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# The Future of LTE: The Femtocells perspective

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The Femtocell is one of the constituents of the LTE-Advanced technology components. It is categorized under the heterogeneous network's small cell concepts. In order to meet one of the most essential desires of mobile network - *better coverage and enhanced system capacity*, femtocell has offered and will offer most definitely a comprehensive solution to the service providers and subscribers alike.

A detail presentation of the past, the present and the future of the femto-cell technology has been studied and considered from the perspective of the LTE straight to LTE-Advanced; and tailored to the variants existence of the femto-cellular architecture.

The much benefits of the femtocells does leave some points of thought for challenges in the existing deployments; to the users', a concern for privacy and confidentiality; and to the operators, most importantly, cost reduction, better coverage and security. That did not leave out the quest to have improved system deployment by considering issues like Interferences, Mobility and Handover, Backhauling, Self-Organizing Networks, Synchronization and so on.

The aim of this thesis is to examine in a top-down approach the femtocells as an important component of the developing LTE-Advanced Technology, with essential projection into the future of the femto-cellular technology and what the future holds for its deployment for operators. *To loathe it or to like it!* The global success of the femtocells will determine its future at best.

Keywords: *LTE, LTE-Advanced, CA, HetNet, Femtocell, SON, MIMO, eMIMO, eNodeB, HNB, HeNB.*

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*Much...*

Thanks to my Family, *for the care and support;*

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Thanks to the friends I have known; *for the impact socially and technically;*

Thanks to the Almighty God, *for the Grace and Strength for completion.*

Oludayo John Oguntoyinbo

Espoo, 24.11.2013.

# DEDICATION

*...to the ones close to my heart ♡!*

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# Contents

<b>Abstract</b>	<b>ii</b>
<b>ACKNOWLEDGEMENT</b>	<b>iii</b>
<b>DEDICATION</b>	<b>iv</b>
<b>CONTENTS</b>	<b>vi</b>
<b>LIST OF ABBREVIATIONS</b>	<b>viii</b>
<b>LIST OF TABLES</b>	<b>xi</b>
<b>LIST OF FIGURES</b>	<b>xii</b>
<b>1 INTRODUCTION</b>	<b>1</b>
1.1 Overview and Motivation . . . . .	1
1.2 Objective and Scope of Thesis . . . . .	4
1.3 Research Methodology . . . . .	5
1.4 Thesis Outline . . . . .	5
<b>2 LONG TERM EVOLUTION (LTE)</b>	<b>6</b>
2.1 LTE Overview and Target System Requirements . . . . .	6
2.2 Overall LTE Architectural Overview . . . . .	8
2.2.1 Core Network . . . . .	11
2.2.2 The LTE Access Network . . . . .	12
2.2.3 The LTE Protocol Architecture . . . . .	14
2.3 LTE Multiple Access Technique . . . . .	16
2.3.1 Downlink: OFDMA . . . . .	16
2.3.2 Uplink: SC-FDMA . . . . .	21
<b>3 LTE-ADVANCED</b>	<b>22</b>
3.1 LTE-Advanced E-UTRAN Overview . . . . .	26
3.2 Carrier Aggregation . . . . .	27
3.3 Enhanced Multi-Antenna Support . . . . .	29
3.3.1 SU-MIMO . . . . .	30
3.3.2 MU-MIMO . . . . .	30
3.3.3 Co-MIMO . . . . .	31
3.4 Cooperative Multi-Point Transmission and Reception . . . . .	31
3.5 Improved Support for Heterogeneous Network Deployment . . . . .	34
3.6 Relaying . . . . .	36
3.6.1 Relay Classification . . . . .	37
3.7 Summarized Comparison of LTE and LTE-Advanced . . . . .	37

<b>4</b>	<b>FEMTOCELLS</b>	<b>39</b>
4.1	Femtocells Overview . . . . .	39
4.1.1	Basic definition of femtocell . . . . .	39
4.1.2	Benefits of femtocell . . . . .	40
4.2	Femtocells Technologies . . . . .	41
4.3	Challenges of Femtocells . . . . .	42
4.3.1	Interferences . . . . .	43
4.3.2	Mobility and Handover . . . . .	44
4.3.3	Backhaul . . . . .	45
4.3.4	Self-configuration and Network Interoperability . . . . .	46
4.4	Typical Femto-cellular Network . . . . .	46
4.4.1	<i>Iuh</i> Interface . . . . .	47
4.4.2	HNB Management System, HMS . . . . .	48
4.4.3	Security Gateway, SeGW . . . . .	48
4.4.4	Home Node B Gateway, HNB-GW . . . . .	48
4.4.5	Home Node B, HNB . . . . .	49
4.5	Architecture Model of an HNB Access Network . . . . .	49
4.6	LTE Femtocells . . . . .	49
4.6.1	Variant 1 of LTE Femto-cellular Architecture . . . . .	51
4.6.2	Variant 2 of LTE Femto-cellular Architecture . . . . .	52
4.6.3	Variant 3 of LTE Femto-cellular Architecture . . . . .	53
4.6.4	Other possibilities . . . . .	55
<b>5</b>	<b>FUTURE OF FEMTOCELLS</b>	<b>56</b>
5.1	General perspective on the femtocells future . . . . .	56
5.2	Technical Challenges for the future . . . . .	57
5.2.1	Security and Backhaul . . . . .	57
5.2.2	Self-Organising Networks (SON) . . . . .	59
5.2.3	Interferences . . . . .	60
5.3	Small Cells today and the future . . . . .	61
<b>6</b>	<b>CONCLUSION</b>	<b>62</b>
6.1	Concluding Remarks . . . . .	62
6.2	Will the future be in 5G Femtocells? . . . . .	63
	<b>REFERENCES</b>	<b>64</b>

## LIST OF ABBREVIATIONS

3G	3rd Generation
3GPP	3rd Generation Partnership Project
4G	4th Generation
5G	Fifth Generation
AAA	Authentication, Authorization and Accounting
AS	Access Stratum
AuC	Authentication Centre
C2C	citizen-to-citizen
CA	Carrier Aggregation
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CN	Core Network
Co-MIMO	Cooperative Multiple-Input Multiple Output
CoMP	Coordinated Multi-Point
ConCA	Contiguous Carrier Aggregation
CP	Cyclic Prefix
C-Plane	Control Plane
CR-Enabled	Cognitive Radio Enabled
CS/CB	Coordinated Scheduling/Beamforming
CSG	Closed Subscriber Group
DL	Downlink
DoS	Denial of Service
E-DCH	Enhanced Dedicated Channel
EDGE	Enhanced Data rates for GSM Evolution
eMBMS	Enhanced Multimedia Broadcast/Multicast Services
E-MIMO	Enhanced Multiple-Input Multiple Output
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-SMLC	Evolved Serving Mobile Location Centre
ESP	Encapsulating Security Payload
E-UTRAN	Enhanced Universal Terrestrial Radio Access Network
FAP	Femto Access Point
FBS	Femto Base Station
FDD	Frequency Division Duplexing
FFT	Fast Fourier Transform
GPRS	General Packet Radio Service
GSM	Global System for Mobile Technology
GTP-U	GPRS Tunnelling Protocol User Plane
HAP	High Altitude Platform
HARQ	Hybrid Automatic Repeat Request
HeNB	Home eNodeB
HeNBS	HeNB Subsystem
HetNet	Heterogeneous Network



HMS	Home Node B Management System
HNB	Home Node Base
HNB-GW	Home Node B Gateway
HPLMN	Home PLMN
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSS	Home Subscriber Service
HSUPA	High Speed Uplink Packet Access
ICI	Inter-Carrier Interference
IFFT	Inverse Fast Fourier Transform
IMT	International Mobile Telecommunication
IMT-A	International Mobile Telecommunication Advanced
IoT	Internet of Things
IP	Internet Protocol
IPSec	Internet Protocol Security
IPSec ESP	IPSec Encapsulating Security Payload
ITU-R	International Telecommunication Union Radio-communication Sector
L1	Layer 1
L2	Layer 2
L3	Layer 3
LIPA	Local IP Access
LMDS	Local Multipoint Distribution System
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
MAC	Medium Access Controller
MBS	Macro-cellular Base Station
MC-MA	Multiple-Carrier Multiple-Antenna
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
MSC	Mobile Switching Centre server
MU-MIMO	Multiple User Multiple-Input Multiple Output
NAS	Non-Access Stratum
NConCA	Non-Contiguous Carrier Aggregation
NSA	National Security Agency
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operational Expenditure
PAPR	Peak-to-Average-Power Ratio
PCC	Policy and Charging Control
PCEF	Policy Control Enforcement Function
PCI	Physical Cell Identification
PCRF	Policy and Charging Rules Function
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network

P-GW	Packet Data Network Gateway
PHY	Physical Layer
PLMN	Public Land Mobile Network
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RACH	Random-Access Channel
RAN	Radio Access Network
RLC	Radio Link Control
RRC	Radio Resource Control
RRH	Remote Radio Head
RTT	Round Trip Times
SAE	System Architecture Evolution
SC-FDMA	Single Carrier Frequency Division Multiple Access
SCN	Small Cells Network
SCTP	Stream Control Transmission Protocol
Se-GW	Security Gateway
S-GW	Serving Gateway
SIPTO	Selected IP Traffic Offload
SON	Self Organising Networks
SU-MIMO	Single User Multiple-Input Multiple Output
TDD	Time Division Duplexing
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System
U-Plane	User Plane
UTRAN	Universal Terrestrial Radio Access Network
VoIP	Voice over Internet Protocol
VPLMN	Visited PLMN
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Inter-Operability for Microwave Access

## List of Tables

2.1	Evolution of UMTS specifications . . . . .	6
2.2	The LTE Main interfaces . . . . .	14
3.1	IMT-Advanced Requirement and LTE fulfilments [72]. . . . .	22
3.2	Low power node categorization for HetNets . . . . .	35
3.3	Summarized Major Comparison of LTE and LTE-Advanced [23]. . . . .	38

## List of Figures

1.1	Cisco Forecasts 11.2 Exabytes per Month of Mobile Data Traffic by 2017 [56] . . . . .	2
1.2	Growth of transferred data in Western Europe [54] . . . . .	3
2.1	Architecture for 3GPP access networks (Adapted from [62]). . . . .	9
2.2	The EPS showing Network Elements and Standardized Interfaces [61].	10
2.3	Functional Split between E-UTRAN and EPC [59]. . . . .	10
2.4	General E-UTRAN Network Architecture (Showing networks of eN-odeBs) [66]. . . . .	13
2.5	User Plane Protocol Stack (shown in grey) [61]. . . . .	15
2.6	Control Plane Protocol Stack [61]. . . . .	15
2.7	Subcarriers in multi-carrier systems [66]. . . . .	17
2.8	Time-Frequency Illustration for OFDMA [8]. . . . .	18
2.9	Typical LTE Frame Structure with CP [46]. . . . .	18
2.10	Resource Grid in LTE DL [68]. . . . .	19
2.11	LTE time-domain structure [63]. . . . .	20
2.12	LTE physical time-frequency resource [63]. . . . .	20
2.13	OFDMA and SC-FDMA Illustrative comparison [69]. . . . .	21
3.1	Capacity Target - 1000x Higher Efficiency Illustration [19]. . . . .	24
3.2	LTE-Advanced Goals Summary [73]. . . . .	24
3.3	LTE-Advanced: Key Ingredients [75]. . . . .	25
3.4	Technology evolution enabled for LTE-Advanced [75]. . . . .	26
3.5	LTE-Advanced E-UTRAN Architecture [20]. . . . .	27
3.6	Carrier Aggregation in FDD [74]. . . . .	28
3.7	Adaptive switching combination scheme [20]. . . . .	29
3.8	LTE-Advanced main MIMO modes [20]. . . . .	30
3.9	Centralised CoMP Architecture [20]. . . . .	32
3.10	Distributed CoMP Architecture [20]. . . . .	32
3.11	CS/CB CoMP Scheme [20]. . . . .	33
3.12	Joint Processing CoMP Scheme (a) Joint Transmission; and (b) Dynamic Cell Selection [20]. . . . .	33
3.13	Overall general overview of the HetNet [22]. . . . .	36
3.14	Basic Relaying Scheme. . . . .	37
4.1	Small cell comparison in terms of range. . . . .	40
4.2	Femtocell basic network [31]. . . . .	42
4.3	Perspective challenges on Femtocells. . . . .	43
4.4	Cross tier interference illustration [29]. . . . .	44
4.5	UTRAN Network Architecture (with CSG provisioning and Access Control) [12]. . . . .	47
4.6	Iuh Interface as shown in the 3G Femtocell logical architecture [3], [32].	48
4.7	Logical Architecture of an HNB Access Network [2]. . . . .	49
4.8	A simplified diagram of LTE Femtocell network architecture [15]. . .	50
4.9	The E-UTRAN network architecture for CSG provisioning and access control [12]. . . . .	50

4.10	LTE Femto-cellular Architecture: Variant 1 <i>with Dedicated HeNB-GW</i> [2], [11]. . . . .	51
4.11	LTE Femto-cellular Architecture: Variant 2 <i>without Dedicated HeNB-GW</i> [2], [11]. . . . .	53
4.12	LTE Femto-cellular Architecture: Variant 3 <i>with Dedicated HeNB-GW in C-plane only</i> [2], [11]. . . . .	54
4.13	Overall variations of the LTE Femto-cellular Architectural Network [15]. . . . .	55
5.1	A three-target malicious attacks on a femto-cellular network as shown indicated by the red arrow [90]. . . . .	59
5.2	Key 3GPP outline principles for SON [86] . . . . .	60

# 1 INTRODUCTION

## 1.1 Overview and Motivation

With recent growth in the use of mobile technology applications, the high demand in the use of voice and data services has created an unprecedented increase for alternative solutions to mobile broadband services. There has been statistical increase in the use of mobile devices for browsing the internet (web trending applications and websites, for examples, Facebook, and Twitter), video streaming (Russia Today, Al-Jazeera and Cable News Network (CNN) live broadcasts), Voice-over Internet Protocol (VoIP) applications for internet calls (MobileVoIP and Skype), medical applications that run on real-time data loggings, video and voice calls and a number of new applications that has greater demands for high data traffic.

The most significant factor involved in this is that the service providers have been struggling to provide the demanded rates their customers want. Achieving a higher data rate with significant wider but better coverage has posed a bigger discussion in what could be the threat in meeting the subscribers' demands.

According to the Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, for 2012-2017, *"the overall mobile data traffic is expected to grow to 11.2 Exabytes per month by 2017, a 13-fold increase over 2012"* as shown in figure 1.1.

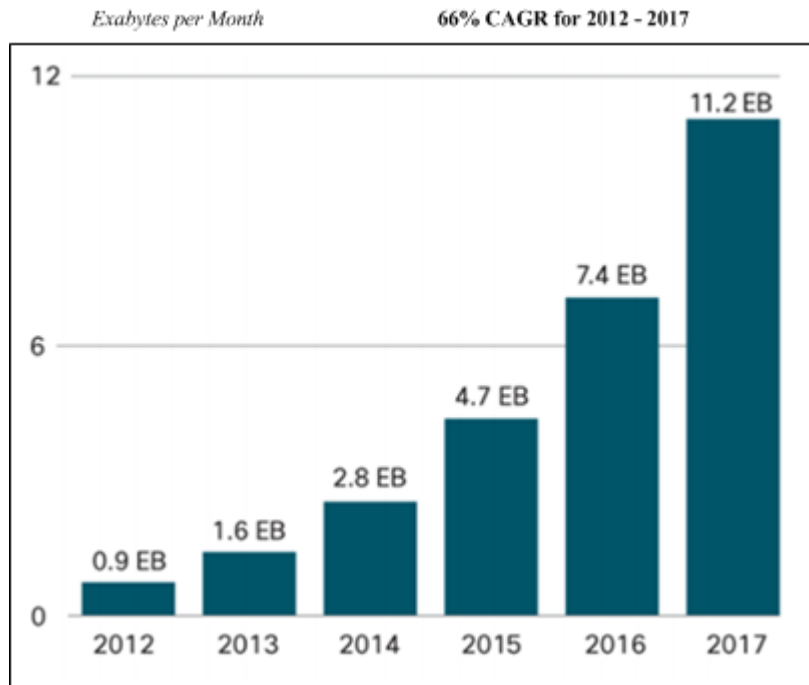


Figure 1.1: Cisco Forecasts 11.2 Exabytes per Month of Mobile Data Traffic by 2017 [56]

Additionally, it is expected that there will be Compound Annual Growth Rate (CAGR) of 66% from 2012 to 2017 for mobile data traffic [56]. This rate increase has been as a result of the tremendous effects of several connected devices that are becoming clustered in cloud computing and (the concept) of the Internet of Things (IoT). The alarming increase in the growth of transferred data in Western Europe is much with an average subscriber transferred data at 56.9 Gigabytes per month as shown in figure 1.2 [54].

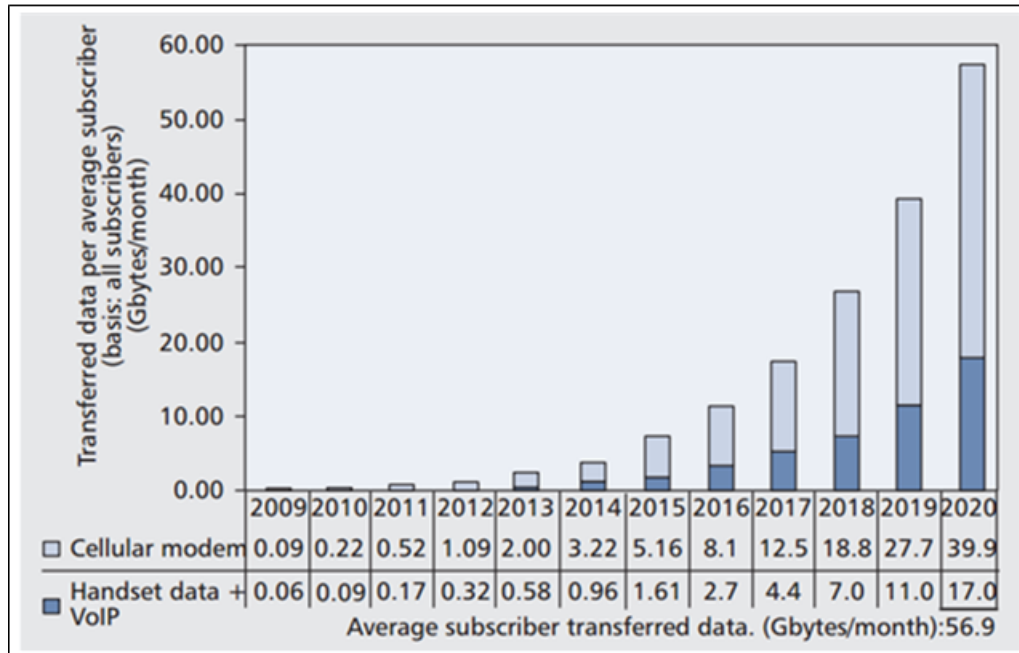


Figure 1.2: Growth of transferred data in Western Europe [54]

Mobile service providers have been working considerably hard to create innovative solutions in meeting the expanding network demands and the unprecedented growth rates in demands [55]. Some of the solutions that have been provided in combating these demands are the provisions of smaller cell sizes like microcells and nanocells to gain increased capacity in more populated areas, basements, underground motor ways, high building areas and so on. As discussed in [50], the use of the microcells and nanocells solutions offered effective solution but the relative cost in planning with corresponding equipment cost, power supply does not make these the best approach in combating the growth demand.

In eliminating the relative cost and offering a highly effective way for meeting the high rate demands, femtocells<sup>1</sup> have been introduced. The use of the femtocells in the offloading of traffic has helped to free considerable capacity and creates an improved user data experience [55]. Femtocells (also known as *Femto Base Station*, FBS) are characterized as *"inexpensive compact base station that provides equal radio access interface as a common macro-cellular base station (MBS) towards User Equipments (UEs)"* [53]; in other words, they are very small, low cost base stations with considerable low transmit power.

<sup>1</sup>*Femto* - one thousandth of a *nano*.



The FBS devices are deployed independently by the subscribers that so desire them in their residential or organizational premises as plug and play devices. They are relatively smaller and could be integrated in small casings or mountings on walls. One significant note is that the femtocells is backhauled to the service provider core network over internet protocol via the customers own broadband connection; also the device is powered locally from the customers' power supply [50], [55].

