Sudan University of Science and Technology
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Performance Evaluation of Enhanced Inter-Cell Interference Coordination with Pico-Cell Adaptive Antenna in Long Term Evolution-Advanced

تقييم الاداء لتحسين تنسيق التداخل بين الخلايا بهوائيات بيكوسيل المتكيفة في التطور طويل الأمد المتقدم

A thesis Submitted in Partial Fulfillment of the Requirement for the Degree of M.Sc. in Electronics Engineering (Communications Engineering)

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الإستهلال

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

وَيَسْأَلُونَكَ عَنِ ٱلرُّوحِ قُلِ ٱلرُّوحُ مِنْ أَمْرِ رَبِّى وَمَا أُوتِيتُمْ مِنَ ٱلْعِلْمِ إِلَّا قَلِيلًا ﴿٨٥﴾

سورة ٱلإسْراءْ

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Abstract

The concept of heterogeneous networks has attracted a lot of interest recently as a way to improve the performance of the network. The heterogeneous networks approach consists of complementing the Macro layer with low power nodes such as Micro or Pico base stations. In LTE-A hetnet , pico-eNBs are deployed to adequately offload traffic from macro layer and bring users closer to the base station to enhance the cell edge user experience. However, macro-eNB causes strong interference to pico cell edge users due to its higher transmission power. Hence, inter-cell interference is the biggest challenge in LTE-A HetNets. The intercell interference management is a critical point to improve the performance of the cellular mobile networks. This thesis aims to mitigate intercell interference in the downlink LTE-A HetNets.

Enhanced Inter-Cell Interference Coordination (eICIC) schemes have been proposed to mitgate the heavy interference in the Range Extension case ranging from time domain schemes like Almost Blank Subframes (ABS).enhanced

This thesis is an in-depth analysis of inter-cell interference in LTE-Advanced HetNets and explores various solutions proposed in the literature to reduce interference. It presents a pioneering tactic based on the blend of eICIC (enhanced Inter-Cell Interference Coordination) and smart antennas to further reduce the macro interference.

The simulations for downlink co-channel deployment of macro-eNB (evolved Node B) and pico-eNB, demonstrates overall network performance gain and improved QoS (Quality of Service) for the pico cell edge users' achieved using the proposed scheme.

المستخلص

لقد اجتذب مفهوم الشبكات غير المتجانسة الكثير من الاهتمام في الآونة الأخيرة كطريقة لتحسين أداء الشبكة. ان منهجية الشبكات غير المتجانسة هي عبارة تكميل طبقة الماكرو بخلية منخفضة الطاقة مثل الخلايا الصغيرة أو ما يسمي بالبيكو. في شبكات الجيل الرابع الغير متجانسة يتم نشر خلايا بيكو لإفراغ حركة المرور بشكل كاف من طبقة الماكرو وجعل المستخدمين اقرب من المحطة الأساسية لتحسين اداء المستخدم الموجود في حافة الخلية. لذلك نجد ان خلايا الماكرو تسبب تدخلا قويا لمستخدمي البيكو الموجودين في حافة الخلية نظرا لقوة إرسالها العالي . ومن ثم ، فإن التدخل بين الخلايا هو أكبر تحد في شبكات الجيل الرابع الغير متجانسة . إدارة التداخل بين الخلايا هي نقطة حرجة لتحسين أداء شبكات المحمول الخلوية. هذا البحث يهدف إلى تخفيف التداخل بين الخلايا في الوصلة الهابطة في شبكات الجيل الرابع الغير متجانسة. تم اقتراح تعزيز تنسيق التدخل بين الخلايا للحد من التداخل العالي في حالة امتداد النطاق ، بدءا من مخططات المجال الزمني مثل الأطر شبه الفارغة . قمنا في هذا البحث بتحليل متعمق للتداخل بين الخلايا في شبكات الجيل الرابع الغير متجانسة ودراسة الحلول المختلفة و المقترحة في الدراسات السابقة للحد من التداخل. وتقديم تكتيكا رائدا يعتمد على دمج كل من تعزيز تنسيق التدخل بين الخلايا والهوائيات الذكية تقليل التداخل بصورة اكبر. وقد بينت نتائج عمليات المحاكاة بالنسبة القنوات المشتركة في الوصلة الهابطة لكل من خلية الماكرو و خلية البيكو ، زيادة في الأداء الكلي للشبكة وتحسين جودة الخدمة بالنسبة المستخدمين الموجودين في حافة خلية البيكو وقد تحقق ذلك باستخدام المخطط المقترح.

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List of Abbreviations

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
3GPP2	Third Generation Partnership Project 2
ABS	Almost Blank Subframe
AMC	Adaptive Modulation and Coding
ARQ	Automatic Repeat Request
AWGN	Additive White Gaussian Noise
BE	Best effort
BLER	Block Error Rate
BS	Base Station
CA	Carrier Aggregation
CDMA	Code Division Multiple Access
CoMP	Coordinated Multi-Point
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CRE	cell range expansion
CRS	cell-specific reference signal
CRS	Cell Specific Reference Signal
CS	Circuit Switched
CSFB	Circuit Switched FallBack
CSG	closed subscriber group
DL	Down link

DPS	Dynamic point selection
ECR	Effective Code Rate
E-DCH	Enhanced Dedicated Channel
EDGE	Enhanced Data Rates for GSM Evolution
eICIC	enhanced Inter-Cell Interference Coordination
eNB	E-UTRAN Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-UTRAN	Evolved-Universal Terrestrial Access Network
EVDO	Evolution-Date Optimized
FBA	Flexible Bandwidth Allocation
FDD	Frequency Division Duplexing
FEICIC	Further Enhanced Inter-Cell Interference Coordination
FFR	Fractional Frequency Reuse
FFT	Fast Fourier Transform
GBR	Guaranteed Bit Rate
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GW	Gate way
HARQ	Hybrid Automatic Repeat Request
HeNB	Home evolved Node B
HetNet	Heterogeneous Network
HSPA	High-Speed Packet Access
HSS	Home Subscriber Server
ICIC	Inter-Cell Interference Coordination
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
IMS	IP Multimedia Subsystem
IMT	International Mobile Telecommunications
IMT-2000	International Mobile Telecommunications-2000
IP	Internet Protocol
IRAT	Inter-Radio Access Technology

ISI	Inter-Symbol Interference
ITU	International Telecommunication Union
ITU-R	ITU-Radio Telecommunication Sector
LDR	Load Distribution Aware
LPN	Low Power Node
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MAC	Media Access Control
MBMS	Multimedia Broadcast Multicast Services
MBMS	Multimedia Broadcast Multicast Services
MBSFN	Multi-Broadcast Single-Frequency Network
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MMSE	Minimum Mean Square Error
MTC	Machine Type Communications
NLOS	Non-Light of Sight
OAM	Operation and Maintenance
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PBCH	Physical Broadcast Channel
PCRF	Policy and Charging Rules Function
PDCCH	Physical Downlink Control Channel
PDN-GW	Packet Data Network Gateway
PDSCH	Physical Downlink Shared Channel
PFR	Partial Frequency Reuse
PRACH	Physical Random-Access Channel
PRE	Pico-cell Range Extension
P-SCH	Primary Synchronization signals
PSS	Primary Synchronization signals
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel

QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RB	Resource Block
RE	Resource Element
RF	Radio Frequency
RRC	Radio Resource Control
RRM	Radio Resource Management
RS	Reference Signal
RS-CS	Resource-Specific Cell-Selection
RSRP	Reference Signal Received Power
RSRQ	reference signal received quality
SAE	Service Architecture Evolution
SC-FDMA	Single Carrier – Frequency Division Multiple Access
SFR	Soft Frequency Reuse
S-GW	Serving Gateway
SIB	System Information block
SIC	Successive Interference Cancellation
SINR	Signal to Interference and Noise Ratio
SINR	Signal to Interference Noise Ratio
SINR	signal to interference plus noise ratio
SI-RNTI	System Information Radio Network Temporary Identifier
SMS	Short Messages Service
SON	Self-Organizing Network
SRVCC	Single Radio Voice Call Continuity
S-SCH	Secondary Synchronization signals
SSS	Secondary Synchronization signals
TA	Tracking Area
TDD	Time Division Duplexing
TDMA	Time Division Multiple Access
TD-SCDMA	Time Division Synchronous Code Division Multiple Access

TP	Transport Block
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
VoIP	Voice over Internet Protocol
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
WiMAX	Worldwide Interoperability for Microwave Access

List of Symbols

$\operatorname{argmax}\{\cdot\}$	arguments of the maxima
$\log$	natural logarithm
$\log_{10}$	logarithm to the base 10
f	frequency
λ_m	Poisson distribution mean parameter for macro cell
λ_p	Poisson distribution mean parameter for pico cell
d	a distance variable
UE_x	User Equipment in X axis
UE_y	User Equipment in Y axis
NB_x	NodeB in X axis
NB_y	NodeB in Y axis
P_E	Pico euclidean
M_E	Macro euclidean
L	Path loss
$P_{\mathrm{Loss}}(\cdot)$	Path loss function
$P_{\mathrm{Loss-Macro}}$	Pathloss for the macrocell case
$P_{\mathrm{Loss-Pico}}$	Pathloss for the picocell case
PL	Pathloss function in dB
P_i	is the loss of the i-th wall number
R	pathloss transmitter-receiver distance parameter
F	Log-normal shadowing factor
P_R	Recieved power
P_T	Transmitted power
P_{Desired}	the power received by the UE from pico-eNB
$P_{\mathrm{Interference}}$	the power coming from the interfering macro-eNB
$P_{\text{TX-marco}}$	Power transmitted from Macro

$P_{\text{TX-Pico}}$	Power transmitted from Pico
N_0	Thermal noise power (dB)
P_n	noise power (Watts)
G_{Macro}	Gain of macro
G_{Pico}	Gain of pico
$G_{\text{Pico,Variable}}$	Variable gain of pico
θ	azimuth angle
$P_0(R)$	average desired received power at distance R
I_K	the interference received from the k-th interferer
ψ_i	is the shadow fading autocorrelation
$v_i(t)$	represent the speed of UE_i
$\mu - ap_i$	represents uncorrelated filtered white Gaussian noise
$c_{i,n}$ $f_{i,n}$	are the Doppler coefficient and discrete Doppler frequency
$\mathit{\Theta}_{i,n}$	is the Doppler phase
f_{max}	is the maximum Doppler frequency
$\mathit{\Theta}_{3dB}$	is the beamwidth

Chapter one
Introduction

1.1 Preface

One of the most widely used devices that appears “magical” today is the smartphone, which allows the user to connect instantaneously with people anywhere on the planet, can provide professional answers to any question, has access to a map of the entire world, and can guide the user to any desired destination. However, the “magic” does not occur in the smartphone but in the network, which enables its functionality, provides ultra-broadband wireless access, and pro-cesses information to deliver voice and data services, invisible to the user. Popular user demand has thus fueled a remarkable growth of cellular network infrastructure and mobile devices. In 2014, the number of connected mobile devices for the first time exceeded the number of people on Earth, increasing rapidly from zero to 7.6 billion connected devices and 3.7 billion unique subscribers in only three decades [1] [2]. This has fundamentally transformed the way we communicate and access information. Today, we are on the brink of another significant change. While up to now the network mainly served humans, in the future, this capability will increasingly be used by machines as well. The emergence of machine-originated data traffic not only drives further the demand for network capacity but also imposes additional requirements on network performance, mainly in the area of end-to-end latency, which currently is the limiting factor for many new applications.

