AALTO UNIVERSITY
School of Electrical Engineering
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WCDMA Mobility Troubleshooting Studies and Enhancements

Master's Thesis

Espoo, September 30, 2011

Supervisor: Prof. Jyri Hämäläinen

Instructor: Jukka Valtanen, M.Sc. (Eng)

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Abstract

Mobility is the key success area in WCDMA technology. To maintain seamless mobility, Radio Resource Management algorithms are essential in network management. Together with Admission Control, Load Control, Packet Scheduler, Resource Manager and Power Control algorithms, Handover Control algorithms are responsible for high quality seamless communication. These algorithms take place in the Radio Network Controller software.

In software life-cycle there can be challenges related with different software program blocks. Other than software problems there can also be radio network planning problems, hardware problems and user-equipment related problems. Those issues have to be analyzed by experienced R&D engineers. Usually it is not straightforward to investigate what is the root cause. Because of this reason troubleshooting tools play a vital role in software development. This thesis analyzes the existing troubleshooting solutions in NSN-WCDMA-Control Plane-Handover Algorithm team and proposes enhanced solutions for those needs.

As a result of this thesis, some of the enhanced solutions are implemented and analyses for the other solutions are provided. Development of troubleshooting tools and methodology will continue in the software development team after the completion of this thesis.

Keywords

WCDMA, radio network controller, handover, troubleshooting

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Tiivistelmä

Mobiliteetti on yksi WCDMA-teknologian menestyksen avaintekijöistä. Saumattoman liikkuvuuden ylläpitämiseksi radioresurssien hallinnan algoritmit ovat tärkeässä roolissa verkon hallinnassa. Yhdessä pääsyvalvonnan, kuormavalvonnan, pakettiskedulerin, resurssimanagerin ja tehovalvonnan kanssa kanavanvaihtoalgoritmit vastaavat laadukkaan, katkeamattoman yhteyden ylläpidosta. Nämä algoritmit on toteutettu radioverkko-ohjaimen (RNC) ohjelmistossa.

Ohjelmiston elinkaaren aikana ohjelmiston eri osissa kohdataan erilaisia haasteita. Ohjelmiston lisäksi ongelmia voi löytyä myös radioverkon suunnittelusta, verkkolaitteistosta tai päätelaitteista. Kaikkien näiden ongelmien analysointiin vaaditaan kokeneita R&D-insinöörejä, eikä ongelmien varsinaisen aiheuttajan löytäminen usein ole yksinkertaista. Tämän takia erilaiset vianetsintätyökalut ovat ohjelmistokehityksessä ensisijaisen tärkeitä. Tämä diplomityö analysoi jo käytössä olevia vianetsintämenetelmiä NSN-WCDMA-Control Plane-Handover Algorithm -ryhmässä sekä esittää erilaisia paranneltuja ratkaisuja näihin menetelmiin.

Tämän diplomityön tuloksena muutamia paranneltuja ratkaisuja toteutettiin ja muutamia muita ratkaisumalleja analysoitiin. Vianetsintätyökalujen sekä -menetelmien kehitys jatkuu tarkastellussa ohjelmistokehitysryhmässä myös tämän diplomityön valmistumisen jälkeen.

Avainsanat

WCDMA, radio network controller, handover

AALTO ÜNİVERSİTESİ

Elektrik Mühendisliği Fakültesi

Haberleşme ve Ağ İletişimi Bölümü

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Tez Başlığı

Geniş Bant Kod Bölmeli Çoklu Erişim (WCDMA) Mobilite Sorun Giderme Çalışmaları ve İyileştirmeleri

Derecesi	Bölümü
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Denetçi

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Özet

Hareketlilik, geniş bant kod bölmeli çoklu erişim (WCDMA) teknolojisindeki en önemli başarı alanıdır. Kesintisiz hareketliliği korumak için, Radyo Kaynakları Yönetim algoritmaları ağ yönetiminde çok önemlidir. Erişim Kontrol, Yük Kontrol, Paket Zamanlayıcısı, Kaynak Yöneticisi ve Güç Kontrol algoritmaları ile birlikte, Hücreler Arası Geçiş Kontrol algoritmaları, yüksek kaliteli kesintisiz bir iletişimdem sorumludur. Bu algoritmalar Radyo Şebeke Kontrolör yazılımında yer alır.

Yazılım geliştirme sürecinde, farklı yazılım program bloklari arasında sıkıntılar olabilir. Yazılımsal sorunlar dışında, radyo şebeke planlama sorunları, donanım sorunları ve kullanıcı ekipmanıyla ilgili sorunlar olabilir. Bu sorunların deneyimli Ar-Ge mühendisleri tarafından analiz edilmesi gerekir. Genellikle kök nedenin ne olduğunu araştırip ortaya çıkarmak kolay değildir. Bu nedenle sorun takip ve giderme araçları, yazılım geliştirmede hayati bir rol oynar. Bu tez, Nokia Siemens Networks şirketi WCDMA Yazılımı - Kontrol Platformu - Hücreler Arası Geçiş Kontrol Algoritmaları takımındaki mevcut sorun takip ve giderme çözümlerini analiz etmekte ve bu ihtiyaçlar için geliştirilmiş çözümler önermektedir.

Bu tezin bir sonucu olarak, bazı gelişmiş çözümler uygulanmakta ve diğer çözümler için analizler sağlanmaktadır. Sorun giderme araçları ve metodolojisinin geliştirilmesi, bu tezin tamamlanmasından sonra, yazılım geliştirme ekibinde devam edecektir.

Anahtar Kelimeler

WCDMA, Radyo Şebeke Kontrolör, Hücreler Arası Geçiş

Preface

This Master's thesis presents the work that was carried out under supervision of Professor Jyri Hämäläinen from Aalto University School of Electrical Engineering and under instruction of M.Sc. Jukka Valtanen from Nokia Siemens Networks. This thesis work was performed at Nokia Siemens Networks premises in Espoo from January 2011 to September 2011.

Acknowledgements

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I would also like to thank my supervisor professor Jyri Hämäläinen, from Aalto University School of Electrical Engineering, for his guidance during the thesis process. After the clarification of the thesis topic by Nokia Siemens Networks he helped me in getting the process started and also thereafter gave me valuable comments on this thesis.

Most of all, I would like to thank to my family, my mother, my father and my beloved Elis for all their support and encouragement that they have given me throughout my studies.

In Espoo, 30.09.2011

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List of Acronyms

2G	2nd Generation
3GPP	3rd Generation Partner Project
8PSK	Eight-Phase Shift Keying
A-GPS	Network-Assisted Global Positioning System
AC	Admission Control
ACK	Acknowledgement
ADJD	Adjacent Detected Cell
ADJG	Adjacent GSM Cell
ADJI	Adjacent Inter-Frequency cell
ADJS	Adjacent Intra-Frequency cell
ALCAP	Access Link Control Application Part
AMPS	Advanced Mobile Phone Service
AS	Active Set
ASU	Active Set Update
AT&T	American Telephone and Telegraph
ATDMA	Advanced TDMA Mobile Access
BCC	Base Station Colour Code
BCCH	Broadcast Control Channel
BER	Bit Error Rate
BLER	Block Error Rate
BoD	Bandwidth on Demand
BSC	Base Station Controller
BSIC	Base Station Identity Code
BSS	Base Station Subsystem
BTS	Base Transceiver Station
C-NETZ	Radio Telephone Network C
CDMA	Code Division Multiple Access
CFCP	Centralized Functions and services in Control Plane
CGI	Cell Global Identification
CI	Cell Identifier
CIO	Cell Individual Offset
CM	Compressed Mode

CN	Core Network
CODIT	Code Division Testbed
CPICH	Common Pilot Channel
CRNC	Controlling Radio Network Controller
CSCP	Cell Specific functions and services in Control Plane
CSUP	Cell Specific functions and services in User Plane
DCCH	Dedicated Control Channels
DCH	Dedicated Channel
DL	Downlink
DMCU	Data and Macro diversity Combining Unit
DMPG	Data and Macro Diversity Processor Group
DPCCH	Dedicated Physical Control Channel
DPCH	Dedicated Physical Channel
DPDCH	Dedicated Physical Data Channel
DRNC	Drifting Radio Network Controller
DS-CDMA	Direct-Sequence Code Division Multiple Access
DSCR	Detected Set Cell Reporting
E-DCH	Enhanced Dedicated Channel
EDGE	Enhanced Data Rates for Global Evolution
EHU	External Hardware Alarm Unit
EITP	External Interface functions in Transport Plane
ETACS	Extended Total Access Communications System
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FM	Frequency Modulation
FRAMES	Future Radio Wideband Multiple Access System
GERAN	GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GMSC	Gateway Mobile Services Switching Center
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communications

HC	Handover Controller
HHO	Hard Handover
HLR	Home Location Register
HO	Handover
HSCSD	High-Speed Circuit-Switched Data
HSDPA	High Speed Downlink Packet Access
HSUPA	High Speed Uplink Packet Access
HSPA	High Speed Packet Access
ICSU	Interface Control and Signalling Unit
I-HSPA	Internet High Speed Packet Access
I&V	Integration and Verification
IFHO	Inter Frequency Handover
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IS-95	Interim Standard 95 for CDMA
IS-136	Interim Standard 136 for Digital AMPS
ISHO	Inter System Handover
LAC	Location Area Code
LC	Load Control
LCS	Location Services
LTE	3GPP Long Term Evolution
MAC	Medium Access Control
MBMS	Multimedia Broadcast Multicast Service
MCC	Mobile Country Code
ME	Mobile Equipment
MEHO	Mobile Evaluated Handover
MIMO	Multiple-Input and Multiple-Output
MNC	Mobile Network Code
MRC	Maximal Ratio Combining
MSC	Mobile Services Switching Centre
MT	Module Test
MXU	Multiplexer Unit
NACK	Negative Acknowledgement
NBAP	Node B Application Part

NCC	Network Colour Code
NEHO	Network Evaluated Handover
NFC	Near Field Communications
NMT	Nordic Mobile Telephony
NodeB	Base Transceiver Station in UMTS Architecture
NPGE	Network Processor Interface Units Gigabit Ethernet
NPS1	Network Processor Interface Unit STM-1
NRT	Non Real Time
NTT	Nippon Telegraph and Telephone
O&M	Operation & Maintenance
ODMA	Opportunity Driven Multiple Access
OFDMA	Orthogonal Frequency Division Multiple Access
OMS	Operation and Maintenance Server
OMU	Operation and Maintenance Unit
QoS	Quality of Service
P-CPICH	Primary Common Pilot Channel
PC	Power Control
PDC	Personal Digital Cellular
PLMN	Public Land Mobile Network
PRB	Program Block
PS	Packet Scheduler
R&D	Research and Development
RAB	Radio Access Bearer
RAC	Routing Area Code
RACE	Research of Advanced Communication Technologies in Europe
RAN	Radio Access Network
RANAP	Radio Access Network Application Part
RAT	Radio Access Technology
RLC	Radio Link Control
RNC	Radio Network Controller
RNS	Radio Network Subsystem
RNSAP	Radio Network Subsystem Application Part
RNW	Radio Network

RRC	Radio Resource Control
RRM	Radio Resource Management
RSCP	Received Signal Code Power
RSMU	Resource and Switch Management Unit
RT	Real Time
RX-TX	Receive – Transmit
SAB	Service Area Broadcast
SAP	Service Access Point
SAS	Stand Alone Serving Mobile location Centre
SC-FDMA	Single Carrier Frequency Division Multiple Access
SEB	Service Block
SFU	Switching Fabric Unit
SGSN	Serving GPRS Support Node
SHO	Soft Handover
SIR	Signal to Interference Ratio
SITP	Signalling Transport Plane
SRNC	Serving Radio Network Controller
SRNS	Serving Radio Network Subsystem
SWU	Switching Unit (Ethernet)
SYB	System Block
TACS	Total Access Communications System
TBU	Timing and Hardware Management Bus Unit
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
UARFCN	UTRA Absolute Radio Frequency Channel Number
UE	User Equipment
UER	UE Specific Radio Resources
UL	Uplink
UMTS	Universal Mobile Telecommunications System
USCP	UE Specific functions and services in Control Plane
USUP	UE Specific functions and services in User Plane
USIM	UMTS Subscriber Identity Module
UTRAN	UTMS Terrestrial Radio Access Network
VAS	Value Added Services

VLR	Visitor Location Register
VOIP	Voice over IP
WCDMA	Wideband Code Division Multiple Access
WDU	Winchester Drive Unit for OMU
WTDMA	Wideband Time Division Multiple Access

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Key Concepts

GSM: 2nd Generation Radio Access Network technology which is standardized by European Telecommunications Standards Institute. It uses FDMA and TDMA as radio access method and at the backbone it uses digital circuit switching.

BSC: Base Station Controller manages radio resources for Base Stations in GSM architecture.

RNC: RNC stands for Radio Network Controller which is defined with UTRA-3G specifications. The key functions of the Radio Network Controller (RNC) are management of terrestrial channels, management of radio channel configurations in the Radio Access Network (RAN), radio resource management, telecom functionality, transmission & transport features and maintenance & operation.

Handover: Handover is the process to maintain seamless communication while users are mobile between different cells/sectors inside the network.

EMIL: An internal tool that is designed to investigate call traces and other logs for verification purposes.

Troubleshooting: Troubleshooting is the chain of processes which aims to identify a particular challenge inside the software and try to propose solutions or workarounds.

1 Introduction

Wireless Communications has become step by step indispensable in people's life as it is utilized more and more. For service providers, it also becomes vital to use their wireless resources efficiently. Radio Resource Management (RRM) is the solution to maintain seamless mobility and resource efficiency. In WCDMA Radio Access Network (RAN) architecture Radio Network Controller (RNC) is responsible from RRM duties. Radio Resource management functions are split into 6 different groups of algorithms:

- Admission Control
- Load Control
- Packet Scheduler
- Resource Manager
- Power Control
- Handover Control

The software development for Nokia DX type of digital switches was started in early 70's and with the ease of its modular design; DX architecture followed the technology evolution and was used for GSM mobile technology as well. As an ancestor, software for Radio Network Controller continued from the existing DX200 software and it became more complex with the specifications of 3GPP for WCDMA networks. Those changes in the software also created new fields to be debugged and investigated. Eventually troubleshooting has become more important and complex for the new systems.

This work examines the troubleshooting experiences for Handover related issues under Radio Resource Management software block in Radio Network Controller.

1.1 Problem Statement and The Objectives

There are different types of challenges in WCDMA Mobility part of the RNC software. From developers and testers point of view, it would be easier for them to investigate those issues by using a specially designed troubleshooting tool or with improvements to the existing tools.

Most of the existing troubleshooting approaches are based on practical analysis which takes time and usually it is hard to figure out the problem. This thesis will analyze the existing challenges and propose better solutions to be implemented by modifying the existing solution or providing a new troubleshooting tool.

1.2 Structure of the Thesis

This thesis consists of 8 chapters.

Chapter 1 includes the introduction of the thesis. Chapter 2 includes the basic information about WCDMA and HSPA. Chapter 3 includes detailed information about mobility concept in terms of UMTS specifications. Chapter 4 explains the Radio Network Controller concept and different solution approaches and detailed information about the Handover Control Algorithm Program Block in Radio Network Controller Software. Chapter 5 includes the troubleshooting experiences and introduces an existing troubleshooting tool called EMIL. Then it depicts and analyzes existing challenges in Handover Control Algorithm Block. Chapter 6 has conclusion statements about the thesis. Chapter 7 includes the list of references and Chapter 8 includes the message details for a particular issue which will be analyzed in **5.3.2**.

The scope of this thesis work was decided with the NSN - Control Plane - Handover Algorithms team. My prior knowledge about WCDMA was not deep enough to analyze the handover algorithm based problems, so I started studying the Radio Resource Management fundamentals focusing on handover types. In the second chapter I try to inform the reader about the short history of WCDMA and in the further chapters I try to focus the attention on Handover Algorithm analysis.

With the Handover Algorithms team we started with initial thesis meetings to define the scope of the work. Then, from different proficiencies, analysis requests were gathered and problem specific small working groups were assigned. After that, thesis progress continued with weekly updates.

2 WCDMA and HSPA Basics

In this chapter, a short history about 3G evolution and basics of WCDMA and HSPA will be presented.

2.1 Evolution to 3G

2.1.1 1st Generation

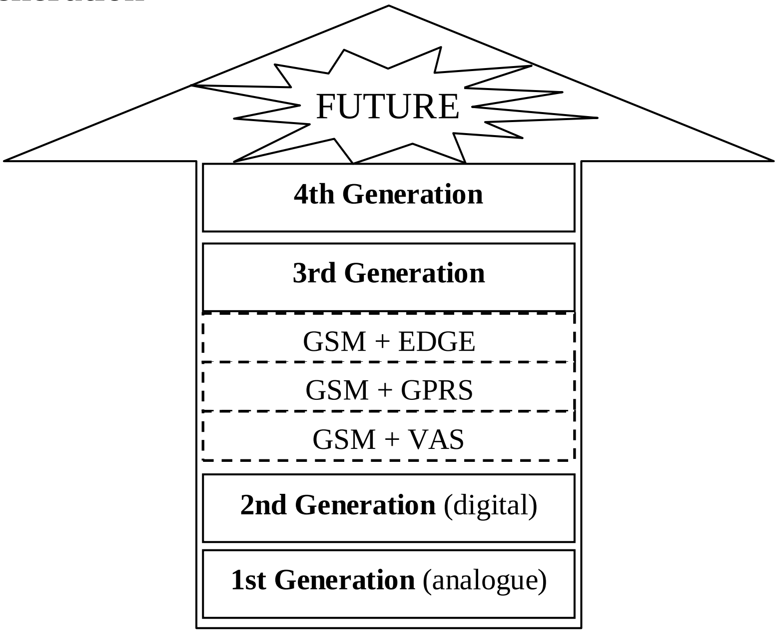

Figure 1: Mobile Evolution [1, pp 4]

The first mobile telephony network was deployed in 1920 for the use of several police departments in the U.S. as an experiment. Then, with the development of frequency modulation (FM), mobile communications became more reliable during World War II. The development continued after the war, and it started to be used in big cities of U.S. But those systems had limited capacity and inefficient transmission methods **[2, pp 3].**

After multiple trials, technology evolved to a level that it could be used as a commercial product. In 1978, American Telephone & Telegraph (AT&T) implemented a Federal Communications Commission (FCC) authorized trial system in Chicago. After analyzing the results of the trial system for a couple of years, AT&T got the licence for Advanced Mobile Phone Service (AMPS). A commercial mobile network was first deployed in Chicago and the other big cities followed. AMPS was operating in 800-

MHz band **[2, pp 3].** At the same time in Japan, Nippon Telegraph and Telephone (NTT) started operating their AMPS network in Tokyo **[3, pp 1].**

In 1980's, Nordic countries launched their Nordic Mobile Telephony (NMT450) network which was using 450 MHz band in the following years it was developed to use 900MHz band. After AMPS and NMT, the British launched a new technology in 1985 which was Total Access Communications System (TACS) **[2, pp 3].** There were also other technologies developed, but widely used technologies were AMPS, NMT and TACS.

System	Countries
NMT-450	Andorra, Austria, Belarus, Belgium, Bulgaria, Cambodia, Croatia, Czech Republic, Denmark, Estonia, Faroe Islands, Finland, France, Germany, Hungary, Iceland, Indonesia, Italy, Latvia, Lithuania, Malaysia, Moldova, Netherlands, Norway, Poland, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Thailand, Turkey, and Ukraine
NMT-900	Cambodia, Cyprus, Denmark, Faroe Islands, Finland, France, Greenland, Netherlands, Norway, Serbia, Sweden, Switzerland, and Thailand
TACS/ETACS	Austria, Azerbaijan, Bahrain, China, Hong Kong, Ireland, Italy, Japan, Kuwait, Macao, Malaysia, Malta, Philippines, Singapore, Spain, Sri Lanka, United Arab Emirates and United Kingdom
AMPS	Argentina, Australia, Bangladesh, Brazil, Brunei, Burma, Cambodia, Canada, China, Georgia, Guam, Hong Kong, Indonesia, Kazakhstan, Kyrgyzstan, Malaysia, Mexico, Mongolia, Nauru, New Zealand, Pakistan, Papua New Guinea, Philippines, Russia, Singapore, South Korea, Sri Lanka, Tajikistan, Taiwan, Thailand, Turkmenistan, United States, Vietnam, and Western Samoa
C-NETZ	Germany, Portugal, and South Africa
Radiocom 2000	France

Table 1 : First Generation Networks [3, pp 2]

2.1.2 2nd Generation

At the beginning, the capacity was enough for the limited amount of subscribers, but when the number of subscribers increased, operators and vendors started to think on better technologies for mobile communications. With this motivation, different 2G technologies were developed in different countries.

The main enhancement with 2G was digital communication. The use of digital transmission brought a number of benefits **[2, pp 52]:**

- Increased capacity over analogue
- Reduced capital infrastructure costs
- Reduced the capital per subscriber cost
- Reduced cellular fraud
- Improved features (such as encryption)

The benefits listed above, mainly helped operators to serve more efficiently (higher capacity with less cost) to their subscribers. The most successful 2G technologies were Interim Standard 136 (IS-136) TDMA, IS-95 CDMA, and the Global System for Mobile communications (GSM).

IS 136 (digital-AMPS) was developed over analogue AMPS system. In the first phase time-division-multiplexing (TDM) was added only for the voice channels. Then in the second phase control channels were also digitalized **[3, pp 3].**

GSM was developed with the standardization movements of European Countries. Even though the standardization was done by European initiatives, it was aimed to be a global standard. As a continuation of NMT900; at first, it was standardized to work in 900 MHz, but later GSM1800 launched in U.K. and GSM1900 launched in U.S. **[2, pp 6].**

CDMA or IS-95 was developed by Qualcomm and standardized in U.S. Besides from other multiple access methods, CDMA uses different codes in the same frequency to share the transmission medium. (In the next chapters there are detailed explanations about CDMA and wide-band CDMA.) It was used in the United States, South Korea, Hong Kong, Japan, Singapore, and many other East Asian countries. In South Korea especially this standard was widely used. IS-95 networks are also known by the brand name cdmaOne **[3, pp 4].**

2.1.3 Generation 2,5

From technological perspective, 2G developments were made to overcome the 1G deficiencies but could not add any additional value to the network. After solving the first generation problems, operators would like to increase their network values by connecting their networks to the big ocean, “Internet”. For that purpose, different standardization committees discussed different technology enhancements to increase the user bandwidth.

First technology that was used was High-speed Circuit-switched Data (HSCSD), it was circuit connection based and could not get much support from the handset manufacturers. HSCSD was a good solution for real-time services but when there is no traffic, reserved resources will be idle which is a waste of money **[3, pp 5].** Then the General Packet Radio Services (GPRS) came to the market. GPRS was suitable for non-real-time applications. Throughput was increased by packet switched transmission. Implementation of GPRS was not as easy as HSCSD, additional hardware was needed for the radio network **[3, pp 6].**

Another approach to increase the user bandwidth was to change the modulation method. Enhanced Data rates for Global Evolution (EDGE) was developed by using eight-phase shift keying (8PSK) modulation method. Because it had the coexistence with Gaussian minimum shift keying (GMSK), EDGE upgraded network and also supported old handsets. Some operators also used EDGE with their existing GPRS infrastructure and reached to great data rates such as 384 kbps **[3, pp 6].**

In U.S. there were technologies that can be named as 2.5G. One of them was IS-95B, which used multiple code channels per user to increase the user data rate. The other one was CDMA2000, which was evolved from CDMA (IS-95).