Nowadays, many service providers have started providing the femtocell services. According to Wireless Federation [52], Chunghwa Telecom in Taiwan has offered free femtocells to users offload the growing traffic, also, it has been reported that Vodafone Qatar and Telefonica Spain have made deployments likewise, with reports suggesting that the femtocells deployments has doubled within twelve months [76]. In the Tekes and Giga joint presentation, *Kotitukiasema (femtocells)* [51], it was estimated that the small base station market must have grown to 12 million units by 2014; considering Giga supports for Finland's national broadband strategy of 100 Megabits for all by the year 2015. In the development of femtocells, much attention has been given to Wideband Code Division Multiple Access (WCDMA) but the standard is getting much attention in WiMAX and LTE solutions likewise. In the third Generation Partnership Project (3GPP), the femtocell is referred to as a Home Node B (HNB) - 3G femtocells, and Home eNode B (HeNB) - LTE femtocell.

## 1.2 Objective and Scope of Thesis

Although, femtocell is significantly useful, there are concerns on how to improve the femtocells standard over the growing technology releases from LTE to LTE-Advanced. More importantly, in achieving peak data rates and support for larger bandwidths, femtocells need to grow and make use of the opportunity the LTE development offers.

This thesis examined and investigated the future of the LTE technology by looking at the femtocells perspective in correlation. The fundamental of the current deployment of femtocells is examined and relations to LTE femtocells are looked into. Also, the future of the femtocells is considered by looking into some of the technical challenges that need to be tackled with the growing technology, especially LTE-Advanced. In addition, some key problems facing the femtocells networks like Broadband femtocells (resource allocation, timing/synchronization and backhauling); Voice femtocells (interference management in femtocells, access allowance to

femtocells, handoffs, mobility and emergency services) and network infrastructure (with concerns for security). The extensive scope of this thesis presents a study into the past, the present and the future of femtocells with a perspective on LTE and LTE-Advanced.

### **1.3 Research Methodology**

As much as there are substantial amount of literature in existence, much focus has been made on originality of presentation. More also, the 3GPP specifications has been the major premise for a major part of the research work. Additionally, this thesis research was done by using the following methods: literature study of white papers, company (vendors, service providers and so on) perspective and journals, literature study on the femtocell technology, discussions and deduced forecast of the femtocell deployments.

### **1.4 Thesis Outline**

The thesis is organized accordingly, with Chapter 2 giving the general overview of the 3GPP LTE features and its emphasis on the basic structure and features.

Chapter 3 is used to present the LTE-Advanced technology components with examined view to make correlations with the major components of the technology.

The chapter 4 is used to describe the general overview of the femtocells by considering the femtocells concept with general technology and system architecture and abounding issues and challenges. The LTE femtocell is also discussed.

Chapter 5 examines the future of femtocells by looking into some technological challenging factors like Security and backhaul, Self-Organizing Network, enhanced MIMO, Interferences and other future issues.

Chapter 6 is on the summary and conclusion based on the study of femtocells. The conclusion is drawn from the chapters' examination and overall perspective on what the future of the femtocells looks like.

## 2 LONG TERM EVOLUTION (LTE)

### 2.1 LTE Overview and Target System Requirements

The Long Term Evolution (LTE) is the standard name given to the mobile technology project of the 3rd Generation Partnership Project (3GPP) to meet up with the set requirements for present and future needs of mobile communications. The 3GPP LTE project started in 2004. The introduction of the LTE is aimed at enhancing the Universal Terrestrial Radio Access Network (UTRAN). Its evolution is aimed towards achieving the fourth generation (4G) mobile technologies. The table 2.1 shows a progression towards the 4G technology based on the UMTS specifications evolution.

	Release	Functional Freeze	Main Radio Features of the Release.
1.	Rel-99	March 2000	UMTS 3.84 Mcps, WCDMA FDD and TDD.
2.	Rel-4	March 2001	1.28 Mcps TDD, also known TD-SCDMA.
3.	Rel-5	June 2002	HSDPA.
4.	Rel-6	March 2005	HSUPA (E-DCH).
5.	Rel-7	Dec 2007	HSPA+ (64QAM DL, MIMO, 16QAM UL), LTE and SAE feasibility study EDGE Evolution.
6.	Rel-8	Dec 2008	LTE work item - OFDMA air interface, SAE work, new IP core network, 3G femtocells, dual carried HSDPA.
7.	Rel-9	Dec 2009	Multi-standard radio (MSR), dual cell HSUPA, LTE-Advanced feasibility study, SON, LTE femtocells.
8.	Rel-10	March 2011	LTE-Advanced (4G) work item, CoMP study, four HSDPA.

Table 2.1: Evolution of UMTS specifications

Under the new LTE system which was to evolve around the 3GPP radio access technology over a period of time, some target summaries were made in order to give summarized targets and requirements for the LTE release 8 [61], some of these are:

- (i) Reduced delays, particularly on latency;
- (ii) Considerable increase in user data rates;

- (iii) Increased in cell edge bit rate, most especially for even provision of services;
- (iv) Decrease in cost per bit, which helps to improve spectral efficiency;
- (v) Absolute increase in flexibility for spectrum use;
- (vi) A better and simpler network architecture;
- (vii) Easy of access in terms of mobility; and most importantly
- (viii) Power consumption reduction for user equipment.

But most essentially, some of the early motivations [43] for the LTE have been the desired continuity in 3G system competition; stronger demand for higher data rates in addition to top Quality of Service (QoS); enhanced packet switch optimization and low latency; the desire for cost reduction in terms of the Capital Expenditures (CAPEX) and Operational Expenditure (OPEX) and considerable low design complexity. The revolutionary approach to reducing the OPEX is aided by the simplification in management of LTE network [57]. Most especially, the essence of the Self Organizing Network (SON) features introduction will considerably enable system self-configuration and self-optimization of networks which will apparently help in cost reduction and improved network planning.

In more technical perspective, some of the LTE requirement targets [7], [61] are itemized below:

1. The need for support for *scalable* or *flexible frequency* in bandwidths of 1.25, 2.5, 5.0, 10.0 and 20.0 MHz.
2. Initial peak *data rate* scaled with system bandwidth for Downlink (DL) for 2 RX Channel MIMO at peak rate of 100 Mbps in 20 MHz channel and for Uplink (UL) for single Channel TX at peak rate of 50 Mbps in 20 MHz channel.
3. Use of scheduling algorithms and supported advanced *multi-antenna* configurations which improves data rates, with DL -  $4 \times 2$ ,  $2 \times 2$ ,  $1 \times 2$  and  $1 \times 1$  and with UL -  $1 \times 2$  and  $1 \times 1$ .
4. *Spectrum efficiency* - DL 3 to  $4 \times$  HSDPA Release 6 and UL 2 to  $3 \times$  HSUPA Release 6.

5. **Latency** - For Control plane (C-plane), less than 50 - 100 ms to establish User plane (U-plane) and for U-plane less than 10 ms from UE to server. In addition, one way latency of below 5 ms which enables 10 ms Round Trip Times (RTT).
6. In terms of **Mobility**, supports optimized for low speeds (< 15 km/hr); high performance for speeds up to 120 km/hr; and maintained link for speeds up to 350 km/hr (and targeted speeds of up to 500 km/hr with frequency band consideration).
7. In addition, a **coverage radius** of full performance up to 5 km; a slight degradation 5 km - 30 km and supports for operation up to 100 km should not be precluded by standard.

Overall, the LTE system requirements are based on System Capability (Peak Data Rates and Latency); System Performance (Throughput, Spectrum Efficiency, Mobility, Coverage and Enhanced Multimedia Broadcast/Multicast Services, eM-BMS); System Spectrum Allocation; System Architecture and Cost Reductions.

## 2.2 Overall LTE Architectural Overview

The LTE is an evolution of the radio access and the non-radio access [58]; with the radio access evolving through the Enhanced UTRAN (E-UTRAN). The radio access basically is the evolution of the LTE Physical Layer, while the non-radio access grouped under the System Architecture Evolution (SAE), is the evolution of the network architecture of the LTE. The major components of the LTE System Architecture are:

1. User Equipment (UE)
2. Radio Access Network (RAN)
3. Evolved Packet Core (EPC)

The Evolved Packet System (EPS) is comprised of the LTE Radio Access Network and Evolved Packet Core (EPC  $\Rightarrow$  RAN + EPS). At the high level, the LTE network is composed of the Core Network (CN), also called the EPC while there is also the Access Network, which is referred to as E-UTRAN [58], [59], [60], [61].

The figure 2.1 shows the basic overall system architecture with corresponding functional domains [62]: The four major domain divisions are - Services, the EPC,

E-UTRAN and the UE as indicated while figure 2.2, shows the EPS network elements and the standardized interfaces.

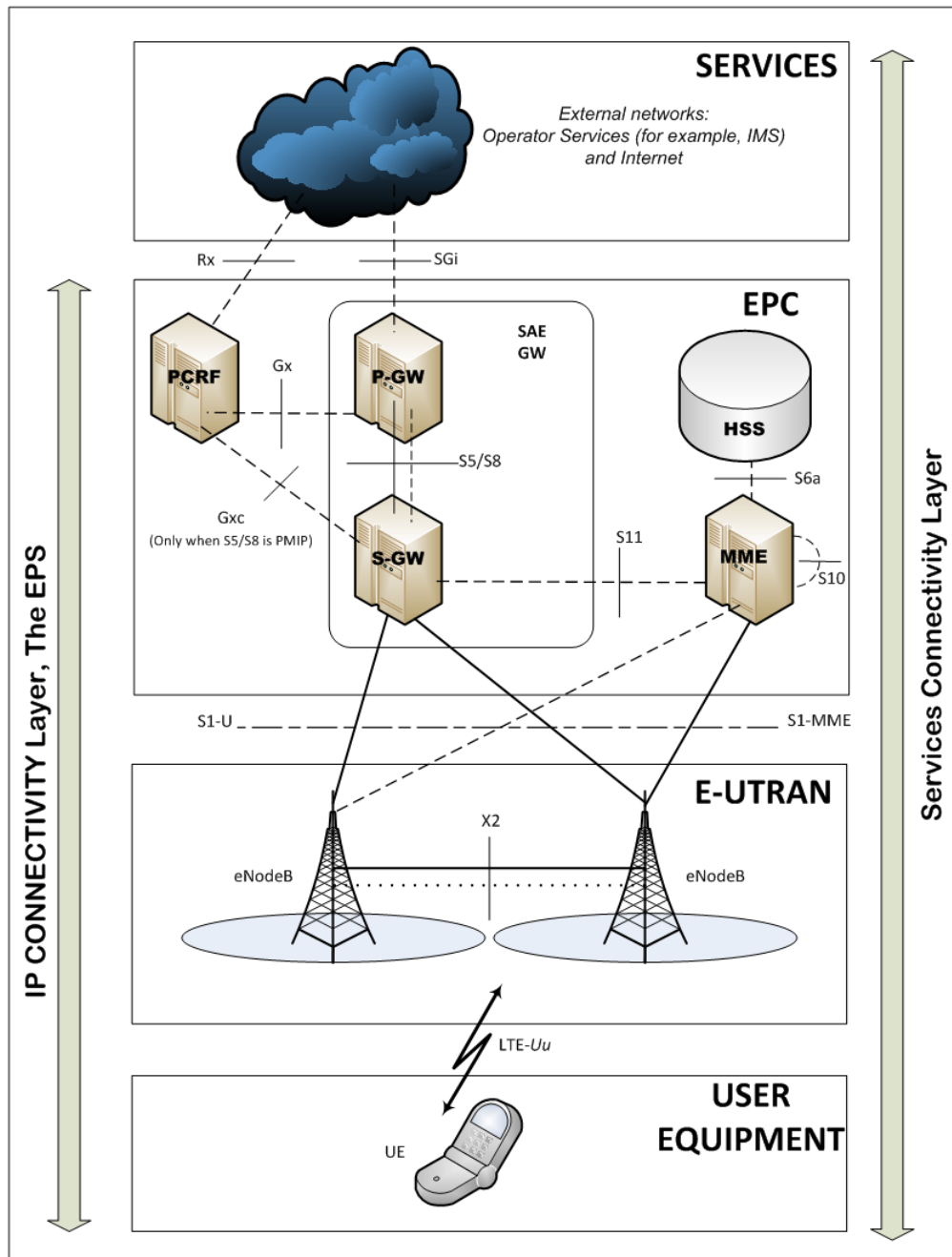


Figure 2.1: Architecture for 3GPP access networks (Adapted from [62]).

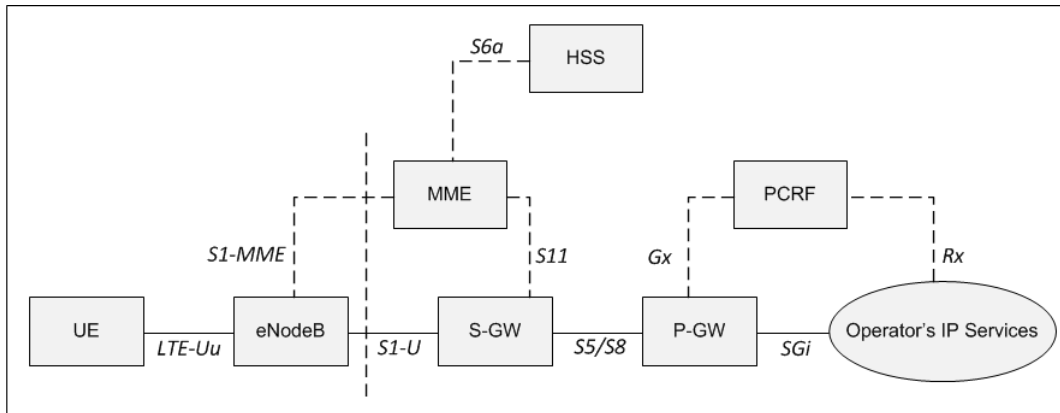


Figure 2.2: The EPS showing Network Elements and Standardized Interfaces [61].

The UE, EPC and the E-UTRAN are the integral part that formed the Internet Protocol Connectivity Layer, which is also referred to the EPS. The EPS provides the IP based connectivity services, with all services offered at the top of the IP layer.

Also, figure 2.3 shows a typical functional split between E-UTRAN and EPC.

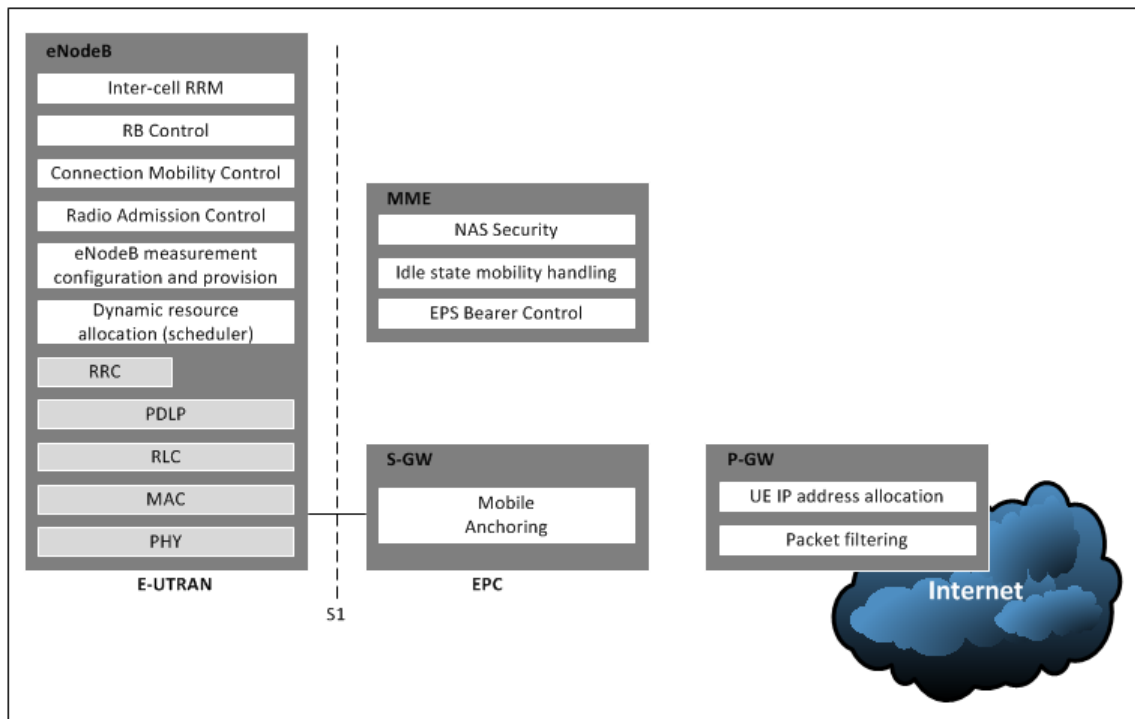


Figure 2.3: Functional Split between E-UTRAN and EPC [59].

### 2.2.1 Core Network

The Core Network (*also known* as EPC) [64], [65] does the overall control of the UE and establishes the bearers<sup>2</sup>. The CN has a number of different logic nodes, some of which are:

1. *Mobility Management Entity (MME)*;
2. *Packet Data Network (PDN) Gateway (P-GW)*;
3. *Serving Gateway (S-GW)*;
4. *Evolved Serving Mobile Location Centre (E-SMLC)*;
5. Policy and Charging Rules Function (PCRF);
6. Home Subscriber Service (HSS);

1. **MME**: The MME is the main control node in the EPC. The control plane information coming from the eNodeB is mainly routed to the MME. One of the most essential functions of the MME is that it handles the signalling between the UE and the CN. Also, it handles the issue of security and authentication for keys offering; in addition to mobility management - where the MME does management functions by making request setup and release of appropriate resources in eNodeB and the S-GW; the MME also manages the subscription profile and service connectivity. The responsible protocols between the UE and the CN are the Non-Access Stratum (NAS) protocols.
2. **P-GW**: The P-GW serves as the end point intermediary router between the EPS and external networks. It mainly provides IP connection at its active point; and is refer to as the highest level mobility or final anchor in the system. Also, it does IP addressing to UEs, performs traffic gating and filtering duties when needed.
3. **S-GW** The S-GW is responsible for the U-plane tunnel management and switching; it acts as the mobile anchor between EPC and the LTE RAN. All the users' packets are routed through the S-GW. Although, the S-GW has a role in control functions, it is very important in terms of inter-connectivity to other 3GPP technologies like GPRS/GSM and UMTS. Also, when the UEs'

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<sup>2</sup>The bearers refer to the IP packet flow that defines the Quality of Service (QoS) between the User Equipment (UE) and the Gateway (GW).



bearers are setup, cleared or undergo modification, the S-GW make resource allocation depending on the various requests from the MME, P-GW and/or PCRF.

4. **E-SMLC** The E-SMLC is responsible for the management of all the coordination and resource scheduling needed for UEs' locations in connection with the E-UTRAN. The final location is estimated based on calculated values from the E-SMLC and it does the estimation for the UE speed and its accuracy level.
5. **PCRF** The PCRF is responsible for the QoS as well as the policy control decision making. Also, it controls the flow-based charging for functions within the Policy Control Enforcement Function (PCEF) which is part of the P-GW. In other words, it does the Policy and Charging Control (PCC) functions.
6. **HSS** The HSS is a database that contains all users' subscription details. It contains the information about the PDN every user is connected to or can connect to. Essentially, it holds all permanent subscribers' data. As part of its side functions, the HSS can also integrate the Authentication Centre (AuC).

### 2.2.2 The LTE Access Network

The LTE access network (referred to as the E-UTRAN) is a composition of networks of eNodeBs. It is responsible for radio related functions within the network; some of these are - Radio Resource Management, Header Compression, Security, Positioning and EPC Connectivity. One important point in the E-UTRAN is that, it does not have a central controller, which implies its name of *Flat Architecture*.

As shown in figure 2.4, the eNodeBs are inter-connected by interfaces known as X2 interface and are connected to the EPC via S1 interfaces (this connection are done to the S-GW by S1-U interface and specifically, by S1-MME interface to the MME).

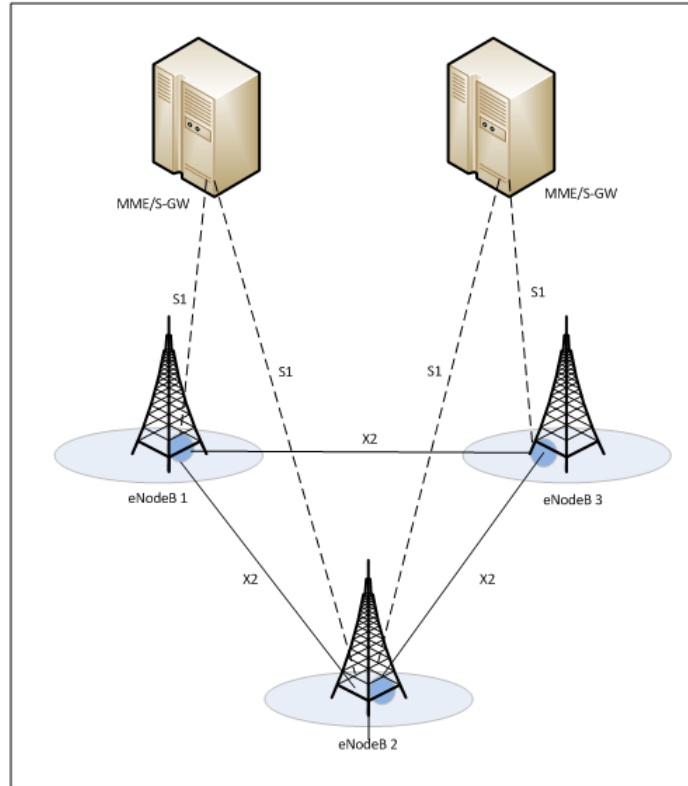


Figure 2.4: General E-UTRAN Network Architecture (Showing networks of eNodeBs) [66].

