Aalto University
School of Science
and Technology

Faculty of Electronics, Communications and Automation
Department of Communications and Networking

Muhammad Farhan Khan

Femtocellular Aspects on UMTS Architecture Evolution

Master's Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Technology.

Espoo, April 20, 2010

Supervisor: Professor Jyri Hämäläinen
Instructor: M.Sc. Matti Laitila, Nokia Siemens Networks

AALTO UNIVERSITY SCHOOL OF SCIENCE AND TECHNOLOGY

ABSTRACT OF THE MASTER'S THESIS

Author:	Muhammad Farhan Khan		
Title:	Femtocellular Aspects on UMTS Architecture Evolution		
Date:	April 20, 2010	**Number of pages:**	14+67
Department:	Department of Communications and Networking		
Professorship:	S-72 Communications Engineering		
Supervisor:	Professor Jyri Hämäläinen		
Instructor:	M.Sc. Matti Laitila		

Recent advancement in System Architecture Evolution (SAE) has opened the door for the deployment of femtocells on a large scale. Deployment of femtocells in the existing macrocell networks and in 4G networks will significantly increase because femtocell offers increase coverage and capacity in both home and office environments. Hence it is likely that these low-power home based access points are going to change the landscape of mobile technology and the networking business in the coming years. This thesis work offers a deep insight into the mobile communication system architecture evolution and typically explains femtocellular aspects in the evolution of Universal Mobile Telecommunication System (UMTS) architecture.

This research work mainly focuses on architectural variations of 3G and 4G femtocells along with the operational functionality of Local IP Access (LIPA). LIPA introduces the functionality in femtocells to access a home Local Area Network (LAN) and enable customers to use the Internet through Internet-enabled devices. Hence users have the capability to have simultaneous access to the operator's network as well as having access to their own home LAN. The way LIPA works is explained How it can create problems for femtocells deployment and what solutions LIPA offers for providing easy femtocell configurations. With the help of the extensive study about LIPA-enabled femtocells, different scenarios are discussed and two different solutions are proposed both for 3G and 4G femtocells.

For maintaining higher data rates, 3G and 4G systems require a good coverage area to increase system performance. But research results suggest that two-thirds of consumers suffer from inadequate indoor signal penetration which actually leads to poor coverage for consumers, who do not enjoy the full data capacity as guaranteed. 4G systems will facilitate high speed data services, but poor coverage and interference will definitely diminish the quality of real-time applications and will significantly slow down high speed data services. The aim of this thesis is to propose different logical indoor 4G femtocell architectures based on 3GPP specifications that will also be capable of providing LIPA functionality.

Keywords: GSM, EDGE, UMTS, UTRAN, LTE, SAE, Femtocell, Architecture, Home NodeB, Home eNodeB, LTE-Advanced, Local IP Access

Acknowledgments

I wish to express my gratitude to the people who have supported me in this work. First and foremost, I want to thank Professor Jyri Hämäläinen for the guidance and insights he has provided throughout the research process. In addition, I am especially grateful to Matti Laitila for his assistance and advice even while working remotely between Espoo and Oulu.

I really enjoyed the experience of working in a cooperative and friendly environment at Aalto University, and I have received enormous experience by interacting and collaborating with other partners of this project from all around Europe.

Finally, I want to thank my family especially my parent Muhammad Moin Khan and Nigar Moin and all my cute nephews and lovely nieces who have always remained a strong emotional support for me throughout my stay in Finland.

This work has been carried out in the Department of Communications and Networking (COMNET), at Aalto University School of Science and Technology as a part of the Celtic HOMESNET Project.

Espoo, April 20th 2010

Muhammad Farhan Khan

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List of Abbreviations

AAA	Authentication, Authorization and Accounting
ACK	Acknowledgements
ALCAP	Access Layer Control Application Part
AMC	Adaptive Modulation and Coding
AP	Access Point
APN	Access Point Names
ARQ	Automatic Repeat Request
ATM	Asynchronous Transfer Mode
AuC	Authentication Center
BCM	Broadcast and Multicast
BG	Boarder Gateway
BICC	Bearer Independent Call Control
BoD	Bandwidth on Demand
BSS	Base Station Subsystem
BSC	Base Station Controller
BTS	Base Transceiver Station
CAPEX	Capital Expenditure
CDMA	Code Division Multiple Access
CGW	Charging Gateway
CN	Core Network
CRNC	Controlling Radio Network Controller
CS	Circuit Switched
CSG	Close Subscriber Group
DHCP	Dynamic Host Control Protocol
DRNC	Drifting Radio Network Controller

DS-CDMA	Direct Sequence Code Division Multiple Access
DSL	Digital Subscriber Line
EAP-AKA	Extensible Authentication Protocol-Authentication and Key Agreement
EAP-SIM	Extensible Authentication Protocol-Subscriber Identity Module
EDGE	Enhanced Data rates for GSM Evolution
EGRPS	Enhanced General Packet Radio Service
EIR	Equipment Identity Register
EPC	Evolved Packet Core
EPS	Evolved Packet System
ETSI	European Telecommunications Standard Institute
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FAP	Femto Access Point
FDD	Frequency Division Duplexing
FPS	Fast Packet Scheduling
GERAN	GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GMSC	Gateway Mobile Switching Center
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
GTP	GPRS Tunneling Protocol
HARQ	Hybrid Automatic Repeat Request
HS-DSCH	High Speed Downlink Shared Channel
HS- SCCH	High Speed Shared Control Channel
HS-DPCCH	High Speed Dedicated uplink Physical and Control Channel
HLR	Home Location Register
HMS	Home NodeB Management System
HNB GW	Home NodeB Gateway
HSCSD	High Speed Circuit Switched Data
HSDPA	High Speed Downlink Packet Access
HSS	Home Subscription Server
HSPA	High Speed Packet Access
HSPA+	High Speed Packet Access Evolution

HSUPA	High Speed Uplink Packet Access
IMEI	International Mobile Equipment Identity
IMT-Advanced	International Mobile Telecommunications Advanced
IMS	IP Multimedia Subsystem
IPSec	Internet Protocol Security
ISP	Internet Service Provider
ISUP	ISDN User Part
LAN	Local Area Network
LIPA	Local IP access
LTE	Long Term Evolution
LQC	Link Quality Control
MAC	Medium Access Control
MBMS	Multimedia Broadcast/Multicast Service
MCS	Modulation and Coding Scheme
MGW	Media Gateway
MGCP	Media Gateway Control Protocol
MIMO	Multiple Input and Multiple Output
MMS	Multimedia Messaging Service
MME	Mobility Management Entity
MS	Mobile Station
MSC	Mobile Switching Center
NACK	Negative Acknowledgements
NBAP	Node B Application Part
NGMN	Next Generation Mobile Network
NSS	Network Subsystem
OAM	Operation Administration and Maintenance
OAMP	Operation Administration Maintenance and Provisioning
OFDMA	Orthogonal Frequency Division Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
OPEX	Operating Expense
OSS	Operation Support Subsystem
OTA	Over-The-Air
PBX	Private Branch Exchange

PCRF	Policy and Charging Rules Function
PDCP	Packet Data Control Protocol
PDN	Packet Data Network
PDP	Packet Data Protocol
P-GW	Packet Data Network Gateway
PLMN	Public Land Mobile Network
PS	Packet Switched
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RAB	Radio Access Bearers
RAN	Radio Access Network
RANAP	Radio Access Network Application Part
RLC	Radio Link Control
RNC	Radio Network Controller
RNS	Radio Network Subsystems
RNSAP	Radio Network System Application Part
RRC	Radio Resource Control
SAE	System Architecture Evolution
SC-FDMA	Single Carrier Frequency Division Multiple Access
SCTP	Stream Control Transmission Protocol
SeGW	Security Gateway
SGSN	Serving GPRS Support Node
S-GW	Serving Gateway
SIM	Subscriber Identity Module
SIPTO	Selected IP Traffic offload
SRNC	Serving Radio Network Controller
TAU	Tracking Area Update
TDD	Time Division Duplexing
TDM	Time Division Multiplexing
TSG	Technical Services Group
UE	User Equipment
UMSC	UMTS Mobile Switching Center

UMTS	Universal Mobile Telecommunications Systems
URA	UTRAN Registration Area
USIM	Universal Subscriber Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
3G	3rd Generation
3GPP	3rd Generation Partnership Project
4G	4th Generation

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Chapter 1

Introduction

This chapter provides the background for the study and describes the motivation, objectives and scope of the research. In addition, the utilized methodology is briefly discussed. Finally, the thesis structure is outlined.

1.1 Motivation

It is known that 66% of the mobile handset initiated calls and 90% of the data service requests are generated from home premises [1]. Hence the huge resource consumption by indoor users encourages operators to provide adequate indoor coverage and a higher peak data rate for data services to home subscribers. Another study show, however, that with the mentioned service usage rate, operators usually fail to provide high quality of services to home users and 45% of home and 30% of business subscribers experience problems with poor indoor coverage [2]. For every operator it is important to provide adequate indoor coverage because it effectively increases an operator's subscriber base and generates more revenues.

With the traditional cellular network, it is very difficult for operators to provide high quality services and cell coverage to indoor users. This is because, in order to improve indoor coverage operators need to install a huge number of outdoor base stations sites and this is nearly impossible in those areas that are densely populated. And even if operators manage to install more base stations, then network planning and optimization become a challenging task for them, because frequency planning and handover management need more care in dense network deployment. The advent of High Speed Downlink Packet Access (HSDPA) [3] in 3G Universal Mobile Telecommunications System (UMTS) provides high data rates and users can only achieve promised data rate only in the absence of interference. HSDPA and its successor technologies require higher modulation and coding schemes and especially better channel conditions to offer peak data rates. For home users to acquire a better channel condition in current network is again a challenging task because of complex building designs and architectures.

The above mentioned concerns effectively need some indoor solutions like hot spots, etc. to minimize indoor cell coverage and interference problems and enable users to experience high service quality. Economical selection of an appropriate indoor solution is also a challenging task for operators because, the solution should provide handover with macrocells and also be capable of facilitating high data rates. Therefore, operators are seeing the femtocell [4] as a potential candidate that can be used to provide high quality packet-switched services at low cost.

The motivation of this thesis work is to study system architecture evolution as well as femtocellular aspects in UMTS architecture evolution [5, 6]. The research work also focuses on how femtocell enables users to use simultaneously, their own IP-enabled Local Area Network [7] along with the operator's provided packet switched service.

1.2 Problem Formulation

The thesis examines the operational and functional impacts of femtocells on the system architecture evolution. The underlying objective of the work is to study UMTS architecture evolution at an abstract level and the role of 3GPP in the mobile communication evolution. This study gives the insight into the background and main characteristics of the Radio Access Network (RAN) and Core Network (CN), as well as evaluates the functional and operational attributes of various network elements and protocols. Another objective of the study is to analyze and evaluate UMTS Terrestrial Radio Access Network (UTRAN) and Long Term Evolution (LTE) network architectures, and to indentify new architectural problems and challenges when used with femtocells. A special study is carried out to propose different femtocell architectures with LIPA-enabled functionalities.

1.3 Scope of the Research

This thesis addresses the needs, requirements, design methodologies and features of the Universal Mobile Telecommunication System (UMTS) architecture evolution. On the abstract level, this work examines the advent of femtocells, their aspects on

UMTS architectural evolution and their future scope and problems. 3G and various 4G femtocell architecture variations are researched in this thesis, along with the operational capability of Local IP Access (LIPA). This thesis also provides insight into LIPA-enabled femtocells, and proposing two different LIPA-enabled 3G and 4G femtocell based solutions.

1.4 Research Methods

This study was performed by using the following methods:

- Literature study of UMTS architecture evolution.
- Literature study of the femtocell concept.
- Analysis of femtocellular aspects on UMTS architecture evolution.
- Analysis of the 3G and 4G femtocell architectures.
- Discussion on LIPA's role and it issues in femtocell.
- Propose different solutions for LIPA-enabled eemtocell.

1.5 Thesis Structure

The subsequent work is organized into the following chapters:

Chapter 2
Discusses the evolution of mobile communication systems from GSM to LTE, along with the discussion about their network elements and architecture arrangements.

Chapter 3
Describes the UTRAN protocol, radio access network and core network architecture, explaining how the UTRAN system works, how mobility is handled in the UTRAN and what are the main functions and characteristics of the UTRAN.

Chapter 4
Evaluates requirements and design targets of LTE and explains the need for the system architecture evolution and discusses the key elements and the driving forces of LTE evolution.

Chapter 5

Proposes different 3G and 4G LIPA-enabled femtocell architectures. It also explains the femtocell concept, its attributes and future scope.

Chapter 6

Offers the conclusions of this thesis investigation and propose areas for future work.

Chapter 2

Mobile Communication Systems

This chapter provides a review of the GSM technology and its network architecture, the main focus being to discuss the GSM EDGE Radio Access Network (GERAN) evolution, standardization, network architecture and its evolving radio network access technologies and protocols. Evolution of UMTS system beyond Release 7 is also discussed in detail.

2.1 GSM Background

The Global System for Mobile communications (GSM) that was developed in Europe in the late 1980s, is the best known mobile communication system. GSM was initially designed to support, narrowband speech telephony with bitrates between 5 and 15 Kbit/s [8], but with the passage of time, the focus of GSM technology is being shifted from voice to data services. The GSM system operates globally at 900, 1800 and 1900 MHz bands. According to research statics provided by 3G Americas [9], there are 3 billion users around the globe who are using GSM technologies including the Universal Mobile Telecommunications System (UMTS), and up until 2013 this count is expected to increase to 3.5 billion mobile users who will be using the GSM family of technologies. Some of the basic operational features of the GSM system are mentioned below:

- GSM provides higher voice quality.
- GSM offers fairly good spectral efficiency.
- Comparing with the technology evolution, the infrastructure cost of the GSM system is low.

- Throughout the world same standard is followed, this brings roaming benefits.
- GSM allows a good degree of flexibility, such that new services may be integrated in future.
- GSM provides a range of features among voice services such as use of facsimile and SMS.

2.2 GSM Architecture

The GSM system consists of three functional blocks which operate with each other to give full system throughput; these are called the Network Subsystem (NSS), Base Station Subsystem (BSS) and Operation Support Subsystem (OSS) [12]. The GSM system provides infrastructure flexibility to operators, such that it empowers them to use several sources of cellular infrastructure equipment. Moreover, the GSM system provides standardized interfaces name not only to the air interface but also to the connecting interfaces of each functional block. The three major interfaces that are used by the above mentioned functional blocks of the GSM system are [11]: an interface between the Mobile Switching Center (MCS) and Base Station Controller (BSC), an A-bis interface between the BSC and Base Transceiver Station (BTS) and finally, a Um over-the-air (OTA) interface between the mobile station (MS) and BTS. Figure 2.1 shows all the functional blocks and interfaces of typical GSM architecture.

2.2.1 Network Subsystem

This functional block of the GSM system consists of the equipments which provides the functionality to make end-to-end calls, mobility to users and facilitates operator to manage subscribers, etc. NSS also provides an interface to the fixed Public Switched Telephone Network (PSTN) for enabling Circuit-Switched (CS) calls. Specifically an NSS includes MSCs, the Visitor Location Register (VLR), Home Location Register (HLR), Authentication Center (AUC) and Equipment Identity Register (EIR).