In Japan, NTT DoCoMo introduced its own concept, i-mode, over Personal Digital Cellular (PDC). Including the internet services, i-mode concept showed great success and became a business model for new concepts and technologies **[3, pp 8].**

2.1.4 3rd Generation

In 1988 the RACE I (Research of Advanced Communication Technologies in Europe) programme started, researching for the basics of third generation communications networks. Between 1992 and 1995 research continued on CDMA-based Code Division Testbed (CODIT) and TDMA-based Advanced TDMA Mobile Access (ATDMA) in the RACE II project. In 1995, Future Radio Wideband Multiple Access System (FRAMES) project was set up by Advanced Communication Technologies and Services (ACTS) research group **[4, pp 61].**

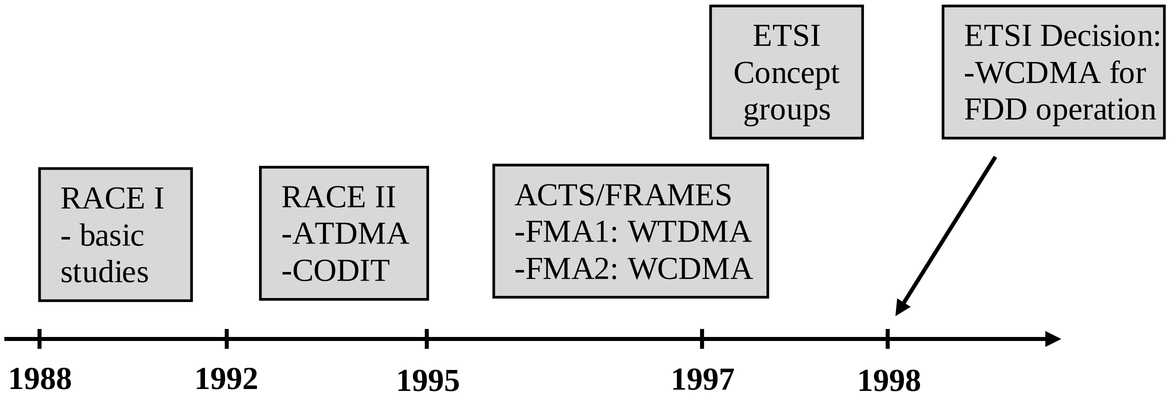

Figure 2 : European research programmes towards 3G systems and the ETSI decision [4, pp 65]

The main objective of the project was to study on a proposal for Universal Mobile Telecommunications System radio access system. FRAMES project was supported by several European Universities, Nokia, Siemens, Ericsson, France Télécom and CSEM / Pro Telecom. After some discussions, two modes were proposed to the European Telecommunications Standards Institute (ETSI) as candidates for UMTS air interface **[4, pp 62]**:

- FMA1: Wideband TDMA
- FMA2: Wideband CDMA

In 1997 after the proposal submissions, ETSI formed 5 working groups **[4, pp 62]**:

- Wideband CDMA (WCDMA)
- Wideband TDMA (WTDMA)
- TDMA / CDMA
- Orthogonal Frequency Division Multiple Access (OFDMA)
- Opportunity Driven Multiple Access (ODMA)

After getting the full solution proposals from work-groups and evaluating the results, WCDMA was chosen as the standard for the UMTS Terrestrial Radio Access (UTRA) air interface on the paired frequency bands and WTDMA/CDMA was chosen for the unpaired frequency bands. In 1999, technical work for the UTRA transferred to 3rd Generation Partnership Project (3GPP) **[4, pp 65]**.

Standardization studies were taking place in different countries under different committees **[4, pp 67]**:

Japan:	The Association for Radio Industries and Businesses (ARIB) and the Telecommunication Technology Committee (TTC)
Korea:	The Telecommunications Technology Association (TTA)
U.S. :	A Technical Subcommittee of Standards Committee T1 Telecommunications (T1P1)
China:	The China Wireless Telecommunication Standard Group (CWTS)

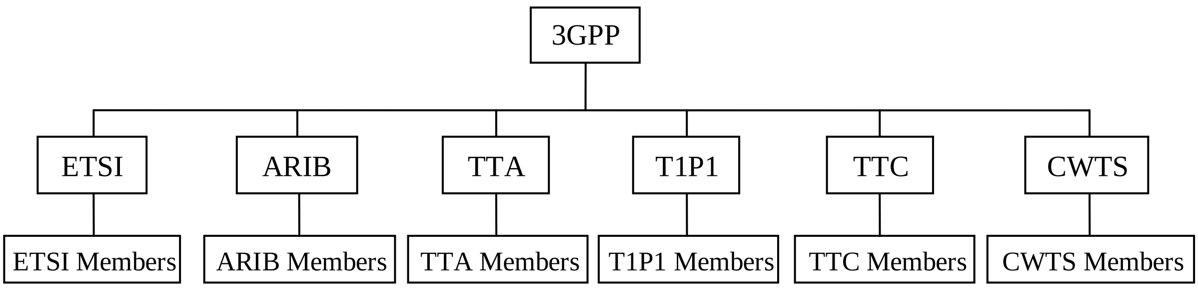

Figure 3 : 3GPP organizational partners [4, pp 67]

In 3GPP, four different technical specification groups (TSG) were set up:

- Radio Access Network TSG
- Core Network TSG
- Service and System Aspects TSG
- Terminals TSG

UTRA air interface specification was produced by the Radio Access Network TSG. Release’99 UMTS specifications from ETSI were identical to the Release’99 specifications produced by 3GPP. During 2000, further work on GSM evolution was moved from ETSI and other forums to 3GPP, including work on GPRS and EDGE. A new technical specification group, TSG GERAN was set up for this purpose **[4, pp 68].**

Within these groups the one most relevant to the WCDMA technology is the Radio Access Network TSG (RAN TSG), which has been divided into four different working groups.

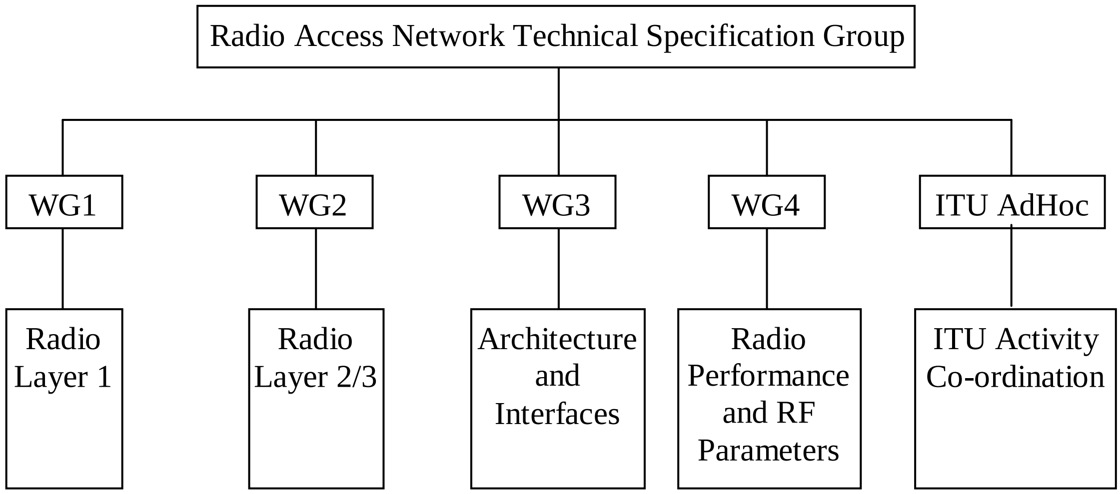

Figure 4 : 3GPP RAN TSG Working Groups [4, pp 68]

As mentioned earlier, the studies of various participating organisations were merged into a single standard, and then the detailed parameters for the first full release (Release 99) of UTRA from 3GPP finalised in 1999. In 3GPP the next version of the specifications was originally considered as Release 2000, but in the meantime the release naming was adjusted, so that the next release in March 2001 was called Release 4 and the numbering continued. 3GPP release history can be seen in **Table 2**.

Version	Date	Release Info
Release 99	2000 Q1	Specification of first UMTS 3G networks.
Release 4	2001 Q2	All-IP Core Network features added.
Release 5	2002 Q1	IP Multimedia Subsystem (IMS) and High-Speed Downlink Packet Access (HSDPA) introduced.
Release 6	2004 Q4	Integration with Wireless-LAN added, High-Speed Uplink Packet Access (HSUPA) and Multimedia Broadcast Multicast Service (MBMS) introduced, enhancements to IMS added
Release 7	2007 Q4	Improvements to QoS and support for real-time applications added. Enhanced Data Rates for GSM Evolution (EDGE Evolution), High-Speed Packet Access Evolution (HSPA+) and Near Field Communications (NFC) introduced,
Release 8	2008 Q4	Specification of first LTE networks. All-IP Network approach introduced. Orthogonal Frequency-Division multiple access (OFDM), Single Carrier Frequency Division Multiple Access (SC-FDMA or FDE) and Multiple-Input and Multiple-Output (MIMO) added. Dual-Cell HSDPA introduced.
Release 9	2009 Q4	All-IP Network enhancements added. WIMAX and LTE/UMTS interoperability added. Dual-Cell HSDPA with MIMO introduced. Dual-Cell HSUPA introduced
Release 10	2011 Q1	LTE Advanced introduced, Multi-cell HSDPA(4 carriers) introduced

Table 2 : 3GPP Release History in a nutshell [5]

2.2 UMTS Radio Access Network Architecture

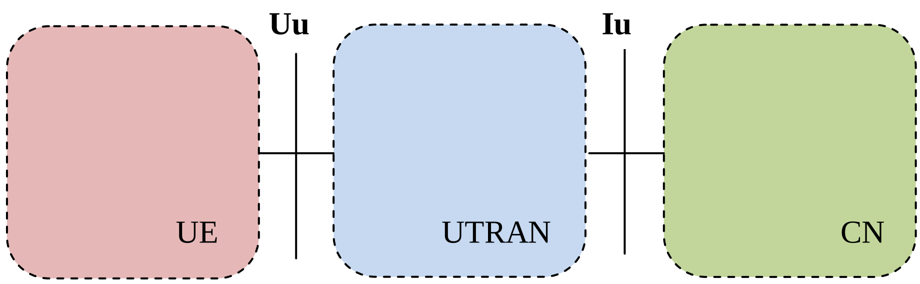

Figure 5 : UMTS high-level system architecture [4, pp 76]

In the standardization phase, network elements were grouped based on their similar functionality and defined at the logical level. The UMTS system consists of a number of logical network elements that each has a defined functionality. The User Equipment (UE) that interfaces with the user and the radio interface is defined, the Radio Access Network (UTRAN) handles all radio-related functionality and the Core Network is responsible for switching and routing calls and data connections to external networks.

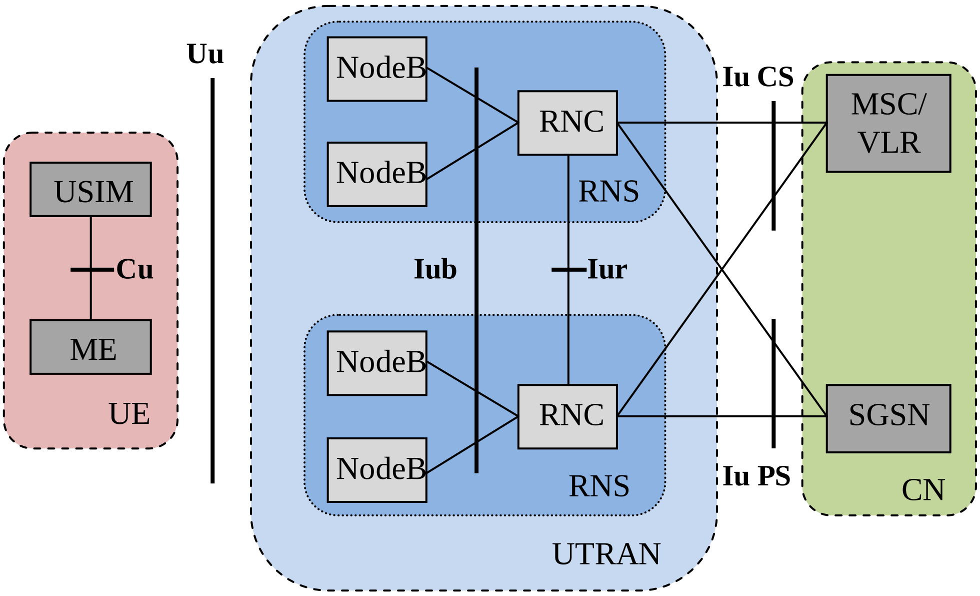

Figure 6 : UTRAN architecture [4, pp 78]

UTRAN consists of one or more Radio Network Sub-systems (RNS). An RNS is a sub-network within UTRAN and consists of one Radio Network Controller (RNC) and one or more Node B’s. RNCs may be connected to each other via an *Iur* interface. RNCs and Node B’s are connected with an *Iub* interface.

The main characteristic of UTRAN can be summarised in the following points **[4, pp79]:**

- Support of UTRA and all the related functionality. In particular, the major impact on the design of UTRAN has been the requirement to support soft handover (one terminal connected to the network via two or more active cells) and the WCDMA-specific Radio Resource Management algorithms.

- Maximization of the commonalities in the handling of packet-switched and circuit switched data, with a unique air interface protocol stack and with the use of the same interface for the connection from UTRAN to both the PS and CS domains of the core network.
- Maximization of the commonalities with GSM, when possible.
- Use of the ATM transport as the main transport mechanism in UTRAN.
- Use of the IP-based transport as the alternative transport mechanism in UTRAN from Release 5 onwards.

2.2.1 UTRAN Elements

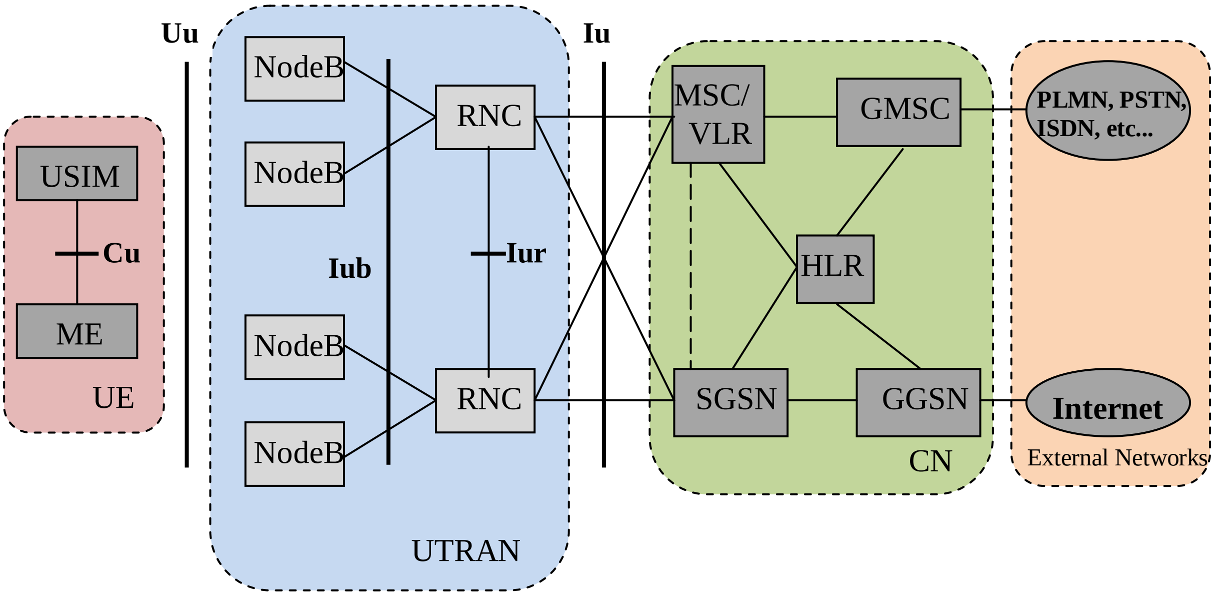

Figure 7 : UTRAN architecture extended [4, pp 76]

The UE consists of two parts:

- The Mobile Equipment (ME) is the radio terminal used for radio communication over the *Uu* interface.
- The UMTS Subscriber Identity Module (USIM) is a smartcard that holds the subscriber identity, performs authentication algorithms, and stores authentication and encryption keys and some subscription information that is needed at the terminal.

UTRAN also consists of two distinct elements:

- The Node B converts the data flow between the *Iub* and Uu interfaces. It also participates in radio resource management.
- The Radio Network Controller (RNC) owns and controls the radio resources in its domain (the Node B's connected to it). RNC is the service access point for all services UTRAN provides to the Core Network, for example, management of connections to the UE.

The main elements of the Core Network are as follows:

- HLR (Home Location Register) is a database located in the user's home system that stores the master copy of the user's service profile.
- MSC/VLR (Mobile Services Switching Centre / Visitor Location Register) is the switch (MSC) and database (VLR) that serves the UE in its current location for Circuit Switched (CS) services.
- GMSC (Gateway MSC) is the switch at the point where UMTS PLMN is connected to external Circuit Switched networks.
- SGSN (Serving GPRS (General Packet Radio Service) Support Node) functionality is similar to that of MSC / VLR but is typically used for Packet Switched (PS) services.
- GGSN (Gateway GPRS Support Node) functionality is close to that of GMSC but is in relation to PS services.

2.3 WCDMA

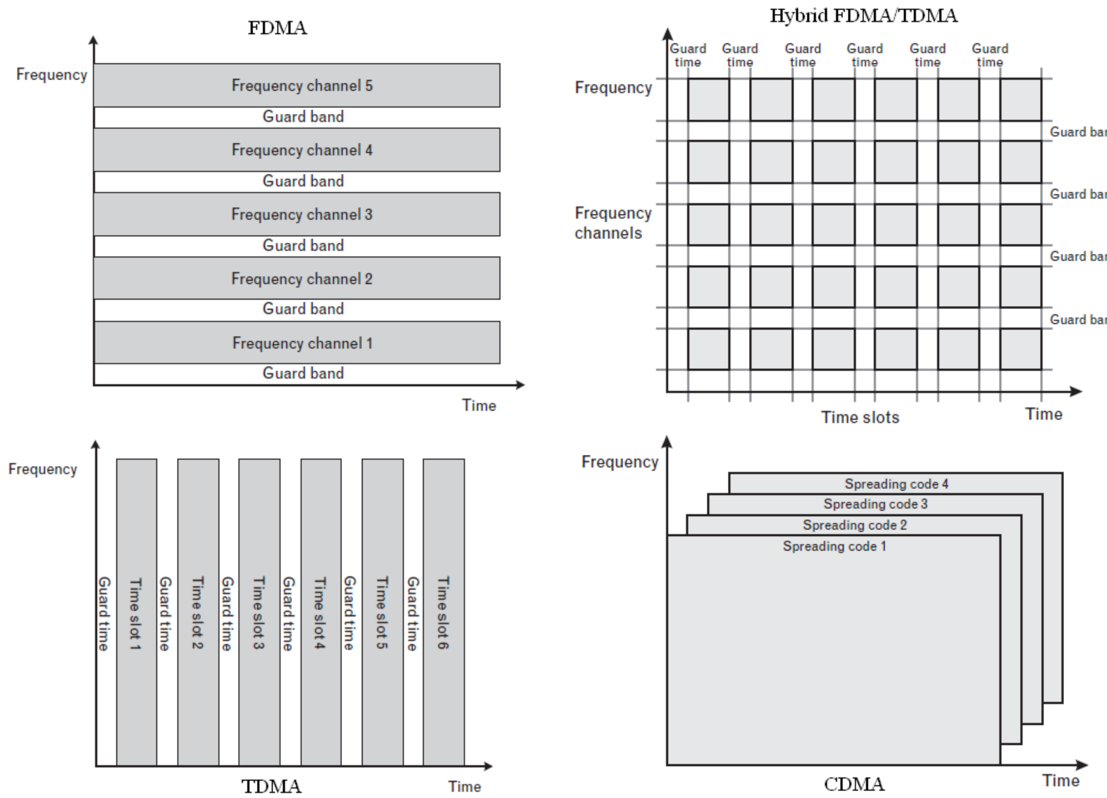

Figure 8 : FDMA, TDMA, Hybrid FDMA/TDMA and CDMA [3, pp 26 - 27]

WCDMA is a wideband Direct-Sequence Code Division Multiple Access (DS-CDMA) system, i.e. user information bits are spread over a wide bandwidth by multiplying the user data with quasi-random bits (called chips) derived from CDMA spreading codes. In order to support very high bit rates (up to 2 Mbps), the use of a variable spreading factor and multi-code connections is supported.