Nowadays, most of the data services reside in the Internet, far away from the user where the speed of light becomes one of the main factors limiting latency. To address this problem, processing will have to move closer to the user into a cloud computing infrastructure as part of the network. In addition, adaptive network management and well-designed congestion control can help to control latencies and enable new real-time applications such as augmented reality or efficient machine to machine communication.

With these changes, the future network is evolving to become our main interface with the virtual world, and increasingly also with the physical world, to simplify and automate much of life. This will allow us to effectively “create time” by improving the efficiency in everything we do [3].

Making this vision of the future network a reality will require both:

- Ultra broadband wireless access, providing orders of magnitude improved performance and quality-of-service control, as well as.
- A flexible and programmable cloud computing infrastructure located close to the edge of the wireless network.

1.1.1 The industry challenge

The proliferation of highly capable mobile devices as well as the user expectation to be fully connected and have access to all services anywhere and anytime has resulted in an exponential increase in cellular capacity demand over the past few years. With the addition of wirelessly connected machines, which can send, receive, and process massive amounts of data, this trend will continue and is driving an explosion of cellu-lar capacity demand. The expectations are that machines will significantly outnumber human users in the future. Figure 1.1 shows the predicted increase in data traffic until 2025, taken from an analysis done by Bell Labs Consulting in 2014 based on LTE traffic models and drawing from multiple data sources, including Alcatel-Lucent field data and [1] . It is shown that the global bearer traffic is expected to grow by a factor between 61× and 115× over the next decade to 22.5 Exabytes per year [4].

Moreover, the control plane demand is predicted to increase proportionally to support an increasing number of short traffic messages generated by machines [4].

However, although the demand for capacity is increasing, users are not willing to pay substantially more for higher data rates, and the average revenues per unique subscriber in recent years have been stagnating [4] . This means we have to provide exponentially more capacity for the same costs as today, adding a significant com-mercial challenge to the already difficult physical challenge of scaling capacity by orders of magnitude.

Traditional networks optimized for homogeneous traffic face unprecedented challenges to meet the demand cost-effectively. More recently, 3GPP LTE-

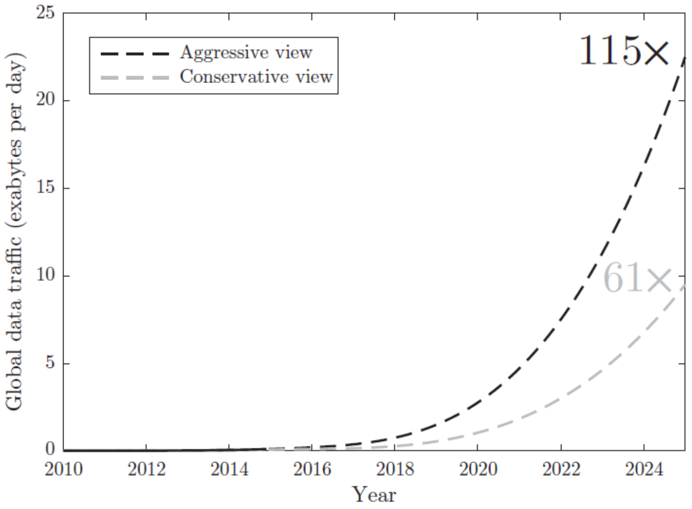


Figure 1.1: Growth in capacity demand [4]

advanced has started a new study item to investigate heterogeneous cellular network deployments as an efficient way to improve system capacity as well as effectively enhance network coverage. Unlike the traditional heterogeneous networks that deal with the interworking of wireless local area networks and cellular networks, in which the research community has already been studied for more than a decade, in this new paradigm in cellular network domain, a heterogeneous network is a network containing network nodes with different characteristics such as transmission power and RF coverage area. The low power micro nodes and high power macro nodes can be maintained under the management of the same operator. They can share the same frequency carrier that the operator provides. In this case, joint radio resource/interference management needs to be provided to ensure the coverage of low power nodes. In some other cases, the low power and high power nodes can be coordinated to use more than one carrier, e.g., through carrier aggregation, so that strong interference to each other can be mitigated, especially on the control channel. The macro network nodes with a large RF coverage area are deployed in a planned way for blanket coverage of urban, suburban, or rural areas. The local nodes with small RF coverage areas aim to complement the macro network nodes for coverage extension and/or capacity enhancement. In addition to this, global coverage can be further provided by satellites (macro-cells), according to an integrated system concept. There is an urgent need in both industry and academia to better understand the technical details and performance gains that are made possible by heterogeneous cellular networks. To address that need, this edited book covers the comprehensive research topics in heterogeneous cellular networks. This book focuses on recent advances and progresses in heterogeneous cellular networks [5].

1.1.2 LTE Technology Evolution

The LTE technology has been standardized by Third Generation Partnership Project (3GPP). The LTE was introduced in 3GPP Release 8. The specifications were completed and the backwards compatibility started in March 2009. Release 8 enabled peak rate of 150 Mbps with 2×2 MIMO, low latency, flat network architecture and the support for 4-antenna base station transmission and reception. Release 8 enabled in theory also 300 Mbps with 4×4 MIMO but the practical devices so far have two antennas limiting the data rate to 150 Mbps. Release 9 was a relatively small update on top of Release 8. Release 9 was completed 1 year after Release 8 and the first deployments started during 2011. Release 9 brought enhanced Multimedia Broadcast Multicast Solution (eMBMS) also known as LTE-Broadcast, emer- gency call support for VoLTE, femto base station handovers and first set of Self-Organizing Network (SON) functionalities. Release 10 provided a major step in terms of data rates and capacity with Carrier Aggregation (CA), higher order MIMO up to eight antennas in downlink and four antennas in uplink. The support for Heterogeneous Network (HetNet) was included in Release 10 with the feature enhanced Inter-Cell Interference Coordination (eICIC). Release 10 was completed in June 2011 and the first commercial carrier aggrega- tion network started in June 2013. Release 10 is also known as LTE-Advanced. Release 11 enhanced LTE-Advanced with Coordinated Multipoint (CoMP) transmission and recep- tion, with further enhanced ICIC (feICIC), advanced UE interference cancellation and carrier aggregation improvements. First Release 11 commercial implementation was available during 2015. Release 12 was completed in 3GPP in March 2015 and the deployments are expected by 2017. Release 12 includes dual connectivity between macro and small cells, enhanced CoMP (eCoMP), machine-to-machine (M2M) optimization and device-to-device (D2D) communica- tion. Release 13 work started during second half of 2014 and is expected to be completed during 2016. Release 13 brings Licensed Assisted Access (LAA) also known as LTE for Unlicensed bands (LTE-U), Authorized Shared Access (ASA), 3-dimensional (3D) beamforming and D2D enhancements.

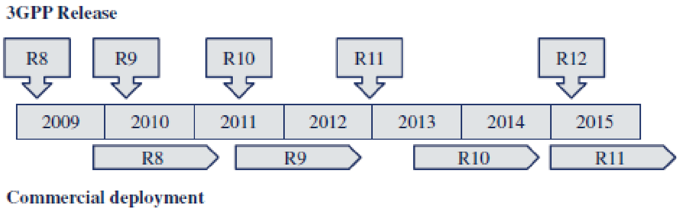


Figure 1.2: 3GPP Release availability dates [6]

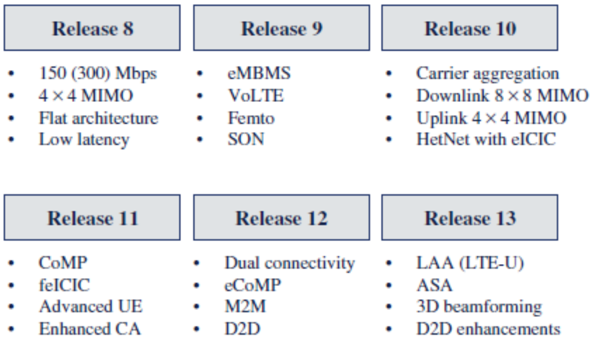
The timing of 3GPP releases in standardization and in first commercial networks is shown in Figure 1.2. The main contents of each release are summarized in Figure 1.3. The radio data rate has increased very fast with LTE and LTE-Advanced and 150 Mbps was available with Release 8 commercially during 2010 when using continuous 20 MHz spectrum allocation and 2×2 MIMO. The carrier aggregation with 10 + 10 MHz during 2013 enabled 150 Mbps also for those operators having just 10 MHz continuous spectrum. The aggregation of 20 + 20 MHz during 2014 pushed the peak rate to 300 Mbps and three-carrier aggregation (3CA) further increased the data rate up to 450 Mbps during 2015. The evolution is expected to continue rapidly in the near future with commercial devices supporting 1 Gbps with 100 MHz of total bandwidth.

1.1.3 LTE Spectrum

The LTE-Advanced needs lot of spectrum to deliver high capacity and data rates. The typical spectrum resources in European or some Asian markets are shown in Figure 1.4.

All the spectrum between 700 and 2600 MHz will be aggregated together. The carrier aggregation of the multiple spectrum blocks together helps in terms of network traffic management and load balancing in addition to providing more capacity and higher data rates.

The higher frequency at 3.5 GHz can also be aggregated in the macro cells especially if the site density is high in the urban areas. Another option is to use 3.5 GHz band in the small cell layer. The unlicensed band at 5 GHz can be utilized in the small cells for more spectrum [7]. In the best case, more than 1 GHz of licensed spectrum is available for the mobile operators and more when considering the unlicensed spectrum.



Release 8
- 150 (300) Mbps
- 4 × 4 MIMO
- Flat architecture
- Low latency

Release 9
- eMBMS
- VoLTE
- Femto
- SON

Release 10
- Carrier aggregation
- Downlink 8 × 8 MIMO
- Uplink 4 × 4 MIMO
- HetNet with eICIC

Release 11
- CoMP
- feICIC
- Advanced UE
- Enhanced CA

Release 12
- Dual connectivity
- eCoMP
- M2M
- D2D

Release 13
- LAA (LTE-U)
- ASA
- 3D beamforming
- D2D enhancements

Figure 1.3: Main contents of each release [6]

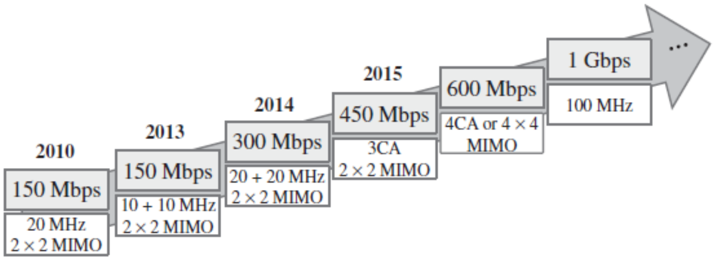


Figure 1.4: Peak data rate evolution in commercial devices [6]

1.2 Problem Statement

Downlink (DL), pico cells and macro-eNBs typically use the same frequency band (frequency reuse).so there is a risk of interference between the pico-cell and the surrounding network which causes low SINR and that may affect directly to network throughput.However, those users in the extended area will suffer from strong interference from the macro base station.

1.3 Proposed Solution

Intercell interference management is one of the most critical issues in HetNets. Due to the scarcity of licensed spectrum resource, cellular operators tend to reuse frequency when deploying small cells over licensed bands which leads to severe intercell interference.