The system of direct tunnelling in HSPA release 7 has been implemented in E-UTRAN, have simplified system architecture, which essentially defines the LTE air interface requirements for LTE. The protocols which operate between the UEs and the eNodeBs are referred to as the Access Stratum (AS) protocols.

The table 2.2 shows the summary of the main interfaces:

	Interface Types	Functions/Connectivity.
1.	X2 interface	Used in mobility between eNodeBs, and also functions handover preparations and eNodeBs' neighbourhoods maintenance. The E-UTRAN can be referred to as a mesh of eNodeBs that are basically connected via the X2 interfaces.
2.	S1-MME interface	This serves as the reference control node protocol between the MME and the E-UTRAN.
3.	S1-U interface	This serves as the connecting interface between the E-UTRAN and the responsible S-GW.

Table 2.2: The LTE Main interfaces

### 2.2.3 The LTE Protocol Architecture

The radio access protocol architecture can be categorized into two [61], [63]:

1. User Plane, U-Plane;
2. Control Plane, C-Plane.

Each of these has its own layered architecture offering different functions. Considering the overall network protocol architecture, many of the protocol constituents are common for the U-Plane and C-Plane. The figure 2.5 and figure 2.6 show the U-Plane and C-Plane protocol stacks.

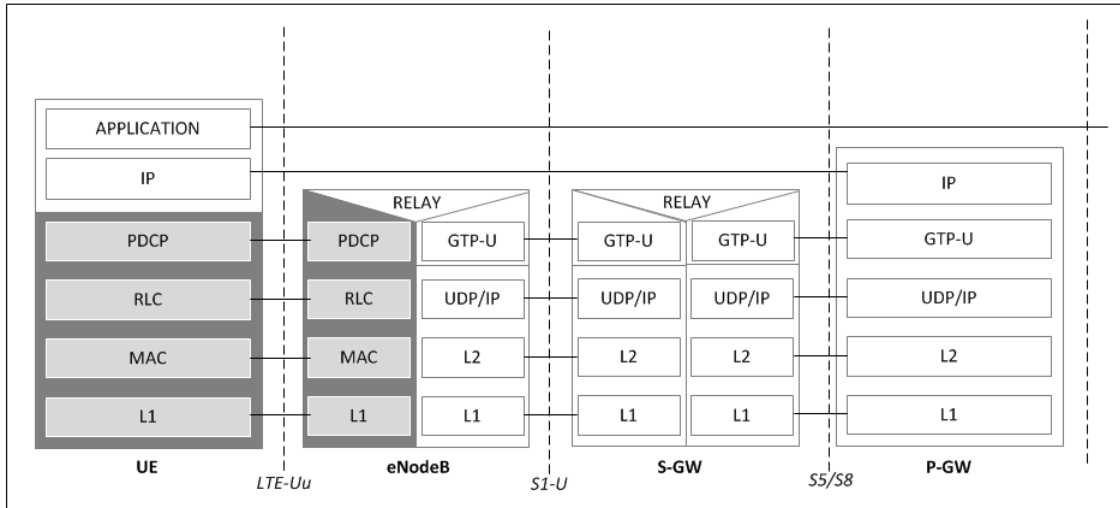


Figure 2.5: User Plane Protocol Stack (shown in grey) [61].

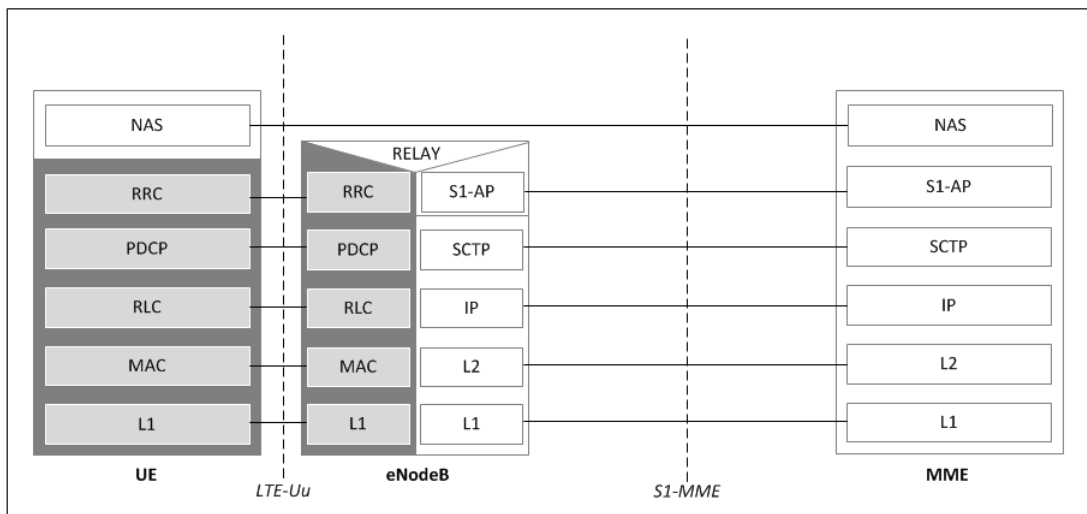


Figure 2.6: Control Plane Protocol Stack [61].

1. **User Plane:** The E-UTRAN user plane protocol stack as shown in figure 2.5, comprises of the Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC) and Medium Access Controller (MAC) sub-layers. These are connected to the eNodeB as part of the network.
2. **Control Plane** The figure 2.6 shows the Control Plane protocol stack between the UE and the MME. The grey region shows a similar stack except for the Radio Resource Control (RRC) protocol. The RRC is the major controlling entity in the control plane; it is used for creating Radio bearers and

essential for the configuration of all layers below the RRC by means of the RRC signalling function between the UE and the eNodeB.

The common protocols to the U-Plane and the C-Plane are given below:

- (a) Packet Data Convergence Protocol (PDCP);
- (b) Radio Link Control (RLC);
- (c) Medium Access Control (MAC); and
- (d) Physical Layer (PHY) or L1 (Layer 1)<sup>3</sup>

## 2.3 LTE Multiple Access Technique

In the previous technologies, like WCDMA, a fixed spectrum allocation is done; and HSPA, scheduling is done particular in the time domain with *appropriate* time interval of 2 ms [64]. A significant change that comes with the LTE is the ease of Multiple Access Scheme in the RAN. With the LTE tipped to achieve the high transmit rates and excellent spectral efficiency in the downlink (DL) and uplink (UL), a number of technological changes to the architecture are incorporated particularly in the Multi-Carrier and Multi-Antenna (MC-MA) transmission techniques, Hybrid Automatic Repeat Request (HARQ) and the likes.

In the LTE E-UTRAN transmission schemes, the Orthogonal Frequency Division Multiple Access (OFDMA) is designed for Downlink, that is, eNodeB to UE, while the Single Carrier-Frequency Division Multiple Access (SC-FDMA) for Uplink - UE to eNodeB.

### 2.3.1 Downlink: OFDMA

The OFDMA uses smaller frequency bands that are dedicated to sub-carriers and they transmit at low power, unlike full transmission for the whole frequency band. The OFDMA provides good system performance with desired high data rates.

In this scheme, the spectrum is basically divided into a series of uniform orthogonal narrowband sub-carriers; with each sub-carrier spaced at 15 KHz and with corresponding modulation symbols. For 1 symbol duration, a number of sub-carriers are

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<sup>3</sup>The L1 is responsible for the physical (PHY) layer functions

transmitted orthogonally in the frequency domain.

For the avoidance Inter Carrier Interference (ICI) and to have efficient spectrum utilization, the peak of one sub-carrier of the spectrum must coincide with the nulls of the other sub-carriers [66], thereby creating zero-ICI. This is illustrated in figure 2.7.

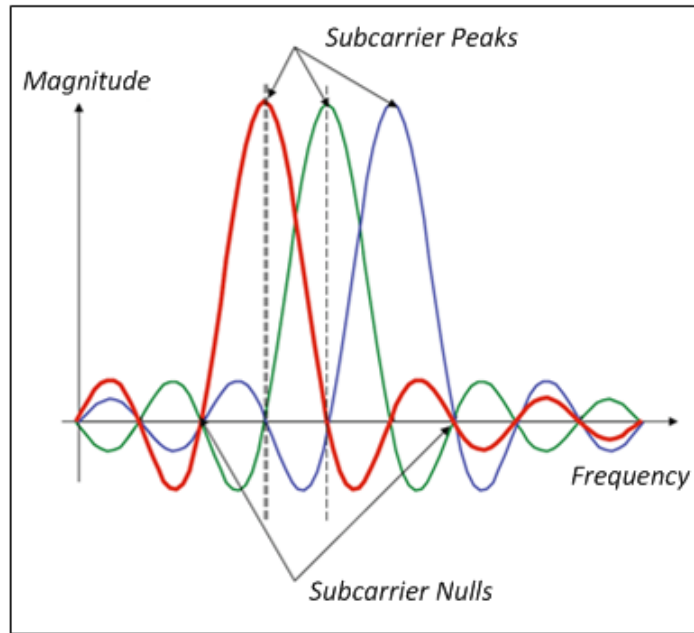


Figure 2.7: Subcarriers in multi-carrier systems [66].

- Cyclic Prefix:** Additionally, to overcome the problem of Inter Symbol Interference (ISI), a Cyclic Prefix (CP) is included as a guard symbol at the beginning of the each of the Orthogonal Frequency Division Multiplexing<sup>4</sup> (OFDM) symbol. The CP has two types [63], the Normal CP, which has 7 symbols per slot and the Extended CP with 6 symbols per slot. The additional of the CP to every subsequent symbol allow for ISI cancellation. To be able to combine multipath components, the CP duration should be longer than the excess delay (delay spread) of the channel.

In LTE, there are two defined CP-length, under the Normal CP, the first symbol is  $5.21 \mu\text{s}$  (symbol 0) with short CP of length  $4.69 \mu\text{s}$  (for symbols 1-6) and for the long CP of length  $16.7 \mu\text{s}$  (which is same for all symbols).

<sup>4</sup>The OFDMA utilizes the OFDM characteristics

- Frame Structure and Resource Blocks:** The Figure 2.8 shows how the resources in a Time-Frequency domain are shared in OFDMA. There are 12 sub-carriers in 1 transmission carrier, which corresponds to 12 symbols over a bandwidth of 180 KHz. The LTE frame structure contains 10 sub-frames of 1 ms in the time domain, for each of the sub-frame, there are 2 time slots of 0.5 ms. One time slot contains 7 OFDM symbols[46].

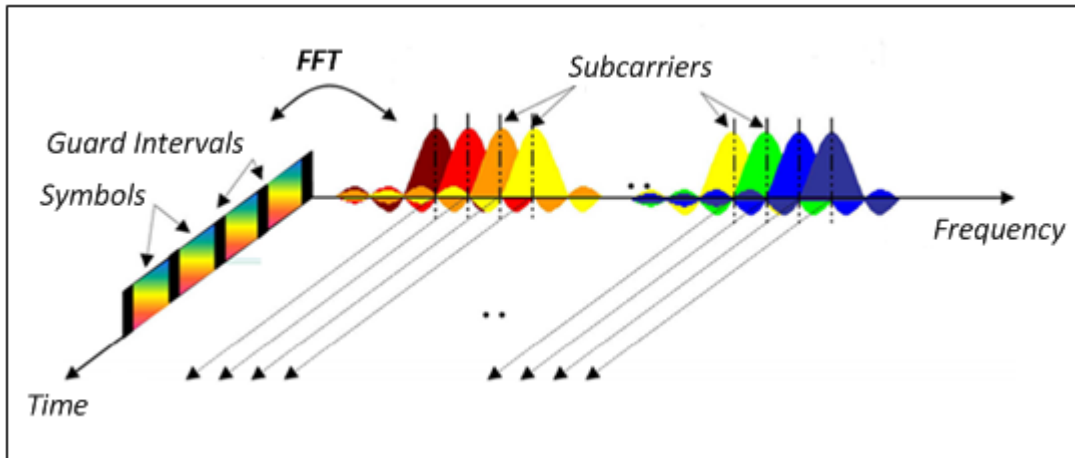


Figure 2.8: Time-Frequency Illustration for OFDMA [8].

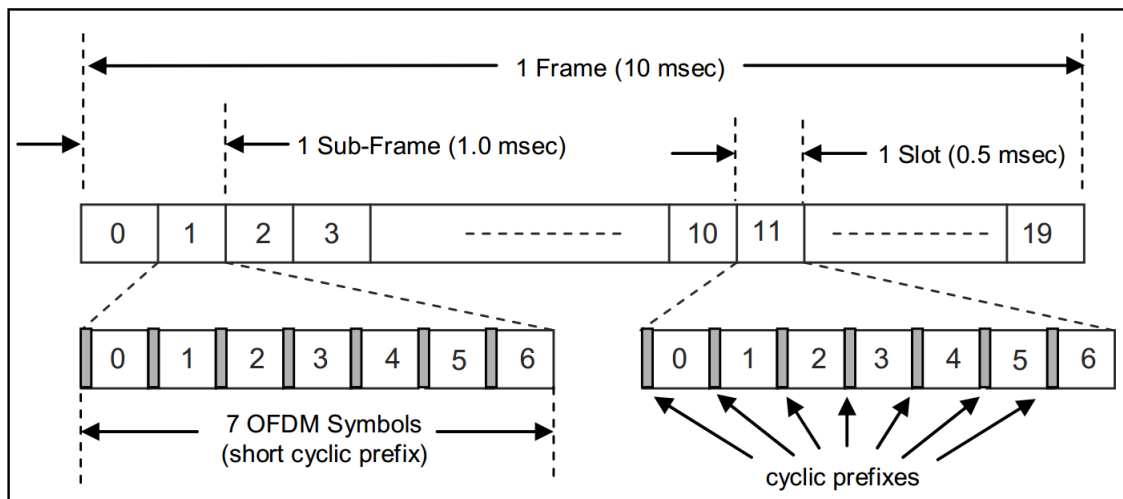


Figure 2.9: Typical LTE Frame Structure with CP [46].

The Resources in the LTE are arranged in 2-dimensional Resource Blocks (RBs). It should be noted that one RB is the minimum unit that can be allocated.

1 RB contains 12 sub-carriers and 7 consecutive OFDM symbols (amounting to 84 Resource Elements, REs). One RB occupies 1 time slot and a bandwidth of 180 KHz. The number of RBs assigned to a user dynamically varies depending on available resources and channel state. In other words, the number of RBs attached to every user at a point depends on the type of service, the data rate, and scheduler buffer states. Figures 2.10-2.12 show the LTE RB grid approach illustration with both time domain and frequency domain diagrams as indicated.

The OFDMA uses a Fast Fourier Transform (FFT) operation coupled with Inverse FFT (IFFT) for carrier transmission between time and frequency domains. A major drawback for the OFDMA is its high Peak-to-Average-Power Ratio (PAPR); this is as a result of the multi-carrier transmission technique involved.

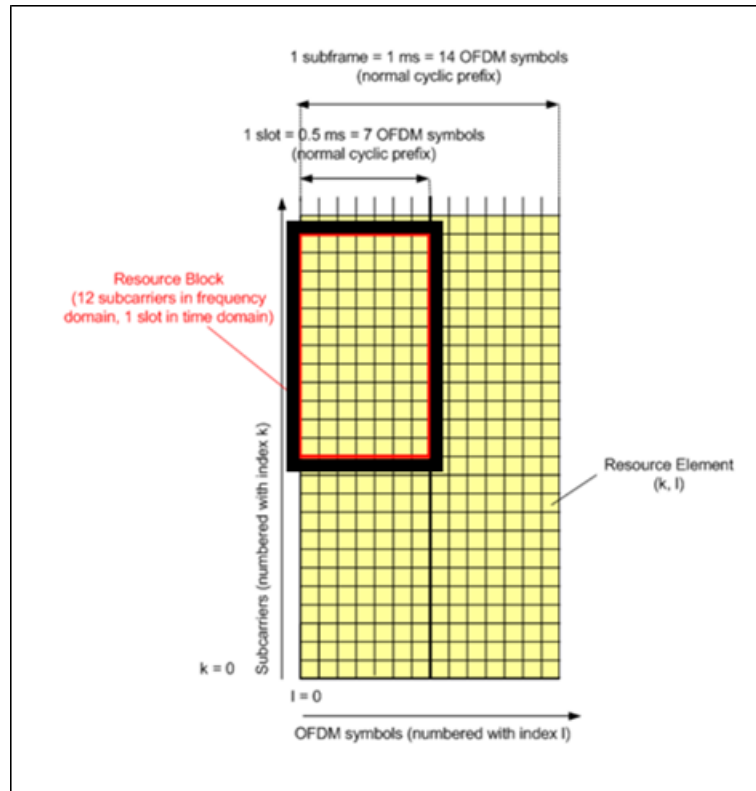


Figure 2.10: Resource Grid in LTE DL [68].



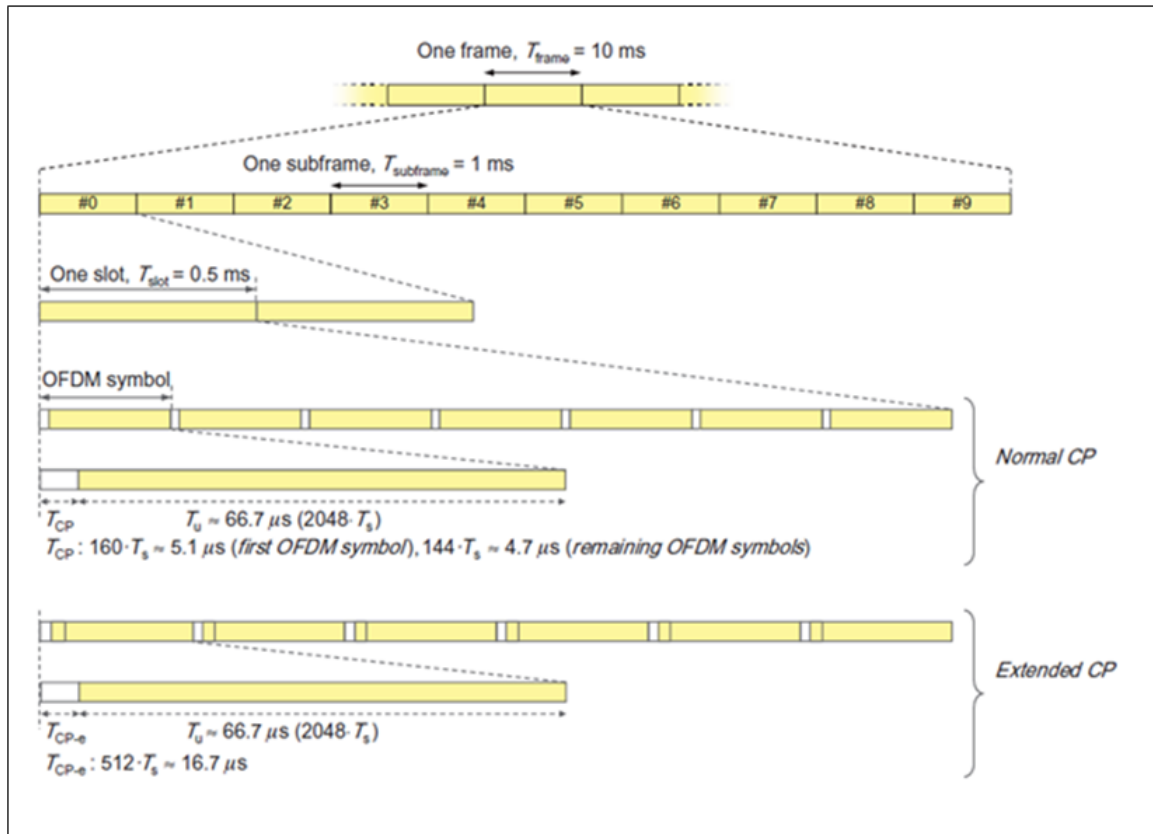


Figure 2.11: LTE time-domain structure [63].