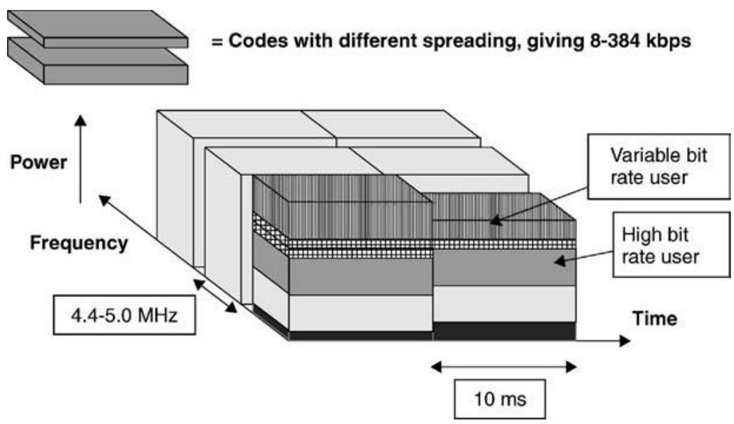

Figure 9 : Allocation of bandwidth in WCDMA in the time–frequency–code space [4, pp 48]

WCDMA is designed to be deployed in conjunction with GSM. Therefore, handovers between GSM and WCDMA are supported in order to be able to leverage the GSM coverage for the introduction of WCDMA. WCDMA supports two basic modes of operation: Frequency Division Duplex (FDD) and Time Division Duplex (TDD). In the FDD mode, separate 5 MHz carrier frequencies are used for the uplink and downlink respectively, whereas in TDD only one 5 MHz is timeshared between the uplink and downlink. Uplink is the connection from the mobile to the base station, and downlink is that from the base station to the mobile. The TDD mode is based heavily on FDD mode concepts and was added in order to leverage the basic WCDMA system also for the unpaired spectrum allocations of the ITU for the IMT-2000 systems **[4, pp 48].**

The WCDMA air interface has been crafted in such a way that advanced CDMA receiver concepts, such as multiuser detection and smart adaptive antennas, can be deployed by the network operator as a system option to increase capacity and/or coverage **[4, pp 49].**

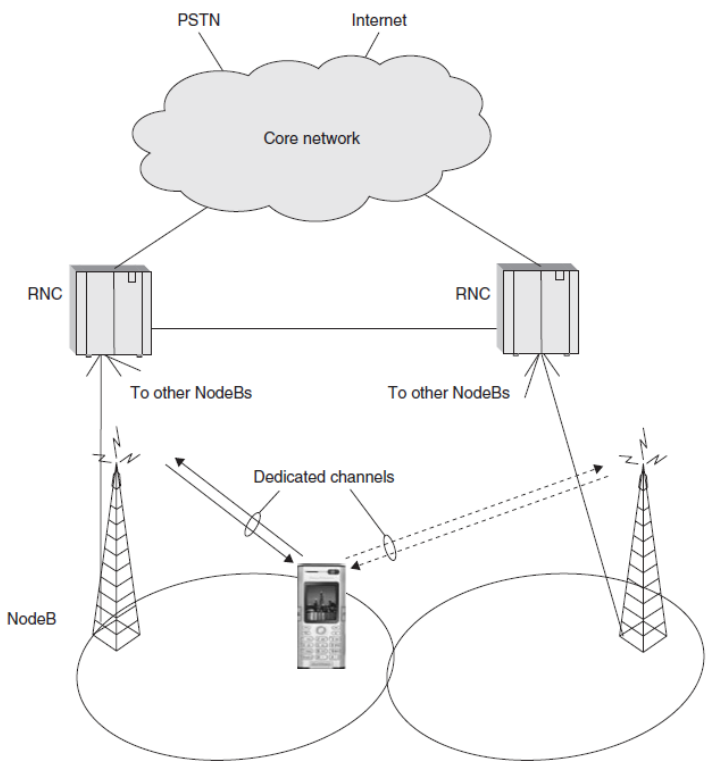

Figure 10 : WCDMA radio-access network architecture [6, pp 132]

The chip rate of 3.84 Mcps leads to a carrier bandwidth of approximately 5 MHz. DS-CDMA systems with a bandwidth of about 1 MHz, such as IS-95, are commonly referred to as narrowband CDMA systems. The inherently wide carrier bandwidth of WCDMA supports high user data rates and also has certain performance benefits, such as increased multipath diversity. Subject to its operating licence, the network operator can deploy multiple 5 MHz carriers to increase capacity, possibly in the form of hierarchical cell layers. The actual carrier spacing can be selected on a 200 kHz grid between approximately 4.4 MHz and 5 MHz, depending on interference between the carriers **[4, pp 47].**

WCDMA supports highly variable user data rates, in other words the concept of obtaining Bandwidth on Demand (BoD) is well supported. The user data rate is kept constant during each 10 ms frame. However, the data capacity among the users can change from frame to frame. This fast radio capacity allocation will typically be controlled by the network to achieve optimum throughput for packet data services **[4, pp 48].**

Furthermore, WCDMA supports the operation of asynchronous base stations, so that, unlike in the synchronous IS-95 system, there is no need for a global time reference such as a GPS. Deployment of indoor and micro base stations is easier when no GPS signal needs to be received. WCDMA employs coherent detection on uplink and downlink based on the use of pilot symbols or common pilot. While already used on the downlink in IS-95, the use of coherent detection on the uplink is new for public CDMA systems and will result in an overall increase of coverage and capacity on the uplink **[4, pp 48].**

2.4 HSPA

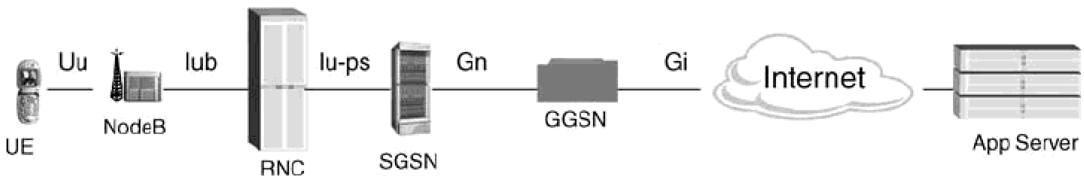

Figure 11 : Network Diagram for HSPA traffic (user plane) [7 , pp 28]

High-Speed Downlink Packet Access (HSDPA) was standardized as a part of 3GPP Release 5 with the first specification version in March 2002. High-speed uplink packet access (HSUPA) was a part of 3GPP Release 6 with the first specification version in December 2004. HSDPA and HSUPA together are called 'High-Speed Packet Access' (HSPA). The first commercial HSDPA networks were available at the end of 2005 and the commercial HSUPA networks were available by 2007 **[8, pp 4].** HSPA development history (including LTE) is illustrated in **Figure 12** and HSPA Evolution is illustrated in **Figure 13**.

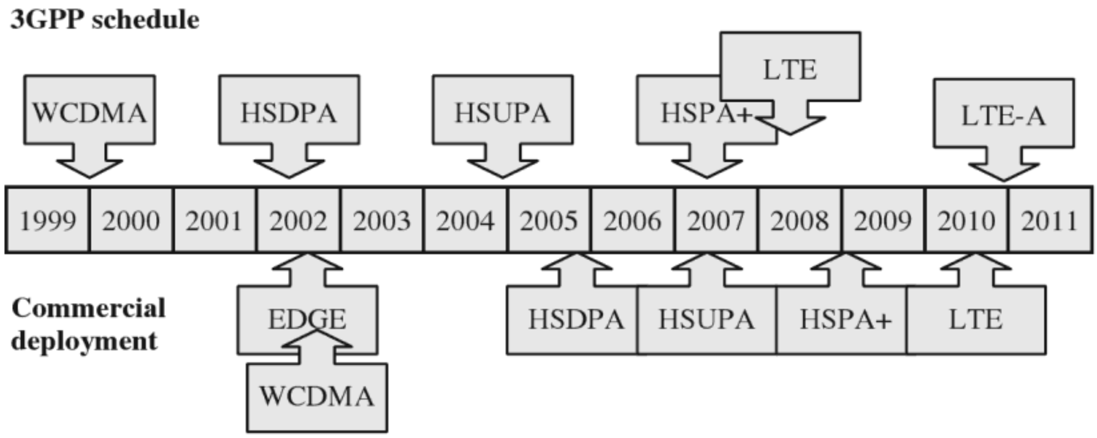

Figure 12 : HSPA Standardization and Deployment Schedule [9, pp 7]

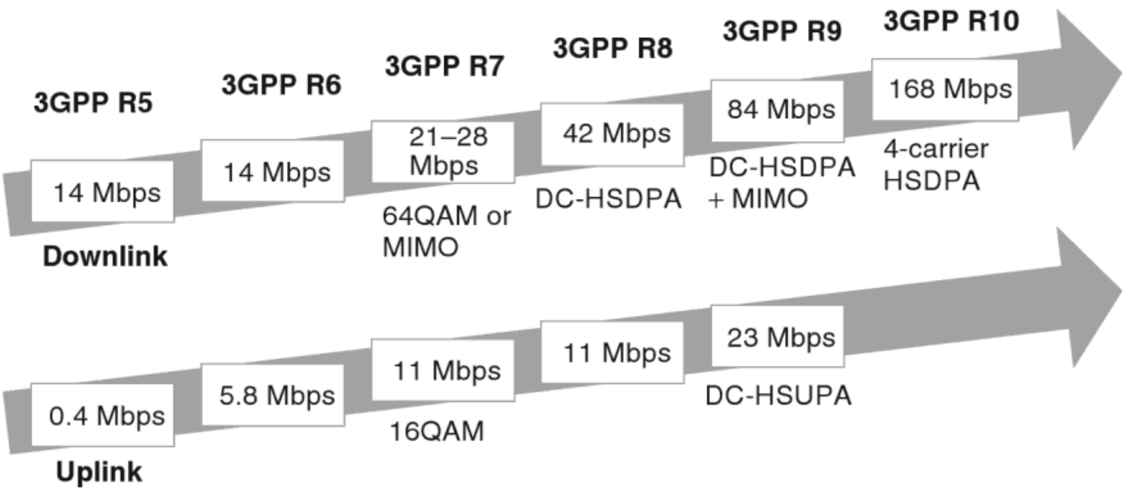

Figure 13 : HSPA Evolution [8, pp 4]

HSPA is deployed on top of the WCDMA network either on the same carrier or – for a high-capacity and high bit rate solution – using another carrier (demonstration can be seen in **Figure 14**). In both cases, HSPA and WCDMA can share all the network elements in the core network and in the radio network including base stations, Radio

Network Controller (RNC), Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). WCDMA and HSPA are also sharing the base station sites, antennas and antenna lines.

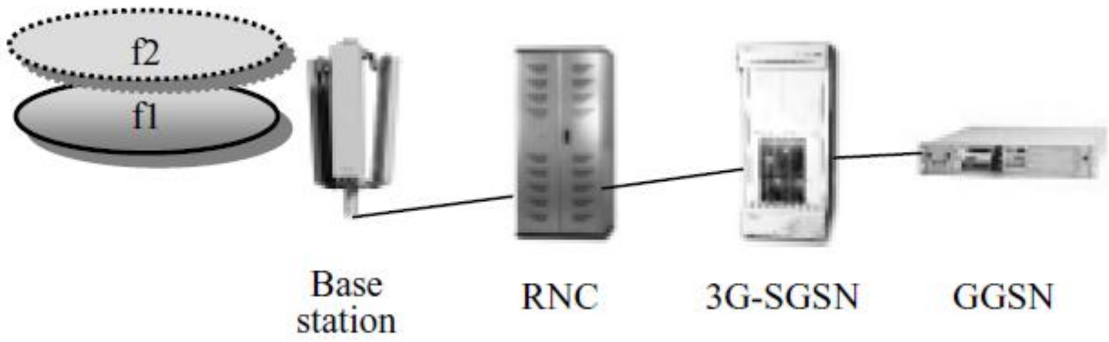

Figure 14 : HSPA deployment with (f2) new carrier deployed with HSPA and (f1) carrier shared between WCDMA and HSPA. [8, pp 5]

The performance of the radio system defines how smoothly applications can be used over the radio network. The key parameters defining application performance include data rate and network latency. There are applications that are happy with low bit rates of a few tens of kbps but require very low delay, like voice-over-IP (VoIP) and real time action games. On the other hand, the download time of a large file is only defined by the maximum data rate, and latency does not play any role. GPRS Release 99 typically provides 30–40 kbps with latency of 600 ms. EGPRS Release 4 pushes the bit rates 3–4 times higher and also reduces latency below 300 ms. The EGPRS data rate and latency allow smooth application performance for several mobile-based applications including Wireless Application Protocol (WAP) browsing and push-to-talk **[8, pp 6].**

WCDMA enables peak data rates of 384 kbps with latency of 100–200 ms, which makes Internet access close to low-end digital subscriber line (DSL) connections and provides good performance for most low-delay Internet Protocol (IP) applications as well. HSPA pushes the data rates up to 1–2 Mbps in practice and even beyond 3Mbps in good conditions. Since HSPA also reduces network latency to below 100 ms, the end user experienced performance is similar to the fixed line DSL connections. No or only little effort is required to adapt Internet applications to the mobile environment. Essentially, HSPA is a broadband access with seamless mobility and extensive coverage. Radio capability evolution from GPRS to HSPA is illustrated in Figure 1.9. HSPA was initially designed to support high bit rate non-real time services. The simulation results show, however, that HSPA can provide attractive capacity also for low bit rate low-latency applications like VoIP. 3GPP Releases 6 and 7 further improve the efficiency of HSPA for VoIP and other similar applications **[8, pp 6].**

Higher cell capacity and higher spectral efficiency are required to provide higher data rates and new services with the current base station sites. Basic HSPA includes a one-antenna Rake receiver in the terminals and two-branch antenna diversity in the base stations. Enhanced HSPA includes two-antenna equalizer mobiles and interference cancellation in the base station. The simulation results show that HSPA can provide substantial capacity benefit. Basic HSDPA offers up to three times WCDMA downlink capacity, and enhanced HSDPA up to six times WCDMA. The spectral efficiency of enhanced HSDPA is close to 1 bit/s/Hz/cell. The uplink capacity improvement with HSUPA is estimated between %30 and %70. HSPA capacity is naturally suited for supporting not only symmetric services but also asymmetric services with higher data rates and volumes in downlink **[8, pp 7].**

3 Mobility in UMTS

3.1 Introduction to Radio Resource Management

The task of Radio Resource Management (RRM) is to optimize the use of the available resources, such as transmitter power and spreading codes, in order to provide users with the largest possible capacity for a specified coverage and quality-of-service (QoS). This is achieved through the concerted effort of a number of closely inter-related radio resource management algorithms. The algorithms can be divided into cell-based and connection-based algorithms on the basis of their different purposes.

Cell Based Algorithms:

Admission Control: When a radio resource related request is received in the RNC, the admission control algorithm estimates the minimum radio resources required to provide the required quality of service, determines whether these radio resources are available, and, if they are, allocates them. Failing this, the request for radio resources is denied **[4, pp 264].**

Load Control: The main task of the load control algorithm is to measure the cell load and prevent the system from becoming overloaded. Should this happen, the load control algorithm returns the system both quickly and controllably to the normal load state defined during the radio network planning phase **[4, pp 267].**

Packet Scheduler: The packet scheduler takes care of scheduling radio resources for the best-effort traffic in both the uplink and the downlink directions **[4, pp 278].**

Resource Manager: The main function of the resource manager is to allocate downlink spreading codes when the admission control entity or the packet scheduler requests this function. The resource manager also optimizes the usage of the code tree in a cell **[10, pp 244].**

Connection Based Algorithms:

Handover Control: Handover control serves in two purposes. Firstly, it ensures that the user equipment is connected to the strongest cell at all times. This helps to control the interference level in the network by minimizing the transmission power. Secondly, handover control supports user mobility by ensuring that the radio connection is uninterrupted while the user equipment moves in the network **[10, pp 211].**

Power Control: Since the capacity of any CDMA system is limited by interference, it is crucial that all base stations and terminals in the radio access network use the least possible transmission power. The purpose of power control is to use as little transmit power as possible in both uplink and downlink while maintaining the quality of the connection **[4 , pp 55].**

From this thesis point of view, the Handover Control algorithms will be examined in detail in the following sections.

3.2 Handover Control

Mobile phones can maintain their connections in cellular networks when they move from one cell area to another. The procedure, which switches a connection from one base station to another, is called a handover (HO) or a handoff. It is possible that an HO does not involve a change of the base station but only a change of radio resources **[3, pp 37-38].**

The primary function of the handover control algorithm is to monitor the quality of a dedicated radio connection, and to perform a soft or a hard handover if the quality is insufficient. Briefly, maintaining seamless communication for mobile users is the main duty of handover control algorithms.

There are various reasons that could cause a handover for an UE. The reasons can be **[11, pp 15]:**

- Uplink quality (e.g. bit error rate (BER))
- Uplink signal measurements (e.g. received signal code power (RSCP) for TDD)
- Downlink quality (e.g. Transport channel BLER)
- Downlink signal measurements (e.g. CPICH RCSP, CPICH E_c/N_0, Pathloss)
- Distance
- Change of service
- Operation & Maintenance intervention
- Directed retry
- Traffic load
- Pre-emption

From Radio Network Controller point of view there are 4 different types of handovers:

- Intra-System Intra-Frequency Handover: Soft Handover (SHO)
- Inter-System Handover (GSM←→WCDMA)
- Intra-System Intra-Frequency Hard Handover
- Intra-System Inter-Frequency Handover

3.2.1 Intra-System Intra-Frequency Handover: Soft Handover(SHO)

Soft Handover (SHO) is a general feature in wireless systems, such as WCDMA, in which neighbouring cells are operated on the same frequency. When in *Connected Mode*, the user equipment (UE) continuously measures serving and neighbouring cells (cells indicated by the RNC) on the current carrier frequency. Periodically, the UE compares the measurement results with HO thresholds provided by the RNC. When the reporting criteria is fulfilled and UE sends a measurement report back to the RNC indicating the SHO presence. The decision algorithm of SHO is located in the RNC. Because of this measurement reporting SHO is a Mobile Evaluated Handover (MEHO) **[10, pp 212].**

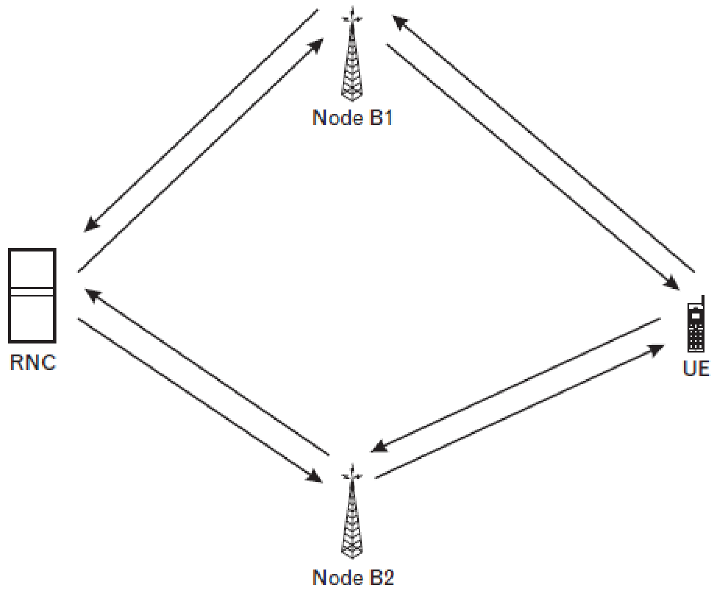

Figure 15 : Soft Handover [3, pp 38]

Softer Handover: A softer HO is an HO between two sectors of a cell. From a UE's point of view, it is just another SHO. The difference is only meaningful to the network, as a softer HO is an internal procedure for a Node B, which saves the transmission capacity between Node Bs and the RNC **[3, pp 39].** In the uplink, the signal from the mobile station MS is received at different sectors, which are combined in softer handover by using Maximal Ratio Combining (MRC) and in soft handover by using selection combining **[10, pp 179].** In softer handover with MRC of the signals from different sectors, the gain is slightly bigger than in soft handover with selection combining **[10, pp 88].**

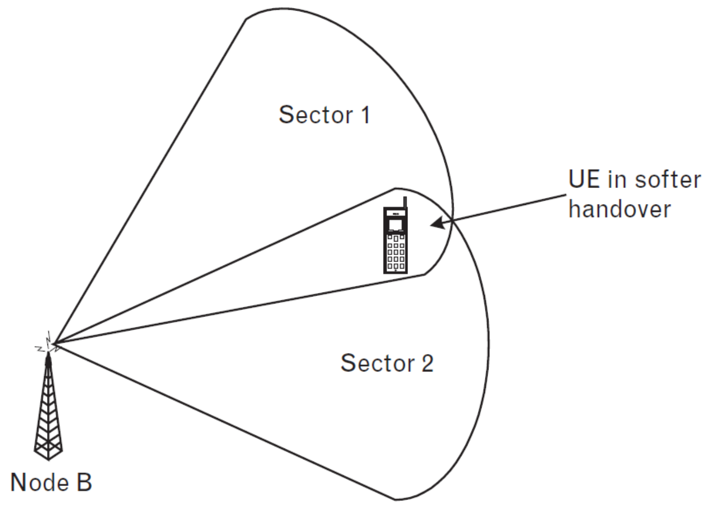

Figure 16 : Softer Handover [3, pp 270]

The main objectives of soft / softer HO are the following **[10, pp 212]:**

- Optimum fast closed-loop Power Control (PC), as the UE is always linked with the strongest cells.
- Seamless HO without any disconnection of the Radio Access Bearer (RAB).
- To enable a sufficient reception level for maintaining communications by combining the received signals (macro-diversity) at symbol level from multiple cells in cases when the UE moves to cell boundary areas, and cannot obtain a sufficient reception level from a single cell.
- Furthermore, the macro-diversity gain achieved by combining the received signal in the Node B (softer HO) or in the RNC (SHO) improves the uplink signal quality and thus decreases the required transmission power of the UE

3.2.2 Inter-System Handover

At the start of WCDMA deployment, handovers to GSM were needed to provide continuous coverage, and handovers from GSM to WCDMA can be used to lower the (congestion) loading in GSM cells **[4, pp 254].** When the coverage areas of WCDMA and the neighbouring system overlap each other, an Inter-System Handover (ISHO) can be used to control the load between the systems **[10, pp 214].** When the traffic in WCDMA networks increases, it is important to have load reason handovers in both directions. The inter-system handovers are triggered in the source RNC / BSC, and from the receiving system point of view, the intersystem handover is similar to inter-RNC or inter-BSC handover. The handover algorithms and triggers are not standardised **[4, pp 254].**

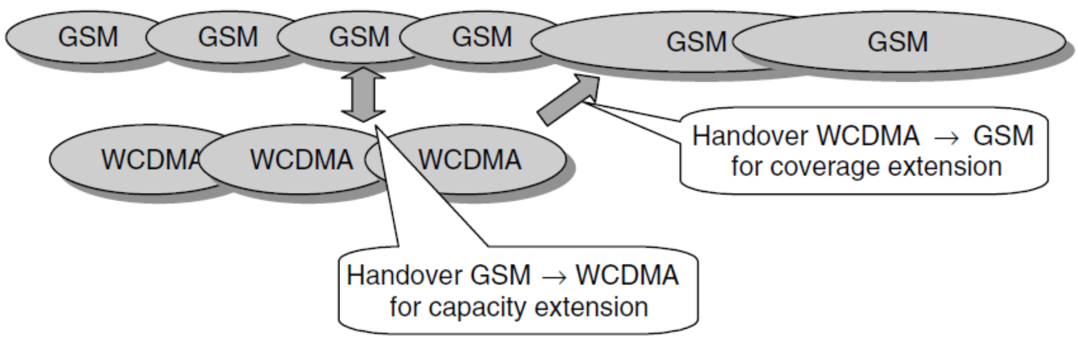

Figure 17 : Inter-system handovers between GSM and WCDMA [4, pp 255]

In a practical example, speech connections can be handed over to a neighbouring second-generation (2G) system and data connections handled within the WCDMA system. Inter-System Handover (ISHO) is a Hard Handover (HHO) and it causes temporary disconnection of the Real Time (RT) Radio Access Bearer (RAB). When an RT RAB is handed over from one system to another, the Core Network (CN) is responsible for adapting the Quality of Service (QoS) parameters included in the RAB attributes according to the new system **[10, pp 214].**