Therefore, it is necessary to deploy intercell interference management schemes (such as the enhanced intercell interference coordination (eICIC) techniques in 3GPP standardization activities), to maximize the capacity expansion gain

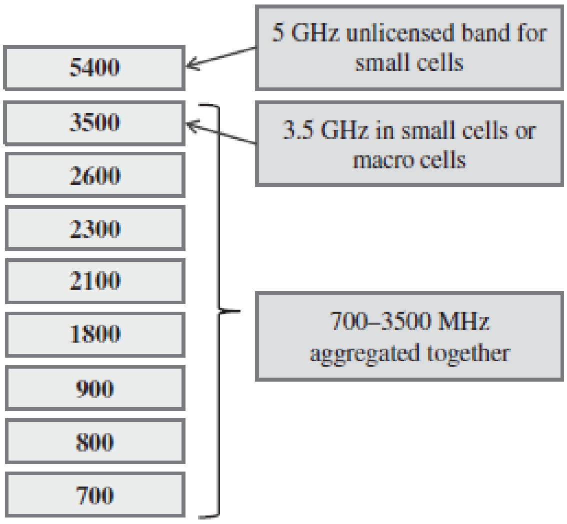


Figure 1.5: Example spectrum resources for LTE usage [6]

of densely deploying small cells. Several categories of eICIC techniques have been proposed, namely, the time-domain techniques such as the almost blank subframes used by pico cells, Moreover, the eICIC techniques will further help us address the intercell interference issue.

Enhanced ICIC (eICIC) was introduced in LTE R10. The major change is the addition of time domain ICIC, realized through use of Almost Blank Subframes (ABS). ABS includes only control channels and cell-specific reference signals, no user data, and is transmitted with reduced power. When eICIC is used, the macro-eNB will transmit ABS according to a semi-static pattern. During these subframes, UEs at the edge, typically in the CRE region of small cells, can receive DL information, both control and user data. The macro-eNB will inform the eNB in the small cell about the ABS pattern.

1.4 Thesis Contribution

The objective of this thesis is to contribute to the domain of interference mitigation techniques for present and future mobile networks. We particularly focus on multiuser OFDMA networks, including heterogeneous LTE/LTE-A networks and dense small cell networks. It is of crucial importance for mobile network operators to increase network capacity, spectral efficiency, and energy efficiency, given the exponentially growing demand for mobile broadband communications. Other concerns include increasing system throughput and improving the performance of cell-edge UEs that are mainly affected by ICI.

1.5 Methodology

This research project adopts a research methodology that mainly relies on evaluation and improvement of the proposed & research methodology that combines the theory model with empirical evaluation and refinement of the proposed scheme on MATLAB simulation tool & atoll Simulator. This downlink system-level simulator, has been modified to support the proposed solution.

The following research methodology has been adopted in the research program:

- Literature review on Heterogeneous deployment of LTE-Advanced (HetNets)
- Construct macro-pico network architecture topology .
- Analyze overall network performance in terms of throughput.
- Develop network performance without eICIC , with eICIC
- Results analysis, evaluation and comparison

1.6 Thesis Organization

This thesis is divided into five main chapters. Chapter One provides the introduction of the topic and states the problem and project challenges. Chapter Two Description of general overview of the LTE-Advanced network as an example of OFDMA mobile systems. It describes the network architecture and its related elements in both homogeneous and heterogeneous deployments Furthermore, the radio frame structure and the physical resource block have been explained thoroughly as basic elements in resource allocation.Heterogeneous Networks Use Scenarios & Features described , eICIC enhanced Inter-cell interference coordination has been discussed in details & survey on various work presented .

In the chapter Three The Intercell Interference Problem & Interference Management by using ABS presented . implemented Macro–Pico Deployment

Scenario system model , This chapter includes also the simulation assumptions, and a description of the traffic models employed and key performance indicators .

All simulation results of the proposed scheme and their findings was shown in chapter four. These results are based on the performance metrics defined in the previous chapter.it also include the evaluation of the scheduling algorithms and validating the proposed scheme by comparing it with other works.

Chapter five Summarized the main ideas and conclusions presented in this study, along with the considerations for the study and what could be done in the future.

Chapter Two
Background and Literature Review

This chapter presents the principles of first LTE version in Release 8 as well as the first development step with LTE Advanced in Releases 10 and 11. First the fundamental principles of LTE in Release 8 are covered, including the key channel structures as well as the key physical layer procedures. Then the enhancements in LTE are introduced. The literature survey on various interference handling techniques in LTE-A heterogeneous networks and time domain muting of macro-eNB is presented.

2.1 Long Term Evolution (LTE)

LTE (Long Term Evolution) or the E-UTRAN (Evolved Universal Terrestrial Access Network), was introduced in 3GPP Release-8 [8]. LTE forms a new access network of the Evolved Packet System (EPS). LTE is the next step in the evolution of mobile cellular networks. It gives extensions and modifications to UMTS system [9]. This technology, which is known in market as 4G LTE, was intended primarily for high-speed data services to encompass a packet-switched network from end to end with no support for circuit-switched services, the basis of 2G and 3G legacy generations. However, it is determined to deal with circuit-switched connections to tackle the latency of LTE and its sophisticated QoS (Quality of Service) architecture. In other words, LTE is designed to carry all types of IP data traffic. Voice is treated as Voice over IP (VoIP). The primary LTE requirements are high spectral efficiency, high peak data rates, low latency and spectrum flexibility.

2.1.1 LTE Requirements

This chapter this scetion the performance requirements of LTE. It contains practical interpretations of the standards' requirements and their effect on network planning, deployment and optimization, the effects of LTE and SAE on system interworking, handover procedures, and mixed user profiles, issues related to network synchronization and the Timing over Packet functionality [10].

- Support for variable bandwidth:means that it is possible to define some of the following bands: 1.4MHz, 3 MHz, 5 MHz, 10MHz, 15MHz and 20 MHz.
- High spectral efficiency:This is accomplished via the OFDM in the downlink, making the system robust against multipath interference and providing high affinity to advanced techniques such as frequency domain channel-dependent scheduling and MIMO. In the uplink, DFTS-OFDM, or Single-Carrier FDMA, is used, which provides a low Peak-to-Average Power Ratio (PAPR) and user orthogonality in the frequency domain. It is also possible to use the multi-antenna application.
- Very low latency:means that there is a short setup time as well as short transfer delay. The handover latency and interruption time are short, as well as the TTI and RRC procedures. To support fast signaling, the RRC states are simply defined.
- Peak data rate: Downlink – 100 Mbps, Uplink – 50Mbps at 20MHz spectrum allocation. LTE encourages peak data rates higher than HSPA+ and WiMAX.
- Simple protocol architecture:means that the communication is shared, channel based, and that only the packet-switched domain is available, yet it is capable of supportingVoice over IP calls.
- Simple architecture:has been achieved by introducing eNodeB as the only E-UTRAN node.This leads to a smaller number of RAN interfaces between the eNodeB and MME/SAEGateway (S1) and between two eNodeB elements (X2).
- Mobility: LTE aims to support an excellent call setup process and high caliber handoffs up to speeds of 15 kmph. While slight degradations are passable for connections up to speeds of 120 kmph. Nonetheless a lower quality support is anticipated for speeds of up to 350 kmph.
- Coverage: The LTE requirements mentioned would work for 5 km cells. On the other hand, some degradation in throughput and spectrum efficiency is acceptable for 30 km cells. Maximum cell range is 100 km.

whereas; cells larger than 100 km are not incorporated in the specifications.

- Duplexing: The LTE standard supports both FDD and TDD modes within a single radio access. Efficient multicast/broadcast functionality is included in the standard, which makes it possible to use a single frequency network SFN concept as an option that is available in OFDM.
- Multiple access: Downlink OFDMA, Uplink SC-FDMA (Single Carrier – Frequency Division Multiple Access).
- LTE integrates SC-FDMA as a cost effective and power efficient transmission scheme for uplink. MIMO: Downlink 2×2, 2×4, 4×4, Uplink 1×2, 1×4.
- Modulation: Selectable form QPSK, 16-QAM, 64-QAM.
- Channel coding: Turbo codes.
- User plane latency: LTE has the lowest (5-15 msec.) user plane latency as well as the lowest call set up time of 50 msec.
- Interworking with existing systems: LTE network seamlessly co-exists with the legacy 2G and 3G systems. Likewise interworking of LTE accommodates non-3GPP standards such as the 3GPP2 CDMA and WiMAX networks. Furthermore, LTE interworking applies to all IP network including wired IP networks.
- Other techniques: Additionally, LTE requirements have been extended to support features as channel sensitive scheduling, power control, link adaptation, HARQ (Hybrid Automatic Repeat Request), ICIC,LTE also supports the Self-Organizing Network (SON) operation, which can be highly efficient in dynamic and automatic network tuning as a function of selected network performance indicators, including feedback from fault management.

2.2 LTE Network Architecture

In LTE architecture, Evolved UTRAN (E-UTRAN) is an important role which is the air interface of LTE upgrade path for mobile networks meanwhile it is accompanied by an evolution of the non-radio aspects under the term ”System Architecture Evolution” (SAE), which includes the Evolved Packet Core (EPC) network. Together LTE and SAE comprise the Evolved Packet System (EPS). Besides that, LTE network uses an eNodeB (evolved node B, essentially an LTE base station), a MME (Mobile management entity), a HSS (home subscriber server), a SGW (serving gateway), and a PGW (a packet data network gateway). These are considered as part of the EPC except eNodeB [11].

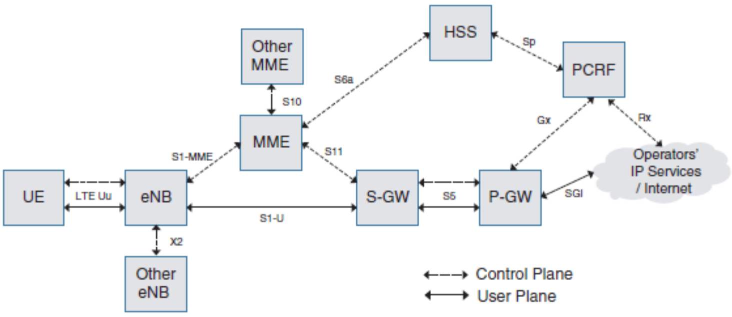


Figure 2.1: LTE Network Architecture [12]

First, let us look into EPS in detail, the following figure showing those elements in EPS network.

In LTE, main function of EPS is to provide the user with IP connectivity to a PDN for accessing the Internet, as well as for running service such as Voice over IP (VoIP). An EPS bearer is typically associated with a QoS. Multiple bearers can be established for a user in order to provide different Qos streams or connectivity to different PDNs. Figure above shows the overall network architecture, including the network elements and the standardized interfaces. At a high level, the network is comprised of the CN (EPC) and the access network E-UTRAN. While the CN consists of many logical nodes, the access network is made up of essentially just one node, the evolved NodeB (eNodeB), which connects to the UEs. Each of these network elements is interconnected by means of interfaces that are standardized in order to allow multi-vendor interoperability. This gives network operators the possibility to source different network elements from different vendors. In fact, network operators may choose in their physical implementations to split or merge these logical network elements depending on commercial considerations. The core network (called EPC in SAE) is responsible for the overall control of the UE and establishment of the bearers. The main logical nodes of the EPC are:

- PDN Gateway (P-GW).
- Serving Gateway (S-GW).
- Mobility Management Entity (MME).

In addition to these nodes, EPC also includes other logical nodes and functions such as the Home Subscriber Server (HSS) and the Policy Control and Charging Rules Function (PCRF). HSS which contains users' SAE subscription data such as the EPS-subscribed QoS profile and holds those information about the PDNs to which the user can connect, while PCRF is responsible for policy control decision-making, as well as for controlling the flow-based charging functionalities in the Policy Control Enforcement Function (PCEF), which resides in the P-GW. From the figure above, MME which is the control node that processes the signaling between the UE and the CN. The protocols running between the UE and the CN are known as the Non Access Stratum (NAS) protocols [11].

