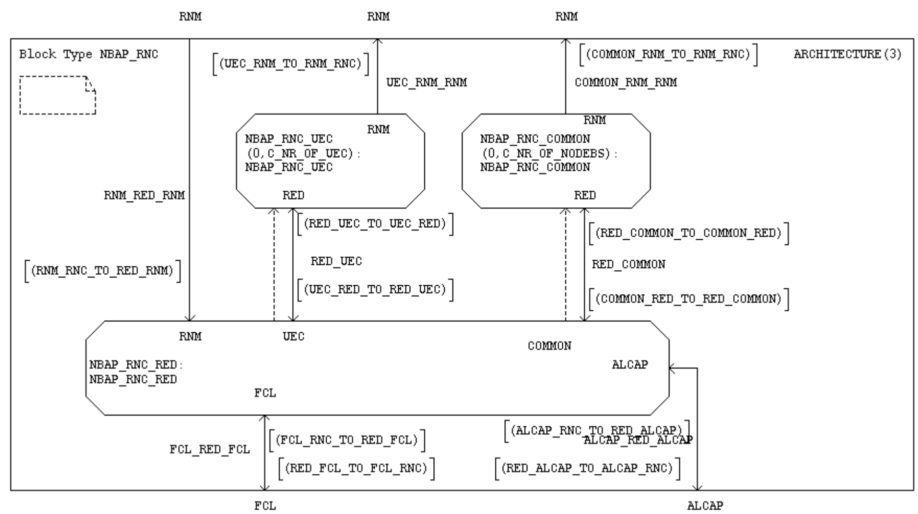

Figure 4.6 Structure of NBAP_RNC block type

So then, the process NBAP_RNC_COMMON executes all common NBAP procedures not related to a particular UE, as it was discussed in the previous chapter. There can be from zero upto the certain number (defined by the constant C_NR_OF_NODEBS) of NBAP_RNC_COMMON processes. They are dynamically created by the NBAP_RNC_RED process on request from the RNM unit. Therefore the logical meaning of the NBAP_RNC_COMMON process is that each process instance represents one Node B belonging to the given RNC. The process has only unidirectional signal routes to the environment. This is due to the basic design concept stating that the all incoming signals from the environment are handled via the RED process [45]. The COMMON, as well as UEC, process can only send signals to the environment, and moreover only those that don't require encoding. For the routing between multiple instances of the NBAP_RNC_COMMON processes the RED process stores the routing table in form of array of PIDs indexed by the

NodeBID. PID stands for the Process Identifier, it is one of the SDL buit-in type. Each process instance after creation has a unique PID value assigned to it.

As it was mentioned above the SDL process is defined in the terms of Extended Finite State Machine. Depending on the number of protocol procedures supported by the process there can be up to hundreds of EFSM transitions within one proscess instance (one transition per PDU or timer). One of such EFSM transition handling the common PDU is shown below.

Figure 4.7. Example of handling common PDU (CELL SETUP REQUEST)

All dedicated procedures and PDUs used by those procedures are handled and implemented in the NBAP_RNC_UEC process. Each NBAP_RNC UEC process correspond to one UE connection. It is dynamically created by the RED process when the first Radio Link for particular UE is setup and destroyed when the last Radio Link for that UE is released.

Thus there may be no UEC processes if none of UEs are in dedicated mode with the given CRNC. The upper limit of UEC processes in practice is determined by the agregated capasity of all Node Bs belonging to given RNC, in current implementation it is limited by the costant C_NR_OF_UEC.