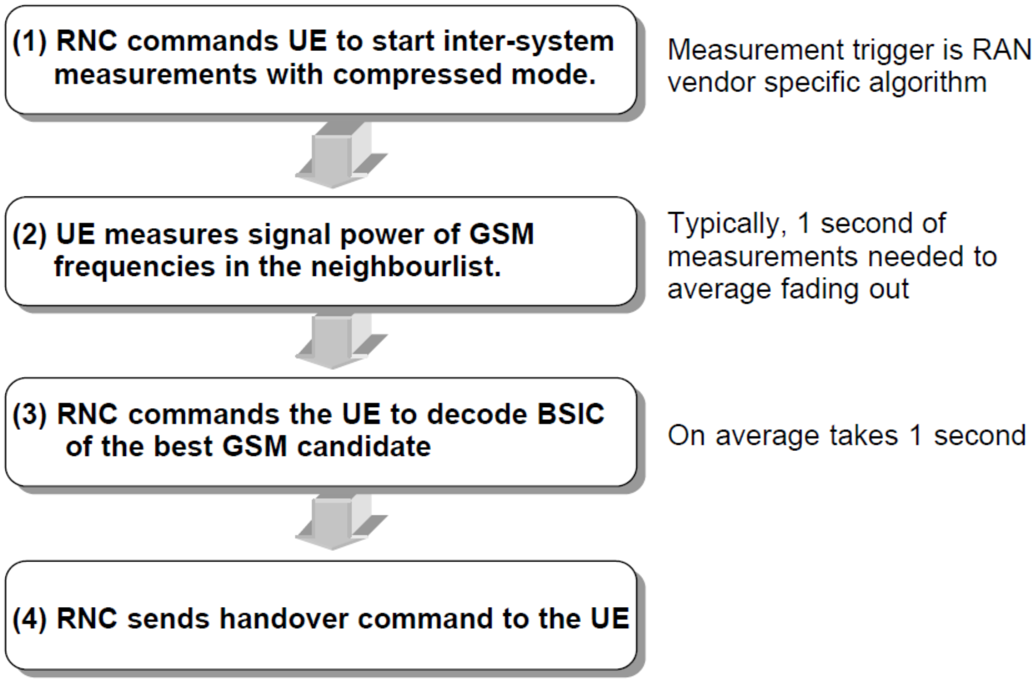

Figure 18 : Inter-system handover procedure [4, pp 256]

The inter-system measurements are not active all the time but are triggered when there is a need to make intersystem handover. The measurement trigger is a Radio Network Controller (RNC) vendor-specific algorithm and could be based, for example, on the quality (block error rate, BER) or on the required transmission power. When the measurements are triggered, the User Equipment (UE) measures first the signal powers of the GSM frequencies on the neighbour-list. Once those measurements are received by RNC, it commands the UE to decode the BSIC (base station identity code) of the best GSM candidate. When the BSIC is received by RNC, a handover command can be sent to the UE. The measurements can be completed in approximately 2 seconds **[4, pp 255].**

The RNC recognises the possibility of Inter System Handover (ISHO) based on the configuration of the radio network (neighbour cell definitions and relevant control parameters). In case the second system is a GSM system, the decision algorithm of the ISHO from GSM to WCDMA is located in the GSM Base Station Controller (BSC). From the viewpoint of the RNC, an ISHO from GSM to WCDMA does not differ from the inter-RNC HHO. Correspondingly, an ISHO from WCDMA to GSM does not differ from the inter-BSC HO from the viewpoint of the GSM BSS. As with inter-frequency measurements, the User Equipment (UE) must be either equipped with a second receiver or support Compressed Mode (CM) to execute inter-system measurements **[10, pp 214].**

3.2.2.1 Compressed Mode

Intra-frequency neighbours can be measured simultaneously with normal transmission by the UE using a RAKE receiver. Inter-frequency and inter-system measurements, however, require the UE to measure on a different frequency. This can be done by incorporating multiple receivers in the UE. A second possibility that avoids receiver multiplicity is stopping the normal transmission and reception for a certain time period, enabling the UE to measure on the other frequency **[10, pp 223].**

WCDMA uses continuous transmission and reception and cannot make inter-system measurements with a single receiver if there are no gaps generated in the WCDMA signals. Therefore, compressed mode is needed both for inter-frequency and for inter-system measurements **[4, pp 255].** Inter-system handovers from GSM to WCDMA are initiated in GSM BSC. No compressed mode is needed for making WCDMA measurements from GSM because GSM uses discontinuous transmission and reception **[4, pp 258].**

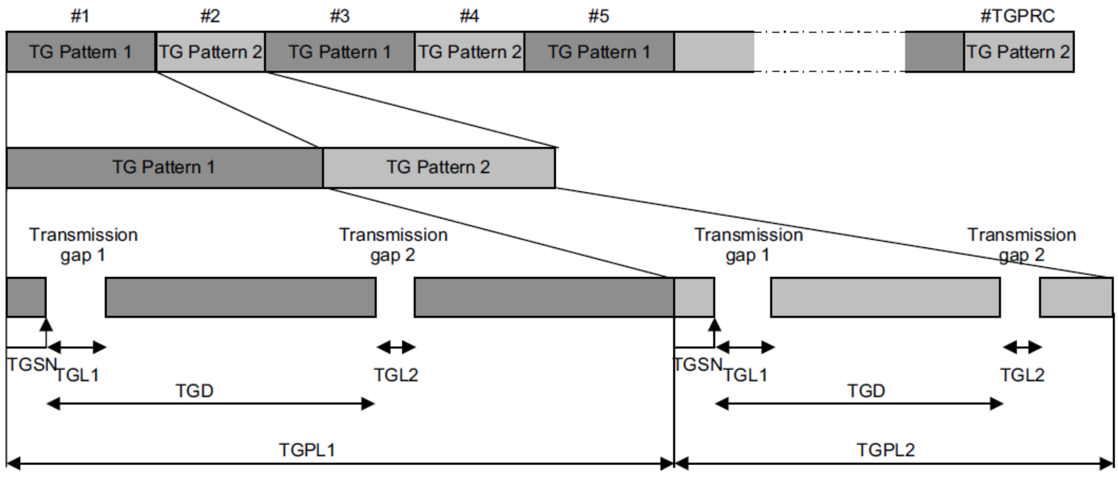

Figure 19 : Compressed Mode pattern [10, pp 224]

During the gaps of the compressed mode, the fast power control cannot be applied and part of the interleaving gain is lost **[4, pp 256].** The RNC algorithms for activating the compressed mode are important to guarantee reliable handovers while maintaining low compressed mode usage **[4, pp 257].**

The RNC determines which frames are compressed, and sends the information both to the Node B and to the UE. There are three methods to generate the gaps to use CM **[10, pp 223]:**

- Reducing the data rate used in the upper layers (higher layer scheduling);
- Reducing the symbol rate used in the physical layer (rate matching and/or puncturing).
- Spreading factor splitting (halving the spreading factor doubles the available symbol rate).

Compressed mode also affects the uplink coverage area of the real time services where the bit rate cannot be lowered during the compressed mode. Therefore, the coverage reason inter-system handover procedure has to be initiated early enough at the cell edge to avoid any quality degradation during the compressed mode **[4, pp 257].**

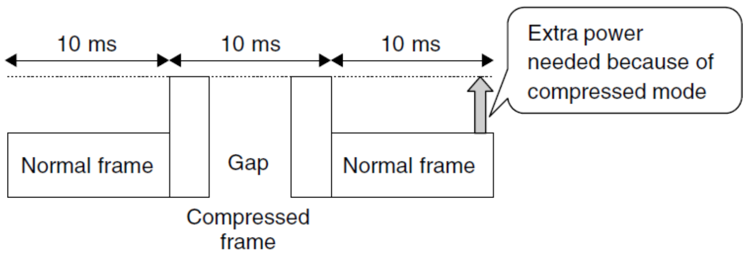

Figure 20 : Effect of compressed mode on the coverage [4, pp 257]

3.2.3 Intra-System Intra-Frequency Hard Handover

Hard-handover (HHO) is a category of handover (HO) procedures in which all the old radio links of a user-equipment (UE) are released before the new radio links are established. For real-time (RT) bearers it means a short disconnection of the bearer, for non-real-time (NRT) bearers HHO is lossless **[10, pp 211].**

Intra-frequency HHO is needed when cells participating in the HO are controlled by different RNCs in situations when the inter-RNC HO cannot be executed as a soft-handover (SHO) or if SHO is not allowed (Intra-frequency HHO causes temporary disconnection of the RT RAB but is lossless for NRT bearers). Its decisions are made by the RNC based on the intra-frequency measurement results the UE is sending periodically after it has reported an intra-frequency triggering event and the active set could not be updated, and relevant control parameters. The reports are usually applied to the SHO procedure, so intra-frequency HHO is a mobile station evaluated handover (MEHO) **[10, pp 213].**

By performing an HHO when SHO is not possible, excessive interference can be avoided. During the HHO procedure all links in the active set are replaced simultaneously by one new link **[10, pp 213].**

3.2.4 Intra-System Inter-Frequency Handover

Inter-frequency Handover (IFHO) is a hard-handover (HHO) between different WCDMA carriers required to ensure a handover (HO) path from one cell to another cell in situations when different carriers have been allocated to the cells in question. Also, HHO here means that IFHO causes temporary disconnection of the real-time radio access bearers (RT RAB) and is lossless for non-real-time (NRT) bearers. IFHO also enables handovers between separate layers of a multi-layered cellular network – e.g., a network consisting of macro- and micro-cells where the cell layers are using different carriers. The radio access network handover controller (RAN HC) should support the following types of IFHO **[10, pp 213]:**

- intra-Base Station (BS) HHO (to control the load between carriers)
- intra-RNC HHO
- inter-RNC HHO

IF-HO is a Network Evaluated Handover (NEHO) since its evaluation algorithm is located in the RNC. The RNC recognises the possibility of an IFHO based on the configuration of the radio network (frequency / carrier allocation, neighbour cell definitions, cell layers etc.). When a UE is located where an IFHO is possible and needed, the RNC commands the UE to start inter-frequency measurements and to report the results periodically. HO decisions are then made by the RNC based on those measurement results (inter and intra-frequency) and relevant control parameters **[10, pp 213 - 214].**

3.3 Handover Measurements

Handover Measurements are important for the decisions that are derived by handover algorithms. HO measurement reporting can be divided into the following stages:

1. Neighbour cell definitions
2. Measurement reporting criteria
3. Reporting of measurement results

3.3.1 Neighbour Cell Definitions

For each cell in the UTRAN an own set of neighbouring cells must be defined in the radio network configuration database, typically located in the RNC. Since a neighbouring cell may be located in the same network on the same frequency, on a different frequency or in any neighbouring Public Land Mobile Network (PLMN), the following neighbour lists need to be defined for each cell in case the corresponding HO needs to be supported **[10, pp 215]:**

- Intra-frequency neighbour cell list: The UE must be able to monitor at least 32 cells on the same WCDMA carrier frequency as the serving cell.
- Inter-frequency neighbour cell list: The UE must be able to monitor at least 32 cells on a maximum of two WCDMA carrier frequencies in addition to the serving cell's frequency.
- Inter-system neighbour cell lists: For each neighbouring PLMN, an own list is needed. In total a maximum of 32 inter-frequency neighbours must be supported by the UE.

The RAN broadcasts the initial neighbour cell list(s) of a cell in the system information messages on the BCCH (Broadcast CCH). In case a required ASU has been performed, a new neighbour list is combined in the RNC based on the neighbour lists of the cells in the new active set and then is sent to the UE on the DCCH.

To identify a WCDMA neighbour cell, this list includes the following information **[10, pp 215]:**

- UTRAN Cell Identifier:
    - Global RNC identifier (PLMN identifier MCC and MNC);
    - Cell Identifier (CI).
- Location Area Code (LAC).
- Routing Area Code (RAC).
- UTRA Absolute Radio Frequency Channel Number (UARFCN).
- Scrambling code of the P-CPICH.

For a GSM neighbouring cell, the following information is sent:

- Cell Global Identification (CGI), Mobile Country Code (MCC), Mobile Network Code (MNC),
  CGI = MCC + MNC + LAC + CI
- BCCH frequency
- Base Station Identity Code (BSIC), Base Station Colour Code (BCC), Network Colour Code (NCC)
  BSIC = BCC + NCC

Neighbour Cell Search on Current Carrier Frequency

In idle mode as well as in connected mode the UE continuously searches for new cells on the current carrier frequency. If the UE detects a candidate cell that has not been defined as a neighbouring cell, it has to decode the cell's BCCH to identify the cell before it can report the measured E_c/I_0 of the detected neighbouring cell to the RNC. In this case, the following Information Elements (IEs) are used to identify the undefined neighbouring cells: the downlink scrambling code, LAC and CI. When reporting the measurement result, the UE may or may not include this information in the measurement report **[10, pp 215].**

3.3.2 Measurement Reporting Criteria

Depending on the handover (HO) type (mobile evaluated handover (MEHO) or network evaluated handover (NEHO)), different measurement reporting criteria can be used. The RNC may request the UE to execute and report the following different types of basic HO measurements:

- intra-frequency measurements (MEHO)
- inter-frequency measurements (NEHO)
- inter-system measurements (NEHO)
- UE internal measurements

All HO measurement types are controlled independently of each other and are defined on a cell-by-cell basis, with the exception of UE internal measurements, which are partly controlled by parameters common to all cells under the same RNC. Two or more HO measurement types can be active simultaneously – e.g., intra- and inter-frequency measurements. Typically, in a RAN separate measurement parameter sets for RT and NRT bearers and for users applying HSDPA can be defined. Control of the HO measurements is explained in detail in the following sections in connection with the relevant HO types **[10, pp 216].**

3.3.2.1 Intra-Frequency Handover Measurements

The RAN broadcasts the measurement reporting criteria (measurement parameters) for intra-frequency measurements on the BCCH. When the criteria are fulfilled, the UE reports the results of its measurements to the RNC. The RNC in turn makes the HO decision. If the ASU could not be executed, the UE continues to measure the neighbouring cells but changes to periodic reporting of the results. For this type of measurements the UE uses separate measurement reporting criteria transmitted to the UE **[10, pp 216].**

3.3.2.2 Inter-Frequency and Inter-System Handover Measurements

Inter-frequency and inter-system measurements are both made only when ordered by the RNC. They use separate measurement reporting criteria transmitted to the UE. When they are initiated, the UE periodically reports the results to the RNC. The measurements are controlled by two parameters: reporting duration and the reporting interval **[10, pp 216].**

3.3.2.3 User Equipment Internal Measurements

UE internal measurement reporting criteria are controlled partly on a cell-by-cell basis and partly by parameters common to all cells in the whole RNC. The measurement information for UE internal measurements is not included in the system information on the BCCH but transmitted to the UE on a Dedicated CCH (DCCH). When the measurement-reporting criteria are fulfilled, the UE reports the results of its measurements to the RNC **[10, pp 216].**

3.3.3 Reporting of Measurement Results

When the UE reports the measurement results from the intra- or inter-frequency measurements of the neighbouring cells back to the UTRAN, the following IEs are included to identify the neighbours **[10, pp 217]**:

- P-CPICH information (downlink scrambling code) identifies active and monitored cells when the UE reports intra-frequency or UE internal measurement results to the RNC.
- P-CPICH information and UTRA RF (Radio Frequency) channel number identifies neighbouring cells when the UE reports IF measurement results to the RNC.
- BCCH frequency identifies neighbouring GSM cells when the UE reports IS (GSM) measurement results to the RNC. The BSIC can be used additionally to verify identification if two or more neighbouring GSM cells have the same BCCH frequency. The RNC always applies the BSIC verification for the target cell before the execution of IS-HO so that the UE can synchronise with the GSM cell before HO execution. The UE reports the BSIC information only if it is requested by the RNC.

The UE generates at least the following event-triggered and periodic measurement reports **[10, pp 217]**:

- event-triggered intra-frequency measurement report
- periodic intra-frequency measurement report
- inter-frequency measurement report
- inter-system measurement report
- measurement reports on common channels
- traffic volume measurement report
- UE internal measurement report
- quality deterioration report

3.3.3.1 Reporting of Intra-frequency Measurements

Intra-frequency measurement reporting can be either event-triggered or periodic. During connected mode, the UE constantly monitors the P-CPICH E_c/I_0 of the cells defined by the intra-frequency neighbour cell list and evaluates the reporting criteria. If one of the reporting events is fulfilled, the UE sends an event-triggered measurement report. Before the P-CPICH E_c/I_0 of a cell is used by the HO algorithm in the UE, an arithmetic mean of a certain number of the latest measured values is taken. The number of the values taken into account is a UE performance specification parameter. The average is taken over the linear values of E_c/I_0, not the dB values **[10, pp 217]**.

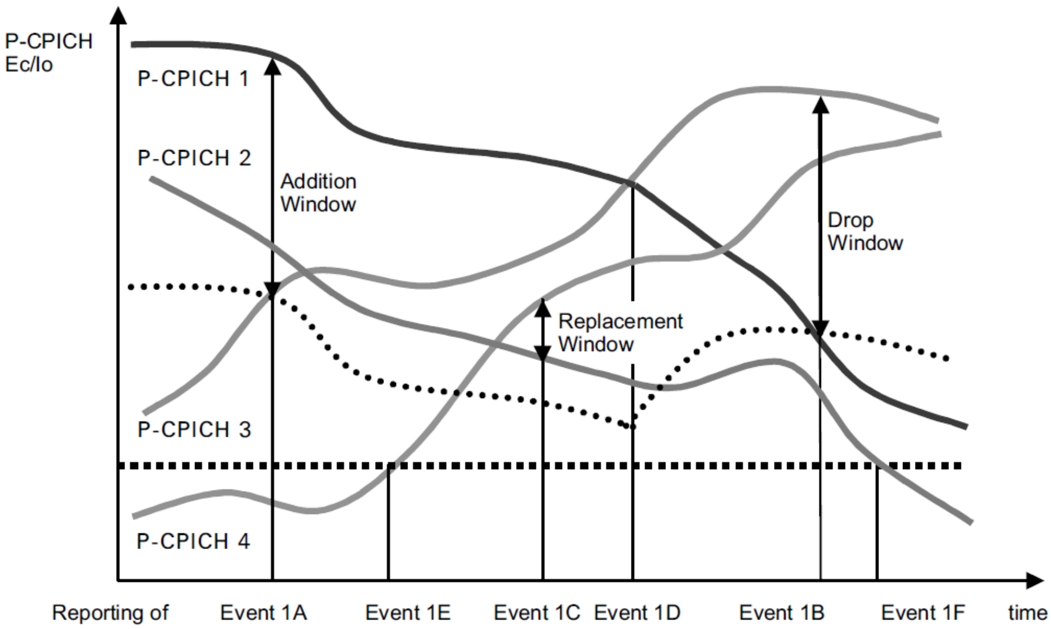

Figure 21 : Intra-frequency Measurements [10, pp 219]

For intra-frequency measurement criteria, the following reporting events are defined **[10, pp 218]**:

Event 1A: A P-CPICH enters the reporting range. A report is triggered when the equation below is fulfilled:

$$10 \cdot log_{10} M_{New} + CIO_{New} \geq W \cdot 10 \cdot log_{10}\left(\sum_{i=1}^{N_A} M_i\right) + (1-W) \cdot 10 \cdot log_{10} M_{Best} - (R_{1a} - H_{1a}/2)$$

where M_{New} is the measurement result of the cell entering the reporting range; CIO_{New} is the cell-individual offset of the cell entering the reporting range; M_i is a measurement result of a cell in the active set not forbidden to affect the reporting range; N_A is the number of cells in the current active set not forbidden to affect the reporting range; M_{Best} is the measurement result of the strongest cell in the active set; W is a weighting parameter sent from the RNC to the UE; R_{1a} is the reporting range constant for Event 1A sent from the RNC to the UE; and H_{1a} is the hysteresis parameter for Event 1A. The hysteresis parameter together with the reporting range constant is usually called the addition window.

Event 1B: A P-CPICH leaves the reporting range. A report is triggered when the equation below is fulfilled:

$$10 \cdot log_{10} M_{Old} + CIO_{Old} \le W \cdot 10 \cdot log_{10}\left(\sum_{i=1}^{N_A} M_i\right) + (1-W) \cdot 10 \cdot log_{10} M_{Best} - (R_{1b} + H_{1b}/2)$$

where R_{1b} is the reporting range constant for event 1B sent from the RNC; M_{Old} is the measurement result of the cell leaving the reporting range; CIO_{Old} is the cell individual offset of the cell leaving the reporting range; and H_{1b} is the hysteresis parameter for Event 1B. The hysteresis parameter together with the reporting range constant is usually called the drop window.

Event 1C: A non-active P-CPICH becomes better than an active one. A report is triggered when the equation below is fulfilled – i.e., when a P-CPICH that is not in the active set gets better than the worst P-CPICH from the active set when the active set is full. Used to replace the cell with the worst P-CPICH:

$$10 \cdot log_{10} M_{New} + CIO_{New} \ge 10 \cdot log_{10} M_{InAS} + CIO_{InAS} + H_{1c}/2$$

where M_{InAS} is the measurement result of the cell in the active set with the lowest measurement result; CIO_{InAS} is the cell-individual offset for the cell in the active set that is becoming worse than the new cell; and H_{1c} is the hysteresis parameter for Event 1C. The hysteresis parameter is usually called the replacement window.

Event 1D: Change of best cell. A report is triggered when any P-CPICH in the reporting range becomes better than the current best plus an optional hysteresis value.

Event 1E: A P-CPICH becomes better than an absolute threshold. A report is triggered when a new cell plus its cell-individual offset becomes better than an absolute threshold plus an optional hysteresis value.

Event 1F: A P-CPICH becomes worse than an absolute threshold. A report is triggered when a new cell plus its cell-individual offset becomes worse than an absolute threshold minus an optional hysteresis value.

3.3.3.2 Time-to-trigger Mechanism

The abundance of possible neighbouring cells together with the variety of triggering events could result in quite frequent reporting. To protect the network from an excessive signalling load, each of the reporting events can be connected with a timer. Only if the measurement criteria have been fulfilled during the whole period until the timer expires is the event reported to the network. **Figure 22** shows an example of the time-to-trigger mechanism in case of Event 1A. On the first two occasions when the event occurs, no report is triggered, since P-CPICH 3 does not stay within the reporting range for a long enough time. Only the third occurrence triggers the reporting of Event 1A **[10, pp 219]**.