2.2.1 Mobility Management Entity (MME)

The MME is a standard element within the LTE core network that can be accessed from anywhere and manages all connections between base stations and the core network [13]. MME performs the following functions:

- Authentication of the User Equipment.
- The MME is the termination point in the network for ciphering/integrity protection for NAS signaling and handles the security key management.
- Paging of Dormant UE's: Inactive users are unable to retain their connections. As soon as they become active again, the MME pages them over its Tracking Area (TA).
- Hand-Off Support: When a handoff cannot be set up over the X2 interface directly, alternatively, the MME makes the handoff possible.
- 2G/3G/4G Interworking: MME establishes interworking with 2G/3G elements and facilitates possible handoffs among 2G/3G and 4G networks.

- SMS and Voice Support: MME is also responsible for the accomplishment of the regular tasks from the legacy networks such as SMS and voice telephony.

The access network of LTE, E-UTRAN, simply consists of a network of eNodeBs.For normal user traffic (as opposed to broadcast), there is no centralized controller in E-UTRAN; hence the E-UTRAN architecture is said to be flat. The eNodeBs are normally interconnected with each other by means of an interface known as “X2” and to the EPC by means of the S1 interface — more specifically, to the MME by means of the S1-MME interface and to the S-GW by means of the S1-U interface. The protocols that run between the eNodeBs and the UE are known as the “AS protocols”

The E-UTRAN is responsible for all radio-related functions, which can be summarized briefly as:

- Radio resource management (RRM) – This covers all functions related to the radio bearers, such as radio bearer control, radio admission control,radio mobility control, scheduling and dynamic allocation of resources to UEs in both uplink and downlink.
- Header Compression – This helps to ensure efficient use of the radio interface by compressing the IP packet headers that could otherwise represent a significant overhead, especially for small packets such as VoIP.
- Security – All data sent over the radio interface is encrypted .
- Connectivity to the EPC – This consists of the signaling toward MME and the bearer path toward the S-GW.

2.2.2 eNodeB

The eNodeB, or eNB element of LTE is responsible for the radio transmission and reception with UE. eNB provides the needed functionality for the radio resource management (RRM), including the admission control, radio bearer control, scheduling of user data, and control signaling over the air interface. In addition, eNB takes care of the ciphering and header compression over the air interface. The eNodeB of LTE now includes basically all the functionalities that previously were concentrated in the RNC of the UTRAN system. In addition, the traditional tasks of the NodeB are still included in the new eNodeB (eNB) element. eNB works thus as the counterpart of the UE in the radio interface, but includes the procedures for the decision-making related to the connections. This solution is indicated in the term “flat architecture” of LTE, meaning that there are fewer interfaces and only one element in the hierarchy of the architecture. As the control has been moved closer to the radio interface, the respective signaling time has also been reduced. This is one of the key solutions for the reduction of the latency of LTE compared to the previous solutions of the 3G [14] . More specifically, the eNB element handles the following tasks [14]:

- Radio Resource Management (RRM).
- Radio Bearer Control.
- Radio Admission Control.
- Connection Mobility Control.
- UE scheduling (DL and UL).
- Security in Access Stratum (AS).

2.2.3 The Serving Gateway (S-GW)

The main aim of the SGW is to route and forward user data packets among different LTE nodes and it also serves as a mobility point for both local inter-eNB handover and inter-3GPP mobility. It is connected to the E-UTRAN via the S1-U interface. Additionally, the S-GW serves as a mobility anchor and makes sure to have a seamless data connection when UEs move across cells served by different eNBs. The S-GW is connected to the eNBs via the S1-U interface [12] [15]. As a summary, the S-GW element takes care of the following functionalities [14]:

- S-GW is the local anchor point for the inter-eNB handover procedure.
- S-GW is also an anchor point for the inter-3GPP network mobility.
- S-GW handles the network-initiated/triggered service request procedure.
- Packet marking in the transport level for both DL and UL.

- Charging Data Record (CDR) collection, which can identify the UE, PDN and QCI.
- Packet routing and forwarding.

2.2.4 Packet Data Network Gateway (PDN-GW)

The Packet Data Network Gateway (P-GW) provides the UE with access to a Packet Data Network (PDN). The PGW accomplishes policy enforcement, packet filtering for each user or charging support among other functions. [13] [12]. More specifically, P-GW includes the following functionalities [16]:

- IP address allocation of UE.
- Packet filtering that can be done at the user-based level. The other term for this functionality is deep packet inspection.
- Packet marking in the transport level, in DL.
- Rate enforcement in DL based on APN-AMBR.

2.2.5 Home Subscriber Server (HSS)

The Home Subscriber Server (HSS) acts as the main subscriber data repository of the IMS user profile. This data contains information related to identities and services of a given subscription. The Subscriber Locator Function (SLF) is required if the IMS network has multiple HSS entities and the requesting function (e.g., I-CSCF or AS) has to know which individual IMS user profile is located in which HSS entity. For voice and video telephony over LTE/LTE-A, the data that is stored in the HSS may contain in addition to the identity of the Telephony Application Server (TAS) entity also information about the supplementary services to be provided [17] [18].

2.2.6 Policy and Charging Rule Function (PCRF)

A important component in LTE network is the policy and charging control (PCC) function that brings together and enhances capabilities from earlier 3GPP releases to deliver dynamic control of policy and charging on a per subscriber and per IP flow basis. The Policy Control and Charging Rules

Function is responsible for policy control decision-making, as well as for controlling the flow-based charging functionalities in the Policy Control Enforcement Function (PCEF), which resides in the P-GW. The PCRF provides the QoS authorization (QoS class identifier [QCI] and bit rates) that decides how a certain data flow will be treated in the PCEF and ensures that this is in accordance with the user's subscription profile. PCRF provides service management and control of the 4G service. It dynamically manages and controls data sessions, enables new business models. Apart from this, PCRF LTE also has the functionality to make it easy for other devices out of the 3GPP network- like WiFi or fixed broadband devices- to access the 4G LTE network. The policy server or PCRF is a key component in the NDN. It provides the critical link between the service and transport layers and is the central decision point – the brain – of LTE networks. The PCRF provides the granular control of service quality, which is critical for managing resources, enabling seamless roaming, establishing new business models, and monetizing services [9].

2.2.7 QoS and bearer service architecture

Applications such as VoIP, web browsing, video telephony and video streaming have special QoS needs. Therefore, an important feature of any all-packet network is the provision of a QoS mechanism to enable differentiation of packet flows based on QoS requirements. In EPS, QoS flows called EPS bearers are established between the UE and the P-GW as shown in Figure 2.2. A radio bearer transports the packets of an EPS bearer between a UE and an eNB. Each IP flow (e.g. VoIP) is associated with a different EPS bearer and the network can prioritize traffic accordingly. When receiving an IP packet from the Internet, P-GW performs packet classification based on certain predefined parameters and sends it an appropriate EPS bearer. Based on the EPS bearer, eNB maps packets to the appropriate radio QoS bearer. There is one-to-one mapping between an EPS bearer and a radio bearer.

2.2.8 Layer 2 structure

The layer 2 of LTE consists of three sublayers namely medium access control, radio link control (RLC) and packet data convergence protocol (PDCP). The service access point (SAP) between the physical (PHY) layer and the

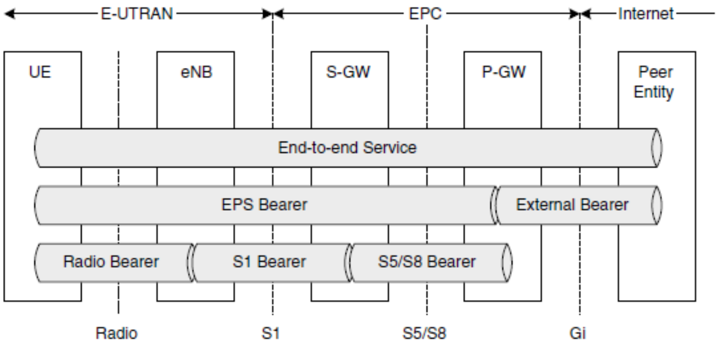


Figure 2.2: EPS bearer service architecture [19]

MAC sublayer provide the transport channels while the SAP between the MAC and RLC sublayers provide the logical channels. The MAC sublayer performs multiplexing of logical channels on to the transport channels. The downlink and uplink layer 2 structures are given in Figures 2.3 and 2.4 respectively. The difference between downlink and uplink structures is that in the downlink, the MAC sublayer also handles the priority among UEs in addition to priority handling among the logical channels of a single UE. The other functions performed by the MAC sublayers in both downlink and uplink include mapping between the logical and the transport channels, multiplexing of RLC packet data units (PDU), padding, transport format selection and hybrid ARQ (HARQ). The main services and functions of the RLC sublayers include segmentation, ARQ in-sequence delivery and duplicate detection, etc. The in-sequence delivery of upper layer PDUs is not guaranteed at handover. The reliability of RLC can be configured to either acknowledge mode (AM) or un-acknowledge mode (UM) transfers. The UM mode can be used for radio bearers that can tolerate some loss. In AM mode, ARQ functionality of RLC retransmits transport blocks that fail recovery by HARQ. The recovery at HARQ may fail due to hybrid ARQ NACK to ACK error or because the maximum number of retransmission attempts is reached. In this case, the relevant transmitting ARQ entities are notified and potential retransmissions and re-segmentation can be initiated.

The PDCP layer performs functions such as header compression and decompression, ciphering and in-sequence delivery and duplicate detection at handover for RLCAM, etc. The header compression and decompression is performed using the robust header compression (ROHC) protocol [20].

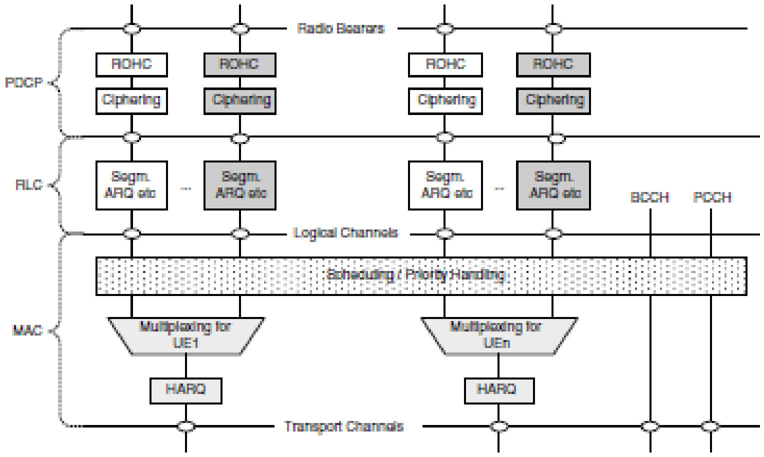


Figure 2.3: Downlink layer 2 structure [19].

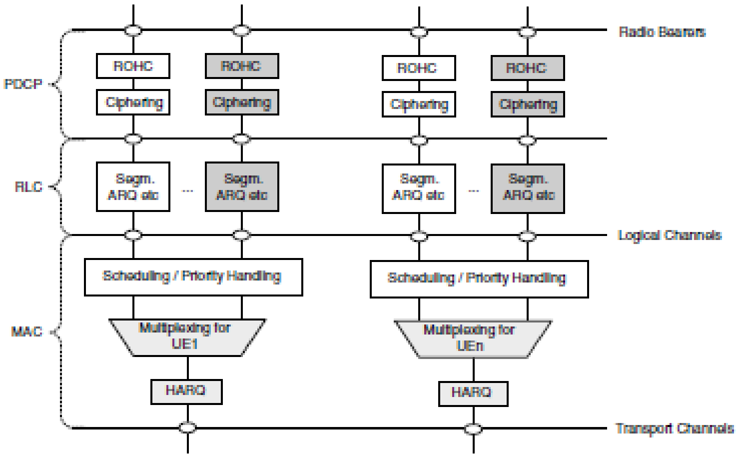


Figure 2.4: Uplink layer 2 structure [19].