The MSC is an important entity in the NSS which provides call setup, routing and handover between BSCs, etc. The MSC also facilitates billing functionality in the NSS for subscribers, such that each subscriber is charged per utilized service. In the GSM system, the HLR is used as a centralized database of all subscribers registered in a Public Land Mobile Network (PLMN) [10]. Similar to the HLR, the

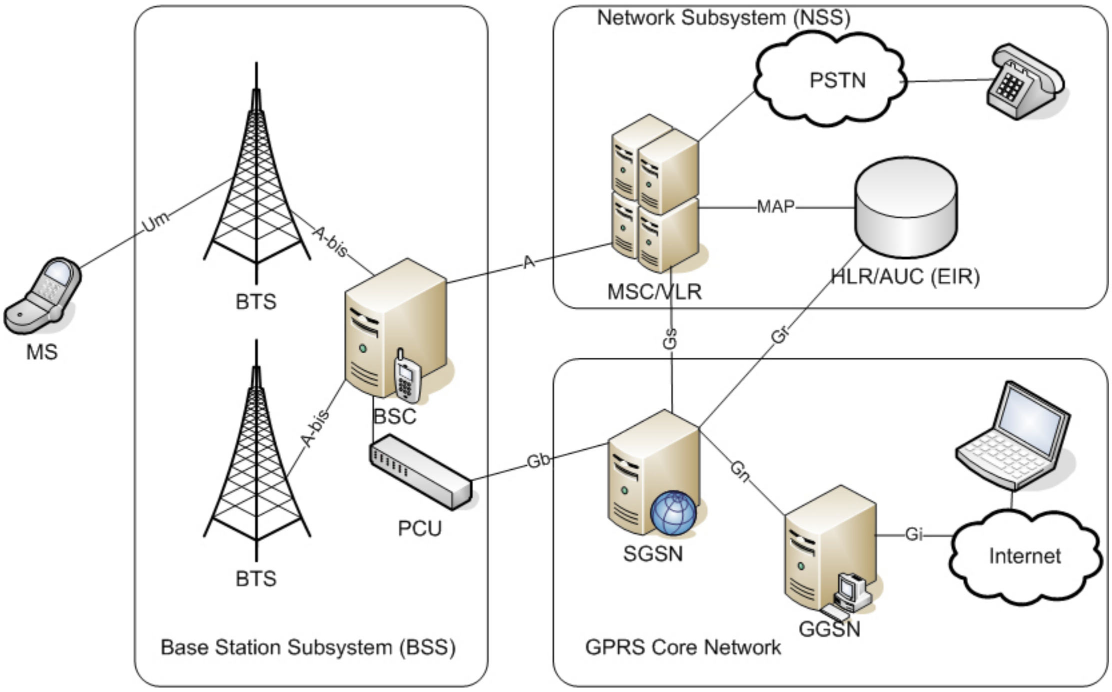

Figure 2.1: GSM network architecture

VLR is also a database but provides services to those mobiles stations who roam in an MSC's controlled area. When an MS roams in to some other MSC area, the VLR connects to the MSC and a request is made for the information about the MS from the HLR. Unlike the HLR, each BTS is served by one VLR; hence the existence of the VLR is seen to be distributed in GSM system.

The AUC in the NSS connects with the HLR, and it is typically used to authenticate Subscriber Identity Module (SIM) cards which attempt to connect with the GSM core network. The AUC also provides security features to each subscriber with the help of authentication parameters and ciphering keys. The last functional entity in the NSS is the EIR; this database is used to store International Mobile Equipment Identity (IMEI) [10] numbers.

2.2.2 Base Station Subsystem

The basic functions of all the entities in the BSS are to provide management of the radio links including Radio Resource Management (RRM) and handovers, etc. The BSS is a set of transceivers and controllers and it connects through A interface with the MSC. Typically, a BSS consists of the BSC, BTS and MS.

In a GSM system, RRM is handled with the BSC which is the main entity which enables the MS to access the core network. The BSC controls power transmission and provides inter-cell handovers to MSs who roam between the BSC controlled BTSs. In the BSS, the BTS is used to serve one cell and it is controlled by the BSC. The BTS consists of various transmission and reception devices including antennas [10]. Typically in a GSM system a BTS is used to encode, encrypt, multiplex and modulate radio signals. The basic function of the BTS is to transmit and receive radio signals from a mobile station over-the-air interface.

2.3 EDGE

Standardization work for GSM has been in progress since the last two decade. Initially the European Telecommunications Standard Institute (ETSI) was taking care of the GSM standardization process, but currently this work is carried out by the 3rd Generation Partnership Project (3GPP) [13]. Typically, 3GPP standardization work focuses on the radio acces network, core network & terminals and service & system aspects. Specifications that 3GPP produces are based on GSM evolution. Under 3GPP, GSM's evolution process has started to evolve the concept of the UMTS multi-radio network. This evolution in its first stage has given the development of Enhanced Data rates for GSM Evolution (EDGE) [14], then GSM EDGE Radio Access Network (GERAN) [15] and, finally, the UMTS Terrestrial Radio Access Network (UTRAN) [16]. Figure 2.2 shows the basic building blocks that are used in the development of UMTS multi-radio technology.

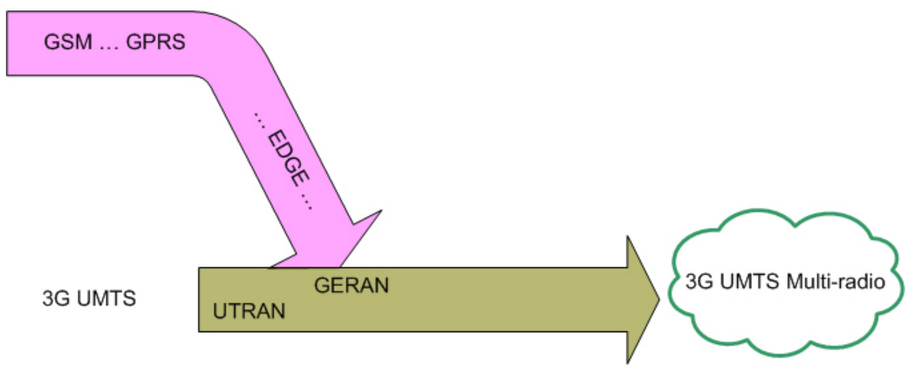

Figure 2.2: UMTS multi-radio technology building blocks

Before the deployment of EDGE or Enhanced GPRS (EGPRS), for providing higher data rate services, High Speed Circuit Switched Data (HSCSD) and the General Packet Radio Service (GPRS) were used by the GSM system. Both HSCSD and GPRS provide peak data rates up to 64 kbps and 160 kbps.

EGPRS is a Packet-Switched (PS) data service, which increases the data rate peak throughput up to three times as compared to HSCSD and GPRS upto 473 kbps. EGPRS enables users to access those services which requires higher data rates. These services are usually comprised of file transfer, web email access, Internet service access and web browsing, etc.

The operating function of EGPRS has a strong impact on both physical and radio interfaces. In EGPRS, Link Quality Control (LQC) [15] provides nine different schemes (MCS-1–MCS-9) for modulation and coding. LQC techniques are used to adapt the channel coding of the radio link to the varying channel quality. Unlike GPRS, for link quality control EGPRS supports both incremental redundancy, type I hybrid ARQ and type II hybrid ARQ [15].

2.4 Evolution of GERAN

In GSM system architecture, the Gb interface between the BSS and the Serving GPRS Support Node (SGSN) was introduced in Release 99 [16]. After the introduction of this interface, all following releases Release 98, Release 99 and Release 4 have come with the concept of two separate interfaces from the BSS to the NSS. These two separate interfaces are known as A and Gb interfaces. In a GSM system the A interface is used between the BSC and MSC, whereas the Gb interface is used between the BSC and SGSN.

As per Release 99, the functional structure of the UMTS system is divided in the Radio Access Network (RAN) and Core Network (CN). The UMTS system has adopted many functionalities of GSM/EDGE. The UMTS system uses the lu interface between the RAN and CN. This interface is further categorized as lu-cs and lu-ps to facilitate circuit-switched and packet switched network services respectively.

The evolution of GSM/EDGE also puts light on the concept of service continuity after the emergence and deployment of Wideband Code Division Multiple Access (WCDMA) [17] networks. In the presence of two different radio access technologies (GSM/EDGE and WCDMA), it was envisaged that there would be a need for dual handsets to support these technologies.

3GPP in its Release 5 [16] gives the adaptation of the lu interface in the GSM/EDGE radio access network (GERAN). With the deployment of GSM/WCDMA networks, there was a huge demand from the operators to have a similar set of services for both radio access technologies. This sort of service set for both the different radio access technologies was only possible in two ways:

1. To meet with the requirements of UMTS networks, increase the functional capabilities of A and Gb interfaces of GSM/EDGE system.
2. Or adopt the lu interface as defined in the UMTS system to increase the operational/functional capabilities of the BSS in GSM/EDGE accordingly.

According to the 3GPP specifications as per Release 5 [16], the lu interface is used by the GERAN along with the UMTS Quality of Service (QoS) architecture. This enables both the GERAN and UTRAN to utilize the same services and CN solutions. This adaptation effectively integrates the GERAN and UMTS terrestrial radio access network (UTRAN) into a single UMTS multi-radio network.Figure 2.3 shows the gradual changes, in terms of capacity and data rates, that have been occurred during the evolution of the GSM system.

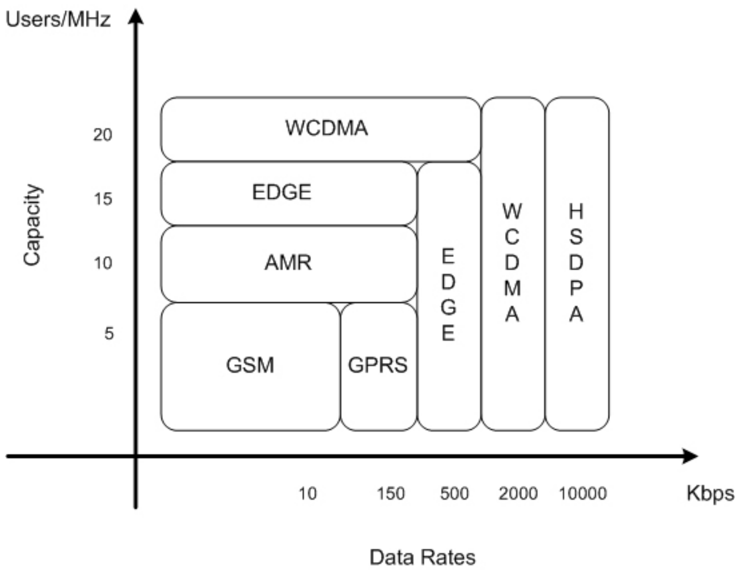

Figure 2.3: GSM evolution towards UTMS

2.4.1 GERAN Architecture

Figure 2.4 depicts the overall architecture of the GERAN system according to the Release 5 specifications. This architecture is basically an integration of both the

GERAN and UTRAN networks. The GERAN system unitizes the network entities and interfaces of GSM and UMTS systems. We have explained already the GSM network entities and interfaces that are shown in the GERAN architecture. Whereas the UMTS system network entities and interfaces are discussed in details in Chapter 3, some major features of the GERAN network are mentioned below:

- System architecture provides efficient resource optimization in multi-radio network effectively with both the GERAN and UTRAN.
- Through this architecture, users of both the GERAN and UTRAN utilize the same set of services.
- Operators can manage the spectrum efficiently.
- Complexity of radio interface protocols increases because radio protocols need significant modification.

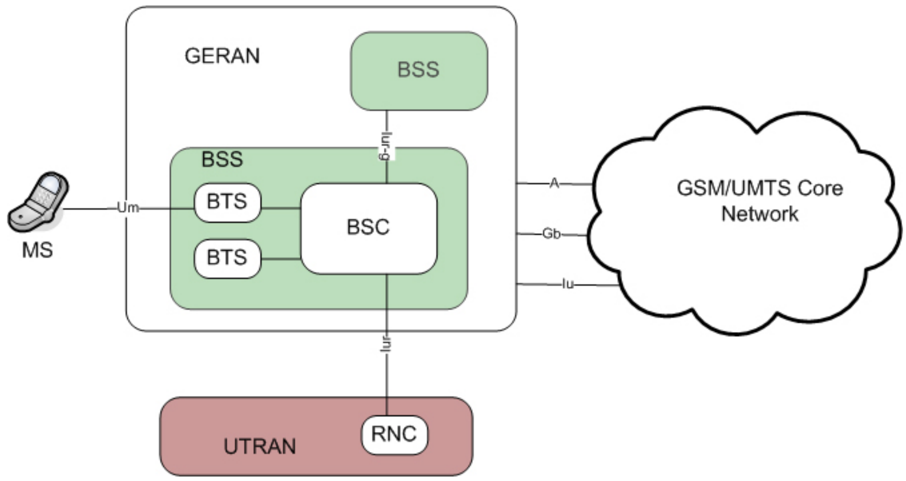

Figure 2.4: Architecture of the GSM/EDGE radio access network

2.5 WCDMA

Wideband Code Division Multiple Access (WCDMA) [17] is the main radio access technology that is used by the UMTS network. Unlike Code Division Multiple Access (CDMA) [18], in order to fully comply with 3G technology, WCDMA offers wider bandwidth and a different control channel and signaling, etc. The CDMA system enables users to access the radio link at the same time on the same frequency. By using user specific spreading codes, users are separated from each other. The WCDMA technique is based on Direct Sequence CDMA (DS-CDMA). In the DS-CDMA multiple access technique, user information bits are spread over a wide bandwidth after multiplying the user data with the spreading code.

With its wide carrier bandwidth, WCDMA enables users to utilize higher data rates. It supports the 3G system in a way to offer high speed Internet access to mobile users and tries to maintain the quality that users experience with fixed Internet. And depending upon the interference level and spectrum arrangements, varying carrier spacing of 4.4 and 5 MHz is used by the operators.

WCDMA in a 3G system also introduces the concept of Bandwidth on Demand (BoD). In BoD, data rates are kept constant when services are provided to the users. In the UMTS, in order to achieve desirable packet data services, various radio resource management functions are used. These functions include handovers, load control, packet data control, medium access control and power control. These RRM functions are also used to control fast allocation of radio capacity and to provide QoS.

Table 2.1: Main WCDMA parameters

Multiple access method	**DS-CDMA**
Duplexing method	FDD/TDD
BS synchronization	Asynchronous Operation
Frame lenght	10ms
Multi-rate concept	Variable sperading factor and multicode

Frequency Division Duplexing (FDD) [17] and Time Division Duplexing (TDD) [17] are the two modes of operations, which are supported by WCDMA in the UMTS. The FDD mode uses different carrier frequencies for facilitating transmission and reception of signals in both uplink and downlink directions. On the other hand, in the TDD mode outward and return signals are separated, by using only one carrier frequency (5 MHz). Figure 2.5 depicts the modes of operation of FDD and TDD.

In WCDMA, bandwidth allocation to the users along with its controlling function is handled by 'channels'. Channels are categorized according to the WCDMA operation at different layers, such as the physical channel, logical channel and transport channel. The use of each channel type defines the need of the channel and how

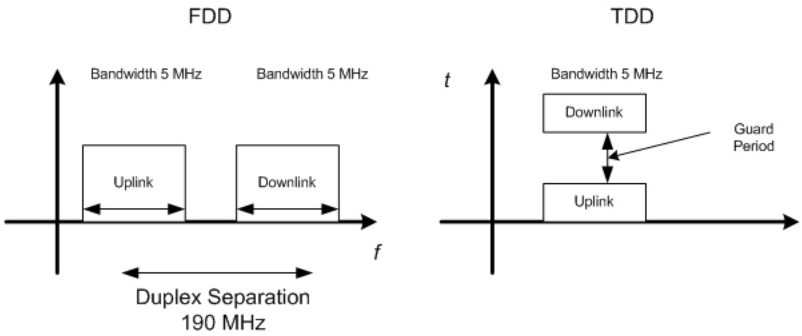

Figure 2.5: FDD and TDD operation principle

the channel will be organized. Physical channels, as shown in Figure 2.6, are used as a transmission medium (radio platform) through which actual information is transmitted. Logical channels are used to describe the types of information to be transmitted, whereas transport channels are used to determine how logical channels are to be transferred. WCDMA also overcomes the near-far problem with the introduction of soft handovers in the WCDMA radio network architecture. In CDMA systems the frequency reuse factor is equal to 1.