Figure 4.7 Example of handling Dedicated PDU

As the NBAP_RNC_RED name tells this process deals with the encoding and decoding of NBAP PDUs and internal routing between different process instances (RED stands for Routing Encoding Decoding). It processes all the incoming signals meaning that it decodes the PDU if needed and determines the actual destination of the signal, after that the signal with ready-to-use parameters is routed to destination process. For routing the RED process stores the routing tables that are used by routing routines. All routing routines are organised in one package *NBAP_Procedures* and in fact can be used by both RNC and Node B RED processes. The routing table for NBAP_RNC_COMMON processes was described above. For NBAP_RNC_UEC processes the routing table is a bit more complicated since the UE is addressed in different ways in downlink and uplink directions. In downlink direction the UE is addressed by the Radio Network Temporary Identity (RNTI) and in uplink direction by the RNC Communication Context Identifier (RNCCCID). Considering that, the routing table is represented by the list container of elements, which in turn are the structure of RNTI, RNCCCID and PID of UEC process. The routing tables are initialized and updated each time when the new process is instantiated.

Above all the NBAP_RNC_RED supports the interfaces toward the ALCAP protocol. the description of this interfece was given in the previous chapter. It's only worth to note here that the NBAP_RNC_RED is responsible for allocation of *RefID* variable used to address any particular AAL2 connection. This reference together with *BindingID* and *Transoport Layer Address* is provided to the ALCAP in the ALCAP ESTABLISH.request (aal2sig_establish_req in our example). Since the RNC receives from Node B only Binding ID for transport bearer to be allocated NBAP_RNC_RED process also stores then association table between the BindingID and generated reference. The EFSM implementing such functionality is shown in the figure 4.8.

In this example the *nbap_rnc_i_alcap_setup* is received by the NBAP_RNC_RED from the NBAP_RNC_UEC process. The UEC process forms this signal based on the parameters received in the *NBAP RADIO LINK SETUP RESPONSE* PDU. It contains the BindingIDs and Transport Layer Address for the data transport bearer to be allocated over the Iub interface. For more information about this procedure, please refer to section 3.5.2 (in particular figure 3.26 and following discussion).