2.2.9 Orthogonal Frequency Division Multiplexing

One of the key elements of LTE is the use of OFDM (Orthogonal Frequency Division Multiplex) as the signal bearer, as well as OFDM's associated access schemes, OFDMA (Orthogonal Frequency Division Multiple Access) and SC-FDMA (Single Carrier Frequency Division Multiple Access). OFDM, Orthogonal Frequency Division Multiplex is the basic format used and this is modified to provide the multiple access scheme: OFDMA, orthogonal frequency division multiple access in the downlink and SC-FDMA, single channel orthogonal frequency division multiple access in the uplink. Using multiple carriers, each carrying a low data rate, OFDM is ideal for high speed data transmission because it provides resilience against narrow band fading that occurs as a result of reflections and the general propagation properties at these frequencies. Within the basic LTE OFDM signal format a variety of modulation formats are used including PSK and QAM. Higher order modulation is used to achieve the higher data rates: the modulation order being determined by the signal quality. Orthogonal Frequency Division Multiplex, OFDM is a form of signal format that uses a large number of close spaced carriers that are each modulated with low rate data stream. The close spaced signals would normally be expected to interfere with each other, but by making the signals orthogonal to each other there is no mutual interference. The data to be transmitted is shared across all the carriers and this provides resilience against selective fading from multi-path effects [21].

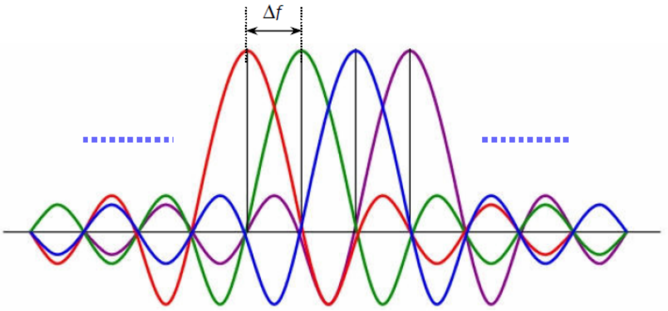


Figure 2.5: OFDM Subcarrier Spacing [21]

2.2.10 LTE OFDMA in the downlink

The OFDM signal used in LTE comprises a maximum of 2048 different sub-carriers having a spacing of 15 kHz. Although it is mandatory for the mobiles to have capability to be able to receive all 2048 sub-carriers, not all need to be transmitted by the base station which only needs to be able to support the transmission of 72 sub-carriers. In this way all mobiles will be able to talk to any base station. Within the OFDM signal it is possible to choose between three types of modulation for the LTE signal:

- QPSK (= 4QAM) 2 bits per symbol.
- 16QAM 4 bits per symbol.
- 64QAM 6 bits per symbol.

The exact LTE modulation format is chosen depending upon the prevailing conditions. The lower forms of modulation, (QPSK) do not require such a large signal to noise ratio but are not able to send the data as fast. Only when there is a sufficient signal to noise ratio can the higher order modulation format be used.

2.2.11 Cyclic Prefix

A guard interval is added at the beginning of each OFDM symbol to mitigate some of the negative effects of the multipath channel. If the duration of the guard interval Tg is larger than the maximum delay of the channel t_{max} , all multipath components will arrive within this guard time and the useful symbol will not be affected, avoiding Inter-Symbol Interference (ISI) as can be seen in Figure 2.6. One particular instance of the guard interval is the so-called cyclic prefix. In this case the last N_g samples of the useful OFDM symbol with N samples in total are copied to the beginning of the same symbol. Since the number of cycles of each orthogonality function per OFDMsymbol will be maintained as an integer, this strategy also allows the orthogonality properties of the transmitted subcarriers to be kept, avoiding ICI. Figure 2.7 shows the cyclic prefix concept where

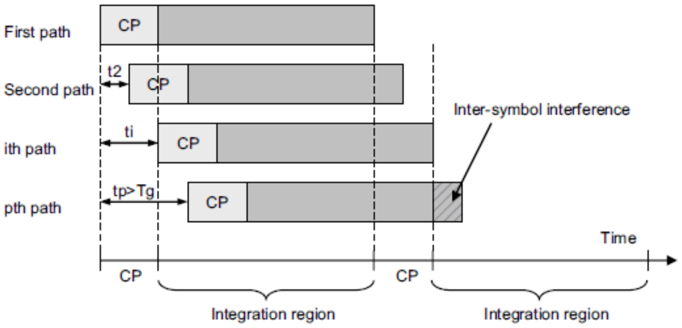


Figure 2.6: Cyclic prefix (CP) avoiding ISI [10].

In addition, cyclic prefix gives a periodic extension to the OFDM signal. This is to ensure that the channel appears to produce a circular convolution to create an ISI (Inter-Symbol Interference) free channel. Having a channel response as circular convolution makes it feasible to perform frequency domain equalization at the receiver.

The length of cyclic prefix is a principal design challenge, due to the fact

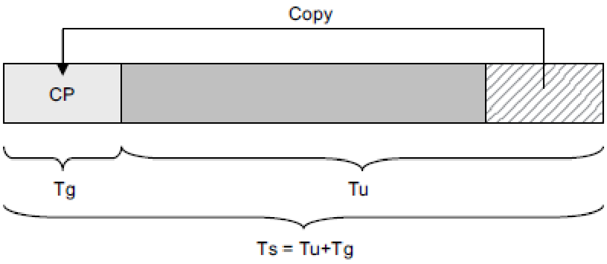


Figure 2.7: Cyclic prefix as a copy of the last part of an OFDM symbol [10].

that, cyclic prefix does not carry any useful information and represents redundant data. In that case, it is preferable to keep cyclic prefix as small as possible to reduce the overhead and boost the spectral efficiency. On the other hand, the length of cyclic prefix should be adequate to cover delay spreads experienced in different propagation environments. In order to address this concern, LTE specifies the cyclic prefix length on the basis of the expected delay spread of the propagation channel. Nonetheless, LTE provisions for errors due to imperfect timing alignment. LTE specifies three different cyclic prefix values: normal (length 4.7 $\mu s.$) and extended (length 16.6 $\mu s.$) for subcarrier spacing of 15kHz and extended (length 33 $\mu s.$) for subcarrier spacing of 7.5kHz. The normal cyclic prefix length is able to handle channel delay spread in most urban and suburban environments. Whereas, an extended cyclic prefix can be considered for broadcast services as well as for environments with longer delay spread.

2.2.12 LTE Frame Structure

TThe radio frame in LTE adopts the 0.5 ms slot structure and uses the 2 slot (1 subframe) allocation period, with duration of 10 ms (i.e. 10 subframes) per frame. In addition, for every subframe, each slot consists of either 6 or 7 Orthogonal Frequency Division Multiplexing (OFDM) symbols for the DL depending on whether extend or short cyclic prefix is used, with a Transmission Time Interval (TTI) of 1 ms. Multiple UEs can share the available resources within each TTI. Figure 2.8 illustrates an example of the LTE frame structure for the short prefix case . Figure 2.8 displays the LTE frame structure.

The time-frequency grid resource in LTE-Advanced is depicted in Figure 2.9 when short cyclic prefix is used. The minimum resource element that can be assigned to a UE for data transmission is called Physical Resource Block

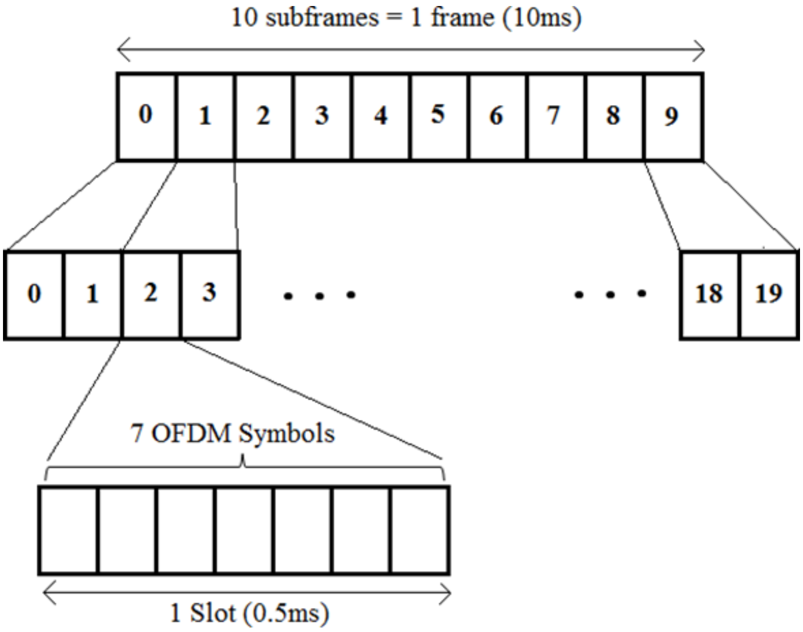


Figure 2.8: LTE Downlink Frame Structure [22]

(PRB), composed by 12 consecutive subcarriers and having a bandwidth of 180 kHz in the frequency domain. Moreover, one PRB also makes reference to a subframe in the time domain i.e. 14 OFDM symbols for the DL.

LTE can operate on variable bandwidth as described in [24] and, therefore, the name of available PRBs to be allocated for the UEs is higher or lower depending on the used transmission bandwidth.It can be represented by a resource grid as depicted in Figure 2.10. Each box within the grid represents a single subcarrier for one symbol period and is referred to as a resource element. Note that in MIMO applications, there is a resource grid for each transmitting antenna. In contrast to packet-oriented networks, LTE does not employ a PHY preamble to facilitate carrier offset estimate, channel estimation, timing synchronization etc. Instead, special reference signals are embedded in the PRBs as shown in Figure 2.10. Reference signals are transmitted during the first and fifth OFDM symbols of each slot when the short CP is used and during the first and fourth OFDM symbols when the long CP is used [21].