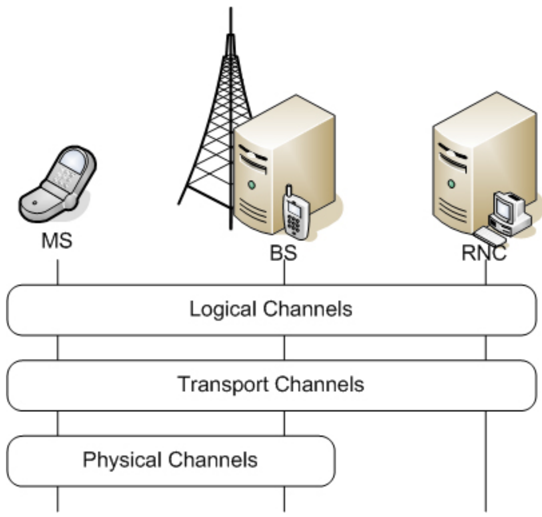

Figure 2.6: Logical, Transport and Physical Channels in WCDMA UTRAN

2.5.1 WCDMA Evolution Towards HSDPA

According to the 3GPP framework, the further development of the UMTS network is based on an 'All IP' solution. This concept also introduces the IP traffic handling in the UMTS core network (CN). In order to make a full UMTS system capable of handling IP traffic, it is also necessary to evolve the UTRAN and introduce an IP based solution especially for its air interfaces.

3GPP has introduced the concept of High Speed Downlink Packet Access (HSDPA) [3, 17] for WCDMA in Release 5 specification. According to this specification, functions of Radio Network Controller (RNC) are implemented into BS and therefore, a separate RNC is not needed. These functions include scheduling and retransmission of packets, etc. HSDPA enables base stations to schedule downlink packet operations and packet retransmission control. In order to increase the performance of packet base transmission, HSDPA uses HARQ and Adaptive Modulation and Coding (AMC) techniques. These techniques provide backward compatibility with Release 4, and are also used as building blocks for HSDPA evolution especially for the enhancement of the UTRAN air interface. The introduction of HSDPA in the UMTS increases packet data performance up to 100% compared to earlier releases.

HSDPA uses Time Division Multiplexing (TDM) to transfer data packets in a single shared channel. In HSDPA over-the-air efficient scheduling, modulation, and encoding is done with the help of certain functions and some set of procedures. The HSDPA main functional entities comprise of cell change procedures, AMC, Fast Packet Scheduling (FPS) and HARQ [3]. As per Release 5, Figure 2.7 illustrates all functional entities of the HSDPA technique.

With the help of the above mentioned functional entities, HSDPA provides higher data throughput up to 10 Mbps [3, 17], mainly this much data rates on the radio link are usually obtained with the help of a modulation mechanism that is used for resource configuration. Along with the variety of benefits, HSDPA also comes with some drawbacks. HSDPA uses adaptive modulation and coding methods which require modifications in the physical layer architecture. These modifications in the physical layer require significant changes in channel structure, multiplexing and a timing mechanism during HSDPA operation. In order to provide fast scheduling, HSDPA requires efficient interaction with the Medium Access Control (MAC) and physical layer, hence it requires more processing capacity in both the BS and UE. HSDPA introduces three different types of channels [3]:

HS-DSCH

The high speed downlink shared channel is a transport channel which is shared among several users.

HS- SCCH

The high speed shared control channel is a logical uplink channel, which is used to control retransmission and decoding.

HS-DPCCH

The high speed dedicated physical control channel associates with HS-DSCH channel, and it is used to carry control information related to retransmission of acknowledgements and negative acknowledge (ACK/NACK) response.

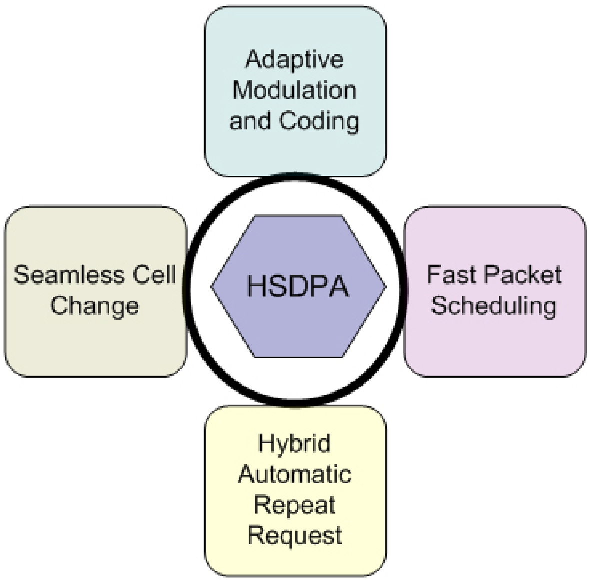

Figure 2.7: Main functional entities of HSDPA

2.6 UMTS Evolution Beyond Release 7

With the ongoing research in the telecommunication industry, it is envisaged to identify the technologies and their capabilities to standardize 4G communication systems. For the evaluation of 4G systems, major research emphasis is put on achieving higher data rates, to improve the coverage and capacity of the radio link and to find a good business model for operators [16].

UMTS networks are now being transformed to packet-switched technology architecture. In 3GPP Release 7 and beyond specifications, UMTS evolution is still in progress. These releases specify the future development, enhancement and migration of the existing telecommunications network architecture and radio interfaces [19]. In the 3GPP vision, the evolution of telecommunication system is explained under High Speed Packet Access Evolution (HSPA+), System Architecture Evolution (SAE) and Long Term Evolution (LTE).

2.6.1 HSPA Evolution (HSPA+)

High Speed Packet Access evolution (HSPA+) [21, 22] is considered as a framework to improve UMTS network performance for further mobile communication development towards LTE and SAE. In Release 7 specifications, 3GPP has specified design targets for HSPA [19] evolution beyond Release 7. This specification also identifies specific areas which need further improvement in HSDPA/HSUPA such as latency, spectrum efficiency and throughput, etc. HSPA+ deployment does not need any radical changes in the existing model of HSDPA/HSUPA except it will require an infrastructure advancement to support higher bandwidths. HSPA evolution brings advancement only in the packet-switched elements of the UMTS system, and it is intended to provide full backward compatibility to evolved UMTS systems.

2.6.2 LTE

In 3GPP the standardization work of LTE was started in early 2004 [6]. The term LTE was first introduced by 3GPP to start the next evolution phase of mobile communication system which is based on Orthogonal Frequency Division Multiplexing (OFDM) [20] technology. LTE is used to provide an all-IP solution with flat network architecture. LTE has a capability to operate in both FDD and TDD modes. Unlike UMTS, LTE does not support soft handover. LTE empowers operators to achieve peak uplink and downlink rates, improves spectrum efficiency, and reduces CAPEX and OPEX. The LTE core network is based on an all-IP solution, and unlike GSM/UMTS there is no separate circuit-switching network element present in the LTE core.

Table 2.2 contains the numbers taken from the LTE forum [23]. This table illustrates the peak data rates for uplink and downlink with two different LTE configurations. According to the LTE forum, the evolution of HSPA will provide three to four times more efficient downlink rates and two to three times more efficient uplink rates.

Table 2.2: LTE peak throughput rates

LTE Configuration	Downlink (Mbps)	Uplink (Mbps)
2x2 MIMO in the downlink and 16 QAM in the Uplink	172.8	57.6
4x4 MIMO in the downlink and 64 QAM in the Uplink	326.4	86.4

Figure 2.8 illustrates the LTE evolution path along with its expected time of deployment. The evolution of the mobile communication system started from the GSM/EGDE technologies under 3GPP supervision. Both GSM/EDGE were based on the TDMA/FDMA technologies. In early 2000, further improvement was seen with the development of the UMTS system, which is based on Wideband Code Division Multiple Access (WCDMA) technology. Over a period of time the UMTS system has continuously matured and it has opened the door to achieve higher data rates over-the-air by introducing the HSDPA/HSUPA technologies.

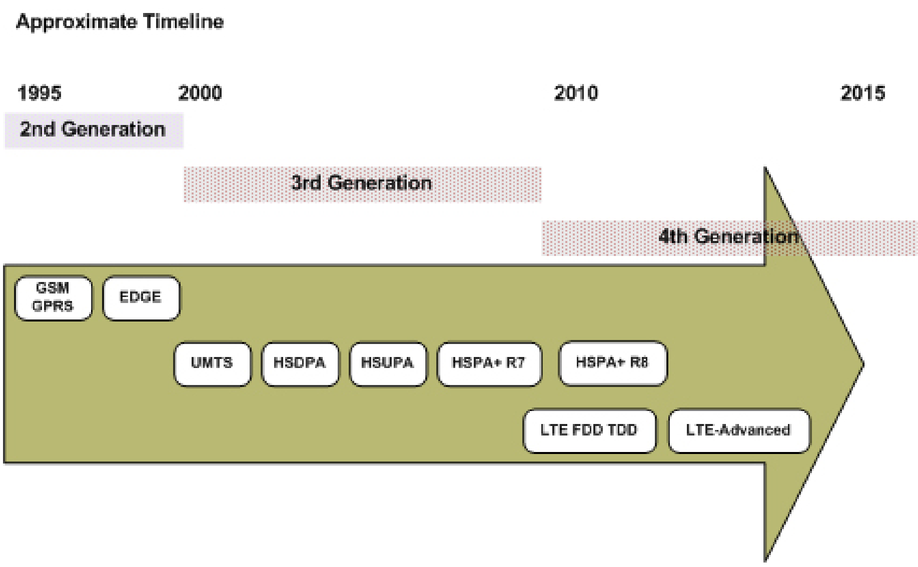

Figure 2.8: Approximate timeline of the mobile communication standards landscape

The world is now going to see the next evolution of the mobile communication system in the form of LTE. Which has emerged to provide a packet-switched solution which uses OFDM as an access technology. The trend of achieving a higher data rate is still continuous in 3GPP and it is known as HSPA+. One step towards the further development of LTE has already been taken and it is known as International Mobile Telecommunications Advanced (IMT-Advanced) [24, 25]. Like its successor technologies, IMT-Advanced also has an expected deployment deadline which has been set for 2015.

Under 3GPP, from an architectural point of view two working groups are putting their efforts into LTE standardization, namely the Radio Access Network (RAN) and Services and System Aspect (SA) [13]. The Technical Services Group RAN (TSG RAN) puts their major effort on air interfaces and radio links whereas the TSG SA work is focused on an all-IP based core network. The details of the LTE system architecture and its operations are discussed in Chapter 4.

Chapter 3

UMTS Architecture

This chapter gives a detailed discussion of the UTRAN access network and core network architectures. Each individual element of the UTRAN architecture is explained in detail. Furthermore, technological evolution of the UTRAN is carried out along with the architecture evolution that has been specified in 3GPP Release 7.

3.1 UMTS Radio Access Network Architecture

To cope with the advancement in the future mobile telecommunication systems, the UMTS is gradually evolving to fully support multi-radio access networks. This evolution process has formed the UMTS terrestrial access network (UTRAN) [16] as the main radio access network technology for the UMTS. Typically the UTRAN is located in between the Uu and Iu UMTS interfaces, and it is used to provide a bearer service over these interfaces [26]. In the UMTS, Radio Access Bearers (RAB) are created by the UTRAN which empowers CN entities to facilitate communication paths among UEs. RABs form logical connections between the UE and RNC, and carry user data. Figure 3.1 shows the high-level system design of the UMTS network, including the UE and CN.

The UTRAN offers various differences in operations and functionalities in comparison to the GSM radio access network, such as:

- The UTRAN introduces several new interfaces in the UMTS radio access network (RAN), such as Uu, Iu, Iub and Iur as well as some new interfaces in the CN like Iu-PS and Iu-CS [16]. All these interfaces provide flexibility of operation while internetworking with other network entities.

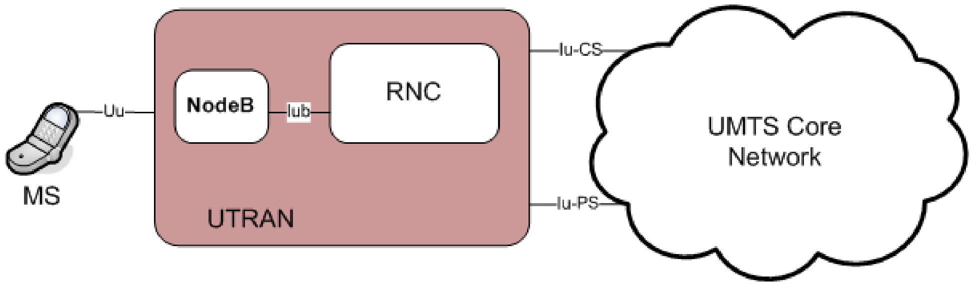

Figure 3.1: UMTS high level system architecture

- Unlike GSM, WCDMA is used as radio access technique in the UTRAN. The use of WCDMA provides macrodiversity which does not exist in TDMA-based radio access systems.
- The UTRAN uses Asynchronous Transfer Mode (ATM) [17] for transporting information with variable bit rates.
- In the UTRAN, mobility management is handled at the cell and UTRAN Registration Area (URA) without involving the CN [27]. This significantly decreases the exchange of signaling between the UE and CN and provides efficient radio resource management.

Table 3.1 shows the shift of operations and functionalities of different interfaces between the UTRAN and GSM systems.

Table 3.1: Comparison between UTRAN and GSM interfaces

Location	**UTRAN Interface**	**Location**	**GSM Interface**
UE–UTRAN	Uu	MS–GERAN	Um
UTRAN–CN	Iu-CS: RNC–MSC Iu-PS: RNC–SGSN	GERAN–CN	A: BSC–MSC Gb: PCU–SGSN
RNC–RNC	Iur	MSC–MSC	None
Node B–RNC	Iub	BTS–BSC	Abis

3.1.1 UTRAN Architecture

Figure 3.2 illustrates the UTRAN architecture, which basically consists of one or more Radio Network Subsystem (RNS). In the UTRAN, the RNS controls the allocation and release of radio resources while establishing a communication path between the UE and UTRAN. Usually the RNS consists of a Radio Network Controller (RNC) and one or many Node Bs, where both the RNC and Node B are connected through the Iub interface in the RNS. In the presence of many RNCs in the UTRAN, the Iur interface is used to connect all of them.

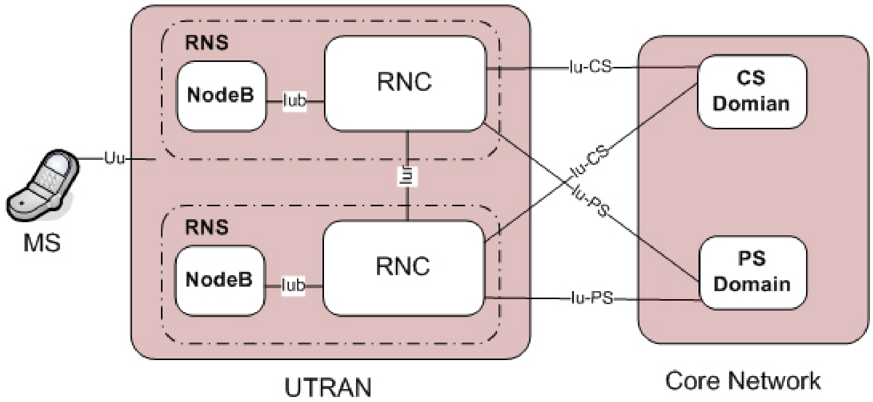

Figure 3.2: UTRAN architecture

3.1.2 UTRAN Interfaces

In the UTRAN, several new interfaces have been introduced which are used to connect the logical network elements in the UTRAN system. All these interfaces also describe the mode of operation of the UTRAN network entities. These are as follows:

- *Cu Interface* is an electrical interface which operates between the Universal Subscriber Identity Module (USIM) and the UE.
- *Uu Interface* is used by the UE to access the UTRAN. This is a typical UMTS open WCDMA radio interface through which mobile stations (MSs) are used to send and receive communication requests.
- *Iu Interface* is used to connect the RNC to the CN. This interface comes with two variants, Iu-CS and Iu-PS [16] to facilitate a user's initiated requests for circuit and packet domains respectively.
- *Iur Interface* is an over-the-air UMTS interface and it links different RNCs. This interface facilitates soft handovers in the presence of RNCs manufactured

by different venders.