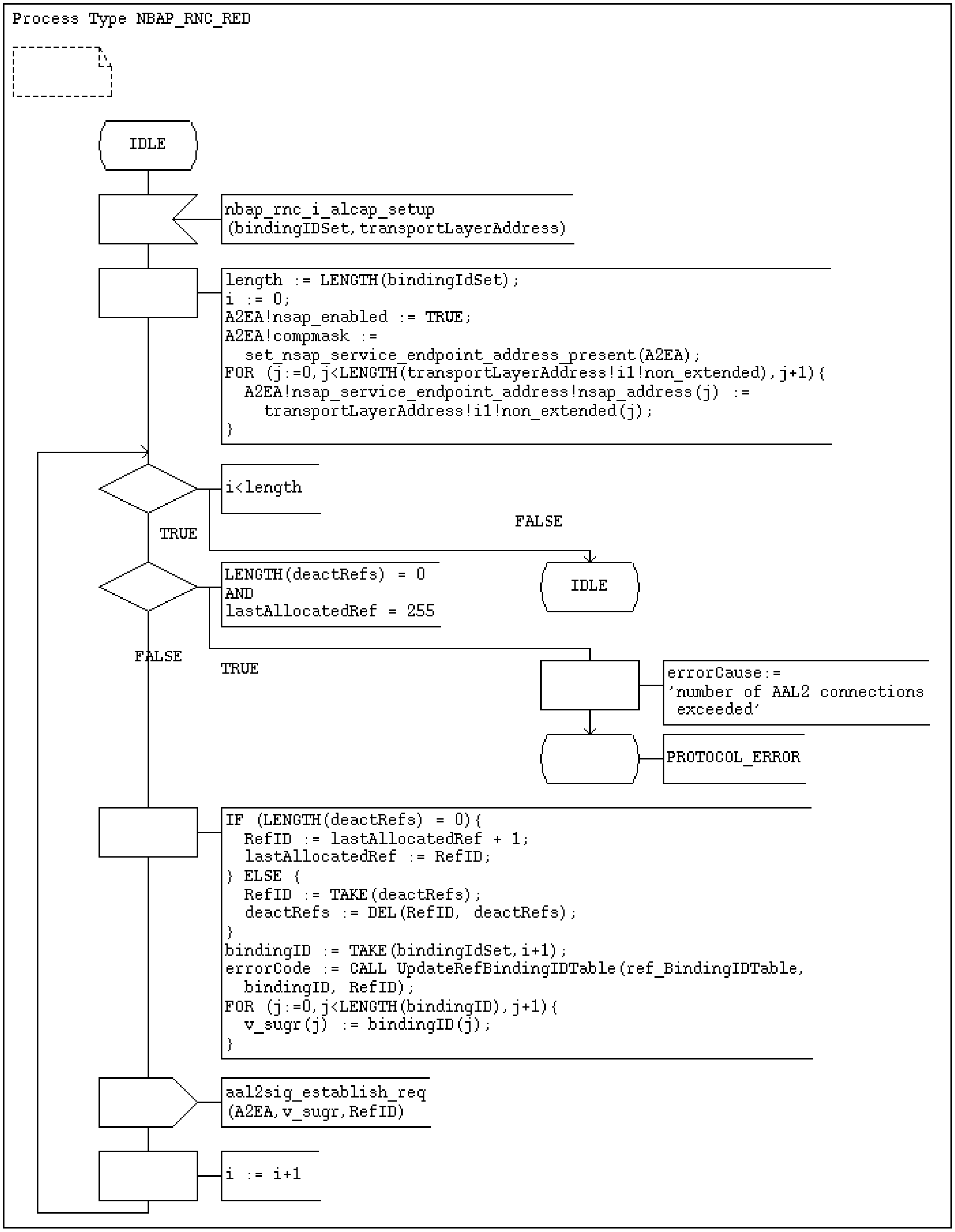

Figure 4.8 Example of SDL code for ALCAP ESTABLISHMENT procedure

4.4 Node B Manager SDL implementation

The Node B Manager is also the part of 3G SDL Library. However it's not standardized by the 3GPP and doesn't mentioned in any specification. The purpose for implementing such a model was to extend the testing possibilities provided by the NBAP model and create the more or less complete picture of UTRAN on the formal level. Some internal Node B functionality and algorithms cannot be implemented in the NBAP model since it's only a signalling protocol. For this some additional functional unit is needed. The NBM plays the role of such kind of unit.

In fact the NBM unit was designed according to the real Node B hardware architecture, i.e. the SDL blocks constituting the NBM block type in some way model the real Node B functional units.

The implementation is done as a single block type named *NBM_NB*. Its internal structure is assembled by the six other blocks, as shown in the figure 4.9.