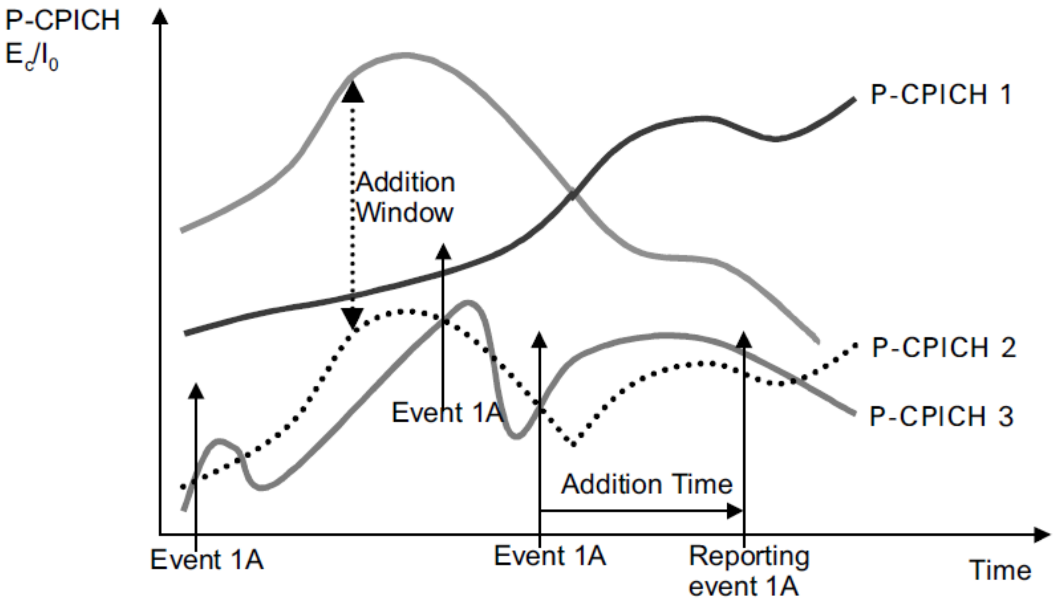

Figure 22 : Time-to-trigger Mechanism for Event 1A [10, pp 219]

3.3.3.3 Event-triggered Periodic Reporting

Reporting one of the above-mentioned events typically results in an active set update. However, if the active set update cannot take place, owing to lack of capacity or hardware resources, for example, the UE changes to periodic reporting. In this case it sends a measurement report every reporting interval until the active set update has taken place, the measurement criteria are no longer fulfilled or the maximum number of measurement reports has been sent **[10, pp 220]**.

3.3.3.4 Mechanism for Forbidding a Neighbouring Cell to Affect the Reporting Range

In case of Events 1A and 1B when the weighting coefficient, W, is non-zero, all cells in the active set are used to evaluate whether or not the measurement criteria are fulfilled. In a RAN, however, it could be beneficial to exclude a specific neighbouring cell – i.e., its P-CPICH – from this active set weighting: for example, when the P-CPICH of that cell is very unstable within the reporting range. For this case, a neighbouring cell parameter can be specified for each cell, indicating whether or not this cell is allowed to affect the reporting range calculation when it is in the active set **[10, pp 220]**.

3.3.3.5 Cell-individual Offsets

To have an efficient means of reporting a monitored cell individually, a P-CPICH offset can be assigned to each neighbouring cell. The offset can be either positive or negative. The UE then adds this offset to the measurement quantity (E_c/I_0, path loss or RSCP) before it evaluates whether a reporting event has occurred **[10, pp 220]**.

3.3.3.6 Reporting of Inter-frequency and Inter-system Measurements

Inter-frequency and inter-system measurement reports are always periodic. The events triggering them are not part of the standards. The RNC may initiate inter-frequency and/or inter-system measurements in various circumstances, for example **[10, pp 221]:**

- Average downlink transmission power of a radio link as it approaches its maximum power level
- Uplink transmission power reaches a threshold or its maximum (events 6A/6D, see below)
- Quality deterioration report from uplink outer-loop PC from the RNC
- Quality deterioration report from the UE
- Unsuccessful SHO (branch addition) procedure
- Unsuccessful RAB setup
- UE located within cell where SHO capability is restricted
- UE located within cell where admitted user bit rate is lower than requested
- Frequent SHOs (cell size and UE speed do not match)
- Radio network recovery management initiates forced HO procedure

- UE located within an area where cell structure is hierarchical (inter-frequency)
- UE located within an area where hierarchical network structure is composed of WCDMA and GSM systems (inter-system only)
- IMSI-based HO is needed
- UE located within a cell with restricted intra-system HO capability (inter-system only)

3.3.3.7 UE Internal Measurements

UE internal measurements can be divided into two groups. The first group is used to indicate to the network the status of the UE transmit power. The reports may be used by the RNC to trigger off inter-frequency or inter-system measurements. The second group is the UE Rx–Tx (Receiver–Transmitter) time difference measurement. It is used to adjust the downlink DPCH air interface timing when the difference in time between the UE uplink DPCCH/DPDCH frame transmission and the first significant path of the downlink DPCH frame from a measured active set cell (UE Rx–Tx time difference) becomes too large**[10, pp 221].**

The following events are specified in 3GPP specifications **[12]:**

- **Event 6A**: UE transmit power becomes larger than an absolute threshold.
- **Event 6B**: UE transmit power becomes less than an absolute threshold.
- **Event 6C**: UE transmit power reaches its minimum value.
- **Event 6D**: UE transmit power reaches its maximum value.
- **Event 6E**: UE RSSI (Received Signal Strength Indicator) reaches the UE receiver dynamic range.
- **Event 6F**: UE Rx–Tx time difference for a radio link included in the active set becomes larger than an absolute threshold.
- **Event 6G**: UE Rx–Tx time difference for a radio link included in the active set becomes less than an absolute threshold.

3.3.3.8 Node B Measurements

The Node B measurement report can be used to trigger off inter-frequency or intersystem (GSM) measurements, and to balance the PC (uplink and downlink) of the diversity branches during SHO. The Node B sends the measurement report to the RNC on a radio link by radio link basis at regular (e.g., 500–1000 ms) intervals. The measurement report from the Node B includes the following radio link measurement results **[10, pp 222]:**

- Average downlink transmission power of the DPCH
- Average measured uplink SIR of the DPCH
- Uplink SIR target currently used on the DPCH

4 Radio Network Controller (RNC)

4.1 UTRAN network elements: Standard concept

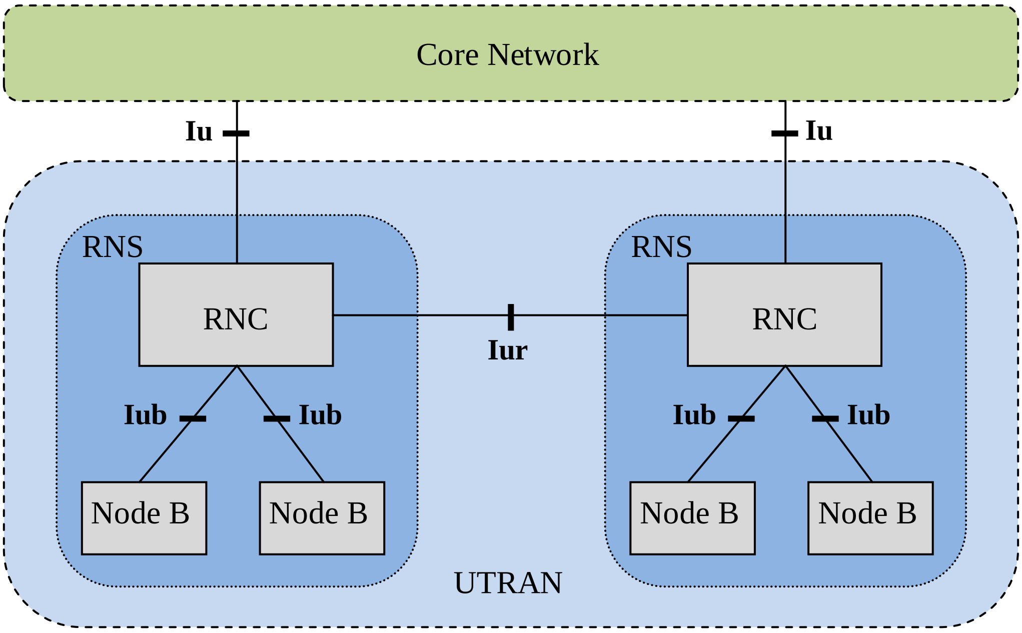

Figure 23 : UTRAN Network Elements

The key functions of the Radio Network Controller (RNC) are management of terrestrial channels, management of radio channel configurations in the Radio Access Network (RAN), radio resource management, telecom functionality, transmission & transport features and maintenance & operation. They are briefly explained in the following sub chapters and more in detail throughout this document.

Defined RNC roles **[13, pp 29]:**

1. **Serving RNC:** Role an RNC can take with respect to a Radio Resource Control (RRC) connection between an UE and RAN. There is one Serving RNC for each UE that has a connection to RAN. The Serving RNC is in charge of the radio connection between a UE and the RAN. The Serving RNC terminates the *Iu* interface for this UE.
2. **Drift RNC:** A role an RNC can take with respect to a specific connection between an UE and RAN. An RNC that supports the Serving RNC with radio resources when the connection between the RAN and the UE need to use cell(s) controlled by this RNC is referred to as Drift RNC

3. **Controlling RNC:** A role an RNC can take with respect to a specific set of BTS's. There is only one Controlling RNC for any BTS. The Controlling RNC has overall control of the logical resources of its BTS's. Both serving and drifting RNCs serve as controlling RNC for the cells they control.

4.2 Nokia Siemens Networks RNC Solutions

4.2.1 IPA2800 Platform

Nokia Siemens Networks continues the work that its predecessor, Nokia Networks, did earlier as a developer of network elements. A network element is a complex network of inter-connected computer units. The system consists of various computers with different tasks of their own, communicating with each other via message connections.

As Jyri Ilama mentioned in his master’s thesis: In early 70’s, the research and development process of DX200 started at Nokia Networks and the first customer deliveries took place in the year 1980, in the form of a Fixed Network Switching Centre (FNC). Later, multiple DX200 based products have been developed, such as MSC, HLR and BSC. Anyhow, the capacity and performance of the old DX200 started to become obsolete before the turn of millennium, and it was discovered that this system won’t be able to handle the requirements of telecommunication systems of the third generation. This was the need that started the developing of IPA2800 – a DX200 based system, which is much more efficient and clearer of its architecture than its predecessor was. But, IPA2800 is not a substitute for DX200: it works in parallel with these old systems, hand in hand, offering new resources and possibilities that are needed by the third generation systems. IPA2800 was designed to be much simpler than DX200 from the architectural point of view **[14, pp 15].**

4.2.2 cRNC

cRNC is the classic RNC solution of Nokia Networks and Nokia Siemens networks that has been developed since 90's. The general functional architecture of the RNC is shown in **Figure 24**. The RNC consists of four parts: network interface functions, switching and multiplexing functions, user plane functions and control functions.

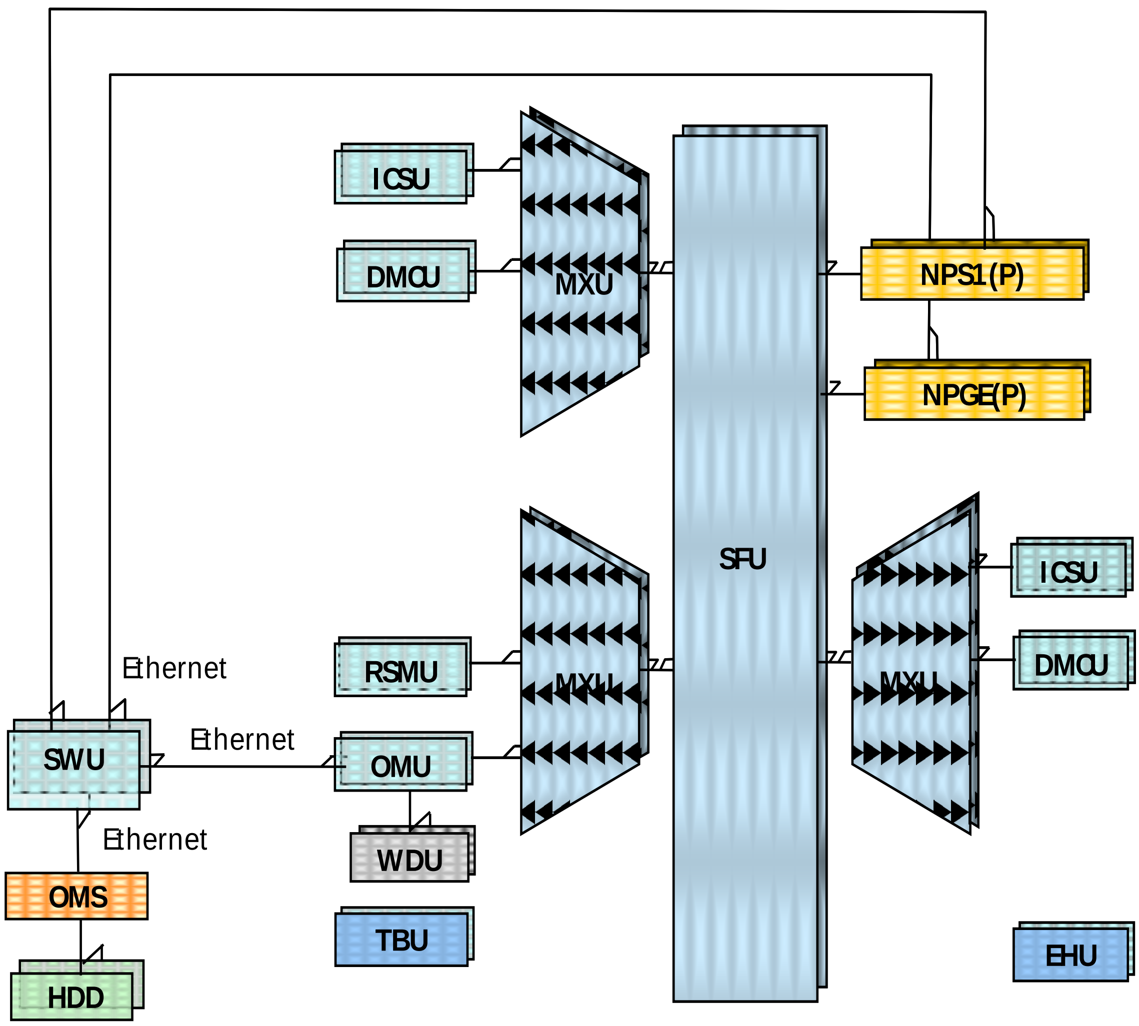

Figure 24 : Functional architecture of the cRNC [13, pp 31]

DMCU	Data and Macro diversity Combining Unit
EHU	External Hardware Alarm Unit
HDD	Hard Disk Drive for OMS
ICSU	Interface Control and Signalling Unit
MXU	Multiplexer Unit
NPGE	Network Processor Interface Units Gigabit Ethernet
NPS1	Network Processor Interface Unit STM-1

OMS	Operation and Maintenance Server
OMU	Operation and Maintenance Unit
RSMU	Resource and Switch Management Unit
SFU	Switching Fabric Unit
SWU	Switching Unit (Ethernet)
TBU	Timing and Hardware Management Bus Unit
WDU	Winchester Drive Unit for OMU

In the scope of this thesis, only Handover/Mobility related functional units of cRNC will be analyzed and explained.

- **The Operation and Management Unit (OMU)** performs the basic system maintenance functions such as hardware configuration, alarm system and centralized recovery functions. It also contains cellular related functions such as performance management, radio network management, radio network recovery, databases and state management.

- **The Interface Control and Signalling Unit (ICSU)** provides the signalling protocols for *Iu*, *Iub*, *Iur* and *Uu* interfaces (NBAP, RNSAP, RANAP, RRC, AAL2). It is also responsible for termination of the SAAL signalling links, monitoring and recovery of the signalling links, admission control, handover control, load control, radio resource scheduling and management and cell based locationing for LCS.

- **Distributed Signal Processing Unit (DMCU)** that provides support for macro diversity handovers and packet data processing as well as other L2 functions related to radio interface.

4.2.3 mcRNC

mcRNC is the new generation of the RNC solution in Nokia Siemens Networks which has a completely new hardware architecture and changes platform and the software side because of the increased capacity and performance requirements. As the mcRNC has only one type of processing hardware, it allows in theory a large degree of freedom in design of functional software architecture. In reality, the reuse of existing software as well as logical structure of RNC limits the option space.

Similar as cRNC; mcRNC can also expressed with 4 planes – Control Plane, User Plane, Transport Plane and Management Plane.

In mcRNC architecture, the services of the Control Plane and User Plane are functionally divided based on whether they are provided for a specific UE, common entities like BTS and cells or centralized in the Network Element for architectural reasons. The resulting functional units are:

CSCP – Cell Specific functions and services in Control Plane
USCP – UE Specific functions and services in Control Plane
CFCP – Centralized Functions and services in Control Plane
CSUP – Cell Specific functions and services in User Plane
USUP – UE Specific functions and services in User Plane. This includes the dedicated and shared channel services since they are relevant for a UE.

The Transport plane is divided based on whether it provides services for the internal network (also referred to as backplane) or external network (external interfaces).
SITP – Signalling Transport Plane
EITP – External Interface functions in Transport Plane.
Backplane - The internal backplane is realized using the Ethernet switch (internal side), a program block from the application domain resembling a Service Access Point (SAP) and services provided by IPA Light including the kernel module for transferring DMX messages.

4.3 RNC SW Architecture

4.3.1 Structural View

cRNC: The general structure of RNC SW architecture that consists of IPA2800 ATM platform and RNC application parts is depicted in **Figure 25**. RNC Network Element includes SW on top of three different Operating Systems; DMX, Chorus and OSE.

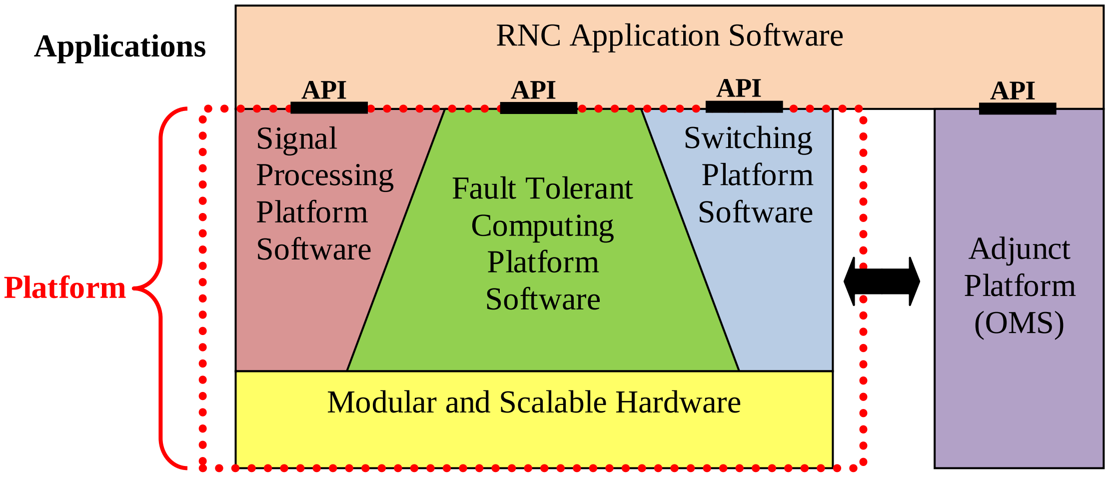

Figure 25 : cRNC SW architecture [13, pp 38]

mcRNC: As it is seen on **Figure 26**, the general structure of the SW architecture remains similar to that of cRNC but the notable differences are in the removal of OMS as a unit of RNC and the change of platforms and middleware that support the new hardware and Linux OS.

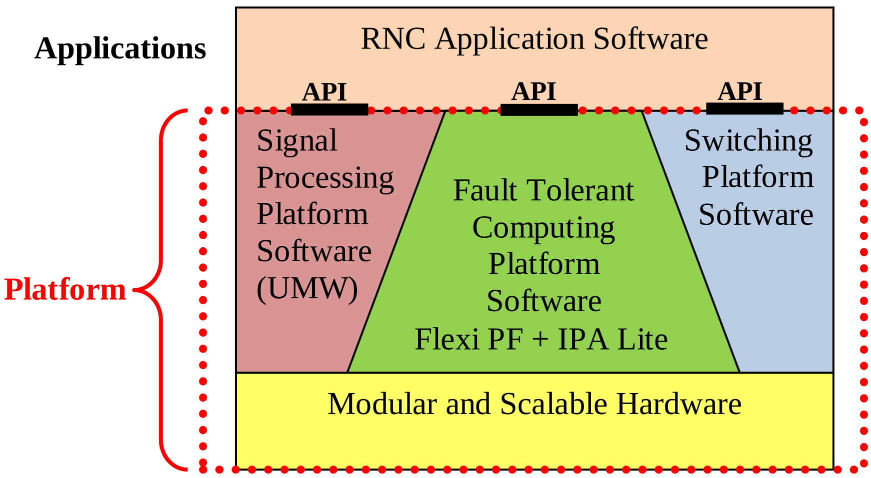

Figure 26 : mcRNC SW architecture [13, pp 39]

4.3.2 SW Architecture

The essentials of the software architecture solutions of the RNC have been the following attributes:

- modular system
- communication
- redundancy
- variations

The software of the RNC consists of various independent software components such as process families, libraries and files. The software is very modular and hence easier to modify and develop than a large monolithic entity **[15].**

The software components are loosely coupled together. Each component implements a functional entity, which functions very independently. On the other hand, each component needs each other to form a system. The RNC contains a message bus which provides a connection for different components in different physical locations **[15].**

A real-time system needs the work contribution of every component all the time. Each computer unit is duplicated into two, a working unit and a spare unit. The working unit is the one which provides the services. The spare unit is taken into use if the working unit malfunctions. The functionality is called the switchover. The switchover is a procedure which provides fast recovery from a malfunction of a computer unit. The switchover requires that the spare unit is available to take over the functionalities of the working unit without delays. In a switchover procedure, all content of all critical variables, files, time supervisions, buffers and utility libraries need to be copied into the spare unit. Critical information is information which needs to be precisely identical in the working and in the spare unit in order for a process to function correctly. The copying process is called a warming process **[15].**

Different customers need different services. Usually, there are different variations of the software package available. Because of the modularity, a version update of a software component or an addition of a software component is relatively easy. This requires efficient version control on a component level as well as on a software package level **[15].**

4.3.3 Service model architecture

The service model means that when executing a task, a process may delegate parts of the task to other processes. What needs to be done defines the services that the other process needs to provide. The whole system can be seen as a network of responsibilities and services. The services become an interface to the process and the outside world sees only the service interfaces **[13, pp 40].**

The service model SW is divided into three levels: system blocks, service blocks and program blocks **[13, pp 40]:**

- System block (SYB) is hierarchically the highest block and it offers a defined number of related services and implements a defined number of functions.
- Service block (SEB) is a part of the implementation of a system block offering certain system block services to others and a number of services used within the system block.
- Program blocks (PRB) is the actual implementation of the service blocks. Program blocks implement the services of service blocks.