- *Iub Interface* is an open UMTS interface which links an RNC to a Node B(s).

3.1.3 Node B

With the evolution of mobile communication systems, in the UTRAN the term base station has also evolved into Node B [16]. Node B is a physical network entity and is situated at the edge of the UTRAN. The main functions of Node B are to transmit and receive radio signals, perform modulation and demodulation of signals, and signal filtering. Node B performs all its operations between the Uu and Iub interfaces.

In the UMTS, the logical structure of Node B is vender dependent, meaning that besides performing its traditional operations, Node B can also have power control and Operation and Maintenance (O&M) functionalities. With O&M [28] enabled functionalities, a Node B can also be used by the operators to perform network management functions. It is also important to note that in release 5, a packet scheduling function is embedded in Node B [29]. Hence with the evolution of the UTRAN, Node B is introduced with those control functions that have a central role in the UTRAN.

3.1.4 Radio Network Controller (RNC)

In the UTRAN, switching and control of communication links are handled through the RNC. The RNC in the UTRAN architecture connects with the Iub and Iu interfaces and in the presence of more RNSs, inter RNC communication is facilitated through the Iur interface. Moreover, the RNC also handles the switching between the RAB and Iu bearers. The RNC can perform several logical roles while operating in the UTRAN such as the Controlling RNC (CRNC), Serving RNC (SRNC) and Drifting RNC (DRNC) [29]. When the RNC is used to control a single Node B then it is termed as the CRNC. The CRNC controls congestion in its cell and when new radio links are establish, it grants them admission and code allocation. In the SRNC logical role, the RNC is responsible for holding the Iu bearer and RAN Application Part (RANAP) signaling between the UE and CN [26, 30]. The last logical role an RNC can perform is known as a DRNC. In drifting mode the RNC controls cells and allocated UE context through itself. It is also capable of routing data between the Iub and Iur interfaces.

In order to understand the RNC operations in the UTRAN, its functionality can be divided into radio resource management (RRM) and controlling functions. When we talk about RRM in the UTRAN, we come to know that it is a set of different algorithms which are used by the RNC to establish a steady radio path. In the UTRAN these algorithms are used for handover, power control, code management, admission control and packet scheduling. The protocol which is used by RRM is called the Radio Resource Control (RRC) protocol. RRM is also responsible for providing QoS to all radio links in terms of efficient resource sharing and management. RNCs use control functions to create, terminate and maintain RABs.

3.2 UMTS Core Network (CN) Architecture

The CN in the UMTS is used to provide services that are needed to set up circuit-switched calls and routing of packet data. The UMTS core network consists of two domains and a subsystem. All these CN entities are used to identify the type of service requested by the user. These entities are called circuit-switched (CS) domain, the packet-switched (PS) domain and IP multimedia subsystem (IMS) [16]. In the UMTS CN, those network entities which interface the access network directly are termed as domains. In between the UTRAN and CN there is a Iu [26] interface which is comprised of two variants, Iu-CS and Iu-PS. These two interfaces are used by the CN to categorize the nature of traffic that is initiated by the user. All the CS traffic between the UTRAN and CN is transported over the Iu-CS interface, whereas the Iu-PS interface is used to transport a packet data request. In release 5, 3GPP has introduced the IMS [31] as a new subsystem in the CN. The introduction of the IMS in the CN opens the door for operators to provide IP-based services and Internet to mobile users. Note that the discussion under this section is focused on the 3GPP release 5 core network specification.

3.2.1 Circuit-Switched Domain

It has been studied that during the evolution phase of the UMTS system, the CN has not evolved in such a straightforward way as the UTRAN [29]. Most of the CN functionalities are inherited from the GSM system during release 99. Hence the UMTS CN that is based on release 5 provides backward compatibility to release 99.

In release 4 [16, 27], the functionality of MSC/VLR is divided into two separate CN entities, the Media Gateway (MGW) and the MSC server. The MGW is used in the CN to convert digital media streams which are accessed through the UTRAN. Its main function is to provide echo cancelation in the UMTS CN. The GMSC functionality is also separated between the MGW and the Gateway MSC (GMSC)

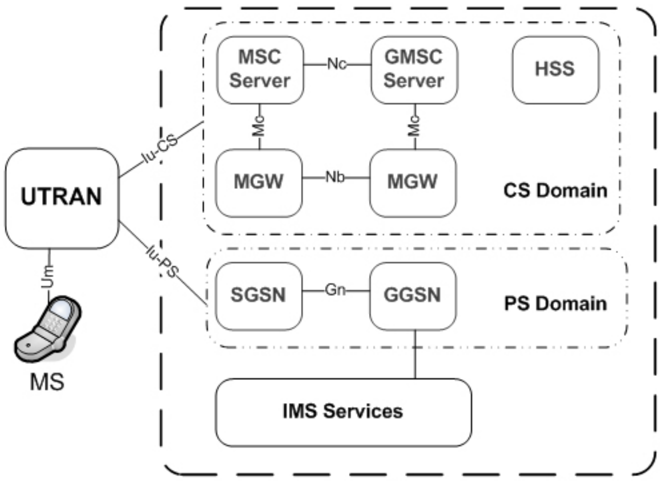

Figure 3.3: UMTS core network architecture release 4

in release 4. The GMSC is an edge entity which terminates signaling originated by the mobile network to the public switched telephone network (PSTN). It inherits all the MSC functionalities that have already been defined in Section 2.2.

In release 5 [16, 27], in order to reduce the number of network elements in the CN, the functionalities of MGW and GMSC are combined in a single entity called the GMSC. Similarly, a new network element UMSC (UMTS MSC) is introduced which combines the functionalities of the SGSN and the MSC/VLR. Therefore, both release 4 and 5, provides immense flexibility to operators to maintain the CS domain according to their needs and increased traffic delivery capacity in the UMTS CN.

However, the distribution of functions between the MGW and the MSC server, practically provides separate paths for control and user plane signaling in the UMTS CN. This separation also in results improved scalability for the CN because one MSC server is capable of handling many MGWs. Separate MGWs also results in geographical optimization for the user plane in the CN. Hence after implementing proper routing techniques, operators can place the MGW in such a place that will provide the shortest path for user plane signalling. Some new interfaces are emerged after distributing the functionalities among various network elements in the CS domain, such as the Ms, Nc and Nb interfaces [15]. These are described in more detail below:

- Mc interface operates between the MGW-MSC server and also between the MGW-GMSC server. It uses the Media Gateway Control Protocol (MGCP)

[32] to control multimedia streams across IP and PSTN networks.

- Nc interface links the MSC server and the GMSC server, and provides call control information. It uses the Bearer Independent Call Control (BICC) [33] protocol which is based on the ISDN User Part (ISUP) protocol.

- Nb interface is used to provide user plane and control plane information between MGWs.

3.2.2 Packet-Switched Domain

The PS domain typically comprises two network elements in the UMTS CN, which are known as the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN) [16, 27]. The SGSN is used to deliver data packets to and from the UE within its service area. The SGSN is capable of storing user location information which helps the SGSN to identify the origination and termination point for a packet data request. Beside its basic operations, the SGSN is also used to provide user authentication, link and mobility management functions.

The GGSN is used as middleware between the SGSN and the Packet Data Network (PDN). The GGSN is used to transport the received data from the SGSN and deliver it to the PDN through the Packet Data Protocol (PDP) [29]. The GGSN is responsible to apply the PDP context to all requests receive from the SGSN. The PDP context assigns an IP address and establishes an end-to-end connection between the UE and PDN. The access network provides an effective security mechanism over the radio link. But at the CN, security functions are integrated in the GGSN. Usually GGSNs are manufactured with a built-in firewall capability. GGSNs are used to provide internetworking between two separate packet networks. For this purpose, a Border Gateway (BG) is used to enable inter-networking and roaming functionalities in the PS domain.

In the PS domain, operators can include separate elements for charging and billing functions. Usually the Charging Gateway (CGW) is used in the PS domain to collect information about received service by the users. Service utilization information is then sent to the billing center for further processing. The Iu-PS [26]interface is used by the PS domain to facilitate the incoming request from the access network. the Iu-PS interface is also capable of handling both the GERAN and UTRAN.

3.2.3 IP Multimedia Subsystem

A traditional mobile communication system offers various higher data rate services but only up to certain limits. Mobile users are capable of sharing videos and pictures through the Multimedia Messaging Service (MMS) and they also can browse the Internet as well. But with the mass development in the content delivery and sharing model of the Internet, things have been changed rapidly as far as print media is concerned. Therefore, it is obvious that the traditional mobile communication system will not support today's evolving multimedia communication which includes online gaming, real-time video streaming, application sharing and interactive web services, etc.

The IMS functionality is integrated as per release 5 in the UMTS CN [31], for providing the above mentioned IP-based multimedia services. The IMS architecture in the CN opens the door for the creation of new mobile-based multimedia applications. The IMS enables the UMTS network to provide rich content delivery service simultaneously to the users. The IMS establishes an IP-based end-to-end multimedia session, and is used to provide transparent communication over different networks. Moreover, the IMS enables applications in the UE to establish peer-to-peer connections, somthing which were not possible before. Figure 3.4 depicts a SIP call session which is utilizing the PS domain in the UMTS CN.

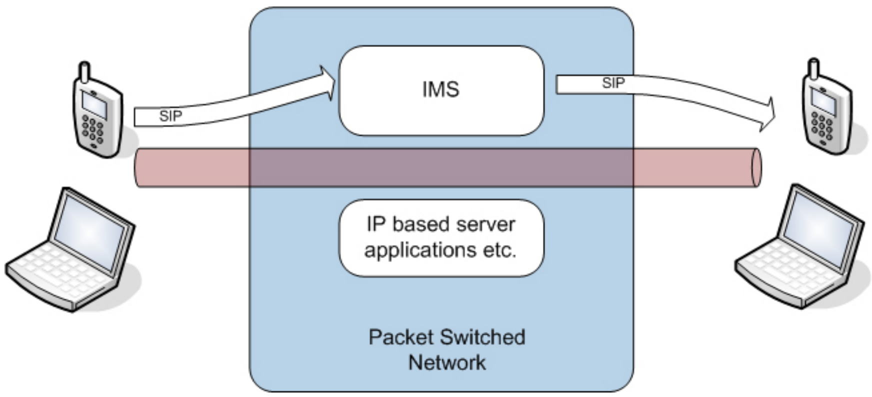

Figure 3.4: IMS brings multimedia session control in the packet-switched domain

3.3 UTRAN Protocol Architecture

Figure 3.5 illustrates the general protocol model for UTRAN interfaces as specified by 3GPP. This model specifies that both the layers and planes are logically separated from each other. Hence modifications in any protocol will not affect any other protocol on any layer. This model also illustrates that, the functionality of each interface is divided between the control and user plane.

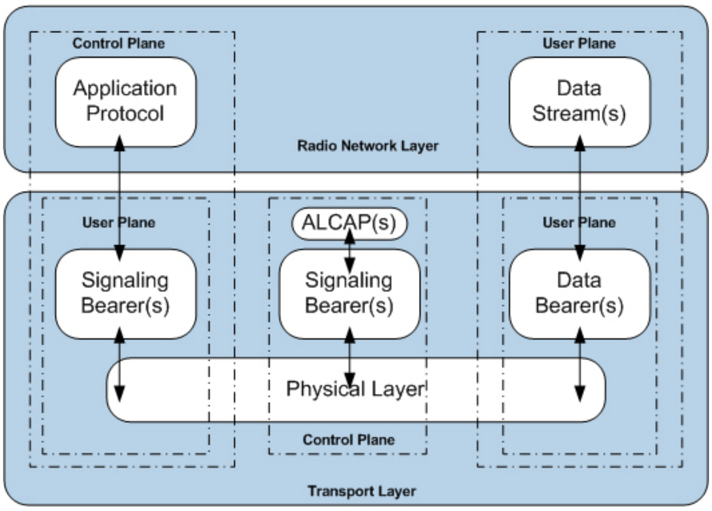

Figure 3.5: General protocol model for UTRAN terrestrial interfaces

3.3.1 Control Plane Protocol

The UTRAN control plane protocols are used to provide messages and procedures to support each interface to perform their functions. The UMTS provides a range of control protocols to set up bearers at each interface. These protocols are comprised of a Radio Access Network Application Part (RANAP) [34] for the Iu interface, a Radio Network System Application Part (RNSAP) [35] for the Iur interface and a Node B Application Part (NBAP) [36] for the Iub interface. In the UMTS, the transport network control plane acts as middleware between the user plane and control plane. It uses the Access Layer Control Application Part (ALCAP) protocol to set up transport bearers (Data Bearers) on the transport layer. According to 3GPP specifications, the operation and maintenance function is responsible for setting up signaling bearers for the ALCAP. Every UE when powered up acquires a logical Radio Resource Control (RRC) [37] connection with the RNC. The operation of the

RRC includes mobility management, set up and release of resources. The RRC connection remains alive until the UE actively sends data and is used to carry control information between the UE and RNC.

3.3.2 User Plane Protocol

User plane protocols are used to transport information which is considered as user data to UMTS interfaces. This information may include coded voice in a voice call, data streams and data packets in an Internet connection. The Packet Data Control Protocol (PDCP) is used to serve both PS and CS domains at the link layer level. At the Iu-PS interface, packets toward the RNC are transported as IP packets. In the UMTS, the Broadcast and Multicast (BMC) protocol is also used as user plane protocol for encapsulating multicast and broadcast data.

3.4 UTRAN Evolution

The evolution process of the UMTS communication system is still under development. This process was started by 3GPP after the release 99 specifications in 2000. To date the concept of the traditional mobile communication system has been changed dramatically with the advent of various efficient communication techniques.

Development of the UMTS network was first witnessed after the 3GPP release 99 in March 2000. This release is considered as the first step towards the evolution of mobile communication systems and has opened the doors for commercial deployment of the UMTS. In this release, various RAN and CN functionalities are inherited from the GSM system, so that the UMTS network can be used to provide backward compatibility with the existing GSM system. In the following release, other improvements in the UMTS network are standardized in release 4. In release 4, there are no major changes introduced into the UMTS, but some new network elements are introduced in the CN such as the MGW, GMSC and MSC server.

Significant developments was introduced by 3GPP in the release 5 specifications. This release introduces the concept of HSDPA and IMS which provides a higher data rate and IP-based multimedia support in the UMTS respectively.

In September 2005, further enhancements for HSPA were defined in release 6 with the introduction of HSUPA. In this release, the concept of UMTS and Wireless Local Area Network (WLAN) integration is also introduced. With this integration, higher data rates and mobility can be experienced by UMTS users in WLAN hotspots.

Release 6 also specifies the concept of the Multimedia Broadcast/Multicast Service (MBMS) [38]. With the deployment of the MBMS, UMTS users will be able to experience multimedia broadcasts such as TV streams, films, etc. Release 7 introduces the concept of Multiple Input and Multiple Output (MIMO) antennas [17, 29]. MIMO can be used to achieve peak rates of up to 14 Mbps. Table 3.2 illustrates the overall evolution of the UMTS according to the release. No further developments for release 7 are introduced after it freezed in December 2007.

Table 3.2: UMTS evolution path on 3GPP releases

Release Name	**Release Date**	**Features**
Release 99	March 2000	Inherits all the GSM core network functionalities, only advancements are observed in the RAN
Release 4	March 2001	- Major changes in CN, new elements such as MSC server are MGW are introduced - In RAN enhanced QoS functions are implemented
Release 5	March 2002	- Major changes in PS, new IMS subsystem introduced - Evolution in RAN with the advent of HSDPA - First step to tranport IP-based packet over RAN
Release 6	September 2005	- Introduction of Multimedia streaming and TV broadcast servie over RAN - Evolution in RAN with the advant of HSUPA - Support for inter networking with WLAN
Release 7	Frozen in 2007	- Advant of MIMO - New charging related functions such as PCRF

3.5 UMTS Architecture Evolution Beyond Release 7

The vision for further development in mobile communications is now gradually shifting towards improved network coverage and capacity, higher data rates to users and progressive business model for the operators. To achieve these targets, there is on-going research to identify the elements which require enhancements and changes to cope with the vision of the forthcoming 4G telecommunication system.