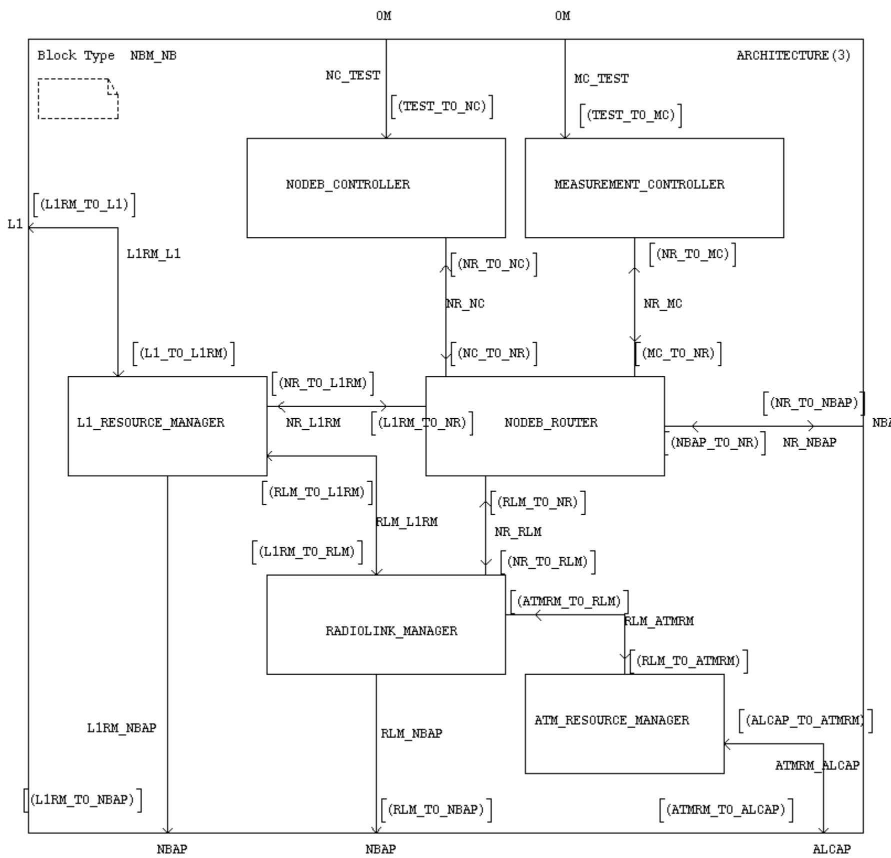

Figure 4.9 NBM_NB block structure

Each block in the NBM_NB architecture contains one process defining behavior of the corresponding block. Following is the brief description of functionality for each block/process in the Node B Manager.

- NODEB_ROUTER has only the responsibility to route all receiving signals to the corresponding destination processes. From this point it act pretty similar as NBAP_RNC_RED process described above, except that it doesn't perform routing. All signals in the downlink direction traverse through the NODEB_ROUTER.
- NODEB_CONTROLLER performs all functionality required for the Logical O&M of Node B. All NBAP primitives related to the Logical O&M are terminated there. Some of the NBAP O&M actions initiated by Node B are trigged in NODEB_CONTROLLER through OM interface.
- MEASUREMENT_CONTROLLER takes care about all measurement related activities. The NBAP COMMON and DEDICATED MEASUREMENT procedures are terminated and treated there.
- RADIOLINK_MANAGER contains the main process that is responsible for setting up first Radio Link for the UE. It has the interface towards the NBAP protocol entity through which it provides its services. The main service provided to NBAP is allocation of Node B Communication Context Id for newly created UE connection. Besides this it partially performs transport resource management tasks. They are concluded in managing Traffic Termination Points. When the Node B Communication Context is created (upon the setup of first Radio Link) the RADIOLINK_MANAGER chooses the Traffic Termination Point to be assigned to that Node B Communication Context, i.e. the point at which all dedicated UE traffic is terminated and mapped to the transport bearer. For that RADIOLINK_MANAGER has the set of Traffic Termination Point Identifiers (TTPIDs) available for the given Node B. The choice for the particular TTPID is done based on the *on-load* algorithm, i.e. the particular UE connection being setup is assigned to that Traffic Termination Point which has the least load (serving the least number of Radio Links). The RADIOLINK_MANAGER continuously controls the load of each Traffic Termination Point. For that it stores the table containing the TTPIDs and number of Radio Links associated with them. Each time when the new Radio Links are added to the existing Node B Communication Context the L1_RESOURCE_MANAGER reports their number to the RADIOLINK_MANAGER, which makes the update of the load table. The choosing algorithm as well as all activities related to the support of load table are implemented in the form of procedures and included in the SDL package *NBM_Procedures*. The example of SDL code from the RADIOLINK_MANAGER block is shown in the figure 4.10.