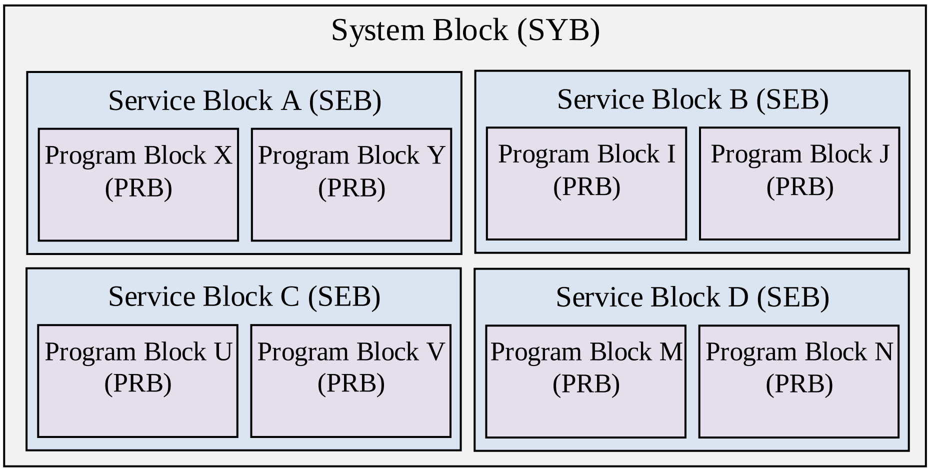

Figure 27 : Service model architecture [13, pp 40]

In the block model illustrated by **Figure 27,** the services can be hidden, so that program blocks belonging to different service blocks do not see each other’s service definitions **[13, pp 40].**

4.3.4 Process Family

A software block is usually implemented as a process family. A process family is a group of independent, dynamically allocated state machines. One of the state machines is on the controlling position towards others. The controlling state machine exists always after the activation of the program **[15].**

A process family consists of a master process and various number of hand processes. A process family can also be implemented without the hand processes. The master functions as the controlling state machine. In a process family, the master process is a service point where service requests are handled. The master process may handle the request and offer the services or it may create a hand process to do the work **[15].**

4.4 Radio Resource Management of WCDMA RAN Service Block

Radio Resource Management of WCDMA RAN Service Block is responsible for air interface resource allocation in RAN. It’s main task is to optimize the use of the available radio resources, such as transmitter power and the usage of spreading codes in order to provide users with the largest possible capacity for given coverage and quality-of-service requirements **[13, pp 46].** Radio Resource Management of WCDMA RAN Service Block provides Load Control, Admission Control, Packet Scheduler, Code Management and Handover Control functionalities to the RNC application.

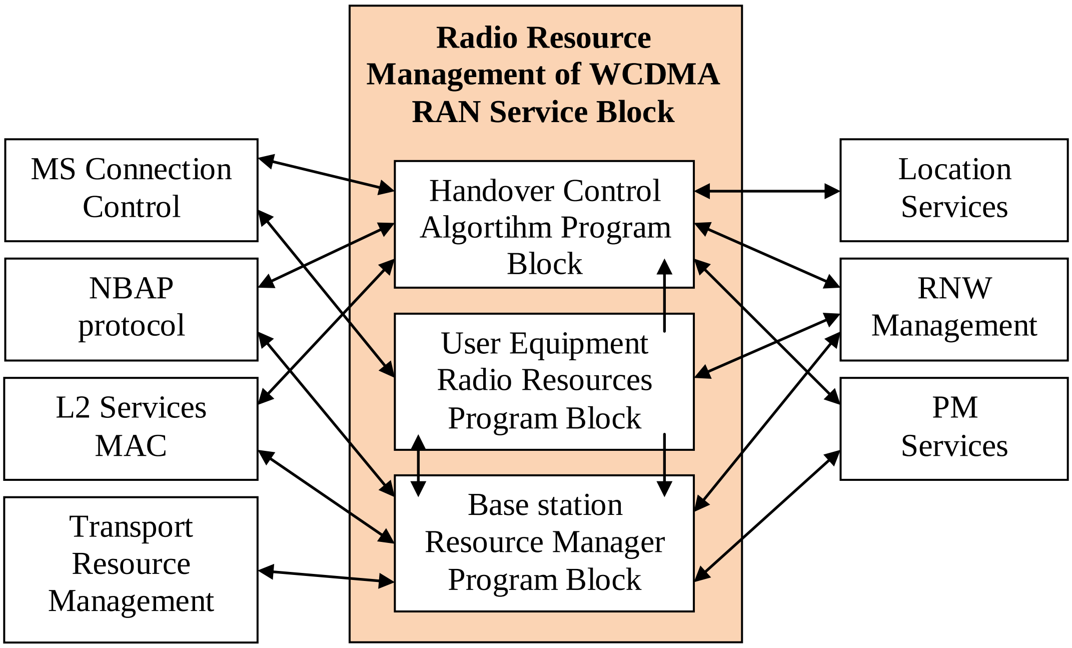

Figure 28 : Radio Resource Management of WCDMA RAN Service Block Diagram [13, pp 48]

Task division inside service block:

- **Handover Control Algorithm Program Block** is responsible for handover control of UEs.
- **Base station Resource Manager Program Block** is responsible for load control, admission control, code management and packet scheduling of base stations.
- **User Equipment Radio Resources Program Block** manages UE specific radio resources.

RNW management can be divided into three functionalities from Radio Resource Management of WCDMA RAN Service Block point of view **[13, pp 48]:**

a) RNW parameter management contains the management and access routines for the radio network configuration database. Radio Resource Management of WCDMA RAN Service Block both reads and receives via message interface radio network parameters from the RNW database in OMU unit. However, base transceiver station (BTS) and cell related radio network parameters are delivered inside ICSU/CSCP via message interface to Base station Resource Manager Program Block first when BTS/cell is setup and thereafter whenever those parameters change.

b) BTS and cell configuration management in ICSU/CSCP is responsible for BTS and cell setup and cell state handling inside ICSU/CSCP. Base station Resource Manager Program Block receives information about cell states through this interface. Base station Resource Manager Program Block provides common channel DL spreading codes for CCH setup purposes.

c) BTS and cell recovery management in OMU is responsible BTS and cell recovery procedures. This interface is also used for triggering cell recovery procedures.

PM Service collects statistical counter data from applications. PM Service interface is used to deliver statistical counter data for traffic and cell resource measurements. Counter data collection is performed through Distributed Statistics Mediator library, which is linked to each provider application. This interface is also used for online monitoring.

User Equipment (UE) connection management controls the UE mobility and connections between UE, RNC, and core network (CN) and performs related signalling at L3 level (also handover (HO) signalling). UE connection management uses UE resource management services for RAB related operations.

NBAP protocol: Node B Application Part (NBAP) protocol sends periodically cell specific load information and radio link specific load information from BTS. Dedicated BTS measurements are controlled and reported through NBAP.

Layer 2 services offer radio lank control (RLC) and medium access control (MAC) protocols. MAC protocol is informed whether common channels can be used for data transfer in downlink direction (depends on load conditions in radio interface). Also it is used for reserving Data and Macro Diversity Processor Group (DMPG) resources for HSDPA channels.

Transport resource management offers a service through which HS-DSCH transport resource allocation can be performed.

Location services (LCS) request Handover Control Algorithm Program Block to perform assisted GPS measurement. Handover Control Algorithm Program Block delivers LCS related measurement results (assisted GPS measurement, Rx-Tx measurement) to location services.

4.4.1 The Interface Control and Signalling Unit

The Interface Control and Signalling Unit (ICSU) performs all the signalling transactions towards the other network elements and UE. The unit is responsible for the following tasks:

- Signalling protocols to *Iu*, *Iub*, *Iur* and *Iu*-BC interfaces for
  - NBAP, RNSAP, RANAP, SABP signalling
  - ALCAP (Q.2630.1) signalling
  - RRC signalling
- Monitoring and recovery of the signalling links
- Service Area Broadcast (SAB)
- Radio resource management functions
  - Admission control (AC)
  - Handover control (HC)
  - Load control (LC)
  - Packet scheduling (PS)
- Location service control functions

Through the focus of this thesis, handover related transactions take place in ICSU. In other words ICSU has a key role in the success of handover functions.

4.4.2 Handover Control Algorithm Program Block

The functionality of handover control is implemented in Handover Control Algorithm Program Block. Handover Control Algorithm Program Block has one master process and several hand processes. A Handover Control Algorithm hand is created in serving RNC together with the radio resource control (RRC) connection establishment for the UE and it exists until the RRC connection is released. In drift RNC, Handover Control Algorithm hand is created when the first radio link is established for diversity handover and it exists until last radio link of the diversity handover is released. The software architecture of Handover Control Algorithm Program Block and the interfaces to other program blocks are illustrated in **Figure 29**.

Interfaces:

1 & 2) Handover Control Algorithm master uses the RNC RNW Database Library to read the relevant operator defined RNC RNW parameters. RNC RNW Database Library in turn uses RNW Database Manager to perform the actual (hand-) fast-reads from the RNW Database. Handover Control Algorithm HC-master reads the relevant parameters at process start up and stores them to its internal data structures. UE dedicated Handover Control Algorithm HC-hand processes (HC-hand) have access to these parameters via internal function interface. If the operator changes these parameters in the RNC RNW database the Radio Network Manager sends a message including the modified parameters to Handover Control Algorithm HC-master process.

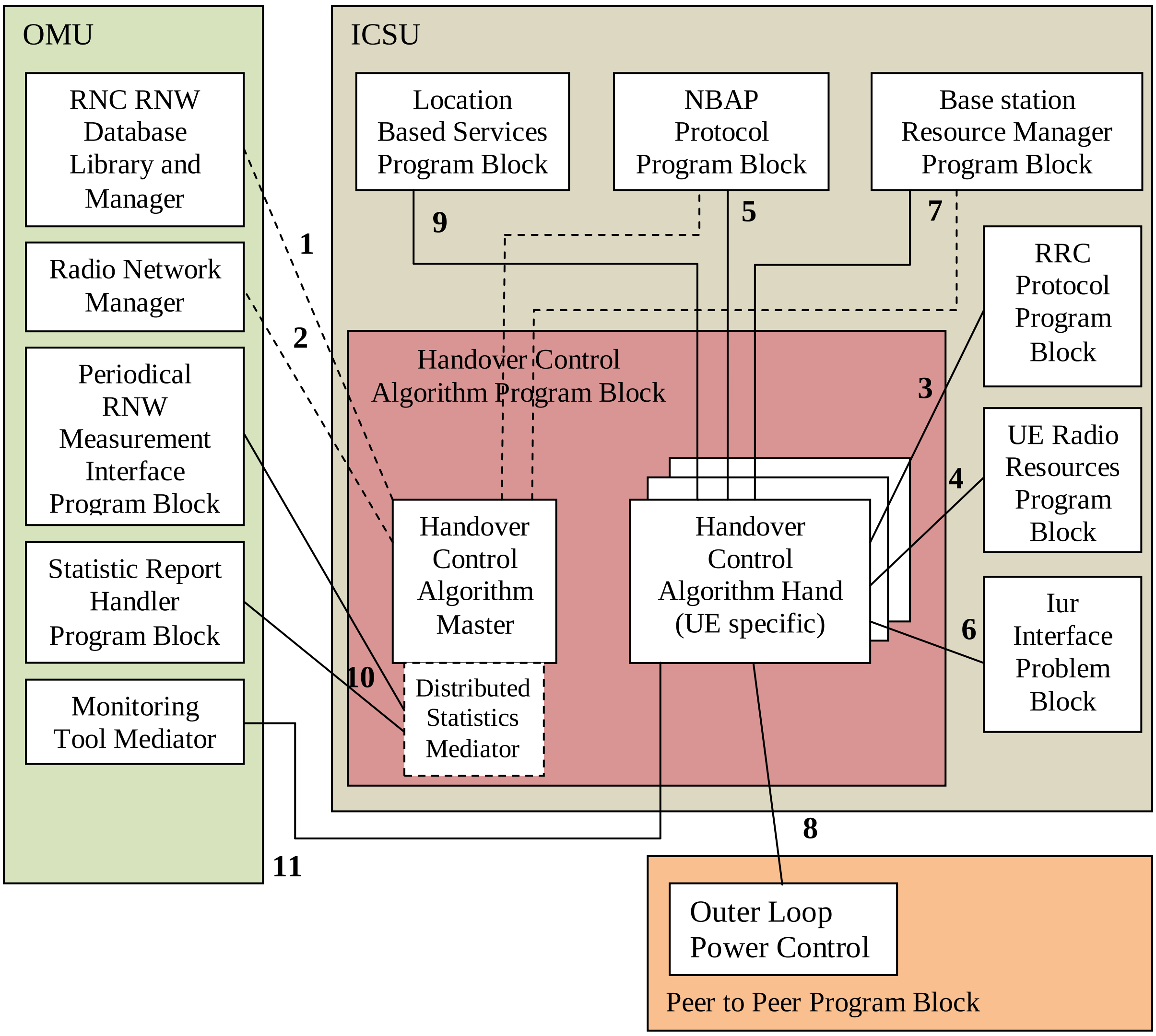

Figure 29 : Handover Algorithms Program Block Diagram

3) This interface is for UE handover measurement. Dedicated RRC process provides RRC protocol for dedicated radio connections. HC-hand receives UE handover measurement reports and also sends and receives UE handover measurement control messages via this interface.

4) There are two interfaces towards UER (UE Specific Radio Resources):

- Start of Handover Control algorithm: UER requests HC-master to start handover control algorithm (HC-hand) for UE connection. HC-hand is always started in the same ICSU as the UER resides.
- Handover algorithm main interface: This is an interface between UE specific Radio Resources (UER) and handover control algorithm in HC-hand. All UE specific control functions related to soft / softer / hard handovers / serving cell change / compressed mode activation and deactivation are handled through this interface.
- Handover Control Algorithm Program Block triggers DCH to HS-DSCH channel switching and vice versa (for not DCH 0/0).

5) This interface is for serving RNC (SRNC) BTS measurement reporting. HC-hand receives dedicated BTS measurement reports in SRNC (NBAP) via this interface. Control of dedicated BTS measurements is also performed through this interface.

6) This interface is for drifting RNC (DRNC) BTS measurement reporting. HA3-m initiates common BTS measurements and receives measurement reports from DRNC (RNSAP) via IUR control process. HC-hand initiates dedicated BTS measurements and receives dedicated BTS measurement reports from DRNC (RNSAP) via dedicated Iur process.

7) Base station Resource Manager Program Block provides cell load information to HA3-m as well as it indicates need for load, service or HSPA Capability based handover to HC-hand via this interface. This interface exists only if service and load or HSPA capability based handover functionality is enabled.

8) This interface is for uplink DCH quality reporting. In serving RNC the outer loop power control informs HC-hand about uplink DCH quality deterioration via this interface.

9) Location Based Services Program Block sends request for assisted GPS measurement to Handover Control Algorithm Program Block, which then later delivers the results of assisted GPS measurement back to Location Based Services Program Block.

10) This interface is for Distributed Statistics Mediator. Distributed Statistics Mediator is a statistical library module linked into Handover Control Algorithm Program Block. Distributed Statistics Mediator provides functions related to statistical counter updates. Periodical RNW Measurement Interface Program Block uses Distributed Statistics Mediator interface to start and stop periodical measurements and to collect measurement data from a data provider such as Handover Control Algorithm Program Block. Data of active measurements is sent to Statistic Report Handler Program Block based on Periodical RNW Measurement Interface Program Block commands. Periodical RNW Measurement Interface Program Block interface is also used for trace and online monitoring. Distributed Statistics Mediator library implements both Periodical RNW Measurement Interface Program Block and Statistic Report Handler Program Block interfaces.

11) This is an interface for monitoring tools. Monitoring Tool Mediator activates and deactivates trace data collection to HC-master. HC-hand sends the actual trace data to Monitoring Tool Mediator.

4.5 Handover Control Process Family

4.5.1 Handover Control Master Process [16]

As explained in the previous chapters, the Handover Control (HC) implements the handover decision algorithm of the RNC. The Handover Control has two processes, a master process and a hand process. The master process is active as long as the RNC is up and running. The hand processes are call-specific and they are created and removed when needed.

The Handover Control Master Process is responsible for maintaining an on-line copy of the Radio Network (RNW) database parameters and providing an interface for every handover control hand process to read these parameters. Only the Handover Control specific RNW parameters are provided to the HC-master. The HC master is also responsible for creating and supervising an HC-hand, providing a statistical interface and managing process warming and switchover. The memory consumption of the HC-master process is dependable on the network configuration. That can be controlled by configuration parameters, and hence the memory usage of the HC master is not an issue in different hardware environments.

In addition to normal hand creation and supervision functions HC master maintains a local copy of RNW parameter database in its own memory and provides an interface for hand processes to read these parameters. Only HC specific RNW parameters are stored in HC-masters memory. Process warming and switchover control functions are implemented in the HC-master as well.

4.5.2 Handover Control Hand Process [16]

An HC-hand is created in the SRNC (serving RNC) when the RRC connection on the Cell_DCH state is set up and it exists until the UE leaves the Cell_DCH state. The UE is in the Cell_DCH state if at least one dedicated transport channel is set up. In the DRNC (drifting RNC), an HC-hand is created when the first soft-handover (SHO) branch over *Iur* is set up and it exists until the last soft handover (SHO) branch over *Iur* is removed.

The HC-hand provides all UE-dedicated handover functionalities in the Cell_DCH state. This is why most of the implementation is done in the HC-hand code area. Because there can be thousands of HC-hand processes in a computer unit at the same time, every new bit of memory needed by the HC-hand is multiplied by the number of the active HC-hand processes.

4.5.3 Module Structure of HC Hand Process [16]

The HC-hand was abstracted according to developed services. The intention was to have one module for one service. The abstraction was implemented by abstract data types, which have their internal data structures and service interface. The service interface consists of many independent service offering operations. This implementation method supports object-oriented programming suggestive of implementation solution, which supports thinking and designing of data structures and combinations of different operations rather than just thinking and designing of the functionality. Parameter and return values of functions are the communication tools of the operations. This section concentrates on the current usage of abstract data types from the point of view of memory consumption.

The HC-hand functionality in the Drifting-RNC (DRNC) and in the Serving-RNC (SRNC) side differs from each other. The DRNC functionality is very limited and contains only the active set update and providing of the neighbour cell lists of the active set cells to the SRNC. The DRNC functionality does not contain any sophisticated handover decision algorithms. The SRNC HC-hand is responsible for all handover decision algorithms. Because the DRNC HC-hand can take a role of the SRNC HC-hand at any time, the DRNC HC-hand uses the same data structure as the SRNC HC-hand.

The challenges and the troubleshooting experiences that are analyzed in the next chapter are mostly related with HC-hand processes and their transactions with different RNC software elements.

5 Troubleshooting Experiences

Serving to all 3GPP requirements, radio network controller software includes millions of lines of code. During the internal testing phase of the software, there can be several bugs or missing features. Bugs can also appear inside the verified versions of the software. Vendors design tailor made software solutions for different operators and this differentiation also hardens the testing and troubleshooting process.

5.1 Troubleshooting Approach for Mobile Networks

In mobile networks, problem solving for software or hardware problems has to be done by experienced (senior) engineers. Each mobile network element is designed to inform its operators for errors or problems. But operators are not always proficient to investigate complex situations. Those situations need to be handled by vendor's own engineers.

In general, troubleshooting is done in 4 steps:

- Fault Identification
- Symptom Collection
- Symptom Analysis
- Fault Repair

In **Fault Identification**, engineers have to identify clearly what the problem is. For this purpose, vendors have developed some tools. Common features of these tools:

- User Interface
- Cell Status Reporting
- Link Status Reporting (Radio, Transport, Signalling)
- Key Performance Indicators (KPI) Threshold Monitoring
- Alarm Monitoring
- Alarm History Tracking
- Problem prioritization
- Process assessment
- Counter analysis

In **Symptom Collection**, engineers have to collect data for the problem investigation. Data collection can take place in interface level or directly from a database. Symptom Collection tools often provide filtering options (by using different query scripts) to the user for better experience. Subscriber tracing is another important option that is provided by symptom collection tools. In addition to IMSI based filtering, complementary data from the different parts of the network for particular subscriber has a big value for troubleshooting.

In **Symptom Analysis**, knowledge for network architecture and signalling protocols become vital for analysis. The tools have to provide network analyzing and subscriber tracing features for advanced troubleshooting. At this level, providing signalling flow charts can easily reveal the causes of the problem. Vendors usually have different tools for data collection and the compatibility of those tools is vital for troubleshooting experiences.

In **Fault Repair** phase; according to the internal fault repair policies, engineers can either report their results by proposing a software change or configuration change to the software development team. They can also do the fix by themselves.

In R&D team, a tool called EMIL is used for the first two phases. Details about EMIL are introduced in the next chapter.

5.2 EMIL

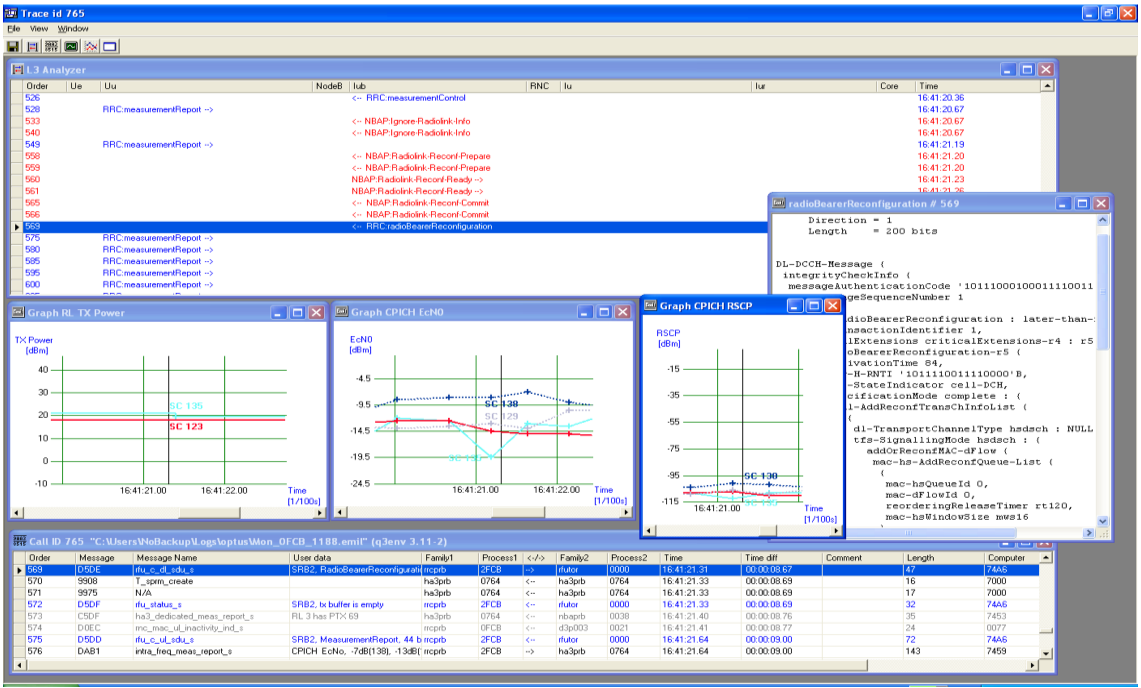

Figure 30 : EMIL Screenshot

EMIL is an internal troubleshooting tool for Nokia Siemens Networks, which can be used for investigating different kinds of message monitoring outputs and other log files. It supports different software versions (different data types) and products. EMIL provides profiles for different products and Software Program Blocks, depending on the needs, for effective fault analysis. A profile consists of several files, which describe how the information in a log file is processed and visualized to the end user.

The main benefit of the profiles is that they can be modified by users for better visualization of the log files. EMIL provides an opportunity to create very powerful automated scripts inside the profiles. With the help of those scripts, thousands of lines (messages) can easily be filtered to tens or hundreds of lines, which can further be highlighted to identify and visualise the problematic issues better. With this flexibility, EMIL platform is open for new scripting implementations and it can easily be customized for different needs around the R&D organization.