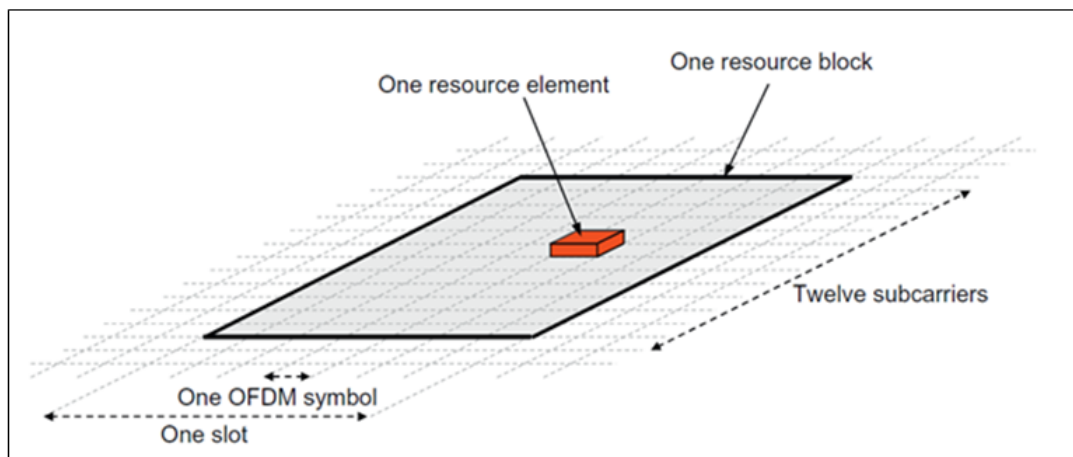


Figure 2.12: LTE physical time-frequency resource [63].

### 2.3.2 Uplink: SC-FDMA

In a bid to reduce the terminal energy consumption, the LTE Uplink utilizes the Single Carrier Frequency Division Multiple Access (SC-FDMA). This is because the UL transmit needs a low PAPR considering its need for high transmits rates. In the UL, the SC-FDMA is preferred as it offers low power, and the transmit power of great importance for emerging technologies.

The SC-FDMA has some similarities to the OFDMA; there are 20 time slots per frame of 0.5 ms. In SC-FDMA, the resource blocks are quite identical, with 6-7 symbols with CP, 15 KHz sub-carriers, 12 sub-carriers in every resource block (180 KHz in length). Conversely, in the SC-FDMA, a symbol is carried mainly under all the sub-carriers as against the OFDMA, where every sub-carrier contains one symbol. Also, it should be noted that CP is added after the block of symbols (6-7), unlike after every symbol as in OFDMA.

In the LTE UL, to have a desired increased data rate, the period of symbol is reduced to allow for more symbols per slot, which subsequently increases the bandwidth of the signal. An illustrative comparison between the OFDMA and the SC-FDMA is shown in figure 2.13. Some more similarities exist between the OFDMA and the SC-FDMA; for example, the resource allocations are done dynamically in the 1 ms time interval.

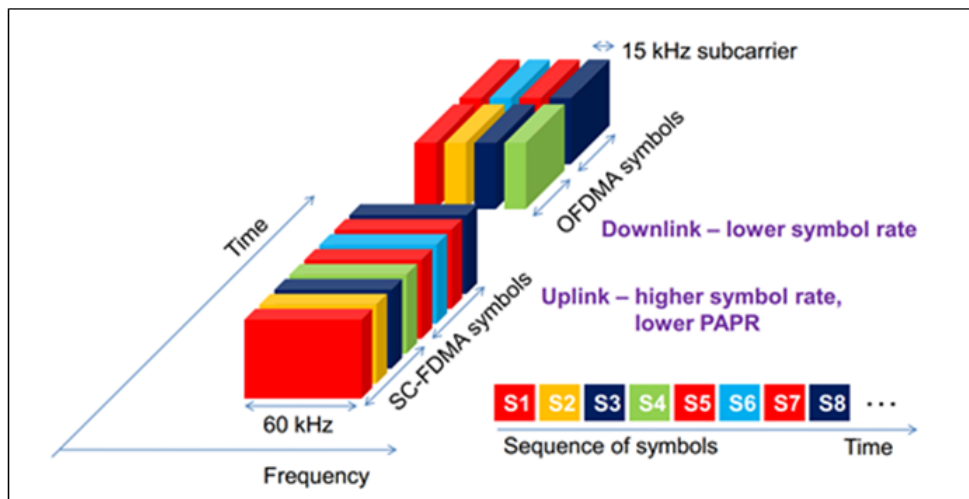


Figure 2.13: OFDMA and SC-FDMA Illustrative comparison [69].

### 3 LTE-ADVANCED

As a result of the continuous growth in the mobile data traffic; and with the considerable desire to meet the big growth in achieving this big traffic demand, air-interface efficiency continuous improvement and unequal spectrum allocation have to be worked on to be able to tailor the developing new radio technologies as an evolution towards an International Mobile Telecommunication (IMT) Advanced System (IMT-Advanced) [71].

The IMT-Advanced is an initiative of the International Telecommunication Union (ITU) Radiocommunication Sector (ITU-R) initiative [71] [70] towards the Fourth Generation (4G) mobile for radio access technologies beyond IMT-2000.

A major effort was made in standardizing IMT-Advanced to the LTE-Advanced by setting out some capabilities for the LTE Release 10. The LTE Release 10<sup>5</sup>, sometimes known as the LTE-Advanced became the standard candidate that evolved from the LTE to new improved performance. The table 3.1 shows some of the enhanced introductions by the IMT-Advanced [72] with LTE fulfilments:

	Requirements	IMT-Advanced	LTE Release 8	LTE Release 10
1.	Transmission Bandwidth	At least 40 MHz	Up to 20 MHz	Up to 100 MHz
2.	Peak Spectral Efficiency:			
	(a) Downlink	15 bits/s/Hz, ( $\approx$ 600 Mbps peak rate)	16 bits/s/Hz	16.0 bits/s/Hz, for 4 x 4 antenna config. [30.0] for 8 x 8 antenna config.
	(b) Uplink	6.75 bits/s/Hz, ( $\approx$ 270 Mbps peak rate)	4 bits/s/Hz	8.1 bits/s/Hz, for 2 x 2 antenna config. [16.1] for 4 x 4 antenna config.
3.	Latency:			
	(a) Control Plane	< 100	50 ms	50 ms
	(a) User Plane	< 10	4.9 ms	4.9 ms

Table 3.1: IMT-Advanced Requirement and LTE fulfilments [72].

<sup>5</sup>The LTE Rel. 10 comes with enhanced features from Rel. 8/9 coupled with many features.

Some additional requirements as stated in the ITU-R are Bandwidth, Cell Spectral Efficiency, Cell edge user spectral efficiency, Mobility<sup>6</sup>, Handover, and VoIP capacity. The main goals of the LTE-Advanced is summarized based on [73],

1. Flexible and Faster Network Deployment (Heterogeneous Networks);
2. Better Coverage and Improved Spectral efficiency (Cell Edge and Average) - Robust Interference Management;
3. Greater Flexibility with Wideband Deployments - Wider Bandwidth by Carrier Aggregation across Bands; and
4. Ubiquitous and Cost Effective Broadband (Higher Peak User Rate by Higher Order DL and UL MIMO); with increased peak data rate, DL 3 Gbps, UL 1.5 Gbps [74].

To actualize the evolution of LTE to the LTE-Advanced in achieving the extremely high data rate, a high Signal-to-Noise Ratio is needed compared to current level [19]. The figure 3.1 shows a simple illustration of this concept as it relates to LTE-Advanced. From the figure 3.1, the displayed equation shows that the number of antennas,  $n$ , will have significant increase on the system capacity; likewise with an increased spectrum of bandwidth),  $W$ ; and a very good interference mitigation via the Signal-to-Noise Ratio, SNR will also make tremendous impact to the system capacity.

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<sup>6</sup>Stationary: 0 km/h; Pedestrian: > 0 km/h to 10 km/h; Vehicular: 10 to 120 km/h; and High speed vehicular: 120 to 350 km/h

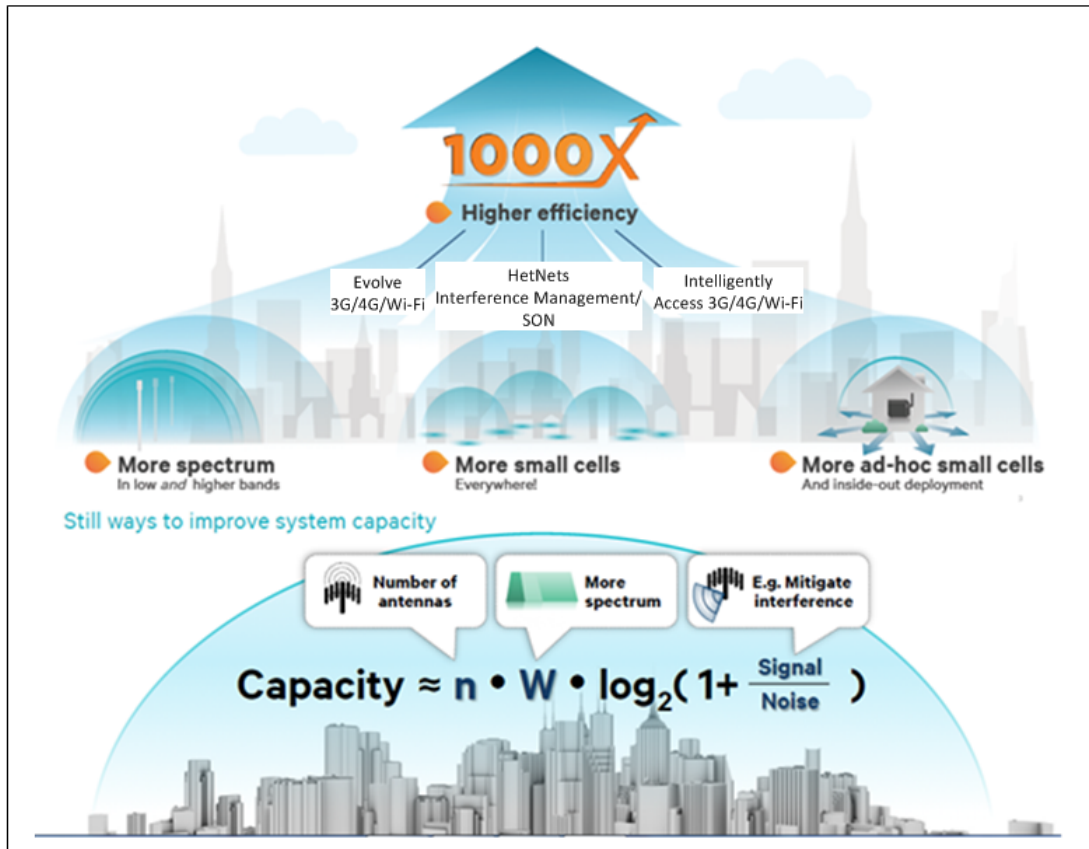


Figure 3.1: Capacity Target - 1000x Higher Efficiency Illustration [19].

The figure 3.2 shows the LTE-Advanced goals in summary as it applies to select corresponding ingredients.

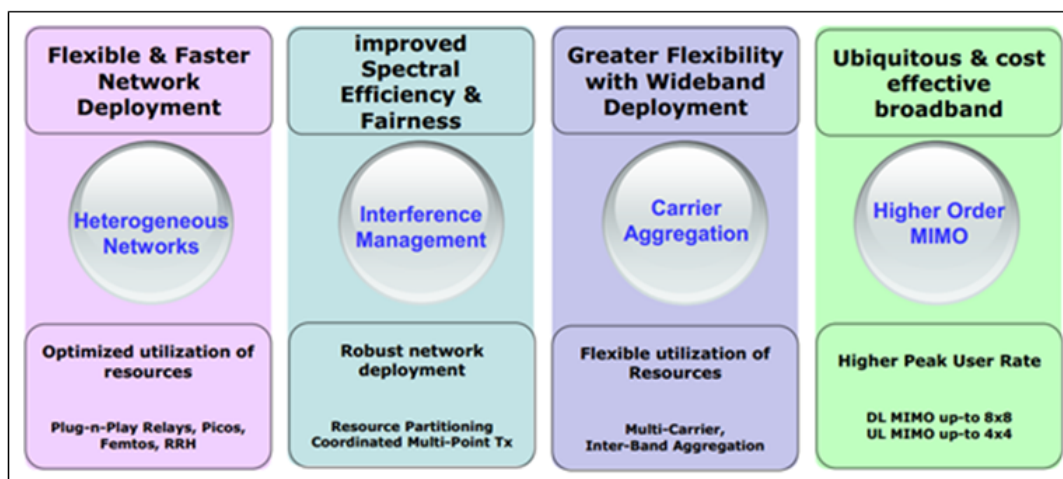


Figure 3.2: LTE-Advanced Goals Summary [73].

A significant reason why the LTE Release 10 is referred to as LTE-Advanced is because it has compliant radio access technology with the IMT-Advanced requirement. Also, some of the most important new features in the enhanced LTE are:

1. Carrier Aggregation (CA);
2. Enhanced Multi-Antenna Support (enhanced MIMO);
3. Coordinated multipoint (CoMP) Transmission/Reception technologies;
4. Improved Support for Heterogeneous Network Deployment (HetNets); and
5. Relaying.

The figure 3.3 and figure 3.4 show the LTE-Advanced Ingredients and Technology Evolution that enabled LTE-Advanced respectively.

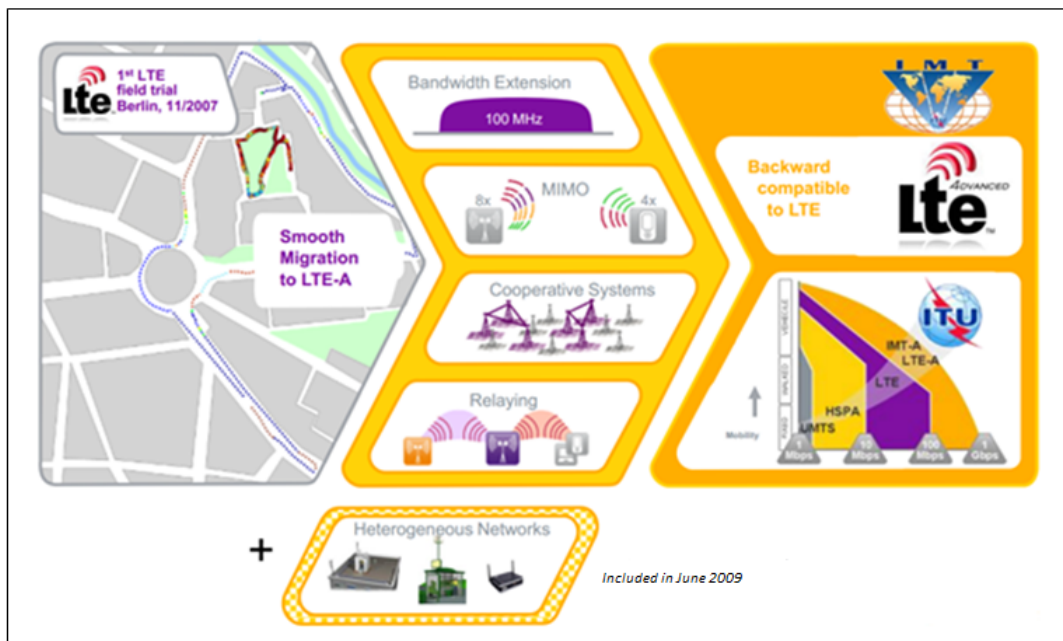


Figure 3.3: LTE-Advanced: Key Ingredients [75].

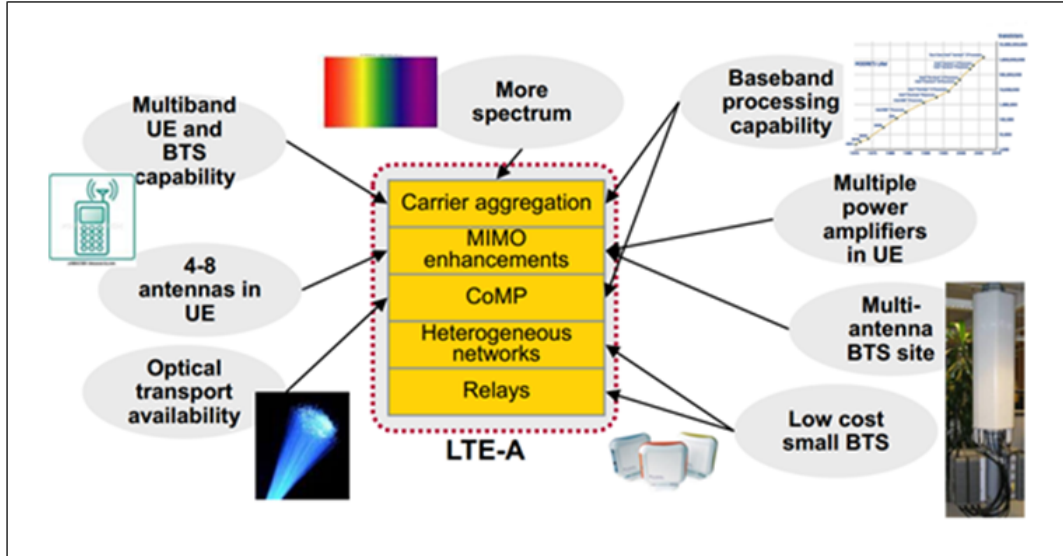


Figure 3.4: Technology evolution enabled for LTE-Advanced [75].

### 3.1 LTE-Advanced E-UTRAN Overview

The core architecture of the LTE-Advanced is enhanced from the LTE E-UTRAN. The figure 3.5 shows a typical LTE-Advanced E-UTRAN architecture as discussed in [20].

The E-UTRAN architecture basically has the eNodeB and this creates the air interface for the U-Plane and C-Plane protocols termination to the UEs. The eNodeBs serve as the logical point used for serving the E-UTRAN cells. Also, there is the Home eNodeB (HeNB)<sup>7</sup>. The HeNBs are a type of eNodeBs with low cost and good indoor coverage. They are mainly connected to the EPC either directly or through a Gateway that can provide supports for a set of HeNBs. As it can be seen from the figure 3.5, relaying is also a considered inclusion to the new enhanced architecture. The use of relay nodes is believed to help network performance with the help of highly advanced relaying concepts to create increased coverage, higher data rates and even high QoS for users.

<sup>7</sup>Also refers to as the *Femtocell*

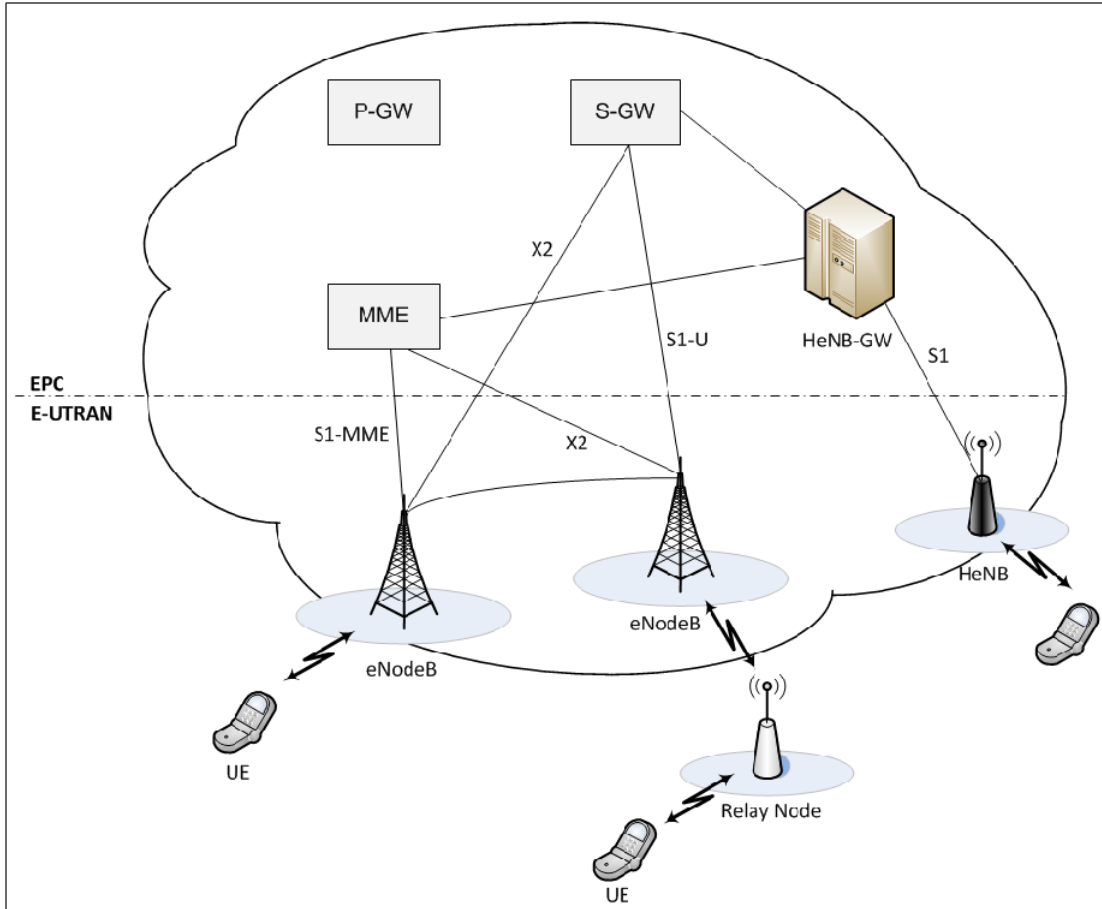


Figure 3.5: LTE-Advanced E-UTRAN Architecture [20].