Evolution in the UMTS network architecture shows significant improvement in the IP-based packet-switching service model. It is scheduled that in 2010, deployment of a fully IP-based UMTS network will take place. It is also foreseen that the advent of a heterogeneous access network in the 4G system will facilitate transparent mobility across a variety of access networks. UMTS evolution is in progress under 3GPP, and further development in this regard is termed as system architecture evolution (SAE) and long term evolution (LTE).

Chapter 4

System Architecture Evolution of LTE

This chapter addresses the needs, requirements and design targets for System Architecture Evolution. The major focus of this chapter is to introduce the concept of LTE and to discuss the evolved RAN and CN operations and functions of their respective network elements.

4.1 System Architecture Evolution of LTE

What research community is currently aiming at through SAE/LTE [39] is to produce everything for the mobile communications system in bulk quantity. This vision includes a communication system that could offer more frequency bands, more networks, more air interface technologies and especially higher volume of data wirelessly.

For LTE [17, 29], two evolution drivers are quite visible. Firstly, the need for accessing data application over the radio access network. Traditional mobile communication systems was built to support mainly voice and are based on circuit-switched technology. With the continuous development in the current Internet, mobile users are in need of having IP-based applications on their handsets and by having these applications they also need a packet-switched communication paradigm. Secondly, for better user experience while utilizing IP-based applications, mobile users need more bandwidth which drives the operator to demand higher capacity in their networks.

The evolution of the UMTS in 3GPP towards LTE is carried out under the vision that future radio access networks would be based on packet-switched technologies. The term SAE suggests that, the future radio communication system will also support non radio services. This approach has given birth to the Evolved Packet Core

(EPC) [17]. The conjunction of both SAE and LTE has introduced the Evolved Packet System (EPS) [29] in 4G communication systems. The EPS radio access network and core network is based on a packet-switching mechanism.

4.1.1 Requirements and Targets for LTE

The need for LTE was felt even before the deployment of High Speed Downlink Packet Access (HSDPA) [3]. The aim was to start work for a radio system which could meet growing user demands in future as well. Since, it takes more than 5 years from setting system targets to their deployment for a radio system, so the work for Long Term Evolution (LTE) began already in 2004.

The work on LTE was started by keeping several targets under consideration: these includes, for instance the evolution in wireline capability with a corresponding need for additional wireless capacity, the need to have a lower cost radio system and to compete with other wireless technologies.

These goals can be explained one by one, such as when the capacity grows in wireline technologies, similar evolution is required in wireless technologies in order to meet the requirement of applications in the wireless domain as well. As new technologies and cheap solutions emerge, it is necessary to find both technical and marketing solutions to compete with other operators in the same field. Since other technologies, like IEEE 802.16, for instance were capable of providing higher data rates so it was ultimately a must for 3GPP to go for a new technology on top of its existing solution based on HSPA. Figure 4.1 shows the key motivation factors for LTE deployment.

LTE must be able to provide superior performance and a cheaper solution compared to other competing technologies and also the previous 3GPP solutions as well. LTE targets have been set relative to HSPA Release 6 [21]. It was aimed at achieving to least 100Mbps throughput in the downlink and 50Mbps in uplink. The latency was to be reduced and terminal power consumption was also required to be minimized to improve overall performance. The targets of LTE can be listed below as:

- Spectral efficiency two to four times more than HSPA Release 6
- Peak data rates 100Mbps in Downlink and 50Mbps in Uplink
- Round trip time less than 10ms
- Optimized for packet based data traffic

- Better mobility and security
- Terminal power efficiency improvement
- Flexibility in frequency allocation from 1.5MHz to 20MHz

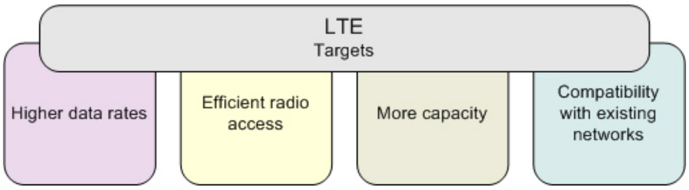

Figure 4.1: Driving forces for LTE development

4.1.2 LTE Design Targets

LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) as a multiple access technique in the downlink and in the uplink it uses Single Carrier Frequency Division Multiple Access (SC-FDMA) [29]. These techniques reduce orthogonal interference and improve network capacity. The frequency allocation in LTE takes place with a resolution of 180 kHz block both in the uplink and downlink. The frequency allocation in the uplink is continuous, thus enabling single frequency use, while in the downlink, frequency blocks are freely chosen from different parts of the spectrum.

In LTE the bandwidth choice is flexible ranging from 1.4MHz to 20MHz [17]. The 20MHz bandwidth can provide up to a 150Mbps downlink data rate using 2x2 MIMO and using 4x4 antenna configuration it can be increased up to 300Mbps [29]. LTE supports a peak data rate in the uplink 75Mbps.

The above advanced radio features and efficient network architecture also enables an LTE system to provide high network capacity. LTE provides efficient request processing, this is achieved by reducing the number of network elements and improving network scalability. All radio-related functionalities and algorithms which were previously part of the RNC have been moved to eNodeB.

An important feature considered in the design of LTE is that it allows smooth interworking with other 3GPP technologies. Bidirectional handovers are supported between LTE and GSM and LTE and the UMTS. Since several network elements have been adopted from the previous 3GPP technologies, existing network will, therefore, also be able to be upgraded to LTE and will support technologies like GSM, HSPA and LTE.

LTE design incorporates several other techniques as well to achieve higher data rates and performance. It allows flexible bandwidths and supports both FDD and TDD modes. Other features include base station based scheduling, physical layer retransmission and link adaptation. These features have been adopted from WCDMA to facilitate the reuse of designs and platforms already developed for HSPA.

The need for a major change was felt in the multiple access technique instead of just adapting it from WCDMA. Orthogonal Frequency Division Multiple Access (OFDMA) came out as the strongest candidate for the downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) for the uplink as it was supported by many vendors and operators.

With changes in the radio interface it was also felt that system architecture needs to be evolved. One strong reason for this was that LTE was going to be a packet-switched only radio network. Other factors for the motivation to evolve system architecture were the removal of soft handover. Here are the key targets for the new system architecture:

- To have packet-switched only an optimized network, since there is no need to support circuit-switched functionality
- To have support for higher throughput for higher user demands
- Better activation and bearer set-up response times
- Improvement of delays in packets delivery
- To have a simpler architecture
- Mobility and optimized interworking with other radio access technologies

Most of the above requirements meant a flatter system architecture with less nodes to reduce the latencies and improve overall system performance.

4.2 LTE Radio Access and Core Network Architecture

An EPS that is illustrated in Figure 4.2, mainly consist of an evolved UTRAN, EPC and IMS services block [6]. The main working entities in LTE network architecture lies in an evolved radio access network and in an evolved core network. In the E-UTRAN, the evolved NodeB (eNodeB) is used to facilitate the radio access connection between the UE and EPC, and the S1 interface [40] is used by eNodeBs to connect with the EPC. Unlike a 3G system, LTE comprises of a single network element in its radio access network. Whereas the core network (EPC) consists of various logical network elements which facilitate the UE with a successful communication path. All these EPC entities are inter-connected with different interfaces. A proper description and the working mechanism of all the elements in the EPS are discussed later in this chapter.

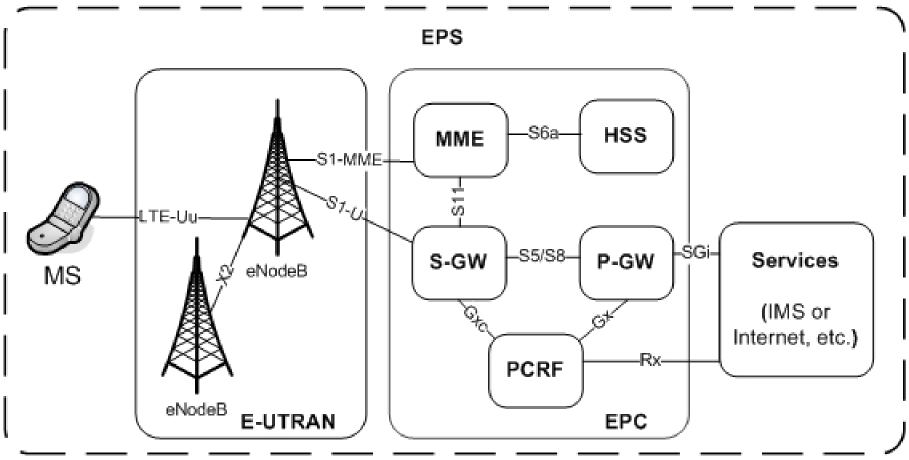

Figure 4.2: System architecture of E-UTRAN

4.2.1 Evolved Radio Access Network Architecture

An OFDM-based LTE access network consists of one or more eNodeBs, which are used to provide transmission and reception of signals over the radio interface. Unlike the UMTS, the physical presence of the RNC is omitted from the E-UTRAN but its functionalities are distributed among the eNodeB and some of the elements of the EPC. In the E-UTRAN, the eNodeB is used to provide inherited functions from Node B, such as modulation and demodulation of signals, channel coding and decoding, controlling of radio resource and mobility management.

In EPS, eNodeBs are used to connect with the EPC through the S1 interface. Operating functionality of the S1 interface is divided between the S1-U and S1-MME interfaces [6]. This division provides ease of control when the eNodeB wants access to the Serving Gateway (S-GW) and Mobility Management Entity (MME) in the EPC [17]. In the E-UTRAN inter eNodeBs communication is facilitated through the X2 interface [41]. During mobility and under a higher data transmission rate the

X2 interface minimizes the packet loss probability. Figure 4.3 depicts the high level architecture of the E-UTRAN, with the interconnections of the S1 and X2 interfaces [40, 41].

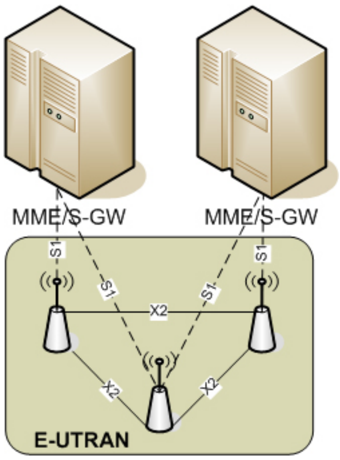

Figure 4.3: Overall E-UTRAN architecture

4.2.2 Evolved Core Network Architecture

As per release 8 specification, the evolved core network is known as the EPC [6], and it provides an all IP core network for LTE. Unlike the UMTS multi-domain (packet-switched and circuit-switched domains) core network, EPC uses single packet-switched IP domain [17]. A single IP domain in the core network significantly improves network performance for both real time and non real-time services. The EPC facilitates an end-to-end IP connection from the UE to any terminating device or network. According to 3GPP specification, a typical EPC consists of the following entities.

- Mobility Management Entity (MME)
- Serving Gateway (S-GW)
- Packet Data Network (PDN) Gateway (P-GW)
- Policy and Charging Rules Function (PCRF)
- Home Subscription Server (HSS)

It is important to note here that, the HSS and PCRF were introduced by 3GPP in its release 7 whereas the MME, S-GW and P-GW were introduced in release 8 specification [6].

4.2.3 Mobility Management Entity (MME)

The MME [29] is considered as the main controlling element which is used to process signaling and control functions between the UE and EPC. The main functions of the MME are to provide network resources and mobility management. The MME uses the S1-MME interface to connect with the eNodeB. The S1-MME [40] interface is used to transport bearer information between the MME and the eNodeB which are used to identify the QoS classes for specific user flows. With this interface these QoS requirements and priorities to user requests are also assigned. The MME accepts an incoming connection request from the UE to establish a communication link. In the EPC, the MME is also responsible for collecting user subscription information from the home subscription server (HSS) through the S6a interface and to keep track of the UE area update. To control and communicate with the S-GW, the MME uses the S11 interface [17]. Usually through this interface the MME informs and update S-GW where to send user requested packet. MME also handles security related functions by using different ciphering and integrity protection algorithms.

4.2.4 Serving Gateway (S-GW)

In the EPC user plane signaling is separated through the S1-U interface, which links the S-GW and eNodeB. The S-GW is used as a mobility anchor for the UE when the user moves from one serving eNodeB to another, or when the UE tries to interwork with earlier 3GPP communication networks. Moreover, the S-GW is used to store user packets temporarily when the user performs inter eNodeB movements. The S1-U interface [40] which is used to link the eNodeB and S-GW performs typically the same functional operations like the Iu-PS interface does in the UMTS network. The S1-U interface is used to transport data over an IP enabled end-to-end tunnel between the eNodeB and S-GW. Furthermore, the S-GW supports policy and charging rules function (PCRF) [42], an EPC entity which is used to collect charging information. Both the S-GW and PCRF connect with the Gxc interface [29] for exchanging the user's charging related information. Data paths between the eNodeB and the P-GW are maintained by the S-GW through the S5/S8 interface.

4.2.5 Packet Data Network Gateway (P-GW)

The role of the P-GW [17] is very important for setting up end-to-end IP based communication, the P-GW being used to provide IP addresses to the UEs and acts as a termination point for delivering user packet data. Allocation of an IP address always occurs when a user requests to establish a PDN connection. The P-GW also enables users to establish a communication link with non 3GPP technologies. Moreover, the P-GW helps operators to apply policy enforcement features and QoS parameters for each user according to agreed resource allocation and usage policy. The P-GW inherits policy and charging rules from the PCRF which connects to the P-GW through the Gx interface [29].

4.2.6 Policy and Charging Rules Function (PCRF)

In the EPC, a policy and charging rules function [42] can be considered as a framework for policy-based admission control for mobile users. The PCRF determines resources access and usage limits for each user according to their user profiles. In 3GPP release 7 specifications, the PCRF is described as part of the core network architecture. As per release 8 specifications, the PCRF inherits all the function as described by release 7 with some additional controlling and charging function for non 3GPP technologies. The PCRF connects with the IMS services through the Rx interface to provide the IMS access to users, and it is also capable of having one or more connections with the P-GW and S-GW.

4.2.7 Home Subscriber Server (HSS)

The home subscriber server is typically a database where user profiles are stored. In the EPC concept of HSS which is not new, the HSS works like the HLR and AuC and inherits their functionalities from release 99 [43]. In the HSS, the HLR functions are used to store and update the database with the user subscription information whereas the AuC functions are used to facilitate the generation of security information from user identity keys. This security information is provided to the HLR for further communication to other entities in the network. In the EPC an HSS is accessed under three circumstances [17], firstly when a UE attempts to register onto the network. Secondly, when the eNodeB sends a UE location update and, finally, when the MME receives a session termination request.

4.2.8 Services Domain

The services domain that is placed over the EPC in the EPS, provides logical mapping of a different set of services including the IMS [44]. Three types of services can be provided via the service domain, such as IMS-based [31] operator services, non IMS-based operator service and other services which will not be facilitated by the operators. 3GPP release 8 inherits the IMS service description as specified in release 7. The concept of the IMS has already been discussed in Chapter 3. No specifications have been standardized for non IMS-based operator services under 3GPP. For providing IMS-based service an operator will be needed to place a server, that will answer all users IMS requests. As far as other services are concerned, no architectural aspects are discussed in any 3GPP specifications.

4.3 E-UTRAN Protocol Architecture

Figure 4.4 illustrates the E-UTRAN protocol reference model, which is quite similar to the one that is explained in Section 3.3. The advancement in this model can be visualized easily in the absence of the transport network control plane. The transport network control plane was used in the UTRAN to provide data bearers over the transport layer. The E-UTRAN reference model is divided according to the functionality of the radio network layer and the transport network layer. This model specifies that both the layers and planes are logically separated from each other. Hence modifications to any protocol will not affect any other protocol at any layer. This model also illustrates that the functionality of each interface is divided between the control and user plane.