5.3 Challenges to be studied related with Handover Control Algorithm

As it is mentioned in the prior chapters, RNC software is a very complex product which came to its final phase through proved success in different technologies. To keep the same success level continuous in different versions of the software, R&D activities are vital. In R&D, mostly Integration & Verification engineers have the responsibility to keep the software parts compatible with each other and working all the time.

R&D support continues after the product is deployed to the live networks. From engineer's point of view, a harder phase starts with the deployment. Problems from different operators come to the R&D engineers to be solved. At this level most important phase is "troubleshooting". The approach that is mentioned in the prior chapters (Troubleshooting Experiences) is commonly used for RNC related challenges.
Troubleshooting phase is usually a cumbersome process that requires analyzing big number of data. Any improvement that is done during this phase would increase the efficiency of software lifecycle.

In NSN; the team that is cooperated for this thesis, is mostly interested about the Handover Algorithm related challenges that occur in any R&D processes which includes the existing software versions and the upcoming versions. As a team it was decided to prepare a thesis work to enhance the troubleshooting experiences.

During the topic and scope decision phase, there were many meetings done to identify the needs of the team from different perspectives and to keep the scope under timing and workload targets. As a result, several use cases were defined and the consultancy for the thesis has mostly continued individually with the responsible senior engineers.

In the following chapters, different use cases will be presented with their problem statements, existing solutions, live network needs, internal integration and verification needs, implementation possibilities, enhancement proposals and testing scenarios for new functionalities.

5.3.1 Radio Network Database parameter consistency checking

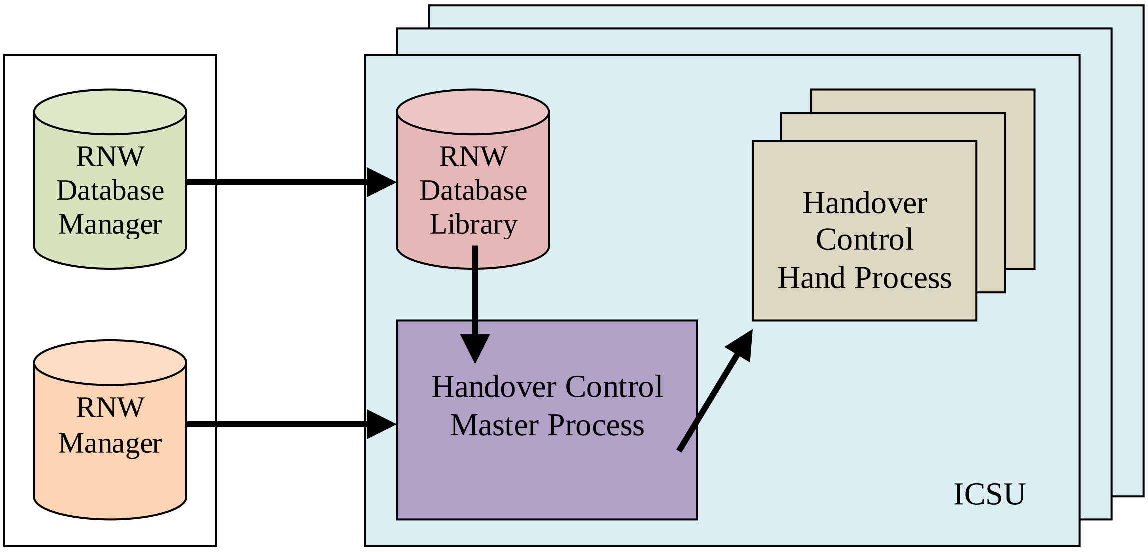

Figure 31 : Handover Control Algorithm Program Block interactions

Problem statement: Parameter values in Handover Control HC-master memory should be the same as in radio network (RNW) database. Communication between the RNW database and HC-master has two interfaces; library interface and messaging interface. When the unit starts up and Handover Control family is started, each HC-master uses RNC RNW Database Library procedures to read the needed RNW parameters from the database. If parameters are created / deleted / modified in the database after the unit start-up (i.e. during normal operation), Radio Network Manager sends notification message to each HC-master process about the new / removed / changed parameters. This messaging interface is hidden from the clients with a library.

If everything works as it should, there should not be any inconsistencies. But in practice; in distributed systems, where database users are in different network units than the actual database, it is always possible that due to some reason data in different network units is not the same. Investigation of this kind of problems is very challenging. More specifically, there might be different parameter values in different ICSU's HC-master memory. There can be several problematic scenarios:

- Radio Network Manager sends wrong data.
- Radio Network Manager sends correct data to a wrong ICSU.
- Radio Network Manager sends correct data to ICSU’s but, not to all of them.

- Radio Network Manager sends correct data but, HC-master is unable to receive or process the data correctly.
- Radio Network Manager does not notify the parameter changes to ICSU's.

Existing solution for the problem: Currently, parameter consistency check can be done by requesting Handover Control Algorithm parameter printout from different ICSU's by:

1- Starting message monitoring in ICSU
2- Sending parameter query to HC-master process
3- Collecting monitoring logs (size of log files are around 10 MB per ICSU)

After parameters have been collected from each ICSU, they are manually checked by comparing with the operator's own RNW plan. No special tool is available for that purpose. Message monitoring is done manually by using EMIL tool.

Live network needs: The tool has to create alarms/warnings for parameter inconsistencies and clearly show the relevant database parameter inconsistencies in terms of related ICSU and parameters. The only way to catch the data corruption that occurs at RNC RNW Database Library interface is to have Handover Control Algorithm message monitoring running already when RNC or ICSU's are starting up or RNW database is being read. This procedure is next to impossible to arrange at customer premises. To make it happen; it is needed to have an experienced scripting or debugging person at the site, but usually they are not available until the problem has already been escalated. As a result, a new monitoring interface is needed to detect / locate / diagnose a problem once it has occurred.

Internal Testing (I&V, MT) needs: The tool has to create alarms or warnings for parameter inconsistencies. The tool also has to provide debugging features for the problems in terms of queries, messages and responsible functional units.

Implementation: Additional functions/features to indicate that "there is a parameter inconsistency" might be needed. New interface for parameter update traffic might be needed (reason for a new interface explained above). New data types might be needed. Example for data types and functions:

Tool ←→ Handover Control Algorithm: inquire counter data, reset counter data, and launch consistency checks. (If something implemented directly to Handover Control Algorithm)

Tool ←→ Radio Network Manager: launch Radio Network data, reload to Handover Control Algorithm Program Block (If reloading not implemented to Handover Control Algorithm)

Tool ←→ RNC RNW Database Library: inquiries (If the interfaces already used by Handover Control Algorithm are not sufficient)

Testing new features: New features have to be tested by forcing the system to have inconsistent parameters. When testing with real RNC, it could be possible that after the RNW data is read from Operation and Maintenance Unit (OMU) during start-up, test program would send modified messages to Handover Control Algorithm in one ICSU to change the parameter values that have been read from database. For simulating the corruption, a test program (maybe a version compiled with special flags) can also be part of the tool itself.

Proposals: The tool can check the parameters from different ICSU's and compare them with the ones that are read from RNW Manager or RNW Database Manager or RNW Database Library.

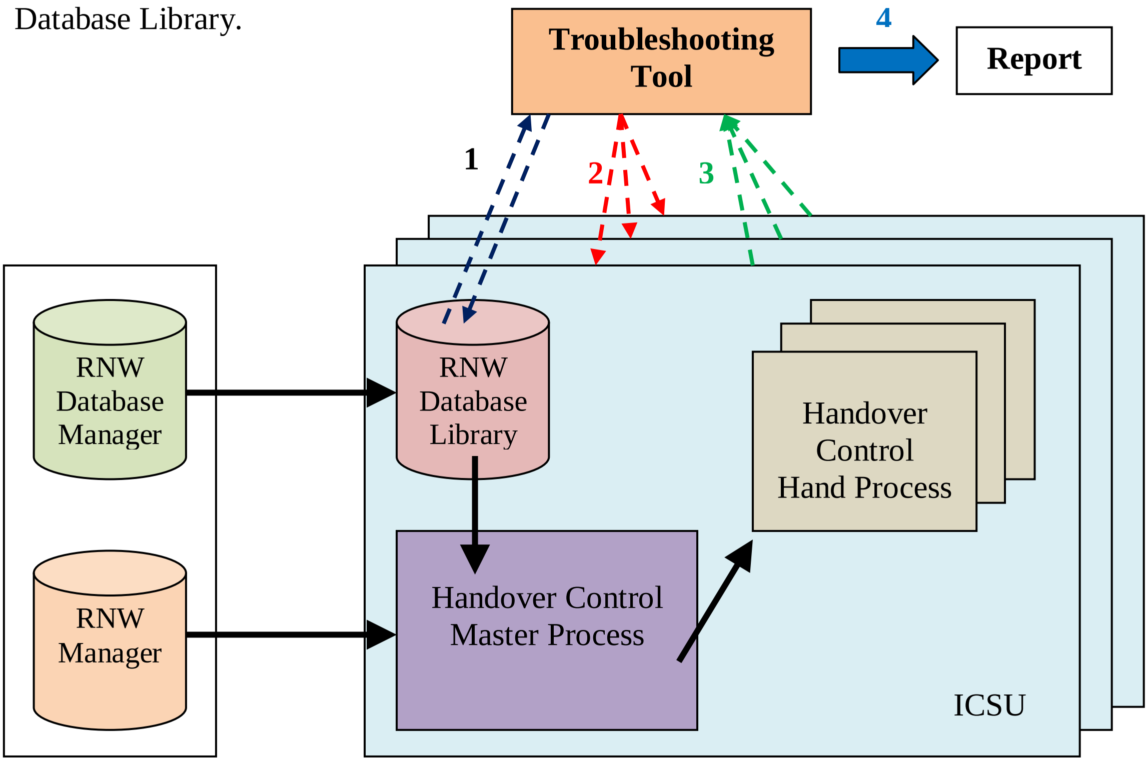

Figure 32 : Database Consistency Check

In a regular consistency check approach (see **Figure 32**):

1 - Correct parameters have to be read from the RNW Database Library.

2 - A parameter query has to be sent (broadcast) to every ICSU.

3 - Received parameters (from ICSU) have to be compared with the ones in the database.

4 - The differences need to be reported.

This procedure should be enough to catch the missing or corrupted parameters, but it does not detect possible excess objects, which are still in Handover Control Algorithm but removed from RNW database. To solve this problem, there can be simple object counters. Handover Control Algorithm can count the number of objects in each object class and report back to the tool by using the counters. Also the number of received updates can be stored as counters which can help to investigate the problems in Radio Network Manager update mechanism. (E.g. how many add / modify / delete attempts have been done). As an additional feature; date and time of the last Radio Network Manager update can be stored in Handover Control Algorithm and printed out by the tool when requested.

If this procedure is followed, full parameter check can create additional traffic in the live network and take a long time. To make this procedure efficient:

- Consistency check can be limited to specific ICSU's.
- Consistency check can be limited to specific object class.
- Consistency check can be limited to specific object.
- Consistency check can be done in a specific time (and once in a day) that will not affect the network (e.g. midnight).

Another approach can be comparing the parameters between two or more ICSU's without sending any query to RNC RNW Database Library. But result may not be satisfying because the comparison will not be done with the raw data.

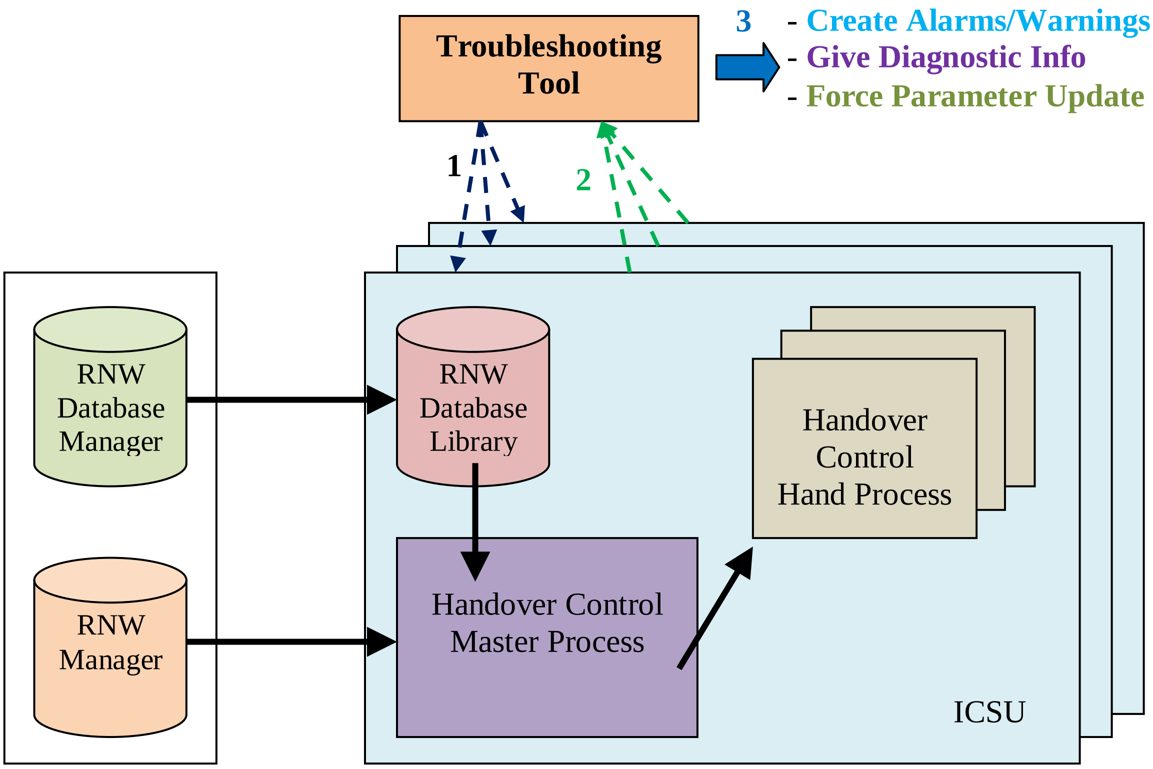

Figure 33 : Actions when inconsistency is identified

According to these approaches; when the parameter inconsistency is identified, the tool can do the following (see **Figure 33**):

1 - Create alarms / warnings

The tool can provide a report about inconsistencies, including the related ICSU information. In addition to different query options, there can also be different reporting options to provide needed information in a meaningful way. The tool can provide options about how to visualize that information to the screen. On the other hand, filtering the results may also create process load. In addition to ICSU, object class, object based results there can also be condensed results such as a list of corrupted ICSU's or a list of corrupted parameters. For end-users (e.g. operators) the tool may also create DMX alarms (DMX alarms are used the report important situations directly to the operators). Implementation of DMX alarms can be analyzed upon request.

For detailed troubleshooting, the tool can also provide a dump file or the printout of the corrupted data to determine the root of the cause or mechanism behind the fault. There can also be EMIL compatibility for detailed investigation.

For data storage; using a computer log is probably not feasible due to its limited size and possibility of overwriting other important information in the log. Storage memory is a problem. Writing all the needed data to a new file can be a suitable solution.

2 - Force RNW Manager for parameter update to the corresponding ICSU's

In addition to pointing that there is a problem, the tool can offer a solution to the problem. It can be user oriented or automated.

After identifying the parameter inconsistency, the tool can force ICSU's to ask for a new set of parameters. This procedure will also create additional network load so the options can be: re-reading all the parameters, a specific class of parameters or a specific parameter (automated or inter-active with user's choice).

Reading Source is another decision point: It can either be from RNW database or from another ICSU's. RNW manager initiated reading has to be analyzed in terms of feasibility by R&D engineers.

3 - Give diagnostic information:

Load time: Handover Control Algorithm Program Block can remember the start and end time of RNW database loading (in unit or system start-up) and report back to tool when asked.

Average DB op time: The program block can calculate the average time that it takes to perform one RNW database library call and report back to tool when asked.

Load source: The program block can remember the number of reads which it performed from RNW database library or different ICSU's, report back to tool when asked.

Number of failures: The program block could calculate the number of failures/retries it had to do when loading the database (corrupted data from RNW database library, error status from RNW database library), report back to tool when asked.

During the studies for this issue; R&D engineers implemented the Database Consistency add-on to the Handover Control Algorithm Program Block. It is not intended for live usage, because consistency check takes a long time and consumes a lot of bandwidth between ICSU units. It basically calculates the checksums locally and then only compare them between ICSU's, which would dramatically reduce the execution time. There is no need to transfer the large amount of data between units, because the checksum calculation is efficient and does not take long time to calculate.

Consistency check procedure:

- Consistency check can be started with a new service terminal extension.
- Service terminal extension sends start message to Handover Control Algorithm Master process in given ICSU unit. HC-master in this ICSU unit reads through all other ICSU units and compares all data of all ICSU units against its own memory.
- If there are any errors, HC-master writes to ICSU computer log.
- Finally, HC-master acknowledges to Service terminal extension with the status only.

5.3.2 Formatted printout of the RNW network topology

Problem Definition: In module testing, it is very hard and slow to get an understandable view of the network topology which is present in some old regression test set (or even in Functional Testing). Because it is needed to open hundreds of network modification messages in module testing environment, memorize the object id's, and try to build a mental image of the relations between them. The best way is to draw it on a piece of paper. In practice, this makes re-using or updating RNW configurations in existing module test projects very hard. It is practically impossible to know what you can modify without breaking an existing test case.

Existing solution for the problem: No present solution at all. It would be very beneficial to have this feature.

Live network needs & Internal testing needs: A topology figure/table has to be drawn by the tool according to collected modification messages.

Implementation: No need to have new functions or data types in Handover Control Algorithm Program Block, the data will be stored and processed by an external tool.

Proposal: Handover Control Algorithm Program Block messages have to be collected and then processed according to relations between cells. After data collection, required radio network topology can be drawn.

A quick sketch can be seen below (displaying object identifiers with some of the key parameters):

BTS id: Defines the identification number for the Base Transceiver Station

WCEL id: Identifies a WCEL unambiguously within a RNC.

ADJS id: Defines the identification of intra- frequency adjacent cell

ADJI id: Defines the identification of inter-frequency adjacent cell

ADJG id: Defines the identification of GSM adjacent cell

<table>
<tr><td rowspan="9">BTS id</td><td rowspan="3">WCEL id</td><td>ADJS id</td></tr>
<tr><td>ADJI id</td></tr>
<tr><td>ADJG id</td></tr>
<tr><td rowspan="2">WCEL id</td><td>ADJS id</td></tr>
<tr><td>ADJI id</td></tr>
<tr><td rowspan="2">WCEL id</td><td>ADJS id</td></tr>
<tr><td>ADJI id</td></tr>
<tr><td rowspan="2">WCEL id</td><td>ADJS id</td></tr>
<tr><td>ADJI id</td></tr>
<tr><td rowspan="7">BTS id</td><td rowspan="2">WCEL id</td><td>ADJS id</td></tr>
<tr><td>ADJI id</td></tr>
<tr><td rowspan="3">WCEL id</td><td>ADJS id</td></tr>
<tr><td>ADJI id</td></tr>
<tr><td>ADJG id</td></tr>
<tr><td rowspan="2">WCEL id</td><td>ADJS id</td></tr>
<tr><td>ADJI id</td></tr>
</table>

Table 3 : Formatted printout of the RNW network topology

One of the implementation possibilities is creating an EMIL script that could draw this type of table or chart. The main concern about EMIL implementation is; how easy or how hard will it be to create a global data structure where the data from filtered query messages can be stored. Processing the information and producing the printout should not be an issue.

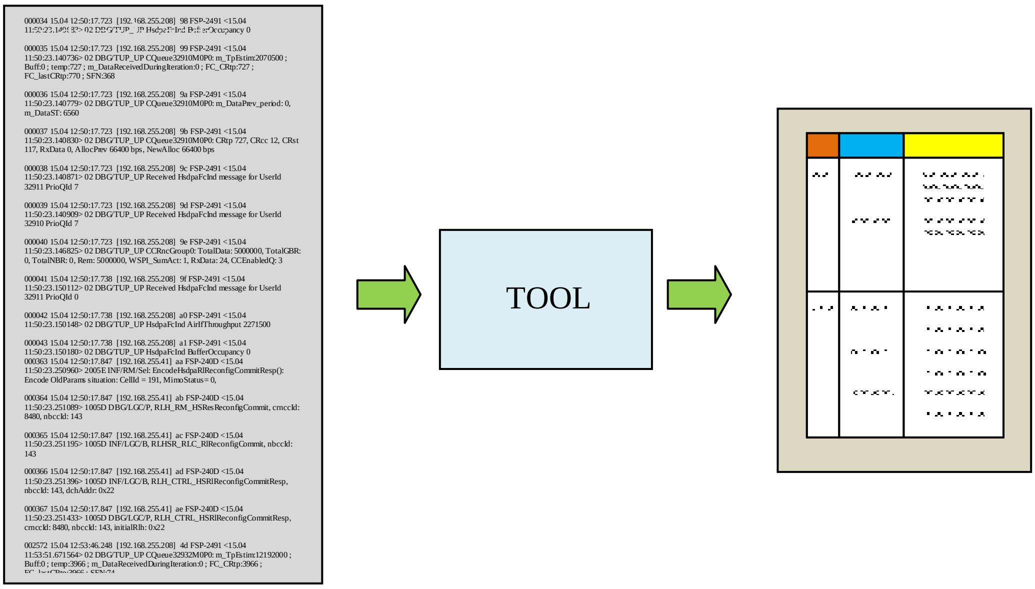

Figure 34 : Transition from log file to network topology table

Another option is to provide this functionality inside a new troubleshooting tool. In both cases, required information has to be collected, stored and processed to create the network topology.

In the log messages, required information is located under certain data types. ha3_rnw_parameter_query_s message includes the desired information to build the network topology table. The same signals are also used when database sends new/updated parameters to Handover Control Algorithm. Detailed information about the signals can be found in **Appendix 8.1.1**. Required messages to build the network topology in a nutshell are given below:

- BTS id can be provided from **rak_create_ha3_wcel_s** signal's **ha3_wbts_param_t** data type, **wbts_id** object.
- WCELL id can be provided from **rak_create_ha3_wcel_s** signal's **ha3_wcel_param_t** data type, **wcell_id** object.
- ADJS id can be provided from **rak_create_ha3_adjs_cell_s** signal's **ha3_adjs_t** data type, **adjs_id** object.
- ADJI id can be provided from **rak_create_ha3_adji_cell_s** signal's **ha3_adji_t** data type, **adji_id** object.
- ADJG id can be provided from **rak_create_ha3_adjg_cell_s** signal's **ha3_adjg_t** data type, **adjg_id** object.

5.3.3 Missing neighbour cell definitions (ADJ's)

Problem Statement: In the radio resource planning phase, some cell's neighbours are defined wrongly or with missing information. UE's detected cells measurements are sent to RNC and the troubleshooting tool can be used to inform operator about the unlisted but detected adjacent cells.