The following subsections outline some of the key technology ingredients in the LTE-Advanced.

### 3.2 Carrier Aggregation

Although there has been considerable flexibility in terms of bandwidth for previous releases, the LTE-Advanced (Release 10) gives more and desired flexibility in terms of transmission bandwidth of up to 100 MHz, while essentially allowing for backward compatibility with its predecessor. To actualize this, the idea of CA [70], [74] scheme is introduced.

The CA is based on aggregating multi-component carriers and jointly makes use of them for transmission to and from mobile terminals (single). Up to 5 transmission components can be aggregated either when they are in the same frequency range or not. The fragmentation of the spectrum allows for the higher data rates



by the combination of the all the small fragments to a big component [47].

A simple illustration is given in figure 3.6, where the component carriers are of 1.4, 3, 5, 10, 15 or 20 MHz bandwidth and could have a maximum of 5 component carriers in the carrier aggregation. Having in mind that the peak bandwidth is 100 MHz, the number of allowed aggregated carriers in the DL and UL can be different but the number of UL component carriers cannot be more than the number of DL component carriers. It should be noted that keeping the backward compatibility will increase in bandwidth in LTE-Advanced as through aggregation. As shown in figure 3.6, the aggregation of Release 8/Release 9 carriers are illustrated with the carrier aggregation of FDD<sup>8</sup>.

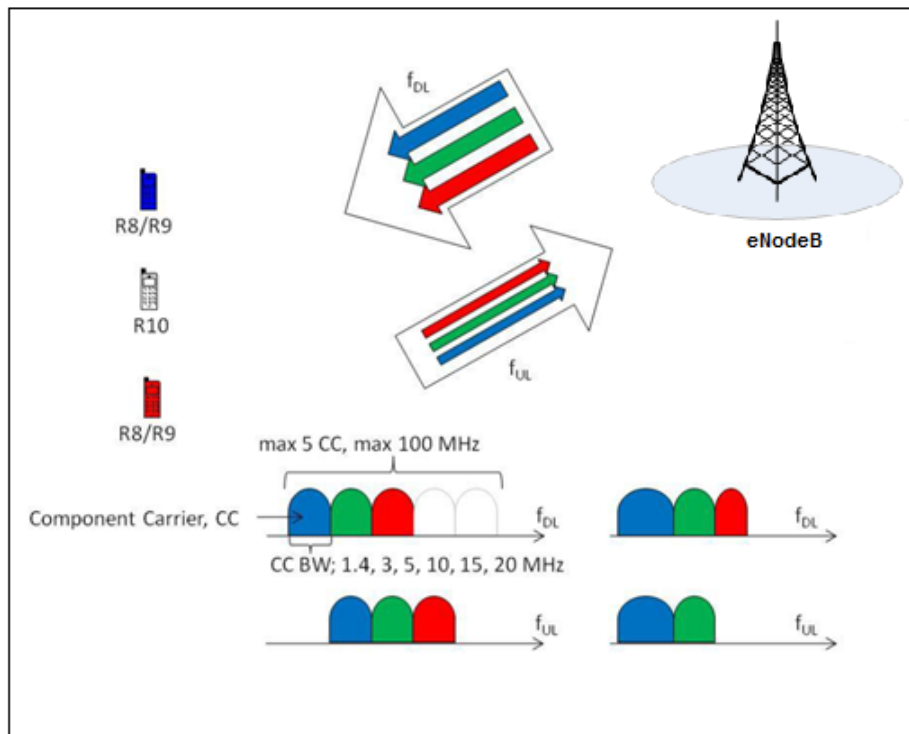


Figure 3.6: Carrier Aggregation in FDD [74].

In the CA deployment plans [20], four scenarios<sup>9</sup> have been specified (but will not be discussed in this thesis); these are - Contiguous CA (ConCA) and Non-Contiguous CA (NConCA) for Single and Multiple Spectrum bands using TDD and FDD accordingly. That is, ConCA-TDD, ConCA-FDD, NConCA-TDD and

<sup>8</sup>Carrier aggregation is possible for both FDD and TDD.

<sup>9</sup>[20] discussed this extensively

NConCA-FDD.

### 3.3 Enhanced Multi-Antenna Support

As one of the most important components of meeting the LTE-Advanced goals, the multi-antenna solution is vital in driving the increased data rates and much system level performance. The enhanced Multi-Input and Multi-Output (MIMO) system is very important as this is a major enhancement technique that uses multiple antennas at both ends of the transmission system, that is transmit and receiving sides. The main components of the MIMO technologies used in the LTE are fundamentally important in the LTE-Advanced. Some of these are: *Beamforming*, *Spatial Multiplexing* and *Spatial Diversity* [20]. These fundamental MIMO technology components are useful in the various combinations of their techniques in having the enhanced or advanced system obtainable in the targeted LTE-Advanced. This idea works based on adaptive selection for the different MIMO switching scheme as shown in figure 3.7.

More also, the multi-antenna configuration in enhanced MIMO is extended for up to 8 x 8 in the DL and up to 4 x 4 in the UL. The transmission diversity and spatial multiplexing are most preferred to be used in actualizing the enhancements for an enhanced improve coverage and absolute peak data rate in the LTE-Advanced targets.

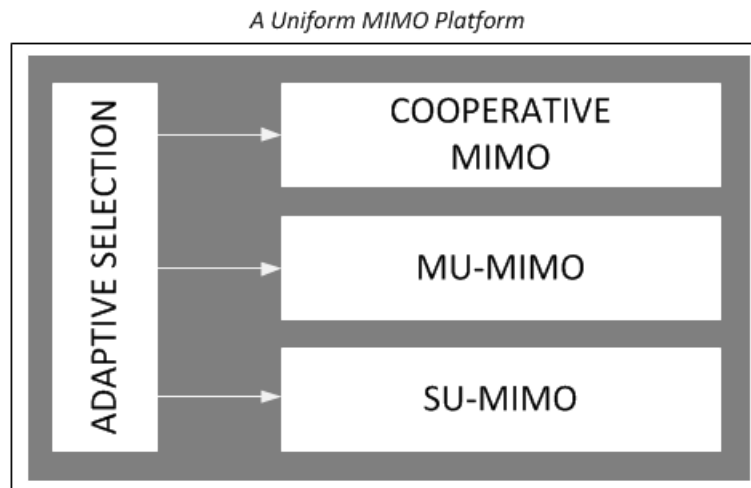


Figure 3.7: Adaptive switching combination scheme [20].

The three operating modes shown in figure 3.7 are illustrated in scenario modes in figure 3.8 with the various operating modes as:

1. Single-User MIMO (SU-MIMO);
2. Multi-User MIMO (MU-MIMO); and
3. Cooperative MIMO (Co-MIMO).

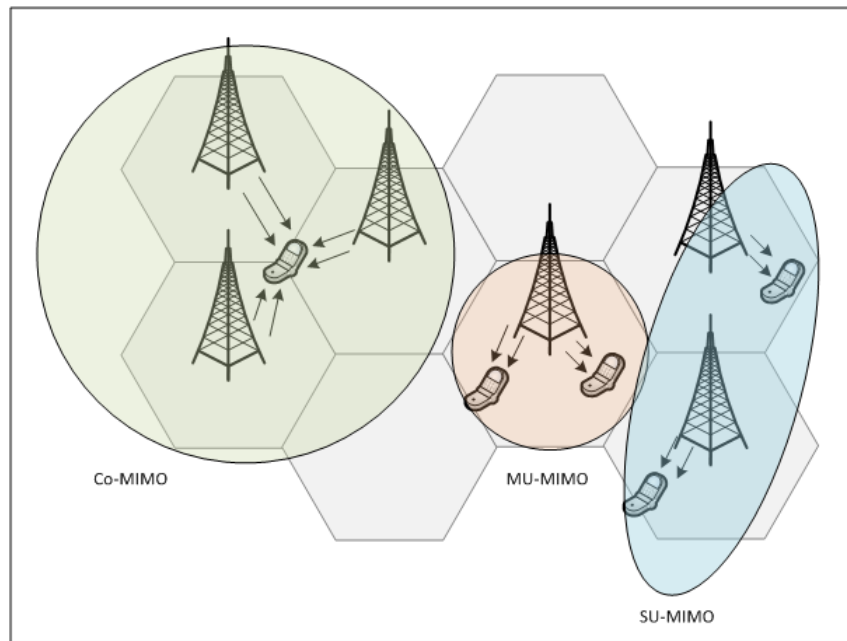


Figure 3.8: LTE-Advanced main MIMO modes [20].

### 3.3.1 SU-MIMO

In this case, the beamforming technique is combined with a selection of the transmit diversity and spatial multiplexing techniques. This gives the possibility for substantial higher data by using higher order MIMO - the combination of increased antenna ports.

### 3.3.2 MU-MIMO

The MU-MIMO offers the *best complexity-performance* tradeoff. Its combination with the SU-MIMO is otherwise known as the *Single-site MIMO*.

### 3.3.3 Co-MIMO

This type of MIMO technique is of emphasis to cell-edge users. It uses the coordination in transmission and reception of signals from different base stations. This in itself helps to reduce ICI. The overall technique involved is also known as the Cooperative<sup>10</sup> Multi-Point (CoMP) Transmission and Reception.

## 3.4 Cooperative Multi-Point Transmission and Reception

The CoMP, as an advanced type of MIMO, provides the higher data rates, with cell edge throughput, coupled with excellent system throughput in high and load scenarios. The CoMP approach follows a select architectural perspective. The coordination techniques among eNodeBs are very useful, especially in the reduction of ICI in the network in both DL and UL. In the DL, a coordinated transmission technique is applied from the base station while interference in the UL is reduced by coordinated reception in the eNodeBs. Based on how information are shared or distributed at different transmission points, the CoMP technique can be divided to two architectural divisions - *Central* and *Distributed*.

The two architectural divisions can be combined with any of the transmission schemes given below:

1. Downlink:
  - (a) Coordinated Scheduling/Beamforming (CS/CB)
  - (b) Joint Processing
2. Uplink:
  - (a) Coordinated Scheduling

The figure 3.9 - figure 3.12 show the various architectural division approaches of CoMP and the CoMP schemes scenarios.

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<sup>10</sup>Also, Coordinated Multi-Point (CoMP), which is another key technology

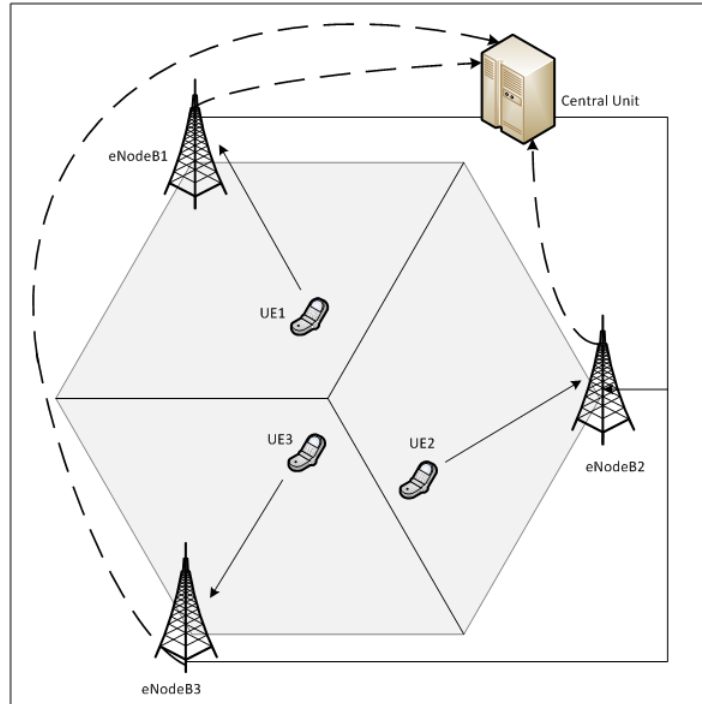


Figure 3.9: Centralised CoMP Architecture [20].

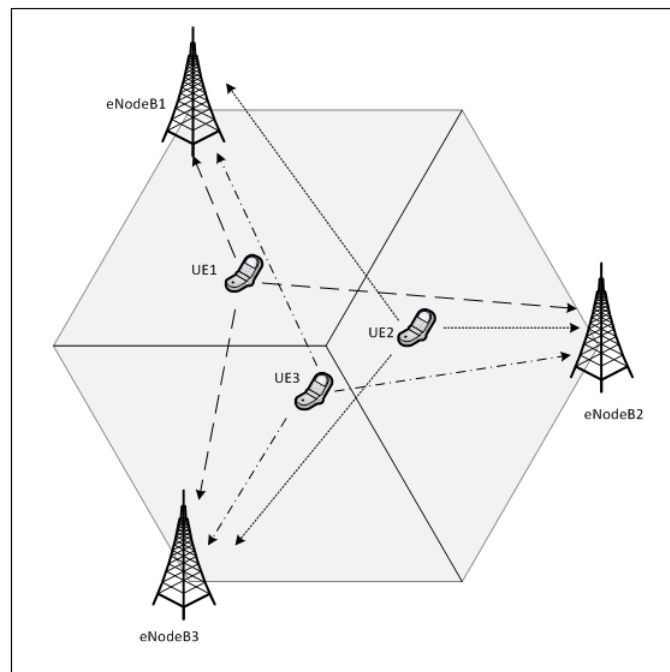


Figure 3.10: Distributed CoMP Architecture [20].

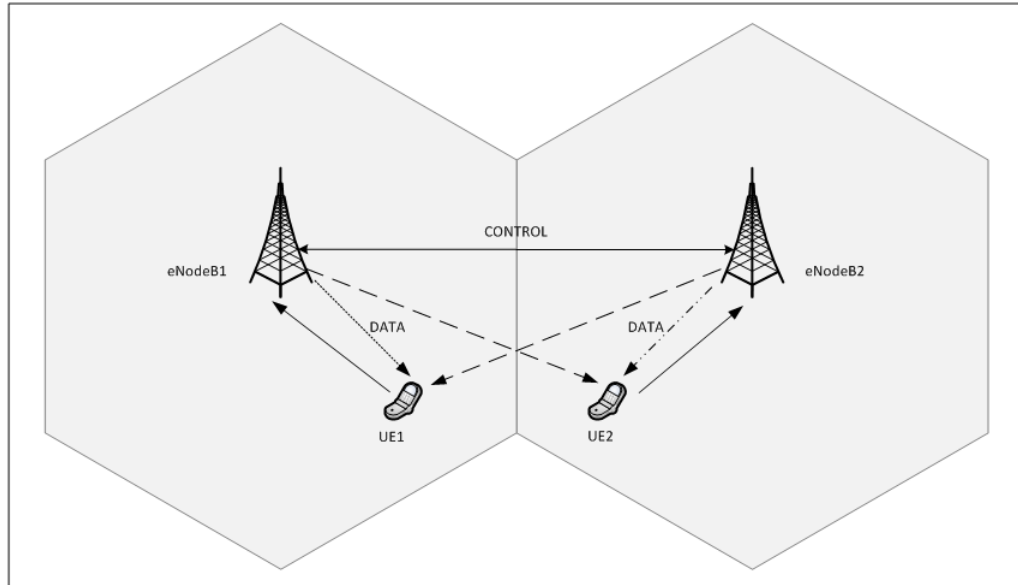


Figure 3.11: CS/CB CoMP Scheme [20].

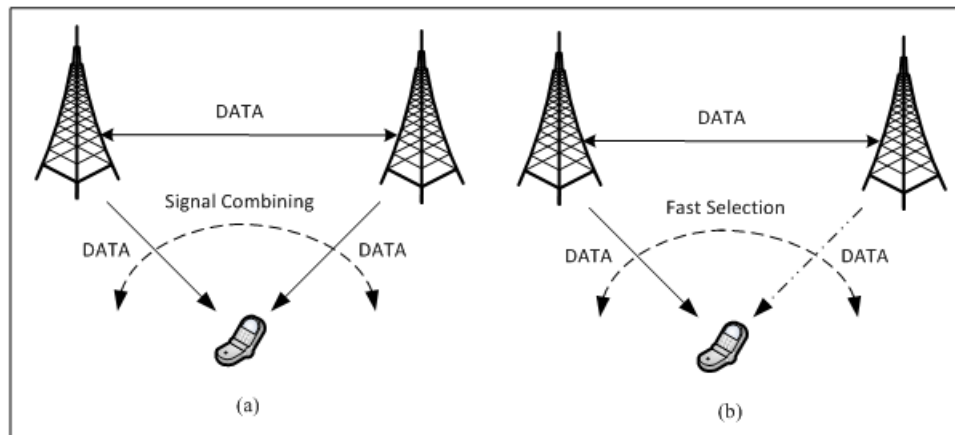


Figure 3.12: Joint Processing CoMP Scheme (a) Joint Transmission; and (b) Dynamic Cell Selection [20].

Although, there are a number of challenges in this technology components like - *Channel Estimation and Feedback*; *Backhaul aspects*; *Reference Signal Design*; and *Cyclic Prefix/OFDM parameters*; The use of the CoMP is still needed significantly in the research to have enhanced of the techniques.

### 3.5 Improved Support for Heterogeneous Network Deployment

The issue of achieving a broader coverage with enhanced performance is of significant importance when it comes to the LTE-Advanced. Aside from the previously mentioned technological components of LTE-Advanced (CA, e-MIMO and CoMP), there is futuristic demand to have improved spectral efficiency per unit area. That is, every user within a particular cell must have a smooth and efficiently uniform service. This whole idea of spectral efficiency centres around the development of new deployment strategy called Heterogeneous Networks.

This system is different from the conventional system of network topology. To achieve this improved coverage and desired capacity in meeting up with low rate services with uniform distribution and high-rate services which covers as many hotspots, heterogeneous networks (HetNets) presents a system of low power base stations and macro cells. The macro cells always serve the medium or low rate services in mainly large areas; and the low power base stations give the essential supports to services in the extended much hotspots area with high rate services.

HetNets will have a mix of *macro-*, *pico-*, *femto-*, remote radio head (RRH) and relay base stations; these are itemized below based on the low power nodes categorization (categorization based on: *Transmission Power*, *Backhaul Connectivity*, *Access* and *Deployment Methods*) [9] as shown in table 3.2. These low power nodes are placed within the larger macro cells.

Low Power Nodes	Backhaul Connectivity	Access	Deployment/Usage. Deployment/Usage.
Remote Radio Head (RRH)	Several $\mu$ s latency to macro	Open to all UEs	Placed indoors or outdoors.
Pico eNodeB (Hotzone cells)	X2	Open to all UEs	Placed indoors or outdoors. Typically planned deployment. Used in mainly public hotspots, such as a market, undergrounds or plaza.
HeNB (Femtocells)	No X2 as baseline $\star$	Closed Subscriber Group (CSG)	Sometimes referred to as Home BS; used in indoor scenarios, such as home and office and mainly consumer deployed.
Relay Nodes	Through air interface with a macro cell $\clubsuit$	Open to all UEs	Placed indoors or outdoors. Enables wireless connection to macro BS through backhaul.

Table 3.2: Low power node categorization for HetNets

*Symbol notes highlighted below:*

$\star$  - The baseline follows the Release 8/9 assumptions coupled with the interference management evaluation for HeNBs (via X2 or other means) that allows for the assessment of the interference management benefits.

$\clubsuit$  - Mainly for in-band RN case.

The figure 3.13 shows an example of the multilayered deployment illustration for heterogeneous networks.