4.3.1 E-UTRAN User Plane Protocols

User plane signaling is performed between the eNodeB and the S-GW. User plane protocols are used to transport information which is considered as user data to the E-UTRAN interfaces. Information that is transported through the user plane consists of actual user data and application level signaling. In the EPC, IP packets are encapsulated with the GPRS Tunneling Protocol (GTP) [45]. Specifications about this protocol are specified by 3GPP in release 8. A GTP end-to-end tunnel is formed over the S1 and S5/S8 interfaces. The E-UTRAN user plane protocols consist of the Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC) and Medium Access Control (MAC) sub layers.

4.3.2 E-UTRAN Control Plane Protocols

The UTRAN control plane protocols are used to provide messages and procedures to support each interface to perform their functions. These messages and procedures are usually used to control handover and bearer management. In the E-UTRAN, control plane signaling is facilitated over the S1-MME interface [40] between the eNodeB and MME. The control plane and user plane shares the same access stratum protocols at the E-UTRAN level. The only difference between the control plane and user plane protocols is that the control plane protocol does not perform header compression. For reliable delivery of data at the EPC level, the control plane uses the Stream Control Transmission Protocol (SCTP) [46].

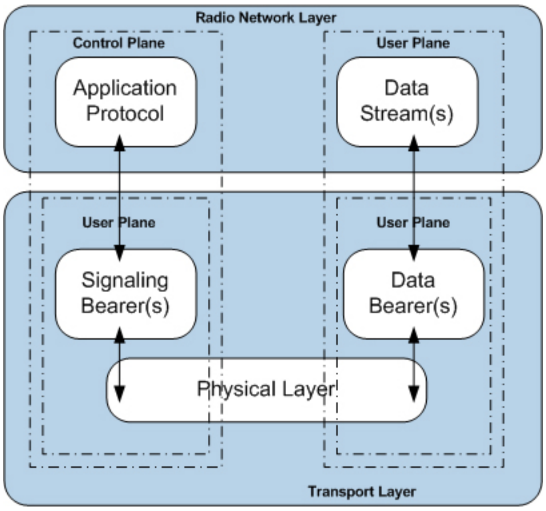

Figure 4.4: General protocol model for E-UTRAN

4.4 LTE Future Architectural Challenges

Where LTE architecture brings simplicity of design, it also brings the complexity of operations of different network entities. In the E-UTRAN all the radio management functions are contained in one entity that is the eNodeB. The eNodeB connects to the core network and with other eNodeBs with the S1 interface and X2 interfaces respectively. This over burdens eNodeB and makes its presence quite critical in the network.

With the increase in system capacity, the LTE architecture opens a new concern in order to choose the type of backhaul technology to support and fulfill the operators need. This is because of each LTE architectural design there is a shift of the capacity bottleneck between the air interface and the core network. LTE promises to give downlink transmission capacity of at least 100 Mbps, but it is quite evident that today's broadband link which is mainly comprised of Digital Subscriber Line (DSL) and cable modems cannot simply provide data rate support with sufficient capacity up to 100+ Mbps. Hence operators have to think about the deployment of new solutions with fiber/Ethernet and WiMAX solutions.

Communication security will remain the main concern whenever new technologies are deployed. Furthermore, LTE also has some significant security risk, but all the open air communication threats are prevented through an encryption mechanism which is known as snow3G. This mechanism works with 32-bit words and supports both 128-bit and 256-bit keys. Hence, it is quite difficult to make attacks to unsecure over-the-air communication. But, on the other hand, the core network in LTE architecture is based on a traditional IP network meaning that it is quite open and vulnerable to attacks such as distributed denial of service attacks. Hence, at the core network there would be a need for the deployment of an intrusion detection and prevention system so that the above mentioned attack could not succeed.

While making the network secure it is also necessary to make and provide a safe communication environment for the terminals as well: In recent days we have seen that attackers decrease the battery power of the terminal by sending bogus signals and consume end terminal resources.

We know that LTE is an evolving technology and over a period of time it will mature and will give quite a huge benefits as it promises. The early deployment of LTE architecture will give us a broader picture of issues such as security, architectural complexity, interoperability and backhaul requirement. But it is assumed that from its launch LTE will fulfill and deliver all the promises related to higher network capacity, greater user experience in terms of better voice quality, high quality of data services, and long and sustainable battery life.

Chapter 5

Femtocellular Aspects on UMTS Architecture Evolution

This chapter provides extensive knowledge about femtocells, their future scope and architectural options in their deployment. This chapter explains a new concept for femtocells that is called Local IP Access and proposes LIPA-based 3G and 4G femtocell architecture solutions for practical deployments.

5.1 New challenges for Architecture Evolution

In order to maintain higher data rates, 4G systems require a good receiver signal level to increase system performance. However, various research results suggest that the majority of mobile users suffer from inadequate indoor signal penetration which actually leads to poor coverage provided to consumers and they do not enjoy the full data capacity marketed by the operators. 4G systems will facilitate high speed data services, but poor indoor coverage and interference will definitely diminish the quality of real-time applications and will significantly slow down high speed data services. In the traditional macrocell network, it is very difficult for operators to provide high quality services and cell coverage to indoor users. Because in order to improve indoor coverage operators need to install a huge number of outdoor base stations sites and this is nearly impossible in those areas that are densely populated. Even if operators manage to install more base stations then network planning and optimization become a challenging task for them, because frequency planning and handover management need more care in dense network deployment. 3GPP is continuously working towards the evolution of new communication models for the next generation mobile communication system. Recent attempts from 3GPP towards improved cell coverage and capacity have brought a new network element, the Home NodeB (HNB), into existing cellular network architecture. The name HNB is proposed by 3GPP in release 8 specifications [5]. The HNB is used especially in home and office environments and its introduction in the existing communication paradigm has already opened new opportunities for operators and service providers. A femtocell is as small private cell which operates on a 3GPP air interface. A femtocell produces a coverage range up to 30-50 meters with a low output power level typically less than 50mW [51].

In the present era, the HNB is usually called as a Femtocell or a Femto Access Point (FAP). Typically HNBs operate over the licensed spectrum and connect to the operator's core network by using a residential Internet connection [7]. A residential Internet connection can be based on a DSL, cable broadband connection, optical fiber or wireless last-mile technologies. Like a Wireless Local Area Network (WLAN) Access Point (AP), the HNB is a small device and it is installed by the user.

5.2 Femtocells

From the discussion about the femtocell in the previous section, we know that the femtocell or 'home base station', is a low-power access point which is basically used to enhance the traditional mobile communication system's coverage and capacity in home and office environments [7]. The femtocell enables users to access voice and broadband services over their own standard broadband Internet connection. A single femtocell supports usually at most four to eight simultaneous voice connections (concurrent maximum voice connection support in femtocell is implementation specific i.e. different products support different amount of simultaneous voice connections) in any indoor environment, permitting many authorized users to be able to connect to the femtocell to utilize services other than voice, such as text or real time multimedia streaming etc. the user's subscription model (service and charging) for femtocell services may vary according to user needs and depends upon operators. There are various factors that affect peak data rates such as the air interface technology used, the user subscription and broadband link capacity.

For supporting femtocells operations, the Home NodeB Gateway (HNB GW) and Home NodeB Management System (HMS) are new network elements that are introduced in release 8 [5]. The HNB GW is used as a concentrator for all traffic received from the HNB. In the femtocell logical architecture designed by 3GPP in release 8, the HNB GW is placed in the operator's premises. The HMS, on the other hand, is used to ensure that the services user is experiencing are of high quality and secured enough. Hence by analyzing the HMS and HNB GW functions, the HNB is considered as an integral part of the operator network.

Figure 5.1 illustrates a basic femtocell deployment model in a real world environment. In order to utilize femtocell services, a user will buy a femtocell and will connect to it through its own fixed broadband access. Upon being connected to the broadband access, the HNB will further connect to the operator's gateway; thereafter the HNB will be authenticated and configured according to the user's subscription policy. Femtocell access is usually available to a restricted number of authorized users. Thus ensures that the coverage area which is provided by femtocell, is only accessible by femtocell owner or by a trusted group of people.

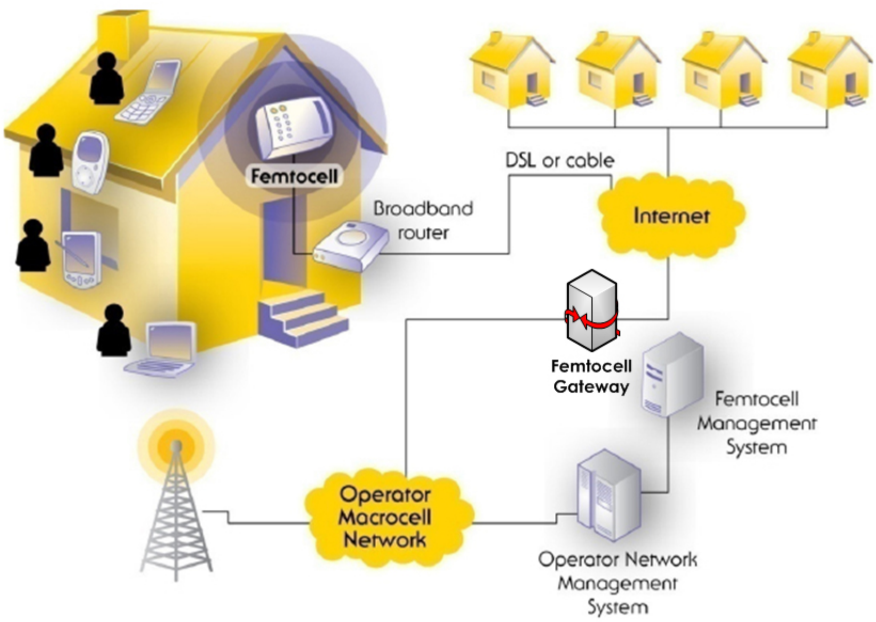

Figure 5.1: Basic femtocell network [57]

5.3 Femtocells Attributes and Future Scope

Femtocells use over-the-air standard protocols, to communicate with standard mobile devices. In flexible deployment scenarios, technology specific femtocells can be deployed easily with any existing and future technologies like GSM, LTE, WiMAX, etc [52]. Femtocells are gaining popularity because they can be used to access the radio link where radio service through traditional macrocells coverage cannot be provided. Furthermore, femtocells provide higher capacity by significantly minimizing the level of interference in home environments. Femtocells create extra network capacity with restricted user access; which allows users to enjoy higher data rate services like multimedia streams, online gaming, video and TV broadcasts. It is widely acknowledge that all mobile devices are power hungry. Moreover, in today's mobile communication system, maintaining terminal battery life is a challenge while providing high data rate services to the mobile stations. The use of femtocells will definitely save UE battery. This is because femtocells offer much smaller distance between the UE and HNB compared to the much larger distance typically between the UEs and macrocells.

The femtocell operates in the licensed spectrum, and assures no interference from unauthorized users, using DSL, broadband connections and optical fiber or wireless last-mile technologies as backhaul to transport data over the Internet protocol. Moreover, the femtocell is a 'Zero-Touch' self organizing and self manageable consumer device [49] which requires no prior configuration and settings. When turned on, femtocells set themselves up according to network conditions. The femtocell can also be used as a central point of service distribution in the home environment. With the integration of Ethernet switch or DSL router functionalities, all IP-enabled domestic devices can connect to the femtocell and it will further facilitates them to access the Internet [50].

Applications of femtocells are not limited to only home users. In a broader perspective, femtocells can be utilized for a wider set of applications. One application of femtocells is to use them in corporate environments. Unlike home installations, in offices more than one femtocell could be used depending upon the size of the organization. In this type of arrangement the femtocell can also be connected with other IP-enabled devices such as Private Branch Exchange (PBX), printers and LANs, etc. Additionally in enterprises, handover between femtocells will be needed. Another model of femtocell application could be to use them in aircrafts, trains or in passenger ferries. This type of femtocell deployment can use satellite as a backhaul.

From operator's point of view, significant amount of traffic can be offloaded from existing macrocell sites after femtocell deployment. Operators in future will need a fewer number of macrocell sites in the presence of the femtocell. This reduction in macrocell sites will produce more revenues for the operators, because operators will save their CAPEX by simply not investing in the radio access network. A similar type of saving will also be achieved by spending less money on site surveys, planning and renting of base station sites.

Figure 5.2 shows the expected global acceptance of the femtocells globally upto the year 2012 [53]. The percentage in figure 5.2 shows the femtocell deployment trends based on the above aspects that makes the femtocell an attractive solution for both end-users and operators in different countries.

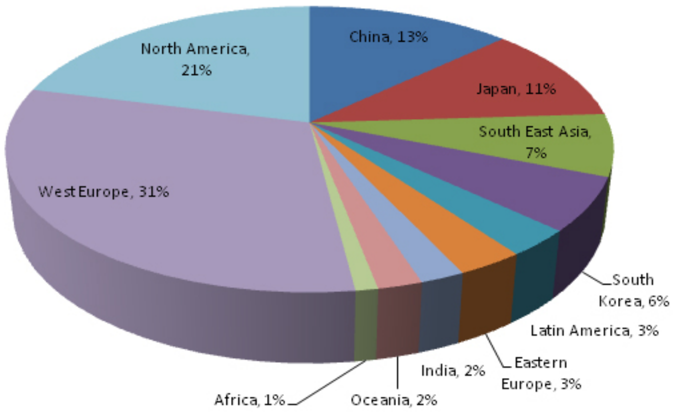

Figure 5.2: Expected 3G femtocell deployment market till 2012

5.4 Femto Network

A femto network consists of a femtocell and various other supporting network elements, and a combination of these elements provide communication security, network provisioning, network management and integration. The typical elements of a femto network are listed below.

5.4.1 Femtocell Access Point/Home NodeB

The HNB is considered as a plug-and-play consumer device. It is zero touch portable equipment, which is easily installed by the users in home and office environments. The HNB uses the subscriber's broadband backhaul to connect to the operator's core network. Technology specific HNBs can provide 3G, 4G or WiMAX coverage for indoor use. Typically the HNB provides dedicated coverage to authorized users over the licensed spectrum, which leads to good QoS and enriches end-user service experience. Furthermore, HNB uses the standard 3GPP Uu over-the-air interface to communicate with the mobile devices. Figure 5.3 illustrates the typical key attributes of the femtocell.

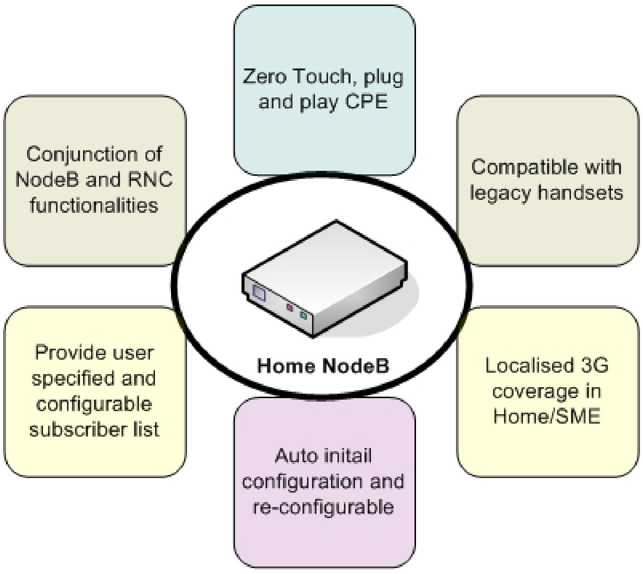

Figure 5.3: Home NodeB key features

5.4.2 Home NodeB Gateway (HNB GW)

As per 3GPP release 9 [5], RAN functionality is distributed between the HNB and the HNB GW. The HNB GW in a femto network is used to provide various functions related to link security, control, and aggregation. In femto network architecture, the HNB supports radio management functions whereas the HNB GW maintains the core network connectivity functions. The HNB and HNB GW work together to perform certain operations which cannot be fulfilled without each other's contribution. Paging is one kind of operation which needs HNB and HNB GW cooperation.