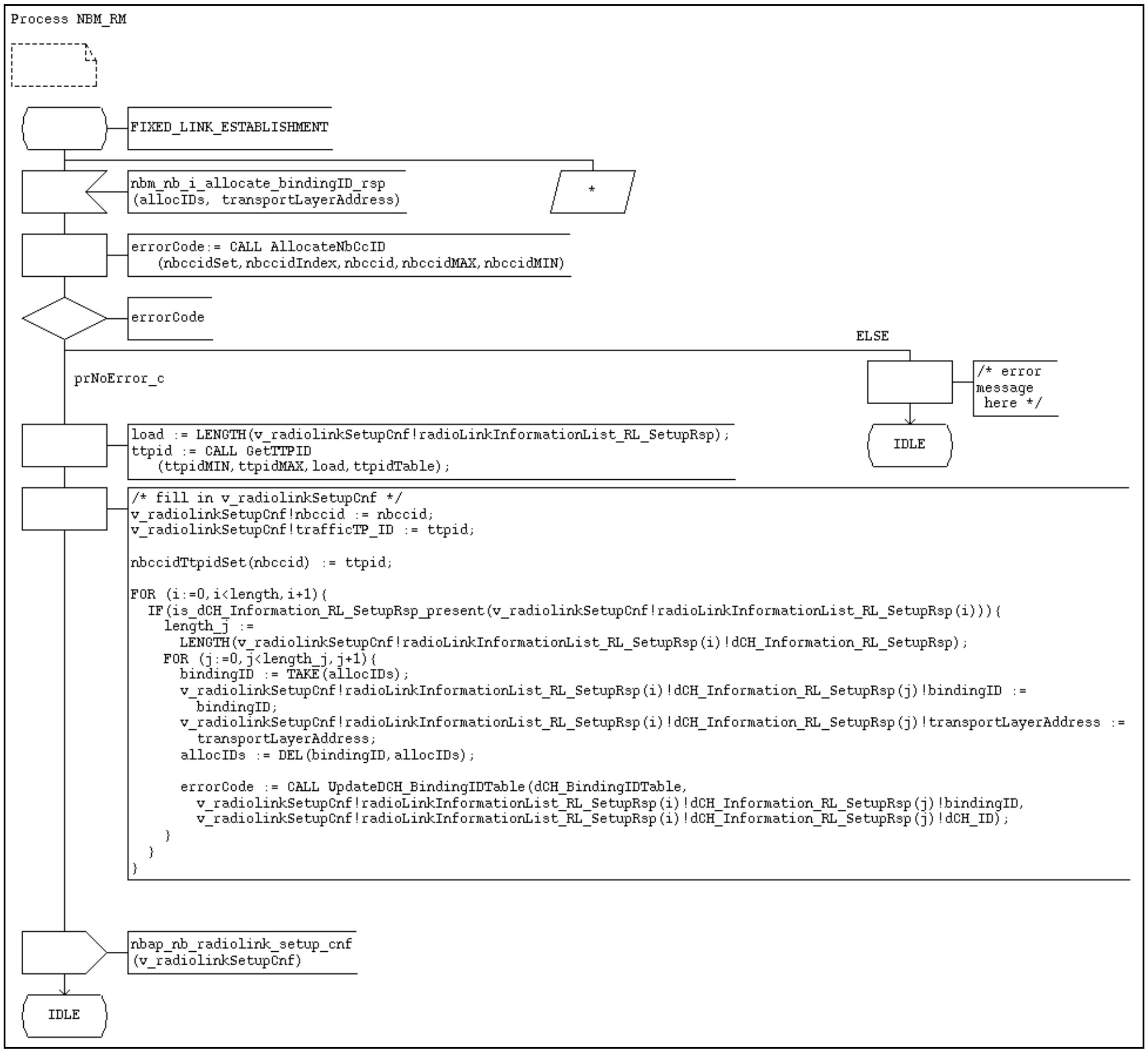

Figure 4.10 Example of SDL code from the RADIOLINK_MANAGER block

- L1_RESOURCE_MANAGER takes care about the interaction with the L1 layer (WCDMA physical layer). This interaction is required when there is need to pass some physical parameters to the L1 layer. Almost all dedicated PDUs coming from NBAP entity cause such kind of interaction.
- ATM_RESOURCE_MANAGER is in charge of the rest part of functionality related to the transport resource management. Its main responsibility is firstly to allocated BindingID for the newly created transport bearer (AAL2 connection) and provide it together with Transport Layer Address to the RADIOLINK_MANAGER that then forwards them to NBAP entity, and secondly to perform required interaction with the Transport Network Layer Control Plane, for that it has direct interface towards the ALCAP protocol. The BindingID