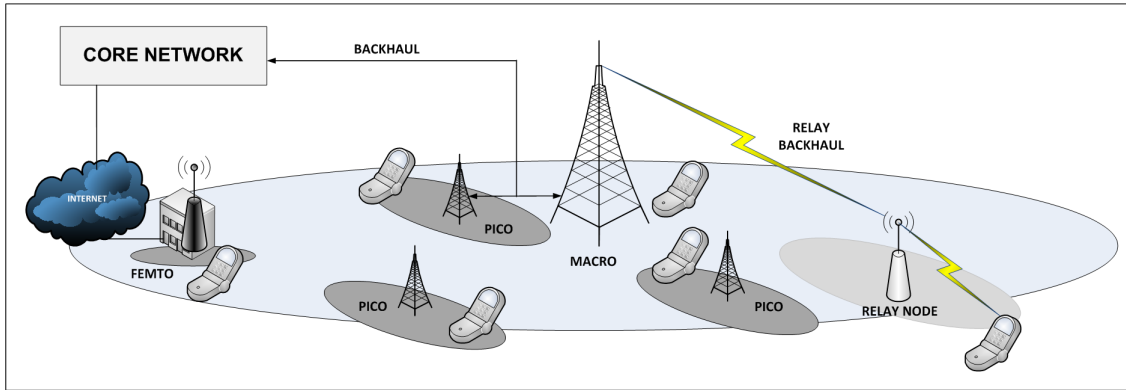


Figure 3.13: Overall general overview of the HetNet [22].

Much of the discussion in the subsequent chapters will be on Femtocells and their capabilities in existing technologies and future technologies.

### 3.6 Relaying

As part of the HetNet types, the relaying concept has significantly become an important element of the LTE-Advanced aimed at improving the coverage and throughput. The use of relaying is made possible by the use of relay nodes (RNs). Relaying operation provides the means to (a) Improved coverage; (b) Improved link budget; and (c) Increased possibility for high data rates. The RN is a low-power base station (30 dBm) and they reduce the distance between terminal and the infrastructure. The RNs are used within the broader macro network. Also, the use of relays is beneficial in cost reduction and power consumption reduction. In the 3GPP specification release [10], relaying is aimed at providing the following:

1. Better coverage provision in new areas;
2. Network deployment for temporary purposes;
3. Improved cell-edge throughput;
4. High data rate coverage; and
5. Introduction of Group Mobility.

In the figure 3.14, the basic scheme used in relaying to be deployed in LTE-Advanced is given. In this figure, the  $Uu$  interface is used to connect the UE with the RN, while the  $Un$  interface is used to connect a donor cell of a donor eNodeB with the RN.

There are two-way type of communication between the RN and eNodeB. These are the *Inband* and *Outband*. The inband communication occurs when the communication between the eNodeB and the RN uses the band, while the one for the outband uses a different band.

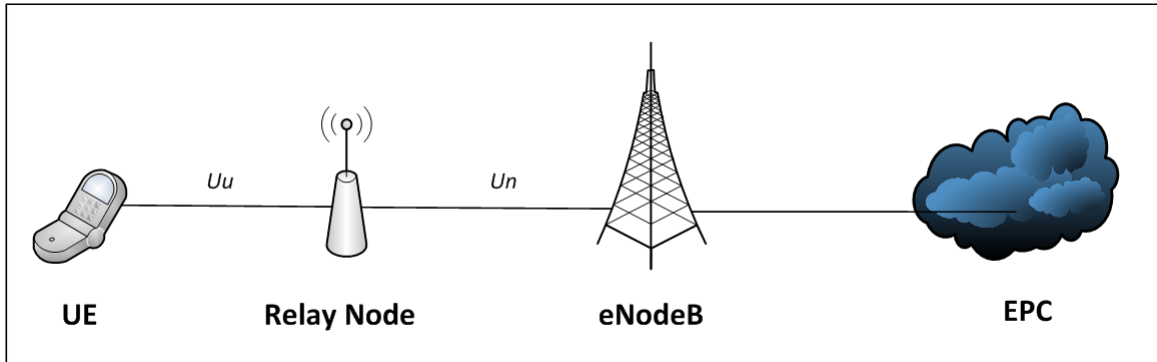


Figure 3.14: Basic Relaying Scheme.

### 3.6.1 Relay Classification

Relays classification can be made accordingly as follows based certain purposes and parameter:

1. *Amplify-and-Forward relays (or Repeaters)* and *Decode-and-Forward relays*;
2. *Inband* and *Outband*;
3. Infrastructure based relays are: *Stationary*, *Nomadic* and *Mobile Relays*;
4. For protocol based relays, there are: *L1*, *L2* and *L3* types;
5. User equipment based relays are: *Transparent* and *Non-transparent* types; and
6. *Type 1* and *Type 2* relaying.

## 3.7 Summarized Comparison of LTE and LTE-Advanced

According to [23], a comprehensive comparison for the LTE<sup>11</sup> and the LTE-Advanced is highlighted in table 3.3.

<sup>11</sup>Popularly referred to as the 3.9G.

LTE	LTE-Advanced
The LTE is not backward compatible with the previous 3G; it is part of the 3GPP Release 8.	The LTE-Advanced (4G) is backward compatible with LTE; and it is part of 3GPP Release 10.
The LTE is meant to give a data rate of 326 Mbps using the 4 x 4 MIMO but 172 Mbps with the 2 x 2 MIMO in 20 MHz spectrum.	The LTE-Advanced offers greater speed of almost more than 40 times faster than 3G. The use of the antenna 8 x 8 in DL and 4 x 4 in the UL also helps.
The LTE covers a range of up to 5 km for full performance	The LTE-A has quite the same as LTE requirements but there a need for optimization in the deployment for local areas and in micro cells.
A major advantage seen in the LTE is its high throughput with low latency.	The LTE-A offers an all-IP, high speed and low latency for mobile network. The throughput is about 3 times higher average user throughput than in the LTE.
In terms of mobility, the LTE support mobility across the cellular network for various mobility speeds up to 350km/h and could be up 500km/h which significantly depends on the frequency band.	For the LTE-A, there is the same mobility as in LTE; the system performance needs more enhancement for 0 - 10 km/h. The LTE-A will use spectrum allocations in different sizes to achieve higher performance.
Deployed in scalable bandwidths of 1.25MHz to 20 MHz.	Allows for transmission bandwidth of about 100 MHz in DL and 40 MHz in UL.
For the peak data rate, the LTE has 100 Mbps for DL and 50 Mbps for UL.	In LTE-A, the peak data rate is 1 Gbps for DL and for UL, 500 Mbps.
For the plane capacity, the LTE has at least 200 users per cell which should be supported in the active state for spectrum allocations up to 5 MHz.	For the LTE-A, the plane capacity is at least 300 active users without DRX (Discontinuous Reception) in a 5 MHz Bandwidth.
For a scalable bandwidth, there are 1.3, 3, 5, 10 and 20 MHz and with connection setup delay of less than 100 ms.	And the LTE-A has a scalable bandwidths of up to 20 to 100 MHz with connection setup delay of less than 50 ms.
The LTE has a capacity of 200 active users for every cell at 5 MHz.	In the case of LTE-A, there are 3 times the capacity of that in the LTE.

Table 3.3: Summarized Major Comparison of LTE and LTE-Advanced [23].

## 4 FEMTOCELLS

In this chapter, an extensive introduction is given to the femtocells background and overview with definitions, challenges and the alignment towards LTE-Femtocells.

### 4.1 Femtocells Overview

From the previous chapters, there has been thorough discussion about the desire to have improved data rate; the femtocell has been characterized as one of the solutions to improving the problems of coverage and capacity for users.

Under the 3GPP releases, there has been significant effort to increase the system capacity by using enhanced antenna configurations, the use of relays, microcells and even nanocells. But the use of the aforementioned has considerable limitations. For example, the use of the relays could not help in terms of the indoors capacity enhancement or better coverage; also, the CAPEX and OPEX for the microcells and nanocells cannot be substantial for cost reduction as this is a major target for reduction.

Therefore, in order to have an enhanced system capacity and better coverage for indoors, the 3GPP Release 8 specifications [10] have proposed the use of indoor home base station in the existing network architecture and future networks. In the 3G, the femtocell is referred to as the Home NodeB and in the LTE and LTE-Advanced, it has been named as the Home enhanced NodeB (HeNB).

#### 4.1.1 Basic definition of femtocell

Femtocells (or Femto Base Station, FBS) are small, low-power cellular base station (or access points) that are user-installed which sufficiently enhance the conventional mobile communication for extended coverage area and improved capacity in cellular networks [29], [30]. Also, they can be referred to as typically designed radio access interfaces that connect the main macro cellular base station with user equipment for home or office use in small or large business locations.

The development of the femtocell is a significant step made to help network density in macrocells. The femtocells help to reduce the cell size for increased quality of service. Of much emphasis is the reduction in the maximum transmit power in

femtocells as compared to the broader macrocells. As part of the small cell group, figure 4.1 shows a significant comparison with respect to radius of coverage.

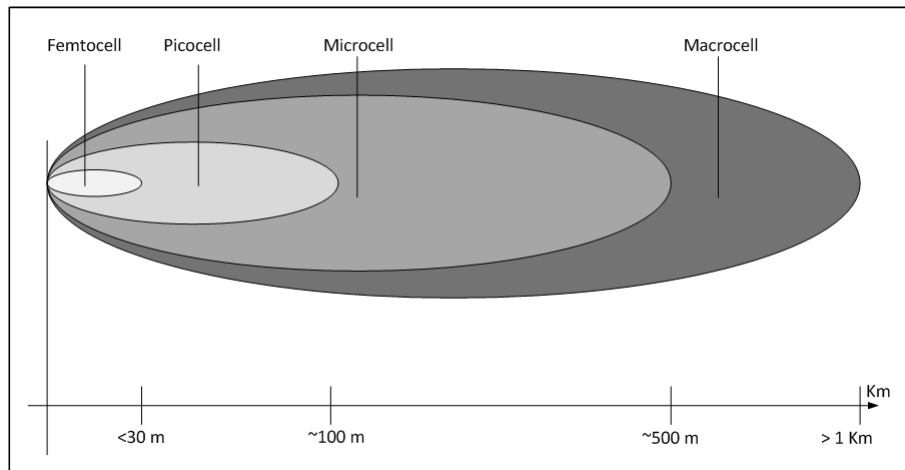


Figure 4.1: Small cell comparison in terms of range.

#### 4.1.2 Benefits of femtocell

The femtocell offers some significant advantages [25], [11] as discussed below:

1. *Coverage and Capacity:* The femtocells operate within a small distance, which helps to have a comparative low transmit power, and help to have higher SINR. As a result, there is always excellent signal reception for coverage and higher capacity.
2. *Macrocell Reliability:* The use of the femtocell helps to reduce the load on the macrocells. The macrocell uses some of its resources for better reception to serve mobile users; this is because the femtocells will absorb some of the indoor traffic.
3. *Cost:* In terms of cost reduction, the deployment of femtocells has been studied to reduce the CAPEX and OPEX for the service providers. Cost of electricity and backhaul is reduced and the cost of deploying extra macrocells is avoided as a result of the femtocells deployment which has significant compensation on the broader macrocell network.
4. *Subscriber Turnover:* It is quite popular that customers are not okay with indoors reception; and this has made customers to change their operators more often. So the use of the femtocell will help in creating a better customers' perspective in this regards.

In summary, the femtocells are essentially beneficial to the mobile operator and the users alike:

- (a) For the mobile operators, there is the data offload from macrocell, expanded operator revenue, lower cost on backhaul and increased or perhaps steady number of customers.
- (b) For the users, they enjoy better indoor coverage, excellent data speed in an all ubiquitous setting and improved terminal power consumption.

## 4.2 Femtocells Technologies

As part of the major benefits attached to the use of femtocells is the use over the licensed spectrum and the use of the operators' network coupled with the use of the internet connections at home or office. The femtocell requires technology designs that could fit into the *carefully planned cellular networks* [29] of service providers.

The ability of the femtocells to offload data and video traffics will depend on how efficient and reliable the technology is [17]. In a broad perspective, the femtocell is not just a small range device or perhaps, a high capacity device but it is significantly a device that has been designed from generation of technologies (or anticipated) to be able to interact easily with existing cellular networks conveniently at all the network layer. It does perform the tasks like *handoffs*, *interference management*, *authentication* and *billing functions*. Some of these functions have necessitated the quest for standardization, research and development coupled with compliance with growing radio access technologies.

The figure 4.2 shows a simple illustration of the basic femtocell network.

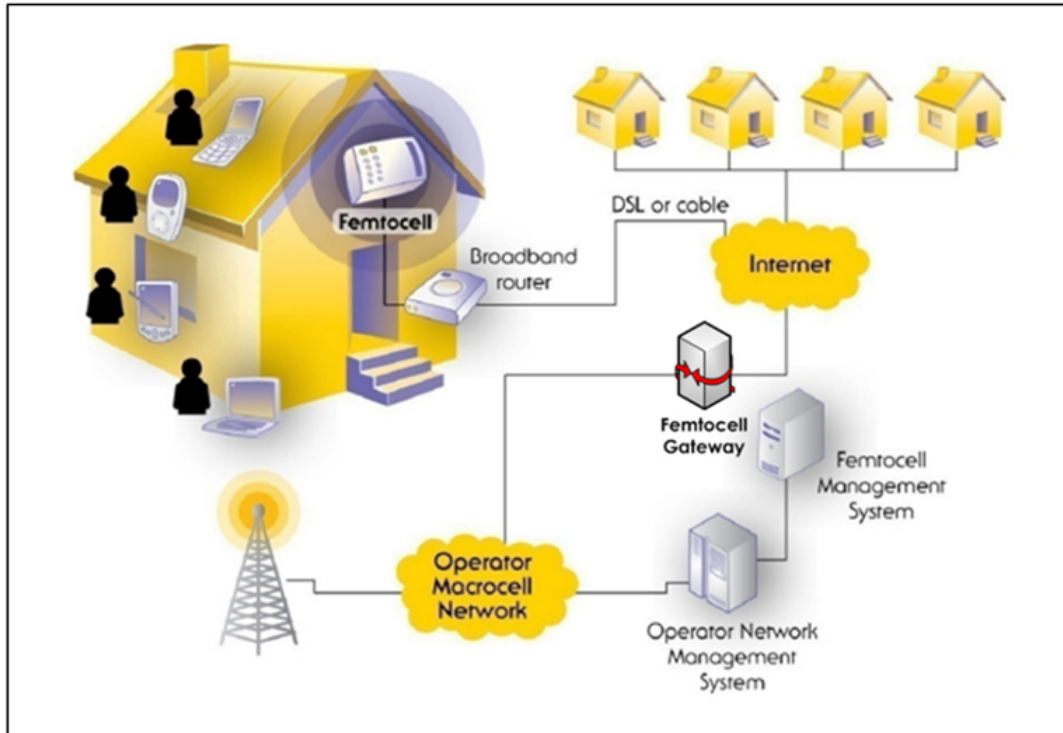


Figure 4.2: Femtocell basic network [31].

According to the *Small Cell Forum*<sup>12</sup>, some of the essential issues to be considered in the development of the femtocell technologies worldwide are primarily focused on: (a) Standardization, regulation and interoperability; and (b) Marketing and promotion of femtocell solutions. From this perspective, the most popular technologies of femtocells are the UMTS/CDMA2000 femtocells and the LTE/LTE-Advanced femtocells.

The femtocell architecture will be discussed based on the 3GPP standard releases subsequently in this chapter.

### 4.3 Challenges of Femtocells

Although, there has been a significant paradigm shift in the use of femtocells, there have been so much so few challenges [26] that the femtocells deployment has to combat. In a short form, some of these challenges have been based on (accordingly to [30]): (a) unplanned deployment; (b) user-installation; (c) restricted access; and (d) inter-operability with existing infrastructure. In a different perspective as grouped

<sup>12</sup>Formerly, Femto Forum [24]

by [3], we have the femtocell challenges based on (i) broadband femtocells; (ii) voice femtocells; and (iii) network infrastructure; this is illustrated in figure 4.3.

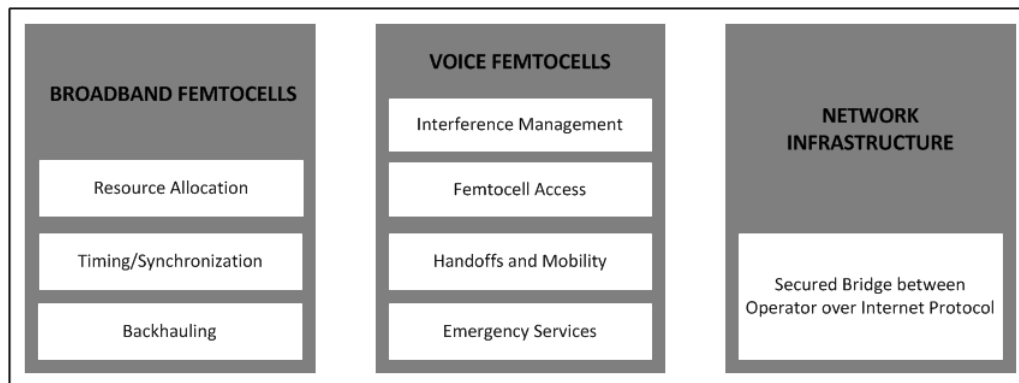


Figure 4.3: Perspective challenges on Femtocells.

In a broader perspective, the key technical challenges [29], [30], [16], [25] of femtocells would be discussed for all categories of femtocells, these are:

1. Interferences<sup>13</sup>;
2. Mobility and Handover;
3. Backhaul;
4. Self-configuration and Network Interoperability;
5. Restricted Access and Selection; and
6. Synchronization and Location.

#### 4.3.1 Interferences

The issue of interference is perhaps the most significant and widely known challenge to the deployment of femtocells. The introduction of femtocell into a cellular network basically alters the network topology. The issue of interferences could arise from interferences related to:

1. Macrocell to Femtocell;
2. Femtocell to Femtocell<sup>14</sup>; and

<sup>13</sup>Interference to/from other femtocells and macrocell BSs

<sup>14</sup>The interference depends on the cell spectrum sharing and co-layers



### 3. Femtocell to Macrocell.

The interferences of Macrocell to/from femtocell are due to the near-far effect of receiving power not uniformly distributed. The interferences among femtocells are at a low end as this is due to apparent low transmit power and (indoor) penetration losses. The figure 4.4 shows a cross tier interference [29] illustration.

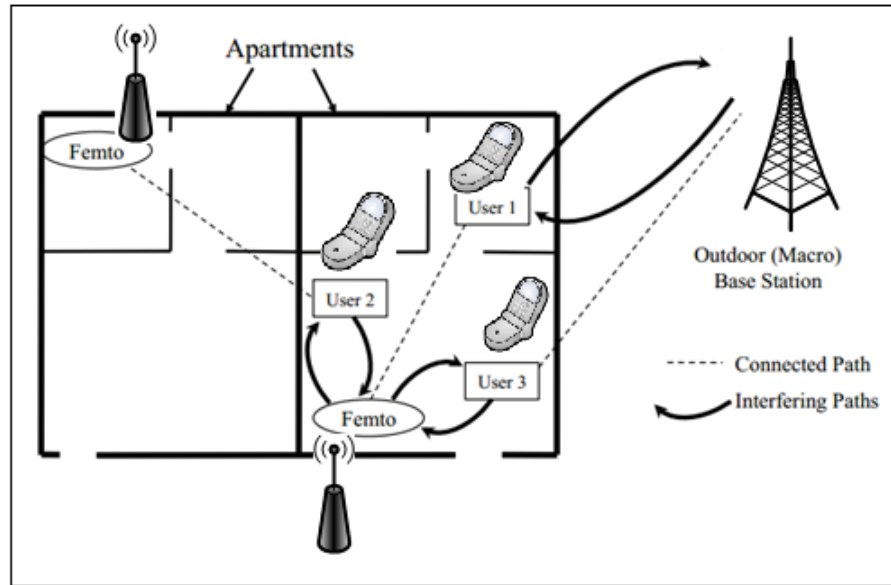


Figure 4.4: Cross tier interference illustration [29].

#### 4.3.2 Mobility and Handover

In a perfectly located position within the macrocell, there is always an excellent capacity and service experience; in the vein, when users are within the femtocell region, they expect to have the same service. It is important that there is a seamless handover between femtocells and macrocells or rather between femtocells for excellent service experience within the femtocell region since there are increasing numbers of femtocells and they are becoming densely deployed.

Although, it is quite possible for UE to search and transition outside of the femtocell region, a big threat to the femtocell technology is the issue of having efficient and seamless transition from femtocell to femtocell or femtocell to macrocell. As a matter of fact, the state of the UE is also dependent on the transition. In other words, this transition creates a bigger problem especially during call handover - *idle* or *active*.