The HNB GW may optionally have Authentication, Authorization and Accounting (AAA) functions in it [54]. AAA functions in the HNB GW improve the level of secure access that is provided by the HNB. Typically the AAA server resides in the operator's core network along with the HLR/HSS. In the HNB GW, AAA functions enable authentication services such as EAP-SIM [48] and EAP-AKA [48] between the HNB and the HLR/HSS. These authentication services are known as the Extensible Authentication Protocol-Subscriber Identity Module and the Extensible Authentication Protocol-Authentication and Key Agreement and both are specified in 3GPP release 9 [48].

The HNB GW may also have MGW functionality in it. The HNB GW supports the H.248 MGW protocol [7] to handle HNB initiated circuit-switched requests. The MGW functions typically terminate at the MCS in the operator's core network. The HNB GW facilitates authentication and authorization functions for the HNB during the registration process. The operational functionality of the HNB GW that is described above can be divided into separate network elements in accordance with operator requirements. A Security Gateway (SeGW), AAA functions or a MGW can be manufactured as standalone devices or in one possible combination: the HNB GW may acquire a SeGW and AAA functionalities whereas the MGW can be used as a separate network entity.

5.4.3 Security Gateway (SeGW)

In a femto network, a SeGW is used to provide a secure communication link between the HNB and the core network. The SeGW enables HNBs to create end-to-end secure Internet Protocol Security (IPSec) tunnels [48]. The SeGW also provides secure data access with the help of the GPRS Tunneling Protocol (GTP) [45] over the Iu-PS interface and it runs inside the IPSec connection. The GTP tunnels usually forms between the RNC and the SGSN and between the SGSN and the GGSN which resides in the core network. With the help of these tunnels, the SeGW provides protection of data integrity.

5.4.4 HNB Management System (HMS)

The functionality of the Home NodeB Management System (HMS) is based on the TR-069 [7] family of standards. The HMS is used to provide Operation Administration Maintenance and Provisioning (OAMP) [49] functions to the HNBs. It empowers operators to control and manage the configuration of HNBs. Furthermore, it produces fault reports and collects different performance variance from the HNBs. With the HMS, an operator grants access to HNBs with additional services and applies service usage policies.

5.4.5 Iu-h Interface

The Iu-h is a multifunctional interface which is used to transport all the messages and procedure between the HNB and HNB GW. The Iu-h uses the Stream Control Transmission Protocol (SCTP) [46] to transfer control and signaling messages to and from the HNB and HNB GW. The messages and procedures are transported over IPv4 and IPv6 through the Iu-h interface. This is the only interface which is used by the SeGW and AAA function to provide an IPSec end-to-end tunnel and ensure data integrity.

5.5 3G Femtocell Architecture

The first step towards the development of a 3G femtocell was taken by 3GPP, when it specified services and requirements for HNBs in Release 8 [5]. The 3G femtocell architecture is based on the UMTS architecture with some additional UTRAN architectural enhancements according to the need to support femtocell functionality. The 3G femtocell architecture defines the use of the Home NodeB (HNB) and Home NodeB Gateway (HNB GW) in place of the NodeB and Radio Network Controller (RNC), specified in the traditional UMTS network architecture. Figure 5.4 shows the 3G femtocell logical architecture defined by 3GPP.

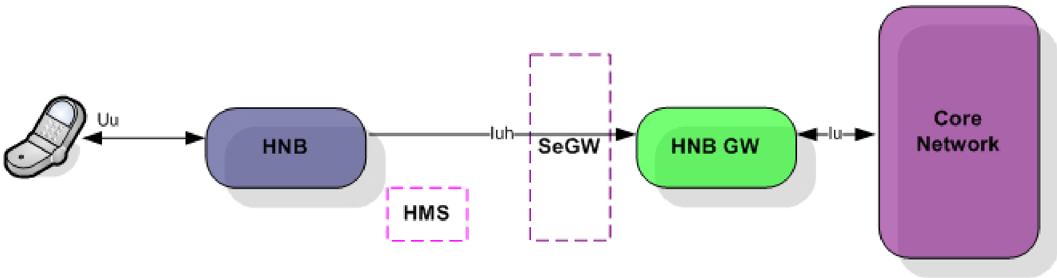

Figure 5.4: 3G femtocell logical architecture

In the above 3G femtocell logical architecture, user equipment (UE) connects to the HNB via the Uu interface. This interface is the standard WCDMA radio interface between the UE and HNB. HNB(s) provides dedicated mobile coverage and capacity in the homes, and, typically, this low-power access point which operates in the licensed spectrum, connects to the HNB GW through the Iuh interface.

The Iuh is a new interface which is specified in release 8, and it is used to link the HNB and HNB GW, inheriting a basic set of functionalities from the Iu interface as discussed in Chapter 3. 3GPP has made some simplifications and additions in order to adjust this interface specifically for 3G a femtocell. The Iuh Interface provides control and user plane functionalities, along with the basic set of functions for the user plane, such as, Radio Access Bearer management, Radio Resource Management, Mobility management and security, etc. Furthermore, the Iuh Interface also performs some additional control plane functions, such as HNB registration, UE registration to the HNB and error handling. There is many to one relationship between HNB(s) and the HNB GW.

The functionality of the Home NodeB Management System (HMS) is based on the TR-069 family of standards. In the 3G femtocell architecture, the HMS set of functionalities includes the discovery of the HNB GW, location verification of the HNB and the assignment of serving elements to the serving network. The use of the HNB GW in 3G femtocell architecture enables better mobility and Operation Administration and Maintenance (OAM) function for UEs. According to the service requirements defined in 3GGP release 9, the HNB GW is used to provide a concentration function for both the control and the user planes. The HNB GW is designed in such a way that it can be used optionally to provide concentration function just for the control plane as well. Moreover, the HNB GW aggregates a large number of HNBs with the Iu interface to the core network. The functionality of the Iu interface is divided between two interfaces, the Iu-PS and Iu-CS. The HNB GW simultaneously interworks with circuit-switch signaling to standard MSC and packet-switched signaling to a standard SGSN through the Iu CS and Iu PS interfaces, respectively.

The security gateway in 3G femtocell architecture is considered as a separate logical entity. The Security Gateway (SeGW) in the 3G femtocell architecture is used to manage and terminate secure IPSec tunnels between the HNB and CN. The SeGW provides protection against potential security threats and network attacks that may occur when mobile traffic is exposed to the public access network. Implementation of the SeGW in the 3G femtocell architecture is somehow vendor specific, whereby in some cases the SeGW comes as an integrated solution within a HNB GW, while in other cases it is a separate network entity.

The functionality of 3G femtocell architecture is separated in the UTRAN and the core network elements, these entities providing radio related functions, call routing and switching along with management of data connections to external networks respectively. Figure 5.5 shows the high-level functional architecture of 3G femtocells.

5.6 4G Femtocell Architecture

During recent years the concept of LTE is gaining momentum in the field of mobile communication systems. The first commercial LTE deployment has been recently witnessed in Norway and Sweden, where the operator TeliaSonera [55] has deployed

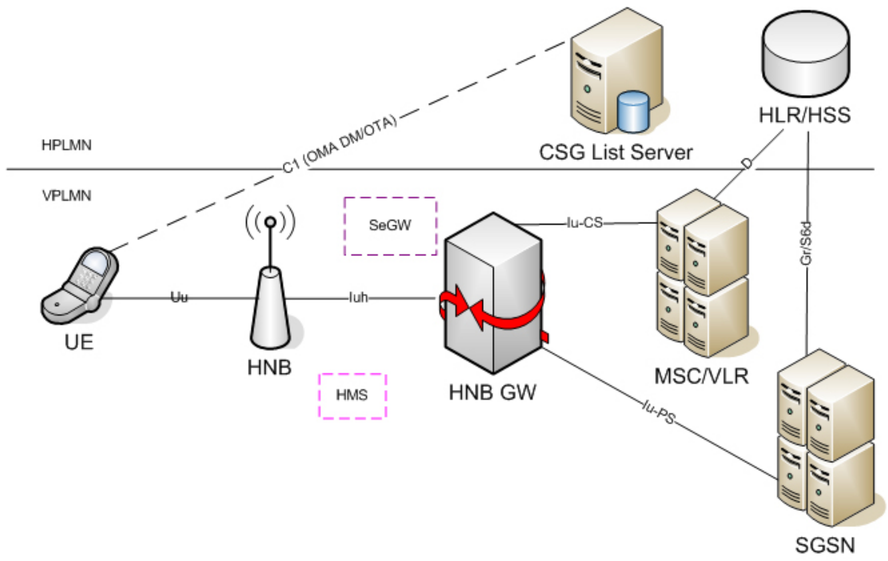

Figure 5.5: High-level functional architecture of 3G femtocell

the world's first 4G mobile communication network.

For a 4G femtocell, this would be quite early, since at this point in time we have only started to think about femtocell deployments and their business proposition in LTE system. This is because development of 4G femtocells is at an early stage, and even 3G femtocell deployments are still not mature enough. However, the femto industry is taking keen interest in the development of 4G femtocell standards. Recent news about 4G femtocell devices is heard from PicoChip [56], who claims that they have built a microchip (fully hardware and software based) for manufacturing 4G femtocell units. At the time of writing this thesis, no trace of 4G femto devices based on PicoChip solution have been found.

Currently, the standardization work of femtocells is in progress under 3GPP. Besides femtocell standardization work, some alliances like the Femto Forum [57] and the Next Generation Mobile Network (NGMN) [58] are rigorously discussing efficient development and deployment opportunities related to 4G femtocells.

Deployment architecture for 4G femtocell is far from being standardized yet. 3GPP in release 9 specifications has proposed three different architecture scenarios for future 4G femtocells [47], but it seems that 4G femtocell deployments will be based on operator specific needs and requirements. Because in any case, with 4G femtocell deployment, operators will have to maintain LTE's all-IP based flat architecture.

The architecture that is proposed by 3GPP for the 4G femtocell is similar to LTE's

EPS architecture with some additional network elements like the Home Evolved NodeB (HeNB) and the HeNB Gateway (HeNB GW). All functional elements of the 4G femto network, inherit operational functionality as defined by 3GPP for the LTE communication system [6]. It is important to note that 4G femtocell network architecture is a combination of the 3G femtocell architecture model and LTE operational functionality. Similar to the 3G femto network, in 4G femtocell architecture, the positions of the HeNB Management System (HeNB MS) and the SeGW are not static or fixed. The SeGW can be used as a separate network element or its functionality can be merged with the HeNB GW. The functionality of the HeNB Management System (HMS) is based in the TR-069 family of standards. Both the mentioned network entities perform their operations based on service requirements specified by 3GPP as per release 9. Figure 5.6 illustrates the 4G femtocell logical architecture as defined by 3GPP.

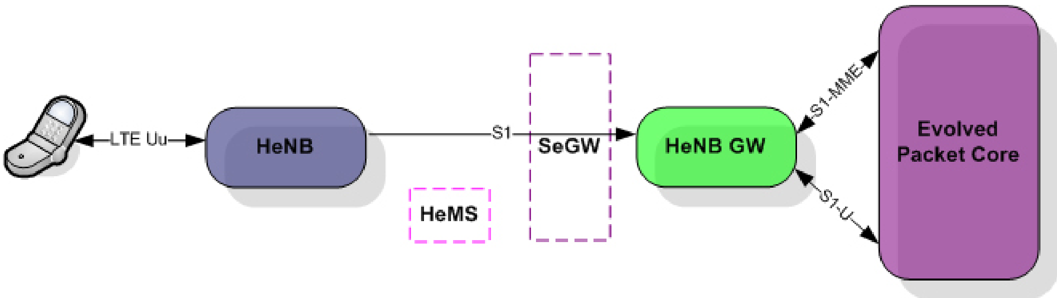

Figure 5.6: 4G femtocell logical architecture

5.6.1 4G Femtocell Architecture Variations

On the basis of the general and specific requirements, 3GPP has proposed three logical architectures for the successful deployment of 4G femtocells. These architectures can be used in a variety of situations and as per the operator's operational requirements. Furthermore, with the advancement of Local IP access (LIPA) and Selected IP Traffic offload (SIPTO) [7, 50], more functional variations can be expected in the mentioned 4G HeNBs deployment scenarios.

5.6.2 First 4G Femtocell Architecture Variation

Figure 5.7 depicts the first rational architecture that will satisfy all the 3GPP requirements and become attractive for the vendors, because of its pretty straightforward deployment scenario. This is a very balanced femtocell architecture and it works by discovering the availability of the serving HeNB GW.

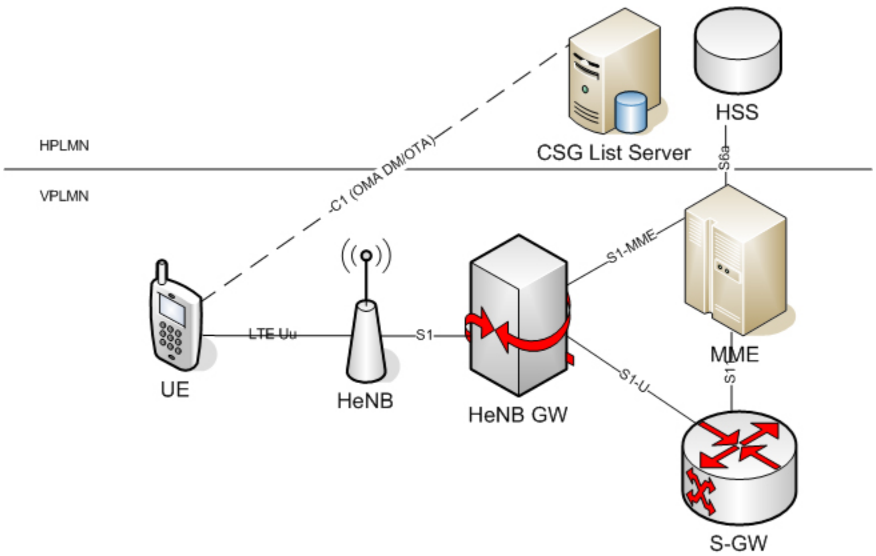

Figure 5.7: First 4G femtocell architecture variation: Dedicated HeNB GW

In this architecture, the HeNB will only connect to a single HeNB GW due to the specific requirements mentioned in the 3GPP specification which defines the architectural aspects of the Home NodeB and Home eNodeB [48]. Hence there will only be one to one mapping between the HeNB and HeNB GW. The HeNB GW is an operator device and it will be placed in the operator's network. The HeNB GW will not create simultaneous connections to the MME while facilitating one HeNB. This is because after authentication of a HeNB, for the transportation of user data in a secure manner there would be a GTP tunnel, IPSec tunnel and SCTP end-to-end session enabled from the HeNB to the MME [46, 45, 48]. In this 4G femtocell architectural variation, all UEs will be capable of handling close subscriber group functionality, such that they can maintain a list of CSG identities. These identities will help in granting the authorized access to those who are members of an associated CSG group [7]. In the case when UEs are not successful in gaining access to the CSG cell, they will be notified with the cause of failure.

5.6.3 Second 4G Femtocell Architecture Variation

Figure 5.8 illustrates another variation of the femtocell architecture without physical existence of the HeNB GW. It is important to note here that all three different architectural variations in this report are based on the distribution of HeNB GW functions among other femto network entities and its physical arrangements. The network entities shown in these different versions of femtocell architectures provide the same functionality that has been described as per Release 8. It is studies that in order to increase system performance and efficiency, functional operation of different network devices are integrated in one device in such a manner that the newly developed network entity can perform better work under certain conditions with other network entities. In the architecture with no physical HeNB GW, the functionality of the HeNB GW is actually integrated between the HeNB and the MME by reducing the network cost and latency.