that is allocated here has the length of four octets. In fact the ATM_RESOURCE_MANAGER allocated only the half of this length, i.e. two octets, the rest two octets are initialized at the RNC side (actually by the NBAP_RNC_UEC process) by the NodeB ID (NID) value. This is required in order to avoid interleaving of Binding Ids allocated in different Node Bs that belong to the same RNC. Besides this the ATM_RESOURCE_MANAGER creates and stores the association between the reference generated by the NBAP_RNC_RED process (RefID), and provided by the ALCAP in ESTABLISH.indication primitive, and BindingID.

4.5 Experience

As it was described in the first chapter the specification of 3G systems is divided into release phases. The release separation was done in order to provide smooth and seamless way of evolution from second-generation to third-generation systems. But from the other hand this implies the continuous nature of changes in specifications. Within each release phase the specifications are changed upto dozen of times. At the moment the specifications for some protocols, such as MAC or RRC are stable enough, but for another are not. The application protocols, and NBAP in particular, are the ones of those that still have a lot of changes from one release version to another. The new version update is released basically once in three – four months, sometimes the ASN.1 definitions are changed or even new procedures are added. All this requires continuous update of the protocol models.

Fortunately the ASN.1 definitions coming from the specifications are quite well unified, that allows to use sometimes uniform methods for adaptation of the definitions and generating encoding/decoding functions, for example. This made possible to create commonly used Perl scripts for generating needed functions and "user friendly" definitions for PDUs.

The concept of "user friendly" PDUs has emerged due to the complexity of ASN.1 definitions coming from the specifications and inability to use them in SDL code. The idea was to create more simple definitions for PDUs keeping their structure intact. That also required extension of encoding/decoding functions to transform decoded PDUs to the "user friendly" format. Although it is good as a temporary solution, it is not an answer for the long-term employment. Instead the support of these advanced ASN.1 features from ASN.1 tools is expected in the future.

Another problem caused by the complexity of ASN.1 definitions was such that sometimes ASN.1 tools were not ready to process such kind of huge and complex ASN.1 structures. As a result system crashed during the simulation. Although the SDT Simulator supports tracing facilitities, they are not enough to find such kind of bugs. Often the debugging on the C level had to be used, which is, considering the amount of C code generated by SDT, extremely difficult task. But step by step as the bugs in tools were reported they have been taken into account and now the ASN.1 tools are more or less stable.

But still one significant problem with ASN.1 tools remains. At the time the implementation was done there was no support for dynamic memory allocation for the types generated from ASN.1 definitions, or that support was not stable enough to be employed throughout the whole library. As a result the ASN.1 type constructors such as SEQUENCE OF and SET OF were translated into static arrays. This has led to the enormous memory consumption. Some temporary solutions have been employed to decrease memory consumption, such as forced limitation of the generated arrays. But it is not a solution for the long-term perspective. Instead the support for dynamic memory from ASN.1 tools is expected to use in the future. In addition there are some ideas how to optimize the ASN.1 structure for primitives and make some changes in SDL code that could also minimize the memory consumption.

In the rest ASN.1 Nokia tools and Telelogic SDT are quite powerful tools and fairly easy to use. The graphical user interface of the SDT as well as SDL graphical notation are quite simple and fast to learn. Besides the implementation the SDT gives a lot of assistant during the testing phase. The MSC and SDL trace functionality of SDT is very handy to use for debugging on the SDL level. Although the SDT takes care about the low-level implementation issues, a lot of responsibility is still left to the programmer, that gives him enough freedom and flexibility in the implementation decisions.