- (i) **Idle Mode:** During idle mode, it is important for UE to transition smoothly from outside the femtocell into the femtocell range; this is very important for efficient paging for registration. But since the femtocell and the macrocell are deployed essentially on different frequency band, there is a need for an efficient mechanism of handover for the UE from the macrocell frequency into the femtocell. A big problem in this case is that the issue of frequency registration affects the level of battery life consumption. Therefore, if there is regular transition from the femtocell to the macrocell, regular frequency searching and registration will steadily affect the battery life.
- (ii) **Active Mode:** In the active mode, identifying the target femtocell is the major problem. For macrocells, the source macrocell easily identifies the target macrocell because of its unique identity and the combination sequence used in transmission. But in the femtocells, the numbers of pilot sequences comparatively in the femtocells are less and they are not unique.

As a result of these challenges, a *solution* has been developed to combat the problem of active mode handover called *femto-aware* [30]. There are femto-aware user equipments and infrastructure, but the cost and complexity of the modification of already deployed network infrastructure has hindered greatly the development of the femto-aware user equipment.

Additionally, the issue of mobility problems as a result of handover is still an ongoing process as the standard organizations are looking for ways to create procedures for vertical handovers between femtocells and non cellular access technologies in the case of femto-to-femto mobility.

### 4.3.3 Backhaul

The issue of security and quality of service over the third party backhaul is a major concern in the deployment of femtocell. Since the femtocells are backhauled over public infrastructure like the internet (which serves as the backhaul for the femtocell gateway and the service provider core network), there are major concerns relating to *security of the femtocell*, reduced level of *QoS* and *bandwidth limitation*.

Compared to the backhaul that is centrally controlled in a macro-cellular system, the femtocell backhaul is a third party entity out of the control of the user or the

operator, and such managing the QoS and the security becomes extremely difficult in a femto-cellular scenario.

#### 4.3.4 Self-configuration and Network Interoperability

It is essential that femtocells are able to self-interface with the rest of the network, especially in terms of management and control. In the macro-cellular network, network planning is necessary to have better coverage, good capacity and efficient interference management, which are very important for network optimization. To follow this system of network planning in femto-cellular will not be cost effective; and more also, femtocells are used by voluntarily by subscribers without the actual consent of the service provider at any time.

Therefore, full standardizations are able to have self-organization and proper remote authentication and integration of femtocells. In other words, the femtocells must be able to function as a *plug-and-play* device with automatic self-configuration and adaptation. That is why the femto-cellular network is *sometimes* refers to the Self-Organizing Network (SON)<sup>15</sup>.

### 4.4 Typical Femto-cellular Network

In the 3GPP standards, some of the femtocell operational elements in the femtocell architecture are the Home Node B Gateway (HNB-GW) and Home Node B Management System (HMS). These two network elements have been released as part of the release 8 which focuses mainly on the 3G UMTS network architecture [12].

In addition to the two main essential network elements, there is the logical element called the Security Gateway (SeGW) and the introduction of the *Iuh* interface which connects the HNB and the HNB-GW.

A detail illustration is given in figure 4.5; where the Closed Subscriber Group (CSG) is used to identify subscribers of a Service Provider that are given permission to access the cells of the PLMN; although they still have restricted access. Also, as indicated in the figure, the HNB Subsystem (a combination of the HNB and HNB-GW), (HNS) serves as an RNS to CN and with connection via *Iu-CS* interface straight to the MSC using the *Iu-PS* interface to the SGSN.

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<sup>15</sup>The SON will be discussed more under chapter 5

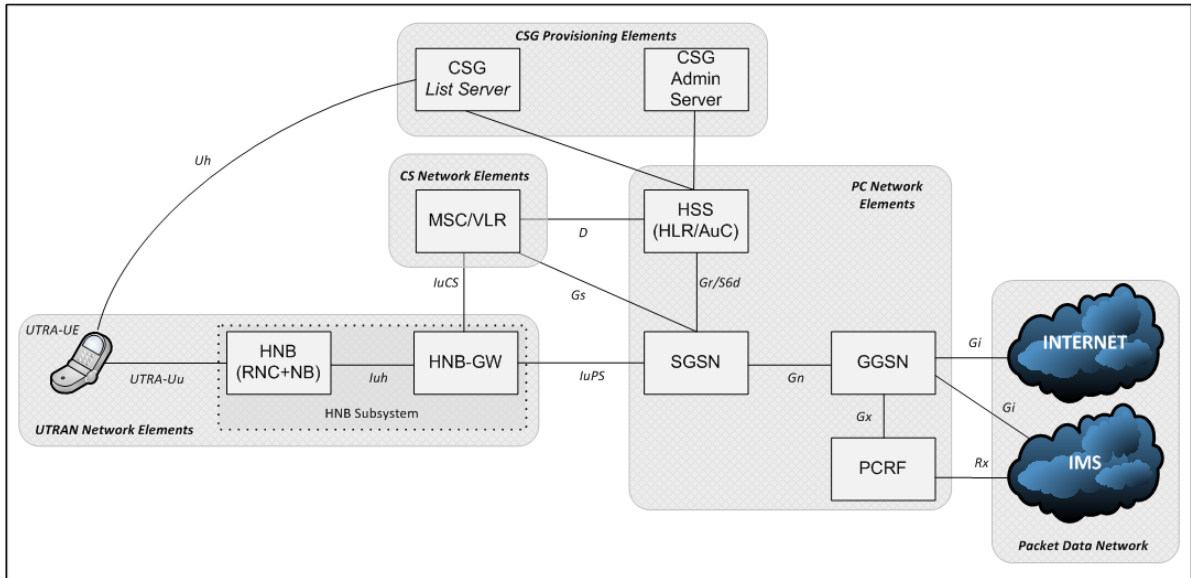


Figure 4.5: UTRAN Network Architecture (with CSG provisioning and Access Control) [12].

1. *Iuh* Interface;
2. HNB Management System, HMS;
3. Security Gateway, SeGW;
4. Home Node B Gateway, HNB-GW;
5. Home Node B<sup>16</sup>, HNB;

#### 4.4.1 *Iuh* Interface

The figure 4.6 shows the *Iuh* reference model extract from the figure 4.5 has described by [3], [32], [1]. The *Iuh* interfaces the HNB and the HNB-GW. It serves as the transport line for the messages for the C-plane and the U-plane. It should be noted that the *Iuh* is the only the interface used by the SeGW and the Authentication, Authorization and Accounting (AAA) from the HNB-GW to provide the needed data integrity in the tunnelling of the IPSec.

<sup>16</sup>Or *Femtocell Access Point*

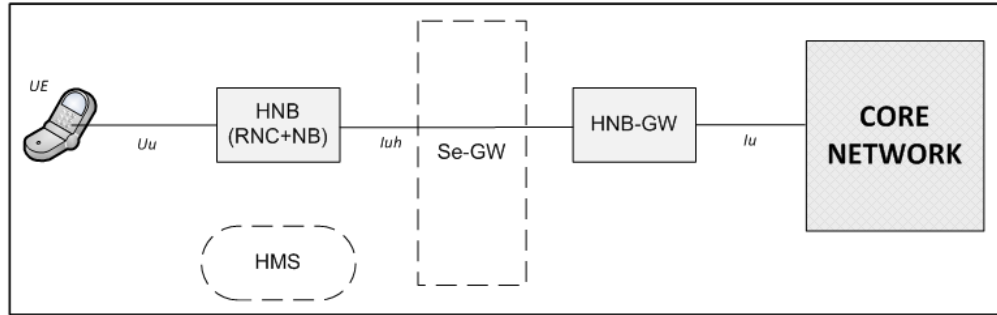


Figure 4.6: Iuh Interface as shown in the 3G Femtocell logical architecture [3], [32].

#### 4.4.2 HNB Management System, HMS

The HMS operation is based on the functionalities description in the TR-069 [13] family of standards. The HMS functions by sending configured data through to the HNB, coupled with functioning as an aid to the HNB-GW and SeGW discovery. In other words, it performs the function of a Location Verification for HNB, and then assigns the necessary elements. With the help of the HMS, the operator is empowered to control and do HNB configuration.

#### 4.4.3 Security Gateway, SeGW

The SeGW serves as a terminating point for secured tunnelling<sup>17</sup> for the TR-069 family of standards described in [13] and likewise the Iuh. In addition, it provides secured link for communication between the CN and HNB. Also, the SeGW provides authentication service for the HNB; most importantly provides access the HMS and the HNB-GW.

#### 4.4.4 Home Node B Gateway, HNB-GW

The HNB-GW is the main device that connects the HNB to the main UMTS network. Its functions are mainly as described in the 3GPP release under [10], [B2]. The HNB-GW is provides many functions in the femto-cellular network, typically link control and security. The HNB-GW serves as the RNC and maintains the CN connectivity. As mentioned *Iuh*, the HNB-GW (may) provide the AAA functions to improve the security level of the femtocell [14].

<sup>17</sup>For example, the IPsec tunnels described in [13].

#### 4.4.5 Home Node B, HNB

The HNB is typically the Femto Access Point installed at the user's residence or in the office. It is the main femtocell device. It is used as a *plug-and-play* device. The HNB offers the same service as though the UE is within the NodeB range. It is everything one can define literarily as the *femtocell*. The HNB uses the subscribers' broadband connection to connect to the Service Provider's core network. Also, the HNB uses the *Uu* interface to interact with the UE.

### 4.5 Architecture Model of an HNB Access Network

The figure 4.7 shows the high-level logical architecture of an HNB access network as presented in [2].

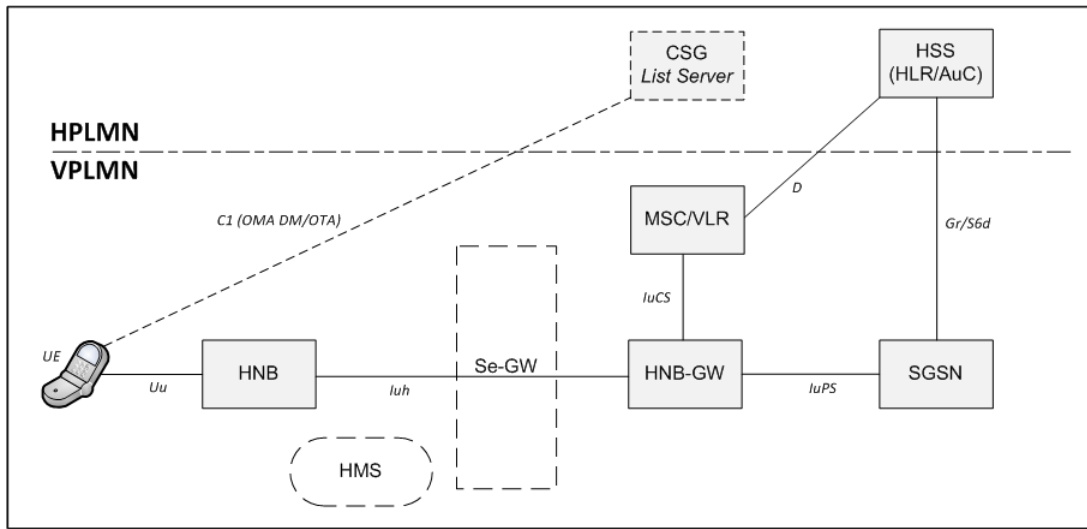


Figure 4.7: Logical Architecture of an HNB Access Network [2].

### 4.6 LTE Femtocells

Tremendous effort has been made to find a way to integrate the HNB into the LTE systems. It has been planned that the HNBs are to be integrated into the EPC of the LTE infrastructure using the same defined interfaces as used in the macro-cellular network. The objective is to make the HNB and the macrocell use the EPC; with the EPC having the flat architecture offered by the LTE architecture. In the real sense, the LTE femtocells is planned to have a flat architecture. A point of note is that the interfaces between the LTE femtocells and the main EPC elements are redundant.

The general architecture of the LTE femtocell architecture is illustrated in figure 4.8.

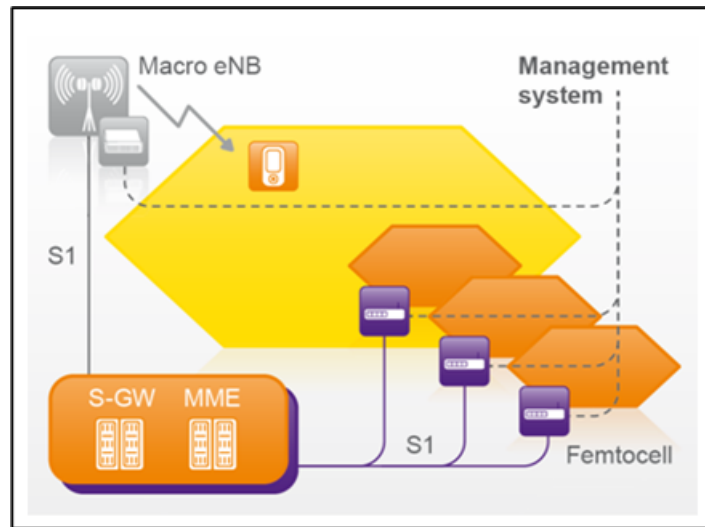


Figure 4.8: A simplified diagram of LTE Femtocell network architecture [15].

The figure 4.9 gives an overview a typical E-UTRAN network architecture that involves a CSG provisioning and access control; and some of elements involved. As shown, the HeNB Subsystem (HeNBS) is a combination of the HeNB and may have the HeNB-GW. The HeNBS is connected to the EPC via the S1 interface; and since the EPC has the MME and S-GW interface points, the HeNBS connects to the MME via the S1-MME interface and to the S-GW via the S1-U.

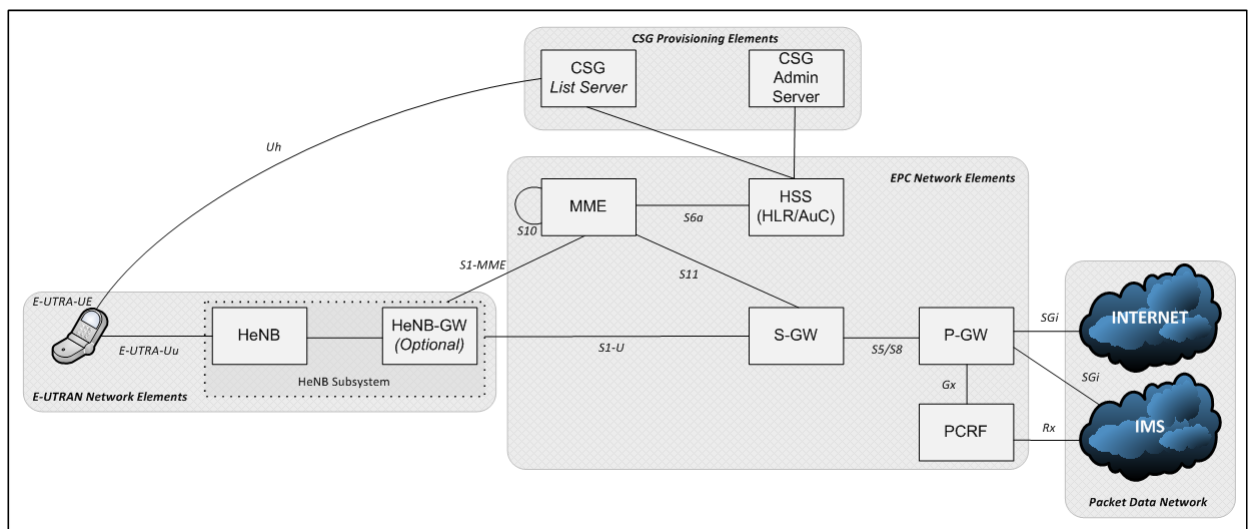


Figure 4.9: The E-UTRAN network architecture for CSG provisioning and access control [12].

The LTE femtocell architecture (or HeNB system) [2], [11] has been proposed in three different variations of implementation by the 3GPP. The three variants depend on how the Femtocell gateway is placed, particularly how the HeNB is connected to the CN. The three different variants are presented accordingly.

#### 4.6.1 Variant 1 of LTE Femto-cellular Architecture

The figure 4.10 shows the architectural model for the Variant 1 of the LTE femtocell. This variant is *with dedicated HeNB-GW*. This is about the most familiar architecture because of its simplicity of deployment. The presence of the HeNB-GW makes its availability and operational convenience. *The HeNB and the HeNB-GW communicate via a secured mandatory Se-GW; also the Se-GW implementation may be done separately as a physical entity or part of the HeNB-GW*<sup>18</sup>.

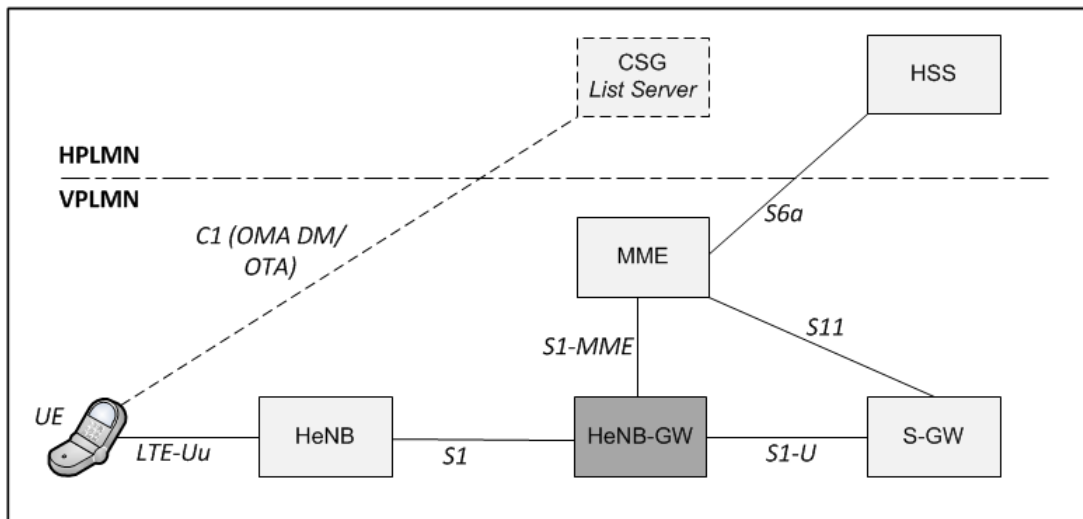


Figure 4.10: LTE Femto-cellular Architecture: Variant 1 *with Dedicated HeNB-GW* [2], [11].

Some of the benefits [11] of using this variant option are highlighted:

- In this variant, there is only a single Stream Control Transmission Protocol (SCTP) involved in between the HeNB-GW and the MME. Also, between the HeNB and the HeNB-GW, there is only one SCTP. It is important to note that, if the HeNBs is increased in a network, the SCTP association with the MME remains the same;

<sup>18</sup>This is not shown in the figure.



- The HeNB does not necessarily need to support the S1-Flex to reduce the total number of S1 interfaces;
- Of much security importance, this variant can hide the IP addresses of the MME and S-GW from the HeNB, thereby creating a better secured system by not revealing the CN IP addresses to the subscribers.
- Another safety and security importance is that, the HeNB-GW has the possibility to implement a Denial of Service (DoS) which protects the MME and the S-GW. It can apparently detect, filter and shield from traffic attacks and at the same time maintains the desired QoS;
- SIPTO implementation is possible under this variant; and the implementation of the local S-GW and the P-GW in the HeNB-GW can help reduce the need for additional network elements within the existing architecture; and so on.

On the low side, this variant offers a processing load which affects the traffic proportionately; and since HeNB connects to just a single HeNB-GW concurrently, redundancy is reduced.

Application scenario of this variant 1 to service providers is that for those who already have a 3G HNB solution, it will be easier to redeploy to an LTE HeNB, due to their similarity in architectural terminations for the C-plane and the U-plane in the GW.

#### 4.6.2 Variant 2 of LTE Femto-cellular Architecture

This type of variant does not have any HeNB-GW physical presence. In this case, the HeNB-GW functionalities are integrated in between the HeNB and the MME so as to reduce the network cost and latency level.

The variant 2 architecture supports the possibility for the HeNB to be able to self-configured, apparently serving as a plug-and-play [4]. Of greater advantage is that, it can be deployed without any prior network planning. *The HeNB and the MME/S-GW communicate via a secured mandatory Se-GW*<sup>19</sup>. The variant architecture is shown in the figure 4.11. Some of the advantages in this variant are discussed below:

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<sup>19</sup>Not illustrated in the figure.