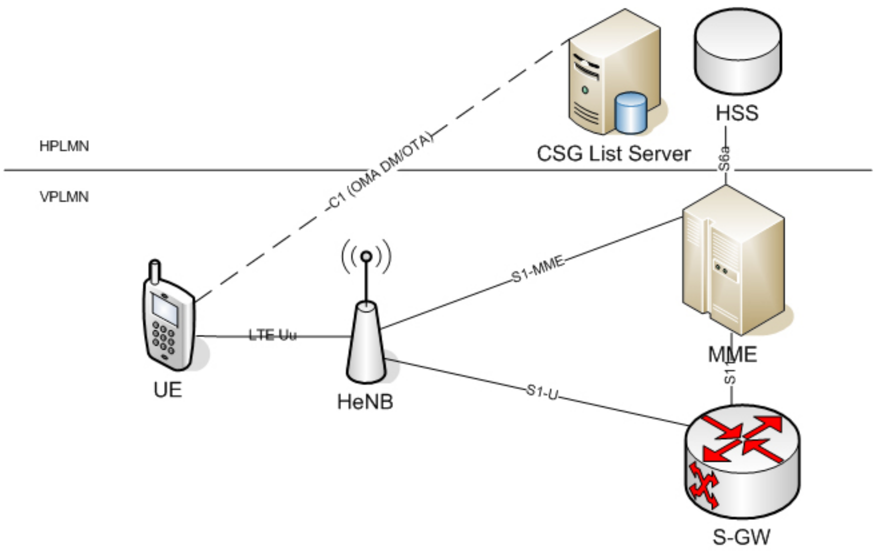

Figure 5.8: Second 4G femtocell architecture variation: No physical HeNB GW

This architecture also enables the HeNB to be self configurable [49] like other femtocell variations, opening several doors for the concept of a self organizing HeNB such that the HeNB would be used as a plug-and-play device and would be deployed without any network planning. A user can move with his HeNB to any new position or can change one geographical location to another and, therefore, the HeNB will just need to connect to the Internet according to its new location. Distributing the HeNB

GW functionalities in the HeNB and CN might cause performance degradation in HeNBs. But at the time of writing this report we have no numbers to measure and analyze performance issues in the HeNB, thus we cannot predict exactly how this architecture will affect the service delivery of 4G communication systems.

5.6.4 Third 4G Femtocell Architecture Variation

We know that the HeNB GW acts as a concentrating device for both the control and user plane signaling [5, 6, 7]. On the other hand, we also know that the S1-U interface which transports user plane signaling can also be terminated in the S-GW. Figure 5.9 shows deployment variation of 4G femtocell architecture in which the HeNB GW will only be used for aggregating the control plane signaling while the user plane will be directly terminated on the S-GW [19]. In this way, by simply not using the HeNB GW for transporting user plane signaling the efficiency of data packet delivery to the S-GW will increase. This will naturally increase the overall data packet transport efficiency in the whole network.

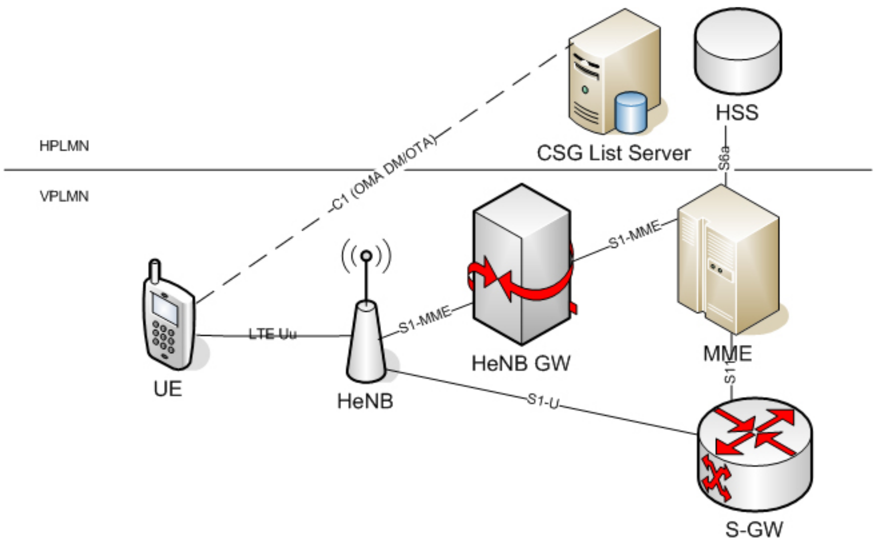

Figure 5.9: Third 4G femtocell architecture variation: HeNB GW for C-Plane

As per the 3GPP specification, there should be many-to-one mapping between the HeNB and the CGS, such that each cell of the HeNB will have a distinguished CSG IDs. It is important to note that in all the mentioned femtocell architectures, the MME is responsible for providing access control for the UEs accessed through CSG cells during the process of attach, combine attach, detach, and service request as well as during the Tracking Area Update (TAU) procedure [7].

5.7 Local IP Access

Femtocells fulfill the flat IP architecture requirements where the network operations are performed at the edge of the operator's network. With the advent of the HNB in release 8, it was envisaged that the HNB on the user premises will also support local access connections to other devices. The concept of Local IP Access (LIPA) [50] in the HNB, ensures IP connectivity to all IP-enabled devices in the home environment (IP-enabled devices can access each other locally through the LAN) and provides Internet or IP services without traversing through the mobile operator network or the HNB GW.

5.8 Role of Local IP Access in Femtocell Deployment

3GPP introduces the use of the local IP access (LIPA) in its release 9 service requirements for HNB and HeNB specifications and provides LIPA's general requirements especially for HNBs [7]. LIPA introduces the functionality in HNBs to access the home local area network and enable customers to use the Internet through Internet-enabled devices. Users, therefore, have the capability to have simultaneous access to the operator's network as well as having access to their own home local area network. The Local IP access offers new ways for customers by not overloading the operator's network and provides various content sharing, file sharing and real-time streaming services with fast and secure data transfer through the LAN. Figure 5.10 gives the high-level architecture for LIPA-enabled femtocell deployment.

With the introduction of LIPA to the HNB in release 9, 3GPP has also specified LIPA's general requirements for HNBs such that by following these requirements customers, operators and ISPs can all take benefits from the operations that are offered by LIPA in 3G and 4G networks. One of the requirements which is also described earlier is that with LIPA a user can have simultaneous access to both the operator's and their own home local area network. Clearly the use of LIPA should not make the network vulnerable and introduce security risks, especially for the operator's network. It is also not necessary for all users to have LIPA functionality within the femtocell coverage area. LIPA access will only be granted to UEs who ensure a valid subscription to the HeNB. Similarly for IP access to the Internet, it is also not necessary for any request to traverse through the operator's network. Some of LIPA's requirements depend upon the regulatory and Service Level Agreements

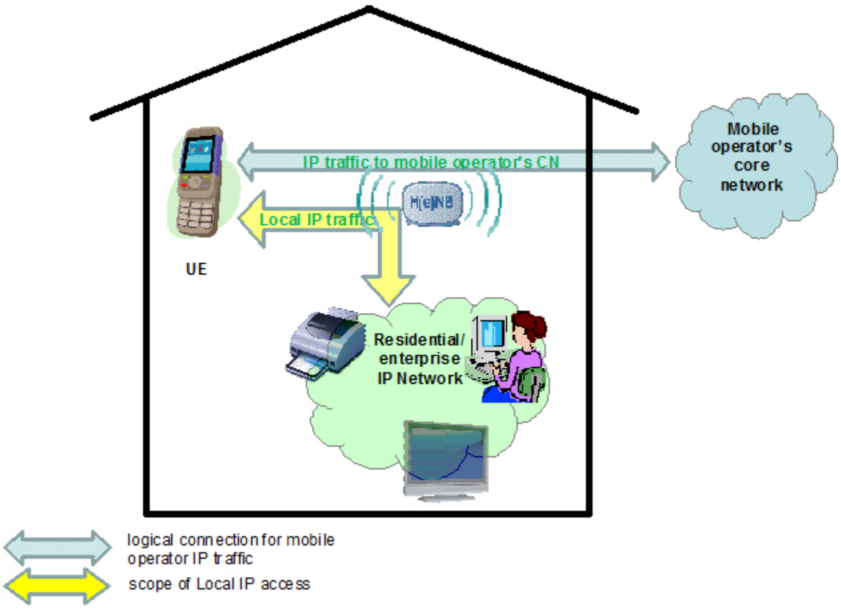

Figure 5.10: High-level functional architecture of LIPA

between customers and operators which empower operators to enable and disable LIPA functionality on the HNB.

5.9 Femtocell Architecture issues with LIPA

In order to minimize data traffic load from the wireless core network, we can enable LIPA's functionality within three different logical architectures, discussed in Section 5.6.1, in two different ways; Firstly with LIPA, the HeNB will facilitate the UE to have two simultaneous data connections, one through the operator network and the other with the local router. Secondly, LIPA will enable the HeNB so that any data connection can directly be routed through the HeNB to the LAN. The approaches discussed below are based on the architecture aspects of the Local IP access and comprise of two different scenarios.

5.9.1 Scenario 1

Simultaneous connections from UE to Operator's and LAN through the HeNB

LIPA will introduce certain question in this approach such that if the UE will request to set up multiple simultaneous transmission paths with the HeNB then which network entity will be responsible for allocating multiple IP addresses to the

UE? This question further opens the door for the availability of a Dynamic Host Control Protocol (DHCP) client for the applications at the UE, meaning that the UE must be able to acquire an IP address when applications will need to setup data links separately. Another problem may arise, when having two different data paths: how the HeNB will distinguish which path is for the EPC and which one is for local network access? Last but not least, when the UE will request for a second data path to the HeNB, how will the HeNB respond and what (message, request or query) will be initiated in the HeNB to set up radio bearers for the UE?

5.9.2 Scenario 2

Single connection to Transport Data Traffic from UE to Operator's Core and LAN

Local IP access provides flexibility for customers to have a separate connection while accessing operator's core and LAN. While offering this flexibility, however, it is important to know how capable the HeNB is while transferring data packets directly to both the differently addressed networks. Will the transportation of data occur transparently or will the HeNB try to make a tunnel for all those packets which will not traverse through the operator's network? It is also important to note that when the UE sends packets to the global Internet how will the HeNB and routers in its path know the UE's IP address? In the presence of different operators and ISP, it will be difficult to route packets because the packet data network gateway (P-GW) [17] will assign a different subnet IP address to the UE compared to the subnet with which the home network will be configured.

5.10 Solutions Offered by LIPA

With the introduction of various issues, LIPA also provides solutions to all the problems that are discussed above in the LIPA-enabled femtocell logical architectures. Here, in this paper we only propose two possible solutions.

5.10.1 Solution 1

According to release 9, separate packet data network (PDN) connections [59] will be established between the UE and core network before utilizing LIPA services. This means that before establishing multiple simultaneous connections, first the UE will be authenticated, authorized and registered by the operator's network, and then the UE will be able to access LIPA services. To ensure LIPA services, all the PDN connections that are enabled through the HeNB will be treated as local

PDN connections. To enable local PDN connections, the UE would be configured with different Access Point Names (APNs) [50] and, in the case when the UE needs to establish two simultaneous connections with the HeNB, then the UE will be configured with two different APNs, such that one APN will be used to provide access to the P-GW, and the second one will be used to establish a connection with the local router. The P-GW in the core network will allocate the IP address; if an active PDP context request with an APN will be routed by the HeNB towards the EPC. Similarly, a DHCP server that would be configured at the HeNB, will allocate the IP address if the APN request will point to a route through the local IP network. It is important to note here that local IP addresses are allocated by the DHCP server in the LAN. HeNB must first apply addresses from it using DHCP, before it can offer addresses to UEs. The HeNB through the HeNB-GW will be responsible for terminating session management signaling to the core network and will be used to set up radio bearers for the UE.

5.10.2 Solution 2

Unlike the first solution, this solution proposes a single PDN connection between the UE and the core network meaning that the UE will operate with a single APN. According to release 9 [7], with a single PDN connection, a UE may simultaneously access the LIPA service and the operator's core network. Like the first solution, assignment of the IP address would be done by the P-GW [17], in the core network, when an active PDP context request with an APN is routed by the HeNB towards the core network. This IP address will then be used by the HeNB when routing P-GW traffic towards the UE. This solution comes with NAT support in the HeNB. For accessing the local network, the HeNB will be responsible for mapping the IP address that will be obtained by the DHCP server with the IP address that would be obtained from the P-GW. This mapping will ensure that the traffic generated for the local access must reach its appropriate destination and vice versa. As discussed in the requirement of LIPA, an operator may enable/disable LIPA services at the HeNB. Hence depending upon the customer subscription, the MME will decide who is eligible for the LIPA service.

Chapter 6

Conclusions and Future Work

This chapter concludes the overall problem description, methodology and results gained during this thesis study. This chapter also identifies future research areas and interests related to the main problem statement of the thesis work.

6.1 Conclusions

The vision for the future mobile communication system is now shifting towards 'information at any time, at any place but only in packet switched format'. UMTS architecture evolution has changed both the service delivery and business models for operators and users. Two evolution drivers have rigorously changed the whole UMTS architecture model towards all-IP UMTS architecture: the continuous development in the UMTS system itself to achieve higher capacity and the extensive use of Internet (IP-enabled voice and multimedia applications) based real-time and non real-time communication. Moving towards UMTS evolution, 3GPP has played an important role to develop the framework for UMTS architecture evolution that provides wider bandwidth, lower latency and packet-optimized radio-access technology with high peak data rates.

The advent of the femtocell in UMTS architecture evolution has changed the expectation for broadband customer experience dramatically. Nobody could even have thought of receiving excellent broadband performance with excellent wireless coverage especially in homes during the past few years. The femtocell has turned itself into the only vaible solution, so far which is used to provide high quality packet-switched services at low cost. Femtocells simultaneously reduce the burden from the operator's core as well as offload traffic from the macrocell access network. Operators are seeing the femtocell as a cost effective solution that can be used to generate more revenue. 4G femtocell architecture variations provide a convenient way to the operators to deploy and facilitate femtocell services according to their business model. The use of LIPA in the HNB and HeNBs makes the femtocell an attractive solution for the users, because LIPA enables users to maintain simultaneous access with both their LAN and with the operator's networks.

The development of LTE/SAE [39] was envisioned during the evolution of the radio access network, because it was necessary that system architecture must also be evolved to provide simplified operations, smooth and cost-efficient deployment. LTE with IP-based flat network architecture incorporates fewer nodes, reduces inter-networking latencies and provides improved overall system performance. LTE also enhances the UMTS communication paradigm and provides improved cell capacity and coverage, multi-antenna support and seamless integration with existing radio access technologies.

The role of 3GPP in the evolution of mobile communication system is commendable. High level research, standardization and development are in progress and the journey of the system evolution is underway in 3GPP, because the world has to see the new era of mobile communication in the form to LTE-Advanced [24].

6.2 Future Work

The system architecture evolution is an ongoing process and does not stop with the advent of LTE. 3GPP is continuously working on different aspects to enhance over-the-air capacity and has been introducing the concept of LTE-Advanced, to improve the broadband user experience in a ubiquitous and cost-effective manner. LTE-Advanced is a candidate technology for the IMT-Advanced, and according to the circular letter issued by ITU-R, IMT-Advanced technologies will be using the Release 8 E-UTRA and E-UTRAN RAN and CN architectures and assumptions [6]. This all means that at an elementary level LTE-Advanced based femtocell solutions will be using the same femtocell architectures that have been proposed in this thesis work. These femtocell architectures can be used as building blocks for further study and development of LTE-Advanced femtocell architectures and to drive the efficiency and performance metrics of LTE-Advanced femtocell networks.

LIPA functionality will also remain the main point of focus in femtocell. Further evolution of system architecture with more operational scenarios for LIPA can be generated for LTE-Advanced enabled femtocells. Selected IP Traffic Offload (SIPTO) [7, 50] is another hot topic under discussion these days which closely relates to the femtocell. SIPTO offers seamless IP traffic offloading especially between 3G/4G and WiFi networks. Hence SIPTO functionality with femtocell (LTE and LTE-Advanced) also opens the door for further research in SAE.

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