2.2.13 LTE Channels

As a general note, the aim of LTE standardization has been to simplify the number of different channels and the mapping of logical and transport channels. The result can be seen in Figures 2.11–2.13 for logical, transport, and

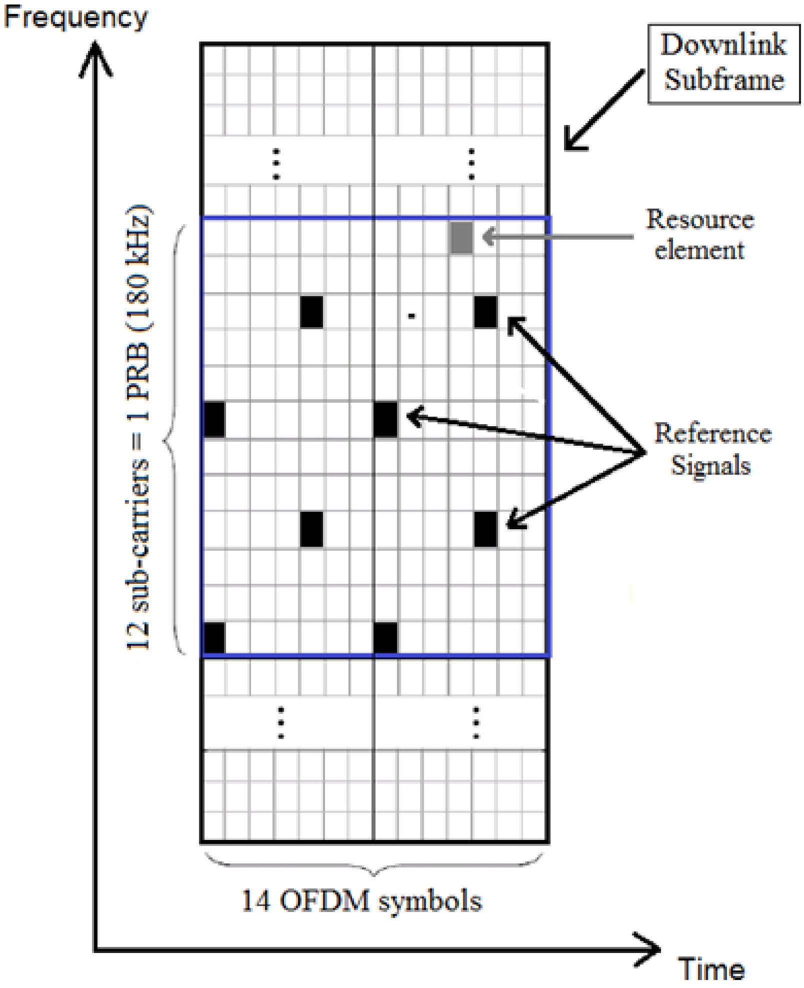


Figure 2.9: Time-frequency domain DL LTE frame structure [23]

physical channels, respectively, which indicates that the number is, in fact, reduced considerably compared to the 3GPP UTRAN channels. The LTE/LTE-A transport channels are differentiated based on the characteristics of the data transmission. The mapping of the logical and transport channels is done in the MAC protocol layer which also manages the UL and DL scheduling of the user equipment and their services, taking into account the relative priority. The MAC layer also selects the transport format. The logical channels, in turn, are characterized by the data they transfer [10].

2.3 Heterogeneous Networks (HetNets)

In cellular radio access networks (RAN), a mesh of macrocells is initially deployed to cover the serving area to provide public cellular access for subscribers . To meet the growing user demand, increasingly densifying macrocell

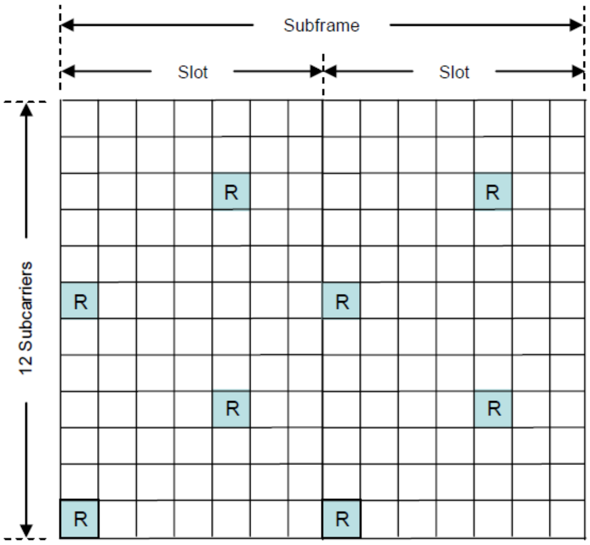


Figure 2.10: LTE Reference Signals are Interspersed Among Resource Elements [21]

to enhance the network capacity does not always work because of fewer cell site options, more frequent handoff of mobile users and increasing cochannel interference. Meanwhile, the user demands are not distributed evenly in the network, nor is the macrocell signal strength at the receiver. An alternative solution by applying tiered network infrastructure in RAN proves to be feasible and beneficial [25] .built upon existing macrocells, low power low cost cellular access nodes are deployed to serve cellular users at the spots where macrocell base stations (MBSs) can not provide effective or efficient coverage. As there are different types of low power access nodes to meet various deployment requirements, cellular networks are mitigating into a heterogenous access infrastructure, commonly known as heterogeneous cellular networks (HetNet) [26].Heterogeneous networking is one of the most widely used but most loosely defined terms in today's wireless communications industry. Some people consider the overlay of macro base station network and small cell network (e.g., micro, pico and femtocells) of the same air interface technology as heterogeneous networks. Others consider cellular network plus WiFi network as a main use case. There are also those who consider the inclusion of new network topologies and connectivity as part of the heterogeneous networks vision, such as personal hotspot, relay, peer-to-peer, device-to-device, near field communication (NFC) and traffic aggregation for machine type devices.

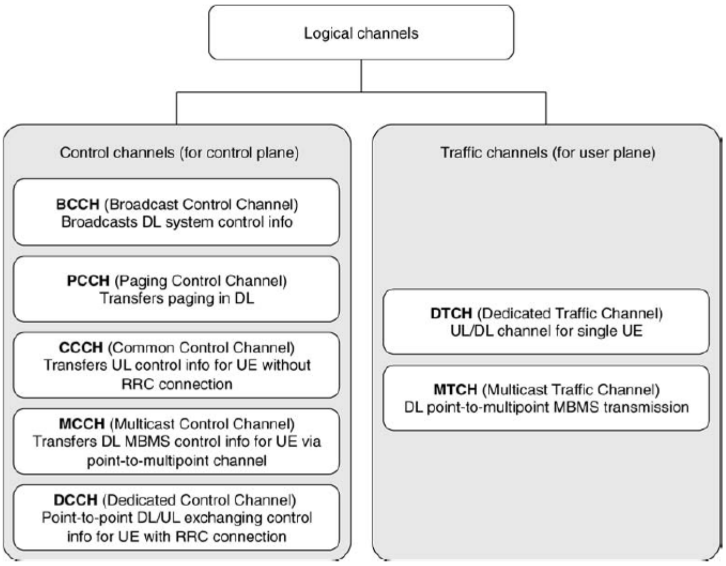


Figure 2.11: The logical channels of LTE are characterized by the information to be transferred. [10]

In fact, as flexible sharing and dynamic access of spectrum become part of the network infrastructure, we can expect heterogeneous networks to also include cognitive radios. Despite these diverse definitions and understandings, heterogeneous network research and deployment have made significant progress in the past several years, in particular in the area of data offloading through small cells (including WiFi access points). In practice, heterogeneous deployments are defined as mixed deployments consisting of macro, pico, femto and relay nodes. To the authors, heterogeneous networking is about a set of essential technologies and capabilities that deliver unprecedented large system capacity through the integration of heterogeneous architectures from WAN to LAN to PAN, provide always-on and always-bestconnected connectivity for compute continuum, and offer innovative services and significantly better user experiences through the introduction of improved network efficiency. In general, a heterogeneous network consists of multiple tiers (or layers) of networks of different cell sizes/footprints and/or of multiple radio access technologies [27].An LTE macro base station network overlaying an LTE pico base station network is a good example of a multi-tier heterogeneous network. In this case since the same LTE air interface technology is used across different layers/tiers of networks, 3GPP (the standards body that created LTE) has developed solutions and design provisions to facilitate the interaction and the integration of

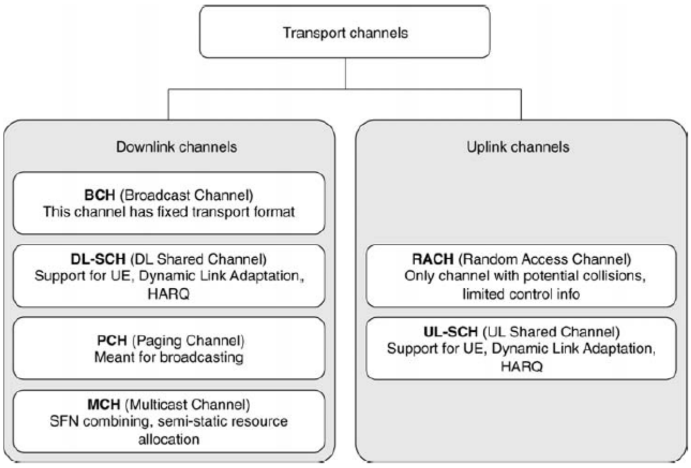


Figure 2.12: The transport channels of LTE are characterized by the way data is transferred over the radio interface [10].

such a heterogeneous network, including an extensive performance evaluation methodology that models a variety of deployment scenarios [28].

2.3.1 Heterogeneous Networks Use Scenarios

Heterogeneous networks have many architectural flavours and implementation variations to meet different market requirements and cost considerations [31]. However, the goals are similar. For consumers, heterogeneous networks need to provide ubiquitous coverage, secure, high data rate, high capacity, always-on, and always-connected-to-the-best-network user experience. For mobile operators, heterogeneous networks need to provide fast time-to-market, optimal network utilization, and operator control and network manageability. The most classical heterogeneous network deployment is home femtocells. They use mobile operator licensed spectrum and are primarily deployed by end users for network coverage extension in an indoor environment or remote rural areas where outdoor macrocells have difficulty in providing coverage. As a cellular coverage extension, they are primarily used for voice services. A home femtocell often limits its access to a ‘closed subscriber group’, which makes economic sense to an end user since he/she pays for the backhaul transmission cost, and there is little reason to share it with others. One unique characteristic of home femtocells is that they are mostly installed by the consumers who do not necessarily have adequate knowledge about radio technologies. As a result, the RF interference from/to a home femtocell may be difficult to

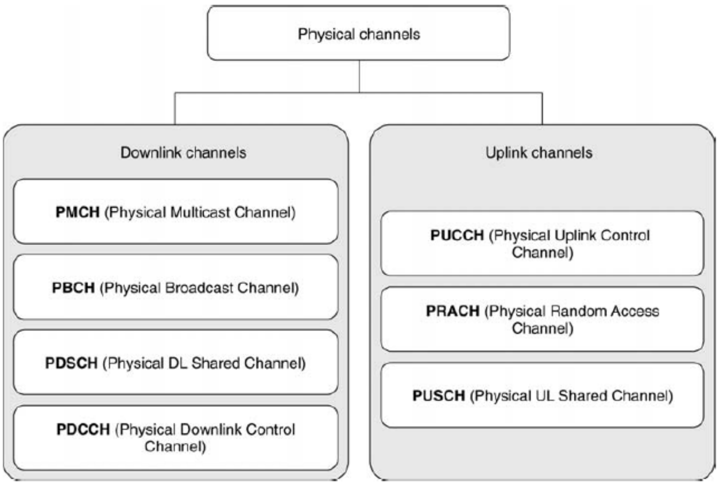


Figure 2.13: The physical channels of the LTE [10].