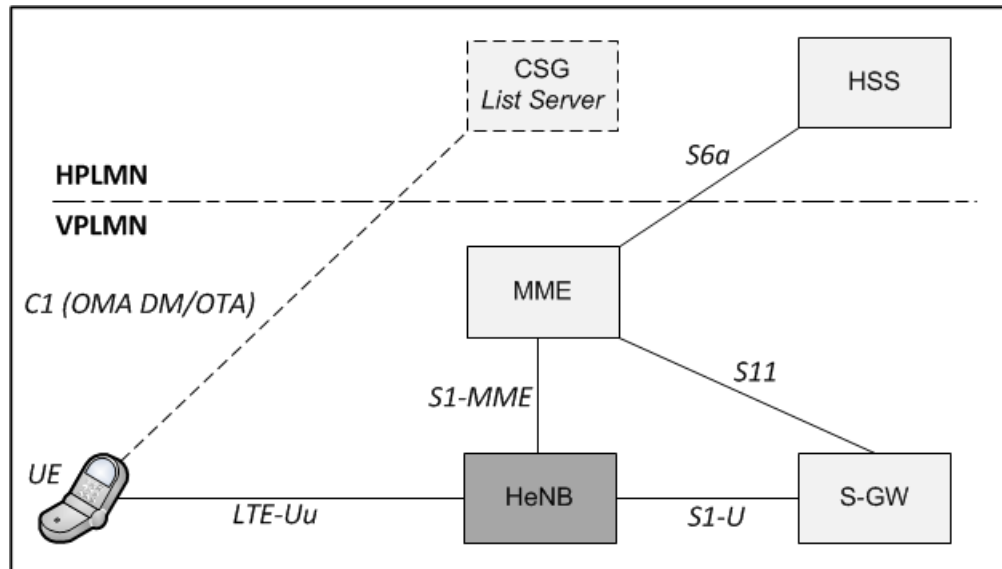


Figure 4.11: LTE Femto-cellular Architecture: Variant 2 *without Dedicated HeNB-GW* [2], [11].

- In this second variant architecture, there is always an isolated failure in the system, that is, when there is a failure below the MME/S-GW in one of the HeNB network elements, all other HeNBs are not affected;
- By having a simple flat architecture of the second variant, there are less number of network elements.

A major short-coming of this variant is that it does not create any connection concentration for SCTP/GTP-U as in variant 1; and of much concern is that if support for the S1-Flex is made, additional system complexity is introduced.

The application deployment scenario benefit for this second variant is that, there is considerable reduction in cost, especially when there are not much HeNBs or less density of the HeNB.

#### 4.6.3 Variant 3 of LTE Femto-cellular Architecture

The figure 4.12 shows the third variant of the LTE femto-cellular architecture. In this variant, there is a dedicated HeNB-GW in C-plane only and the S1-U interface of the HeNB is terminated at the S-GW. In other words, the HeNB-GW is used for the C-plane aggregated signalling and the U-plane is terminated at the S-GW.

Some of the advantages associated with using this type of variants are:

- *The HeNB does not have to support the S1-Flex on the C-plane;*
- The use of this kind of variant will allow for Paging optimization mechanism implementation within the broader HeNB-GW.
- Also, in this variant, the HeNB-GW is allowed to implement an overflowing of MME mechanism when there are unexpected HeNBs failures, for example due to power supply disruption or emergency.

On the negative side, this variant 3 does not supports GTP-U connection; if there is desired increase in the number of HeNBs within the system, an overload situation might occur as a result of the UDP/IP. More also, in this variant, in the C-plane, the HeNBs connect to every single HeNB-GW at a time.

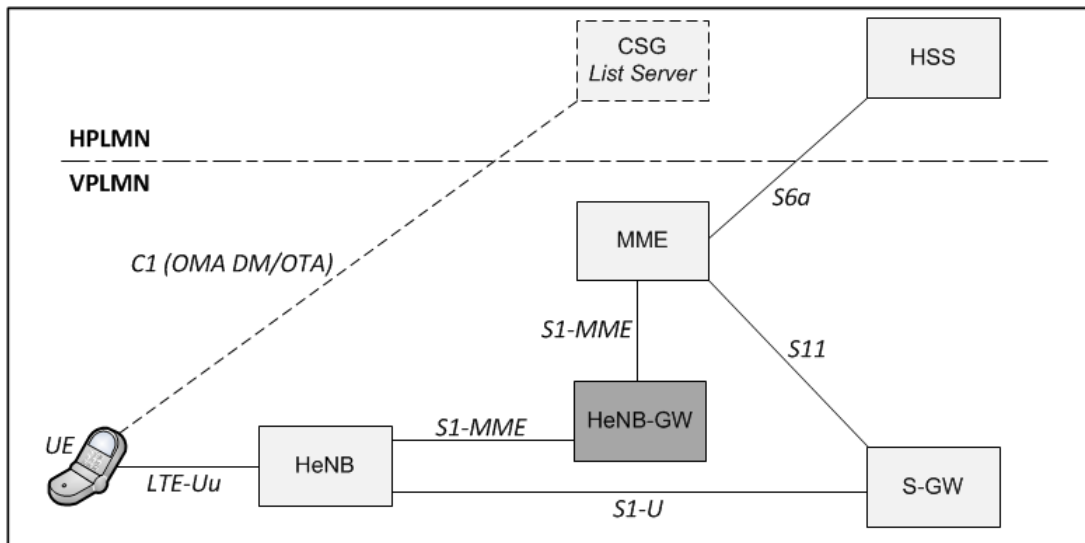


Figure 4.12: LTE Femto-cellular Architecture: Variant 3 *with Dedicated HeNB-GW in C-plane only* [2], [11].

As a summary of the variants for the LTE femto-cellular architecture, the figure 4.13 shows the combined possibilities in the architecture as presented in [15].

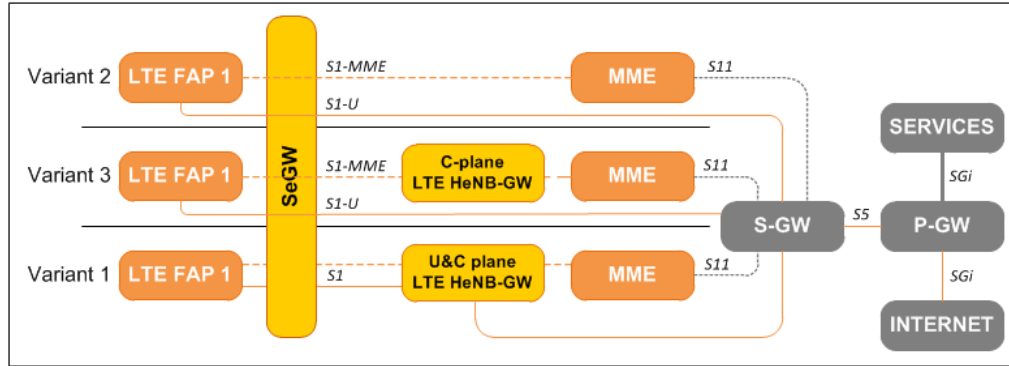


Figure 4.13: Overall variations of the LTE Femto-cellular Architectural Network [15].

#### 4.6.4 Other possibilities

Although the three variants discussed above could become implementation options for vendors and service providers alike, the LTE Femtocell architecture are not limited to the three variants. More future developments have been considered with respect to the operational needs of the service providers. More also, with the Local IP Access (LIPA) and Selected IP Traffic Offload (SIPTO) concepts [5], [6], the introduction of new possibilities with different functional variations are not impossible for the development, deployment and future of femtocells.

## 5 FUTURE OF FEMTOCELLS

This chapter is considered from perspective the users, press reviews, the operators concern and the perspective on the technical related future issues as it may apply.

### 5.1 General perspective on the femtocells future

According to *FierceWireless*, Europe [77], over 95% of service providers believe that small cells are essential for the future. It is a known that the resurgence witnessed in the enhancement of the mobile wireless network has been significantly improved by the use of the small cells (and most importantly by the femtocells). In the case of *The Mobile Network, two thirds of operators claim 2014 will be 'year of deployment'* [78].

Obviously, the future of femtocells is dependent on several factors that would either see the prospects of the development or mar its desired use by subscribers over the coming years, thereby reducing the confidence level. In examining the future of the femtocells with respect to this thesis, a close look has been given into examining most of the vital challenges faced by the femtocells in general. An evolving LTE roadmap with specific issues of advance interference management and enhanced self organising network techniques are very critical to the success of reducing the operating cost of HetNets in general. The issue of cost reduction is a particular point of concern for the network operators.

In addition, it is noteworthy to say that the use of femtocell has come with recent attacks from some security experts who view the femtocells has been vulnerable to hacking. With the recent releases of clarified documents of the National Security Agency (NSA) [79] and raw intelligence of citizens alike; allegations abound that a larger percentage of the snooping has been done due to the security lapses with some femtocells. In [80], CNNMoney and the iSEC Partners, made known the level of vulnerability in the present femtocells operating under Verizon Network. This security flaws has potentially caused a rethink by users. Tom Ritter, a Senior Security Consultant with iSEC Partners made a claim, *We see everything that your phone would send to a cell phone tower: phone calls, text messages, picture messages, mobile web surfing.*

Also, the use of femtocells for emergency services like (911, 112 and the likes) has been faced with a couple of challenges. To ensure a public safety solution, it is im-

portant that the future of femtocells get proper standardization in terms of its use for emergency services. At the moment, lack of properly defined standards poses some challenges especially when it comes to its use. Some of these (as discussed in [81]) are: (a) provision of subscriber information; (b) data delivery to the Public-Safety Answering Point (PSAP); and (c) Verification of the Radio Frequency Coverage. Although, a considerable effort has been made in solving some of these problems, much needs to be done in terms of standardization.

## 5.2 Technical Challenges for the future

In solving some of the problems associated with the current deployments of femto-cells, listed below are some of the most technically challenging areas of concerns:

1. Security and backhaul
2. Self-Organizing Network
3. enhanced MIMO
4. Interferences

### 5.2.1 Security and Backhaul

One of the factors that will have tremendous impact on the global success of the femtocells will be the issue of security. As examined in [82], security is a critical point in the femto-cellular network, particularly in all aspects of its operation or use. For a device placed in the customer's own premises, the level of attack or vulnerability will be higher as compared to under the operator's jurisdiction. Therefore, it is important that Femtocells are designed to avoid security attacks either physically or remotely via hacking.

To further make emphasis on the vulnerability of the present situation of femto-cells, an example of an attack on a femtocell network was by *the Hacker's choice* on the Vodafone Access Gateway<sup>20</sup>; with supposed claims that more attacks will be published as a follow-up which shows the extent of insecurity involved [83]. As presented in [82], certain level of operational requirements must be set to combat the issue of security breach in future femtocells. Some of these are highlighted below

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<sup>20</sup>Vodafone upgraded its femtocell system, but more still need to be done.

as specific requirements operators or service providers need to strictly adhere to and strongly regulated by respective regulatory bodies.

- Higher level of cryptographic algorithm needed that will protect the confidentiality and integrity, coupled with excellent authentication;
- The use or modification of the Hosting Party<sup>21</sup> information must be allowed only with strict permission obtained by the Service Providers from the hosting party;
- The International Mobile Subscriber Identity (IMSI) data of users who are connected to the femtocell network with not be displaced or released to the Hosting party.

Worthy of note is that the femtocell is still legally the property of the operator but placed in custody of the Hosting party.

Furthermore, to enhance the security of the femtocells, set requirements should be created relative to the overall femtocell, the Se-GW, and the HMS<sup>22</sup>. Also, since the femtocell relies on the backhaul for connection; and the backhaul connection requires the public internet; a very high level of attack is very much possible. The Backhaul is a major tool by *anti-femtocell guilds* [91], but it could be overcome. Since the backhaul is used in Wi-Fi and even LTE macrocell, it can be said that the issue of backhaul does not have only femtocell peculiarity.

Therefore, there are essential needs to have a well secured backhaul link encryption as presented in [84]. Of great importance is that a better secured backhaul will provide high level of integrity protection for data transmission and may ensure dependable confidential level. More also, creating a backhaul security solution based on Internet Protocol Security (IPSec)<sup>23</sup> [85] Encapsulating Security Payload (ESP) tunnel mode will be an excellent security solution.

The figure 5.1 shows a simple illustration of the three level vulnerability attacks in a femto-cellular network as depicted by [90].

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<sup>21</sup> *This refers to the person or entity or premises where the Femtocell is placed or deployed*

<sup>22</sup> Or Femto Access Management System

<sup>23</sup> Essentially important for attacks

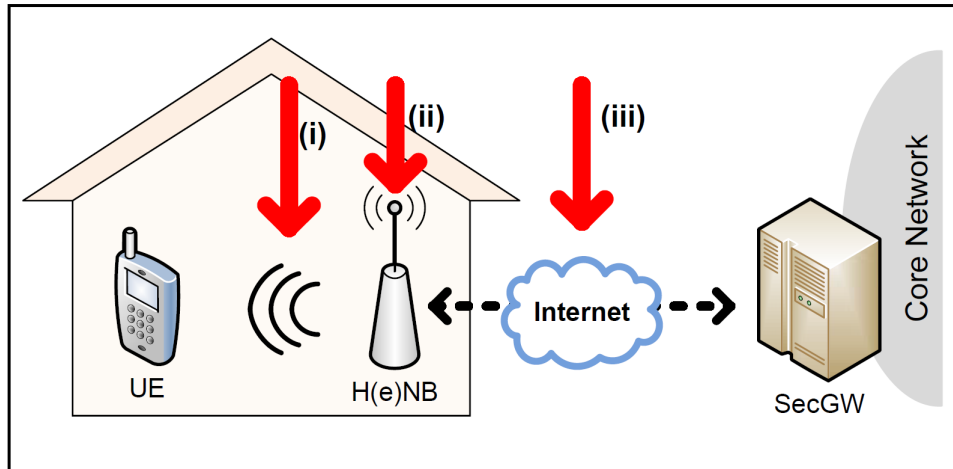


Figure 5.1: A three-target malicious attacks on a femto-cellular network as shown indicated by the red arrow [90]

The three targets malicious attacks could be on the air interface between the UE and the HeNB; attack on the HeNB; and/or attack on the public internet link between the SeGW and the HeNB.

### 5.2.2 Self-Organising Networks (SON)

The future of femtocells (and particularly, the future networks) depends on SON's capabilities. Although, some of the concepts of SON have been used in some regards, a number of key 3GPP principles still need to be addressed in the future. The ones highlighted in the figure 5.2 are based on the Ubiquisys System. To have a self organizing network that caters for the femtocells without the assistance of human control, the following concept of SON [87] are needed and are presented as follows:

- Efficient self-configuration system;
- Spectrum selection;
- Power tuning;
- Resource block assignment; and
- Access control policy.



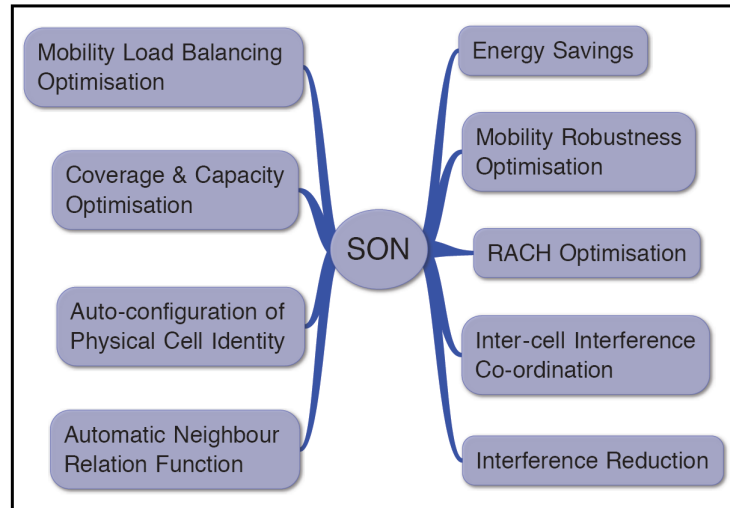


Figure 5.2: Key 3GPP outline principles for SON [86]

Some of the previous releases of the 3GPP towards a better standardization of the SON concepts [88] have been SON Release 8, which focuses on Automatic Inventory, Automatic Software download, Automatic Neighbour relations, Automatic Physical Cell Identification (PCI) assignment and subsequently the release 9 which caters for the functionality introduction for the developing networks: Coverage and Capacity Optimization, Mobility Optimization [89], Random-Access Channel, RACH and Load Balancing optimization.

Some of the original ideas of the SON were main focus on the femtocell originally, it is therefore important to improve this sophisticated technology to be able to meet up with the future demands of the femtocell development. Due to insufficient materials on the Femtocells SON, future works should focus on how to efficiently develop femtocells to be better *self-configured* and *self-optimized*; and inclusively, *self-healing* by being able to detect failures in the network and to be able to correct or reduce their occurrence [92].

### 5.2.3 Interferences

The issue of interference is a vital concern for the future of femtocell. To efficiently have an excellent link quality and efficient spectral re-use, the issue of interference needs to be addressed squarely. In [94], a cognitive radio enabled (CR-Enabled) femtocell has been proposed as a solution to the many problems of interference in femtocells deployment. Of much importance is the ability of the CR-Enabled

femtocell to reduce or eliminate the very complicated interferences. The CR-Enabled techniques offer a new paradigm that includes *opportunistic interference avoidance, interference cancellation and interference alignment*.

### 5.3 Small Cells today and the future

As the small cells network (SCN) becomes more prosperous with the help of femto-cells deployment, it is important to note that the future of small cells generally can not be limited to femtocells but all other cells alike need their potentials harnessed critically.

As presented in [95], as much as some of the major challenges of the SCN abound; issues like Suboptimal spectrum utilization, dense deployment interference, mobility in SCN, energy consumption and so on, the future of the SCN is dependent on the solution provision to combat most of these problems [95].

As presented in the Alcatel-Lucent Strategic White Paper [96], if operators will plan to turn small cells into big profits, they must be ready to use the SCN to solve target challenges the deployment of femtocells.

## 6 CONCLUSION

### 6.1 Concluding Remarks

In a broader perspectives, this thesis has given a top-down overview into the past, the present and what the future holds for the femtocells. From the advent of the LTE to LTE-Advanced and the incorporation of some of the key ingredients of the LTE-Advanced; it is important to know that the development of femtocells as a part of the *big* small-cell pictures has a place in the present and future of wireless networks.

Of much significance, the femtocells benefits were considered with discussion on what they offer and will continue to offer in terms of improved coverage and better capacity; more system reliability; cost reduction and a boost to subscribers' confidence. In additional, presented accordingly also, are some of the major issues that might set in if the future of the femtocells is not given necessary attention in terms of the security and some technical challenges it is facing by the deployment or installation or operation of the femtocells by some operators.

It is worthy to say that this thesis has within the confine of the scope of this work given an extensive dissection into the femtocells benefits and challenges; and some examination with respects to some critical situations that might jeopardize the trust and confidence the operators are getting from their customers.

As a point of emphasis, it should be noted that femtocells can be a formidable force to reckon with at the present and in the future, if very sensitive concerns are looked into critically. The issue of privacy and confidentiality are of paramount importance in our world of technology today; and every user wants a certainty within a particular level of trust. As said earlier, recent allegations about snooping or hacking by some government agencies via the femto-cellular networks has created much of a greater concern of how secured or safe to use the femtocell. Aside from that, there has been discussions about citizen-to-citizen (C2C) attack via the femtocells.

Furthermore, this thesis presented within its scope, the facts that even if the security issues are some of the most obvious concerns for femtocells users, the service providers or the operators need more worry to combat with when it comes to some of the other issues that need much attention in development of future femtocells.

Particularly in the area of interference management, self-organization, enhanced antenna system and so on.

As it stands, a paradigm shift is happening in the broader cellular networks. A shift that will need new models, new tools, new techniques and top researches to be able to catch up with the demand for higher data rates, seamless communication and much interference-free system in the clusters of the Internet of Things.

## 6.2 Will the future be in 5G Femtocells?

With the 4G networks currently been deployed in some locations, and some of the problems being faced by femtocell deployments and usage have not been addressed; the future awaits *probably* a different horizon that straightens things for the femtocells.

Some of the *features*<sup>24</sup> of the fifth Generation (5G) technology have been given as: high resolution and *bi-directional large bandwidth shaping*; high quality of services based on error avoidance; very large data in Gigabit and a number of more that have not been decided on. Although, there are no official proposals as per the requirements of the 5G network yet, but it is absolutely expected to address so much concerns that are currently in the current deployments.

In [93], titled - *Design Considerations for 5G Mobile Network*, high performance platform was presented as a necessity towards the development of the future networks which apparently will be beneficial to future femtocells. Also, there is a suggestion that the development of High Altitude Platform (HAP) will be one of the innovative ideas the future networks will have, especially for rural and maritime areas, broadband Local Multipoint Distribution System (LMDS).

Nevertheless, what has been proposed as a major significance is the introduction of Cognitive Radio for a Cognitive Femtocell System. This has been tagged as the future internet wireless networks [93]. With the anticipation of the creation of high throughput demands for UEs in the future, way better than the current system, it is firm to say that the femtocell is a journey that has just begun. The prospects it will offer is broad and will absolutely be a force to reckon with in the future.

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<sup>24</sup>No standard specification targets yet

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