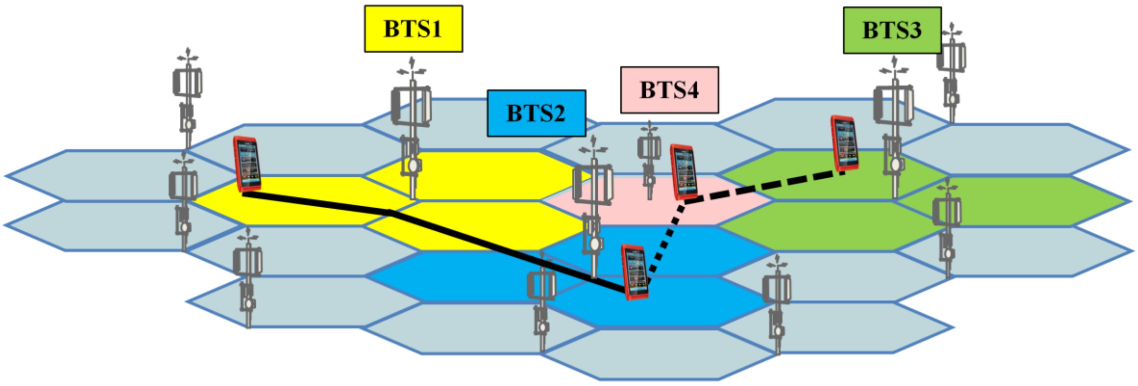

Figure 35 : Example for missing Neighbour Cell Definitions and Handover fail

There is an example radio network topology in **Figure 35**. At the beginning, there are only BTS1, BTS2 and BTS3. Then a new BTS (BTS4) is added by operator due to congestion, but updating the neighbour cell definitions is forgotten. If a call is started by a mobile user within the coverage area of BTS1, following a path through BTS1→BTS2→BTS4→BTS3, first handover occurs between BTS1 and BTS2 to maintain the call state. When the user moves to the edge of BTS2 coverage area and gets the radio signals of BTS4, BTS4 is added to the active set. As it enters to the coverage area of BTS4, there has to be a handover and the call has to be forwarded to BTS4. But the call is dropped because the neighbour cell definitions are missing at the responsible RNC.

Existing solution for the problem:

If missing neighbour cell definitions are known to be the cause of the problem, then the collected data is analyzed with some effort and the determination is done which neighbouring cell definitions are missing.

After the data has been collected, it can be (with some effort) analyzed and determined if / which neighbouring definitions are missing. Another method is to analyze the "call drop" counters and try to solve why and where the call drops are happened. In most of the cases, it is found out that, there is neighbour information missing from a cell located at the call drop area.

The problem about this approach is that: the results are not obtained as quickly as they are needed; required data has to be provided correctly from customer's network. Also, analyzing that data can be a time consuming task.

Live network needs: The tool has to create alarms or warnings for missing neighbour cell definitions. The tool has to have ability to check Cell based, IMSI based, RNC based neighbour cell lists and compare the results within Detected Cell's list.

Internal Testing (I&V, MT) needs: The tool has to create alarms or warnings for missing neighbour cell definitions. The tool also has to provide debugging features for missing neighbour cell definitions and measurements. The tool has to have ability to check Cell based, IMSI based, RNC based neighbour cell lists (UE's Detected Cell list as well).

Implementation: Additional functions or features to indicate that there is a problem in neighbour cell definitions might be needed. Comparison between ADJD (Detected adjacent cells) and neighbour cell list might be needed.

Testing new features: New features have to be tested by forcing system to have missing neighbour cell definitions.

Proposals: Majority of the comparison and analyzing code for this tool can be located inside Handover Control Algorithm and only results passed to / presented by / post-processed by the tool. In this case, newly implemented software part requires access to the network related information that is known by Handover Control Algorithm, for example, the neighbour cell configurations and data counters. After that, the tool has to check the measurement reports that are done by UE as "detected cells". And according to decision algorithm, it can inform operator about missing or wrongly configured neighbour cell definitions. For this enhancement, it is important to have "detected cell reporting" feature in working mode.

5.3.4 Handover Related Troubleshooting

Mobile Operators are monitoring their networks in terms of KPIs and customer complaints. According to their business types, they focus on certain KPIs and most of the time they calculate their own KPIs by using the default counters. Furthermore vendors are also monitoring their customers in terms of certain KPIs.

The KPIs listed below are important to recognize the problems related with mobility.

- Number of Call Drops
- Handover success rate
- Number of Handover attempts
- Change of average active set size (increase / decrease)
- Average *Ec/No*
- Number of IFHO
- Number of ISHO
- Number of SHO

Depending on those indications, the root cause of a problem can be:

- Configuration problems
  - Missing neighbour cell definitions
  - Wrong measurement control parameters
  - Wrong *Iur* / *Iu* parameterization
- Problems caused by other network elements
  - UE specific problems
  - Problems between RNCs (*Iur* interface problems)
  - Problems with BTS (*Iub* interface problems)
  - Problems with Core Network (*Iu* interface problems)
- Software related issues
  - New features
  - New set of configuration parameters
  - Software bugs

Investigation of handover related problems is quite often very time-consuming. Because handover is the basic state of the call thus handover problems can cause many kind of other problems and it has to be investigated in detail.

There are many enhancement opportunities for the troubleshooting process that is related with handover problems. For this thesis work, some major ones were studied and analyzed in the following sub-chapters.

5.3.4.1 Investigation of large ICSU-files

Problem Definition:

Amount of information that is needed to analyze handover problems can be very huge (ICSU log files, parameter data and counter data). Thus it would be good to have some tool which can be configured to search certain patterns which indicate some certain problems. For example: statistical data of Handover Control Algorithm initiated channel type switch requests and serving cell changes. Furthermore the tool can provide summarized statistics by using cell based filtering.

Useful information related to channel type switch requests and serving cell changes would be:

- Number of requests
- Trigger cause for the request
- Intra frequency measurement reports from UE
- Handling Events 1A and 1C
- Target cell
- Number of ACKs for the request
- Number of NACKs for the request
- Failure cause of the request

That information can be collected from investigated ICSU-logs by searching following messages:

- Handover failure related messages (ICSU messages sent/received by Handover Control Algorithm Program Block)
- Handling of Event 1A – Cell Addition
- Handling of Event 1C – Cell Replacement
- Call release reasons (for possible call drops)

Existing Solution for the problem: The ICSU-files are analyzed with EMIL manually which takes a lot of time. Desired information is visible also from statistics but that data is sometimes difficult to get from customer and also difficult to analyze. By getting the information directly out from the ICSU-data would be a good advantage. For a better solution, provided by this tool, detailed information can be collected from ICSU-logs and processed or demonstrated in desired way.

Live network needs & Internal testing needs: Condensed information could be useful in numerical format and also in some graphical format. For example:

- Frequency of requests
- Number of requests per trigger cause
- Number of ACKs and Number of NACKs (with specific failure cause)
- The success and failure ratio on cell level
- How many requests from a certain cell and how many NACKs / ACKs from a certain cell and BTS (The information would be useful to get on cell level and on BTS level)

Implementation: No need to have new functions or data types in Handover Control Algorithm Program Block, the values will be stored and processed by the tool.

Proposals: ICSU-logs have to be collected and then processed in terms of important values to report. After doing required calculations, condensed values can be reported in table or graphic format. Those calculations can be done by using EMIL scripts and those scripts can be saved as an EMIL profile that can be used later as well.

5.3.4.2 SHO KPI Problems

Problem Definition: As it is mentioned earlier, KPIs have importance on indicating problems about the network. But time to time, there can also be problems about the KPIs itself. Besides the default KPI values, operators can have their own specific KPIs to monitor their network. With a new software release to the network elements, there can be a change in the KPIs by %1 ~ %2 due to many reasons such as new feature activations (required changes to RRM parameter adjustments). After software baseline upgrades, there can be KPI problems which also affect handover processes.

Existing Solution for the problem: Currently, the problem is investigated by analyzing the logs manually to check which parameter is calculated wrongly or configured wrongly.

Live network needs & internal testing needs: Internally, correct values of the KPIs have to be calculated and compared to identify the problem. This feature can also be provided to the field engineers or operators upon request.

Implementation: A new EMIL profile can be created with embedded KPI calculations. Message monitoring has to be triggered by Handover Control Algorithm.

Proposals: KPIs are calculated from counters, the raw data has to be read from counters and exact KPI values can be calculated from them. An EMIL profile can be designed for this purpose. But to achieve this, Distributed Statistics Mediator’s debug feature has to be turned on.

Furthermore, Radio Resource Control Program Block is doing message monitoring for failure situations and dropped calls. For a better investigation, Handover Control Algorithm Program Block can trigger message monitoring via Radio Resource Control Master process and get the required logs. The logs include the message monitoring between:

- UE Radio Resources Program Block ←→ Handover Control Algorithm Program Block
- Radio Resources Control Program Block (dedicated RRC protocol hand)←→ Handover Control Algorithm Program Block

Message traffic and counter changes are vital to identify the source of the problem about KPIs.

5.3.5 HSPA related items to be improved

5.3.5.1 Investigation of large ICSU-files

Problem Definition: Because there is a huge traffic in the operator's live network, it is difficult to find the root cause of certain HSDPA or HSPA accessibility problem without proper tool which would easily show the required information. Typically the problems that have to be investigated are HSDPA or HSPA accessibility issues which would mean that Handover Control Algorithm Program Block does not grant HSDPA or HSPA for the user during user plane creation or that Handover Control Algorithm Program Block triggers user-plane to DCH/DCH allocation from HS(D)PA allocation which means again lower bit rates.

Another typical issue is, Handover Control Algorithm Program Block serving cell algorithm does not work correctly and it is not able to keep the best active set cell as HS-DSCH serving cell or it triggers CTS to DCH/DCH instead of serving cell change. Also serving cell change KPI is one which operators are keen and if there happens even %0.01 worsening in this KPI, the operators start to complain. And for this kind of KPI worsening it is very hard to find root cause without good statistical information.

Some kind of tool which could be used to collect statistical data of Handover Control Algorithm initiated channel type switch requests and serving cell changes would be useful when investigating large ICSU-files from customer live networks.

Monitoring should be done cell based, responsible cell and the target cell. Useful information related to channel type switch requests and serving cell changes would be:

- Number of requests
- Trigger cause for the request
- Number of ACKs for the request
- Number of NACKs for the request
- Failure cause of the request

Existing Solution for the problem: The ICSU-files are analyzed with EMIL which takes a lot of time. Desired information is visible also from statistics but that data is sometimes difficult to get from customer and it is sometimes also difficult to analyze. By getting the information directly out from the ICSU-data would be good advantage.

For a better solution, provided by this tool, detailed information can be collected from ICSU-logs and processed or demonstrated in desired way.

Live network needs & Internal testing needs: Condensed information could be useful in numerical format and also in some graphical format. For example:

- Frequency of requests
- Number of requests per trigger cause
- Number of ACKs and Number of NACKs (with specific failure cause)
- The success and failure ratio on cell level
- How many requests from certain cell and how many NACKs or ACKs from certain cell and BTS (The information would be useful to get on cell level and on BTS level)

Implementation: No need to have new functions/data types in Handover Control Algorithm Program Block, the values will be stored and processed by the tool.

Proposals: ICSU-logs have to be collected and then processed in terms of important values to report. After doing required calculations condensed values can be reported in table or graphic format.

5.3.5.2 HSPA Accessibility Problems (Parameter Inconsistency):

Problem Definition: E_DCH operational state is used by BTS to report to HSUPA operational state of the cell. In order to use HSUPA in a cell the BTS must have reported HSUPA Operational state to be enabled in that cell. Otherwise HSPA cannot be used in that cell (meaning no accessibility for high uplink (UL) bit rates from end user point of view).

HS-DSCH operational state is used by BTS to report to HSDPA operational state of the cell. In order to use HSDPA in a cell the BTS must have reported HSDPA Operational state to be enabled in that cell. Otherwise HSDPA cannot be used in that cell meaning no accessibility for high downlink (DL) bit rates.

HSDPAOperationalState and *HSUPAOperationalState* indications are the most error prone and also the most difficult one to catch from live network. Handover Control Algorithm gets this information from Radio Network Initiator on WBTS (cell) level basis and there has been some problems that Radio Network Initiator has not always sent this information correctly to Handover Control Algorithm or sometimes it has not sent it at all. That will cause huge problems for HS(D)PA accessibility. From end user point of view; problem can be seen with lower bit rates than expected because HSDPA or HSUPA cannot be allocated for the user.

Existing Solution for the problem: Currently the R&D just need to try to get Operation and Maintenance Unit logs from customer and try to search from there (by using EMIL) any Radio Network Initiator notifications that have been sent to Handover Control Algorithm.

Live network expectations from the desired tool: The tool has to create alarms or warnings for parameter inconsistency and clearly show the relevant database parameter inconsistencies in terms of ICSU and parameters.

Internal testing expectations from the desired tool: The tool has to create alarms or warnings for parameter inconsistency. The tool also has to provide debugging features for the problem in terms of queries, messages and responsible functional units.

Implementation: Additional functions or features to get the information from Radio Network Initiator and ICSU’s might be needed. After getting the *HSDPAOperationalState* and *HSUPAOperationalState* parameters the tool can compare them.

Proposals: The tool has to get the correct values of the parameters from Radio Network Initiator and then compare with the ones in Handover Control Algorithm and then it can:

- Create alarms or warnings
- Force Radio Network Initiator for parameter update
- Force Handover Control Algorithm to ask for new set of parameters.
- Debug messages can be used between Base Station Resource Manager Program Block←→ Handover Control Algorithm Program Block

5.3.5.3 Calculation of certain Parameters related with HSPA

Problem Definition: *UL SIRerror* and periodical *CPICH Ec/No* values are used in handover control algorithm decisions. While investigating issues/problems in handover control algorithm related to HS(D)PA functionality, those values has to be analyzed in order to see if the algorithm works correctly and utilizes correctly those inputs that are coming from UE and BTS. Currently the R&D team needs to calculate averaged *UL SIRerror* and periodical *CPICH Ec/No* measurement results of a certain cell based on ICSU-log by hand which is not a very efficient way.

Existing Solution for the problem: Periodical *CPICH Ec/No* reports come from UE and *UL SIRerror* reports come from BTS. Those values are captured in logs by automated macros and then calculated by hand.

Live network needs & Internal testing needs: Averaged *UL SIRerror* and periodical *CPICH Ec/No* measurement results of a certain cell (which is defined by the user) are needed.

Implementation: No need to have new functions or data types in Handover Control Algorithm Program Block, the values will be stored and processed by the tool. Another option is using EMIL scripts for calculation.

Proposals: The tool has to get the *UL SIRerror* and *CPICH Ec/No* values from the ICSU-log. Then it will calculate the averaged UL SIRerror and periodical CPICH *Ec/No* measurement results for certain cell which is defined by the user.

6 Conclusion

During the topic decision phase of this thesis, the main problem statement was how to enhance the troubleshooting experiences of the R&D engineers. At the beginning I was guided to increase my knowledge more on Radio Resource Management and then particularly about Handover Algorithms. Later on, team meetings were organized to reveal the existing troubleshooting experiences and difficulties. At that point, I started to be informed about the software architecture of RNC and Handover Control Algorithm.

Needs of R&D engineers were discussed and a list for enhancement opportunities was decided during the meetings. Then, efficiency evaluation was done case by case basis to prioritize the cases for the thesis work duration. Some enhancement cases were eliminated due to their complex analysis and implementation techniques. After the study cases were determined, individual meetings with the senior engineers took place on a weekly schedule. Enhancement cases were studied with their problem statements, existing solutions, live network needs, internal integration and verification needs, implementation possibilities, enhancement proposals and testing scenarios for new functionalities.

In Radio Network Database Parameter Consistency checking case; different solutions are proposed for implementation (see **5.3.1** for detailed analysis). As a consequence of analysis, reliable and efficient implementation was done for internal usage. With the pace of the radio network technology evolution, future networks are designed to be flexible in terms of network resources. To maintain same configuration information, databases in the network elements must be same in terms of common parameters. For future studies this database consistency check feature can be added to the RNC software itself as an automated self-check tool.

In Formatted Printout of the RNW topology case; implementation proposal has been made (see **5.3.2** for detailed analysis). Required message types were identified to build the topology. For future studies, new type of visualization objects can be added such as downlink RF channel number, downlink scrambling code of the WCEL and Absolute radio frequency number. And it is important to update the implementation according to the software baseline (data type) changes.

In Missing Neighbour Cell Definitions, implementation proposal has been made (see **5.3.3** for detailed analysis). For this issue, detected cell reporting feature has to be turned on. Throughout the evolution of Cellular Radio systems, cell sizes are decreasing and number of cells is increasing thus number of handover attempts are also increasing. Neighbour cell definitions are very important for handover algorithms. For future studies, there can be an automated self-check in the RNC software for neighbour cell definitions which is based on the reports that are received from UE's.

In Handover Related Troubleshooting, KPI calculation comparisons and log file filtering is very important. Implementation possibilities were proposed (see **5.3.4** for detailed analysis). A KPI calculation comparison is a complex process that cannot be used for all handover related problems. Only if there is a suspicion about KPI values comparison can be done for the KPI values. On the other hand, log file analysis is a n every day activity for troubleshooting experiences. For future studies, there can be new parameters required to be in the filtered report.

In HSPA related issues, similar problems were analyzed from HSPA perspective and implementation proposals have been made (see **5.3.5** for detailed analysis). Calculation of certain parameters related with HSPA is an everyday need for troubleshooting experiences. Required parameters can be updated upon request in the future. The enhancement for HSPA Accessibility problems is important because it is hard to investigate the problem from log files. In the future parameter set can be updated if there is a new software baseline. Similar to previous analyses, using large log files is always time-consuming thus it is also important to provide this feature.

To sum up, the scope of this thesis was to analyze the existing troubleshooting experiences in NSN-WCDMA-Control Plane-Handover Algorithms team and study the enhancements opportunities to increase the efficiency of R&D engineers. Study cases were chosen after long discussions to increase the R&D engineer's benefit from this work. The benefit of this study will show itself in the long run. In the future, it would be good to continue this type of efficiency related studies for different troubleshooting cases and for different software platforms.

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8 Appendixes

8.1 Data types

8.1.1 ha3_rnw_parameter_query_s message

rak_create_ha3_adjd_cell_s: RNW Manager hand process sends this message to Handover Control Algorithm HC-master process to notify, that one new additional intra-frequency adjacent cell to specified WCDMA cell has been created into the RNW RNC database.

RNW Manager hand process → HC-master process

WCEL_ID: WCDMA cell identifier of cell under which the new intra-frequency adjacent cell is created. (Identifies a WCEL unambiguously within a RNC)

HA3_ADJD_PARAM: Additional adjacent cell parameters needed by Handover Control Algorithm Program Block. (In ha3_adjd_t data type; adjd_id defines the identification of ADJD (Additional Intra-Frequency ADJ), utran_cell_id defines the UTRAN cell identifier identifies neighbouring cell uniquely within UTRAN. This one is used internally in RNC.)

rak_create_ha3_adjg_cell_s: RNW Manager hand process sends this message to HC-master process to notify, that one new GSM adjacent cell to specified WCDMA cell has been created into the RNW RNC database.

RNW hand process → HC-master process

WCEL_ID: WCDMA cell identifier of the modified WCDMA cell. (Identifies a WCEL unambiguously within a RNC)

HA3_ADJG_PARAM: GSM neighbour cell parameters needed by Handover Control Algorithm Program Block. (In ha3_adjg_t data type; adjg_id defines the Identification of ADJG, cell_id identifies a WCEL unambiguously within a RNC)

rak_create_ha3_adji_cell_s: RNW Manager hand process sends this message to HC-master process to notify, that one new inter-frequency adjacent cell to specified WCDMA cell has been created into the RNW RNC database.

RNW hand process → HC-master process

WCEL_ID: Cell id of the modified WCDMA cell.

HA3_ADJI_PARAM: Inter-frequency neighbour cell parameters needed by Handover Control Algorithm Program Block. (In ha3_adji_t data type; adji_id defines the identification of the ADJI, and utran_cell_id defines the UTRAN cell identifier identifies neighbouring cell uniquely within UTRAN. This one is used internally in RNC.)

rak_create_ha3_adjs_cell_s: RNW Manager hand process sends this message to HC-master process to notify, that one new intra- frequency adjacent cell to specified WCDMA cell has been created into the RNW RNC database.

RNW hand process → HC-master process

WCEL_ID: WCDMA cell identifier of cell under which the new intra-frequency adjacent cell is created. (Identifies a WCEL unambiguously within a RNC)

HA3_ADJS_PARAM: Adjacent cell parameters needed by Handover Control Algorithm Program Block. (In ha3_adjs_t data type; adjs_id defines the identification of ADJS (Intra-Frequency ADJ), utran_cell_id defines the UTRAN cell identifier identifies neighbouring cell uniquely within UTRAN. This one is used internally in RNC.)

rak_create_ha3_fmcg_s: RNW Manager hand process sends this message to HC-master process to notify, that one new set of GSM measurement control parameters has been created into the RNW RNC database.

rak_create_ha3_fmci_s: RNW Manager hand process sends this message to HC-master process to notify, that one new set of inter-frequency measurement control parameters has been created into the RNW RNC database.

rak_create_ha3_fmcs_s: RNW Manager hand process sends this message to HC-master process to notify, that one new set of intra-frequency measurement control parameters has been created into the RNW RNC database.

rak_create_ha3_hopg_s: RNW Manager hand process sends this message to HC-master process to notify, that one new set of GSM handover path parameters has been created into the RNW RNC database.

rak_create_ha3_hopi_s: RNW Manager hand process sends this message to HC-master process to notify, that one new set of inter-frequency handover path parameters has been created into the RNW RNC database.

rak_create_ha3_hops_s: RNW Manager hand process sends this message to HC-master process to notify, that one new set of intra-frequency handover path parameters has been created into the RNW RNC database.

rak_create_ha3_wane_s: RNW Manager hand process sends this message to HC-master process to notify that one new set of WCDMA authorized network parameters has been created into the RNC RNW database.

rak_create_ha3_wcel_s: RNW Manager hand process sends this message to HC-master process to notify, that one new WCDMA cell has been created into the RNW RNC database.

RNW hand process → Handover Control Algorithm master process

WBTS_PARAM: Handover Control Algorithm Program Block related WCDMA base transceiver station parameters of the WCDMA cell, which is created.(In ha3_wbts_param_t data type wbts_id defines the identification of the WBTS)

WCEL_PARAM: WCDMA cell parameters, which concern only the Handover Control Algorithm processes. (In ha3_wcel_param_t data type wcel_id identifies a WCEL unambiguously within a RNC)

rak_create_ha3_wsg_s: RNW Manager hand process sends this message to HC-master process to notify, that one new WCDMA subscriber group has been created to RNC RNW database.

rak_modify_ha3_rnc_param_s: RNW Manager hand process sends this message to HC-master process to notify, that RNC parameters has been modified.

rak_modify_ha3_vbts_param_s: RNW Manager hand process sends this message to HC-master process to notify that VBTS parameters have been modified.

rak_modify_ha3_vcel_param_s: RNW Manager hand process sends this message to HC-master process to notify that VCEL parameters have been modified.