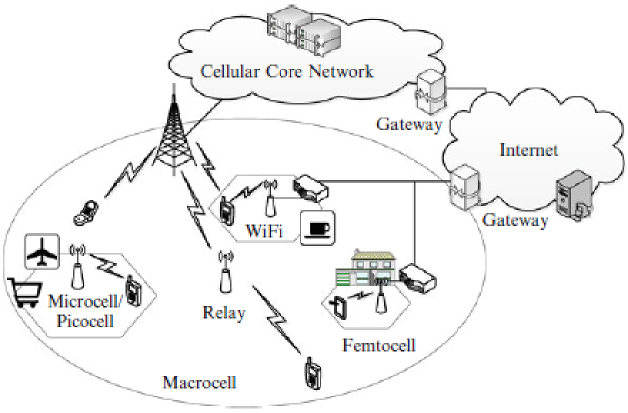


Figure 2.14: Heterogeneous cellular networks [29]

manage. Another class of small cells is the so-called picocell, sometimes also referred to as an enterprise femtocell or metro femtocell. They use the same air interface technology over mobile operator's licensed spectrum, and serve as an extension of the macrocellular network. This class of small cells usually has a larger subscriber capacity compared to home femtocells and provides voice and data services in office environments, indoor coverage in places like shopping centres or outdoor hotspot coverage such as a busy shopping street or sports stadium. They are often environmentally hardened in particular for outdoor deployment, professionally installed with more advanced antennas, with service open to all qualified subscribers instead of only to the members of a closed subscriber group. It should be noted that a home femtocell

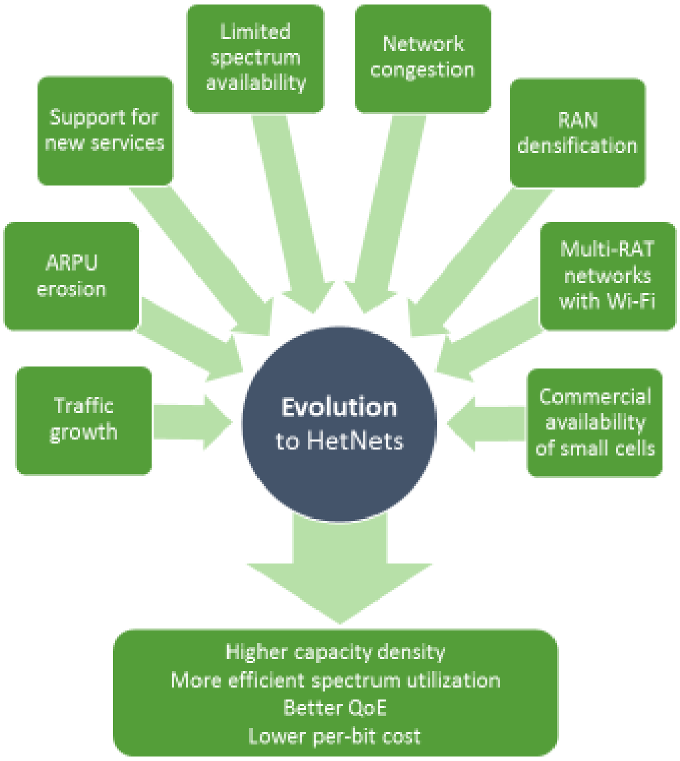


Figure 2.15: The evolution to heterogeneous networks [30]

and a picocell may not be very different in terms of subscriber capacity and transmission power.

2.3.2 Features of Heterogeneous Networks

Heterogeneous networks have several features that set them apart from macro-only networks,some of which have already been alluded to in previous sections. This section presents a broad overview of some of the important features .

- Association and Load Balancing:One of the main functions of small cells is to offload user equipment (UE) traffic from the macro. The amount of offloading depends on the criterion by which a UE associates with a base station. Downlink reference signal received power (RSRP) is the most basic criterion but this does not lead to much offloading since the transmit power of a macrocell is much greater than that of the small cell. Adding a bias to the small cell RSRP is an example of an association method that increases offloading [32]. The macrocell and the picocell can operate at different carrier frequencies. This is especially true for future heterogeneous networks, where small cells will be deployed in newly available spectrum in higher-frequency bands. RSRP does not capture the information about the difference in the levels of interference in the macrocell and small cell carrier frequencies. The interference information is captured in a reference signal received quality (RSRQ) based association and hence leads to better load balancing.Association is also tied to the network load. For highly loaded systems, load balancing will distribute the UE load across all base stations uniformly. This will homogenize the inter cell interference and lead to a fair distribution of a base station's resources among all its associated UEs. For networkswith lowload, it may however be better to concentrate the load on a fewbase stations as this will reduce intercell interference from the base stations with little or no associated UEs.

- Interference Management:The dense deployment of small cells increases interference; unless interference mitigation techniques are applied, the gains of heterogeneous networks will not be realized. For example, when a CSG femtocell is deployed, it may interfere with the UEs that are close but cannot associate with it as they are not part of its subscriber group. Another example could be a UE that is originally connected to amacrocell but is later handed over to a picocell with a cell range expansion (CRE) bias for the purpose of load balancing. In this case, the UE will experience an interference level that is higher than the desired signal. The system performance will degrade if the intercell interference is not managed properly.order to coordinate the intercell interference, various techniques have been proposed and adopted in LTE Releases 8–12. Frequency-domain techniques were proposed in Release 8, where two neighboring cells can coordinate their data transmission and interference in frequency domain. Time-domain techniques and their enhancements were proposed in Releases 10 and 11, where a cell can mute some subframes to reduce its interference to its neighboring cell. In Release 12, a small cell can perform dynamic activation/deactivation based on its traffic load and interference situation. Implementation of full-dimension (FD) multiple-input-multiple-output (MIMO), where a base station can direct a narrow and focused beam directed towards the three-dimensional location of the UE, is a new area for interference management in dense heterogeneous networks. Interference can also be mitigated by coordinated multipoint transmission/reception (CoMP) technology where a macrocell and a small cell can cooperate to simultaneously serve a UE.

- Self-Organizing Networks: Self-organizing networks (SON) are an important class of base station functionalities through which the various base stations in the network (notably the small cells) can sense their environment, coordinate with other base stations and automatically configure their parameters such as cell ID, automatic power control gains, and so on. Previously these properties formed part of the network configuration tools and processes which were configured by the operators manually. The manual methods work for a small number of homogeneous macrocell deployments but do not scale in a dense small-cell-based heterogeneous network. SONs are therefore critical to small cell deployments A SON optimizes network parameters for controlling interference which has a major impact on performance. It also manages the traffic load among different cells and different radio access networks and provides the user with the best possible service while maintaining an acceptable level of overall network performance. SONs reduce OPEX and thus save money for operators.
- Mobility Management:In a cellular network, handover is performed between cells to ensure that amobile UE is always connected to the best serving cell. The general handover process is as follows. A UE measures the signal strength of its neighboring cells. If the signal strength of a neighboring cell is higher than that of its serving cell plus an offset for a particular time period called the time to trigger (TTT), the UE will report this information to its serving cell. The serving cell then initiates the handover process. In a homogeneous network, the handover parameters such as the handover offset and TTT are common for all cells and all UEs. However, using the same set of handover parameters for all cells/UEs may degrade the mobility performance in a heterogeneous network. It is desirable to have a cell-specific handover offset for different classes of small cells. Furthermore, for high-mobility UEs passing through a dense heterogeneous network, the normal handover process

between small cells will lead to very frequent changes in the serving cell. This can be solved by associating this UE to the macrocell at all times, leading to UE-specific handover parameter optimization. Both cell-specific and UE-specific handover functionalities therefore need to be considered for heterogeneous networks.

2.3.3 Motivation for Heterogeneous Networks

- Explosive Growth of Data Capacity Demands: In recent years, mobile internet has witnessed an explosive growth in demand for data capacity [33]. This is largely fuelled by the proliferation of more intelligent mobile devices. Market studies have shown that the data traffic volume is a direct function of the device's screen size, the user-friendliness of its operating system and the responsiveness of wireless network that the device is connected to.In addition to this organic growth in capacity, demand from the improved mobile devices and communication infrastructure, user-generated content and social networking add significant additional burden to the network. The combined capacity demands from organic traffic growth, user-generated contents, social networking and machine-type connected devices require orders of magnitude capacity increase in future wireless networks. This heterogeneous data traffic growth also mandates a paradigm shift in network architecture design and provisioning.
- From Spectral Efficiency to Network Efficiency: The wireless industry has several options for meeting the explosive data traffic growth. After decades of relentless air interface innovations, today we are practically reaching the theoretical limit of radio channel capacity, commonly known as the Shannon limit. Although air interface improvement will continue to maximize the benefits of advanced wireless communication research and take full advantage of advanced signal processing technologies for an even higher spectral efficiency, we need several orders of magnitude greater system capacity than what the air interface spectral efficiency improvement can offer. The future capacity increases therefore need to come from a combination of technology solutions, including, in partic-

ular, maximizing the overall network efficiency instead of solely relying on the spectral efficiency improvement at the radio link level.Heterogeneous networks are a fundamental technology behind most of these solutions. The wireless industry and regulators are working together to investigate the possibility of adding more frequency bands, both licensed and unlicensed, for mobile internet applications. However, since there is a limited supply of spectrum, and there is the strong desire for globally harmonized frequency allocation to maximize the economy of scale, the progress in new frequency allocation has been slow.Since these bands have very different radio propagation characteristics from the traditional lower frequency bands (usually below 3 GHz) used for high mobility cellular networks, the technology, design and operation of these networks are expected to be very different from traditional cellular networks. Therefore, heterogeneous networks consisting of layers of networks operating at different frequency bands become the main venue for achieving higher system capacity.In addition to obtaining additional spectrum allocation and developing new technologies for the higher frequency bands, the wireless industry and the research community are also looking at innovative ways for more flexible spectrum utilization, including spectrum sharing, dynamic spectrum access and cognitive radio with opportunistic network From a telecommunication infrastructure viewpoint, such new types of networks are expected to become part of the global heterogeneous networks.

– Challenges in Service Revenue and Capacity Investment:In recent years, mobile service revenue growth has shifted from circuit-switched voice and short message service (SMS) to data services. This shift adds significant pressure to mobile network operators' profitability for three main reasons. First, mobile data in general yields a lower revenue per bit compared to the traditional voice services and SMS. Secondly, the highly profitable operator walled-garden mobile applications are facing stiff competition from over-the-top mobile applications. Finally, as mobile data traffic explodes, operators need extensive capital investment in new network capacity to meet the demand.Since mobile network operators are instrumental in investing, operating and maintaining global mobile internet infrastructure, it is crucial for the wireless industry and the academic research communities to develop new networking technologies that allow operators to remain profitable and competitive so that they can continue to invest in capacity and new services. Heterogeneous networking is considered one of the most important technologies that not only deliver tens- to thousands-fold system capacity increase but also enable new generations of services to replace the revenue from traditional but diminishing voice-centric telecom services To summarize, while the demand for data capacity is exploding and the improvement in spectral efficiency in homogeneous networks is slowing down due to the approaching Shannon limit, it becomes essential that the future focus of wireless technology shifts from further increasing the spectral efficiency of the radio link to improving the overall network efficiency through heterogeneous network architecture and related signal processing technologies. We need heterogeneous networks to deliver a higher system capacity to meet the higher traffic density.We want to leverage heterogeneous network architectures to expand network coverage,to improve service quality and fairness throughout the network coverage areas, in particular at the cell edge.We also want to use heterogeneous networks as a platform for future technological innovations, including the integration of new types of networks, new types of connectivity and new types of connected devices and applications.

2.3.4 eICIC enhanced Inter-cell interference coordination

The small cell deployment on the same frequency with macro cell requires efficient interference management. The challenge is that the small cell coverage area can be very small in a cochannel deployment due to the difference in the transmission power between the macro cell and the pico cell. If there would be no co-channel macro cell, the pico cell could provide service to larger coverage area.The target is to increase the pico cell coverage area in the case of co-channel deployment. One option is to coordinate the interference in the time domain, which is defined in

3GPP Release 10 and called enhanced inter-cell interference coordination (eICIC) [6]. In this section , we explain the details of the enhanced Inter-Cell Interference Coordination (eICIC) techniques that are standardized in LTE-Advanced Release 10 for small cell deployments.

2.3.4.1 Typical Deployment Scenarios

One of the most important features in LTE Release 10 is the support of heterogeneous network deployments, in which macrocells provide the basic coverage and small cells are deployed within the coverage area of macrocells to further enhance UE throughput. The following two typical small cell deployment scenarios are considered in Release 10: the macro–pico deployment and the macro–femto deployment. The basic difference between the two scenarios is that femtocells cannot be accessed by all UEs in the network and femto UEs form a closed subscriber group (CSG), whereas picocells are open to all UEs. These two deployment scenarios have different interference situations and backhaul supports, which require different techniques for interference management.