5. CONCLUSION

Selection of transport architecture for the 3G cellular network is not an easy task. Explosive growth in cellular users, new services including Internet and multimedia, backward compartibility and convergence of wireless and wireline networks are some of the key issues that will play a major role in selecting a transport architecture. The aim of this paper was to indicate the different options possible for future cellular networks (that was done in the first section), and then to examine the current choice of transport technology within the UTRAN on the example of Iub interface (presented in the rest of the paper). The work was concentrated on the overview of transport resource management tasks performed by different protocols at the Iub interface and in particular by the NBAP application protocol that was in question of practical implementation.

As the study has indicated, to meet the stringent requirements of cellular telephony the standardization process consider the ATM to be the essential transport technology at the current stage of 3G evolution (3GPP Rel99). And at least in part of UTRAN the ATM dominates also in the next phase, defined in 3GPP Release 4.

The ATM offers an integrated solution to voice (circuit mode as well as packet voice), data and video. QoS guarantee, reliability and a service model that is similar to telecom networks are other reasons why ATM is a preferred option as a transport technology. To meet a specific requirements of mobile telephony the ATM is used together with its adaptation layers, namely with AAL2 and AAL5.

At the same time the dominance of IP protocols in data networks and recent efforts in incorporating QoS provisioning mechanisms in IP have given impetus to a number of studies on experimenting with IP as a transport technology in 3G cellular networks. As mentioned earlier mobile telephony has been the dominant application in the wireless networks, and requires that the underlying transport technology is capable of supporting QoS guarantee. One of the hurdles for IP has been its inability to solve the QoS issues.

The standrdization of the transport protocols for the UMTS Release 99 has already been completed in 3GPP. When the work was started several years ago, ATM was thought to be the default transport technology in 3G. However during the last few years there has been a change in this view: the role of IP gained more and more importance during the standardization process. The efforts towards integrating QoS provisioning mechanisms such as differentiated services (Diff-serv) and integrating services have given a new hope of using IP in 3G cellular infrastructure. Not the least, IP terminal adaptability, the same terminals being used in both wireless and wireline networks, is also an important factor which favours the use of IP.

From this point the Voice over IP solutions are considered as a key for a successful IP based cellular infrastructure. For data and video, it has been proven that IP is the optimal technology.

All this efforts has led to the so called All-IP based architecture defined in the 3GPP Release 5 (see figure 1.3).

Although the transport resource management objectives and functionality changes significantly together with changing of transport technology itself, the view on the transport resources and thus the means to manage them from the Radio Network Layer point of view remains intact. That was the main idea in order to provide seamless protocol evolution along with the evolution of transport in UTRAN from ATM to IP. The application protocols have been successfully isolated from the transport layers, which makes the protocol evolution easy. On the example of NBAP implementation this work has shown that it's independent from the underlying transport technology in terms of both signalling transport and management of transport resources (in part of NBAP responsibility); the latter is ensured by the introduction of the Transport Network Control Plane at the Iub interface, physically implemented by the ALCAP protocol.

In that way this work has shown that the transport resource management tasks can be divided into different abstraction levels seen from the Radio Network Layer and Transport Network Layer. The direct transport technology dependent activity is performed from the Transport Network Layer by the ALCAP protocol, which itself obeys the commands from the Radio Network Layer. In current realization of 3G SDL Library the NBAP and NBM are the ones that provide such kind of interaction with ALCAP. To such an extent the NBAP and the NBM contribute to the transport resource management at the Iub interface.

However the interface between the NBAP and ALCAP, and all the more Node B Manager, is not standardized by the 3GPP; all these are left as implementation specific issues. Nevertheless their design and implementation should be done very carefully, because the efficiency of transport resource management functions at the Iub interface have the crusial impact on the successful operation of the overall UMTS network.

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