- Macro–Pico Deployment Scenario:In the macro–pico deployment scenario, picocells are deployed by the network operator in a planned way. For example, they can be placed on the edge of a macrocell or in a hotspot to enhance UE throughput. A Pico eNodeB (PeNodeB) that forms a picocell has the same protocol stack and functionalities as a Macro eNodeB (MeNodeB), but transmits with lower power. In the macro–pico deployment scenario, a UE measures the downlink Reference Signal Received Power (RSRP) of its neighboring cells and chooses the one with the highest RSRP level as its serving cell. As a result, a picocell will serve a small number of UEs due to its low transmit power. In order to offload more data traffic to picocells, a logical bias can be added to the RSRP of the picocell before comparing it with the RSRP of another cell such as the macro. This biasing technique, called the Cell Range Expansion (CRE) bias, has been proposed to expand the serving area of a picocell without increasing its transmit power [34] [35] An example is shown in Figure 2.16 where PeNodeB 1 with positive CRE bias has a larger serving area than PeNodeB 2 which does not apply a

CRE bias when the two PeNodeBs have the same transmit power. How does CRE biasing work? In order to answer this question, we first briefly review the UE handover procedure. Figure 2.17 illustrates the X2-based handover procedure between a macro- and a picocell. As shown in the figure, $aRRC_{CONNECTED}$ UE is initially connected to aMeNodeB. The UE measures the RSRP from its neighboring eNodeBs and reports these values to its associated MeNodeB periodically. The MeNodeB decides whether to hand over the UE to other eNodeBs based on the received RSRP measurement report.

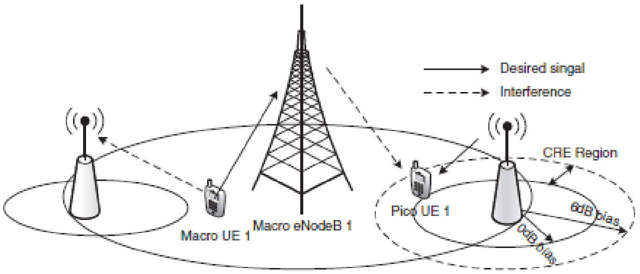


Figure 2.16: The interference situations in the macro–pico deployment scenario [32]

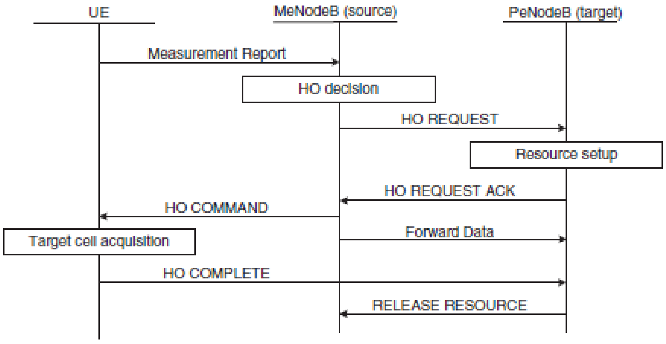


Figure 2.17: X2-based handover procedure [32]

In the macro–pico deployment scenario, interference management is a key issue especially when CRE is configured. The problem is most severe in downlink for the $RRC_{CONNECTED}$ UEs in the CRE region of a picocel .The minimum value of UE SINR values decrease as the CRE bias increases. The UEs corresponding to these SINR values are located in the CRE region and face strong interference.

- Macro–Femto Deployment Scenario: In themacro–femto deployment scenario, the femtocells are usually deployed by the customer in an unplanned way. Femtocells can be placed inside an office building or a residential area to enhance UE throughput. A Home eNodeB (HeNodeB) that forms a femtocell is similar to a PeNodeB in the sense that both nodes have the full protocol stack and functionalities of a MeNodeB but transmit with lower power. The major differences between a HeNodeB and a PeNodeB are listed as follows.

  Firstly: HeNodeB is accessible only to a particular group of UEs in the network, i.e. the femtocells are Closed Subscriber Group (CSG) cells. This affects the network architecture and requires extra functionalities of the HeNodeB such as CSG provisioning and broadcasting. Furthermore, the mobility management of HeNodeBs is more complicated than that of picocells. The deployment of CSG cells also creates a unique interference situation in downlink.

  Secondly: No direct backhaul exists between a HeNodeB and a MeNodeB; an X2-based handover between aMeNodeB and a HeNodeB is therefore not supported. Moreover, the interference coordination between a macrocell and a HeNodeB is more difficult due to the lack of direct backhaul. The UE stores two kinds of CSG lists, called the allowed CSG list and the operator CSG list, in its SIM card. Both these lists contain entries of cells with their CSG Identity (ID) and associated Public Land Mobile Network (PLMN) ID. The difference between the two is that the allowed CSG list is managed by the UE and/or the network, while the operator CSG list is controlled only by the network.The CSG server updates these lists via the Open Mobile Alliance Device Management (OMADM) or Over The Air (OTA) procedures. The combination of the two CSG lists is called the CSG white-list. The UE considers the CSG

IDs stored in the CSG white-list valid only within the scope of its registered PLMN.

2.3.4.2 Time Domain Techniques

From the discussion in the previous section, there is a potential need of interference management in the downlink to avoid severe interference caused by macrocells in the macro–pico deployment scenario, and by non-accessible CSG femtocells in the macro–femto deployment scenario. In this section, we focus on the time domain eICIC techniques. We first introduce Almost Blank Subframe (ABS) which is the key concept for the time domain interference mitigation. We then discuss how to utilize ABSs for interference management in the macro–pico and macro–femto deployment scenarios

2.3.4.3 Almost Blank Subframe

The basic idea of the time domain techniques is to mute certain subframes of some cells in order to reduce the interference to the other cells [36] [37] [38].We call a cell that causes interference to UEs of another cell an aggressor cell and the latter the victim cell; the UEs that are interfered are referred to as the victim UEs. Ideally, the muted subframes configured by an aggressor cell should be totally blank (i.e. all REs are muted) in order to reduce the interference as much as possible. However, the broadcast channel (i.e. the PBCH) and the reference signals (e.g. the CRS and the PSS/SSS) cannot be muted as they are needed to support important.legacy operations such as cell acquisition and maintaining link connectivity. In addition, the PDCCH may have to be transmitted to support an uplink transmission such as uplink grants. Based on the above considerations, ABSs that are introduced in Release 10 allow only unicast PDSCH transmissions to be suspended. Interference is therefore reduced significantly but not completely. ABSs can be configured by a cell in either normal subframes or MBSFN subframes. If a normal subframe is configured as an ABS, the CRS and the PBCH (where applicable) are still transmitted as shown in Figure 2.18. If a MBSFN subframe is configured as an ABS, it does not contain the

CRS in the PDSCH region and thus causes less interference than a normal ABS. Note that the PDCCH region is also almost blank in ABSs since no DCI corresponding to the unicast PDSCH transmission is transmitted. As mentioned earlier however, if an uplink grant is scheduled in that subframe there could be a corresponding PDCCH transmission in some REs. Given the fact that a MBSFN ABS causes less interference than a normal ABS, the obvious question is whether it is possible to configure all ABSs in MBSFN subframes. Unfortunately, this is not possible as it may violate the uplink HARQ process configurations. To understand this, consider a simple example in the macro–pico deployment scenario as shown in Figure 2.19, where a macrocell configures ABSs to reduce the interference to a picocell. If the picocell transmits a PUSCH grant for a UE in subframe 1 (which is configured as MBSFN ABS by the macrocell), it will transmit the HARQ ACK/NACK for the scheduled PUSCH transmission in subframe 9. In this case, it is desirable for the macrocell to configure subframe 9 as a normal ABS to protect the HARQ ACK/NACK transmission.

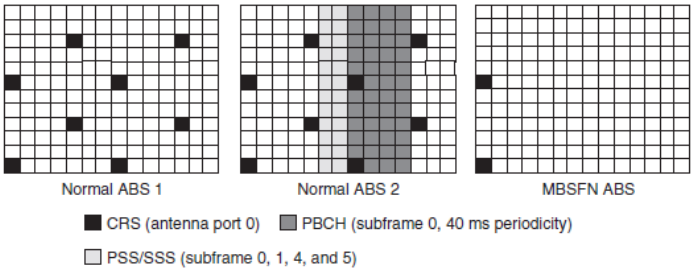


Figure 2.18: Normal and MBSFN ABSs [32]

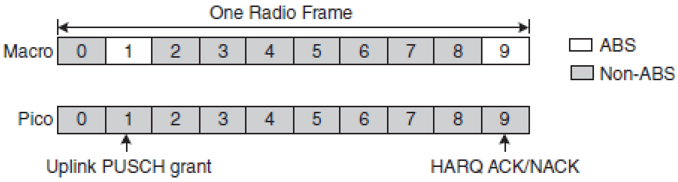


Figure 2.19: An example of using ABSs to protect uplink grants and HARQ ACKs/NACKs

2.3.4.4 ABS Use Cases

In this section, we explain how to utilize ABSs in heterogeneous networks. We consider the following two typical deployment scenarios:

- the macro–pico deployment scenario, where the pico UEs in the CRE region of a picocell suffer strong interference from a macrocell; and
- the macro–femto deployment scenario, where the macro UEs that are located in the proximity of a CSG femtocell suffer strong interference from it.

In the macro–pico deployment scenario, the expected behaviors of the macro- and picocells are described in the following.

- Step 1: The macrocell predicts that the traffic demand may exceed its capacity and it has to offload some UEs to the picocell.
- Step 2: The macrocell hands over some UEs to the picocell by employing CRE.
- Step 3: Themacrocellmutes some subframes by configuring ABSs. These subframes are also called protected subframes from the context of the picocell.
- Step 4: The macrocell informs the picocell of the ABS pattern via the X2 interface .
- Step 5: The picocell schedules those UEs in the protected subframes based on the received ABS pattern. It configures its UEs to report channel state information of the protected and non-protected subframes separately as the nature of interference is very different in the two types of subframes. This principle is called restricted measurements.

The percentage of ABSs configured by the macrocell depends on the CRE bias. In principle,if a large CRE bias is configured, more UEs will be served by the picocell and thus a higher ratio of ABSs is desirable. The CRE bias and ABS ratio need to be optimized jointly to achieve the maximum system throughput. Note that the subframes of the two eNodeBs are shifted, i.e. subframe 0 of the picocell is aligned with subframe 1 of the macro. Subframe shifting has been introduced in

LTE to ensure that the PSS/SSS and the PBCH transmitted by the picocell can be protected. With subframe shifting, the macro transmits PSS/SSS signals and PBCH channels in a different subframe than the pico. The macro has two ways to avoid interference to pico PSS/SSS and PBCH when subframe shifting is used, described in the following:

- the macro configures an ABS corresponding to the subframe where pico transmits PSS/SSS and PBCH; and
- the macro configures a non-subframe ABS corresponding to the subframe where pico transmits PSS/SSS and PBCH, but it avoids scheduling any UEs in the central 6 RBs of the subframe (because the pico PSS/SSS and PBCH will be transmitted in the central 6 RBs).

2.3.4.5 UE Measurement and Reporting

In a LTE network, a UE performs various measurements for different purposes (e.g. cell selection/reselection, handover, or link adaptation) and reports them to its serving cell periodically.In this section, we discuss the impact of configuring ABSs on the following three UE measurement and report procedures:

- Radio Resource Management (RRM) measurements.
- Radio Link Monitoring (RLM) measurements, and
- Channel State Information (CSI) measurements.

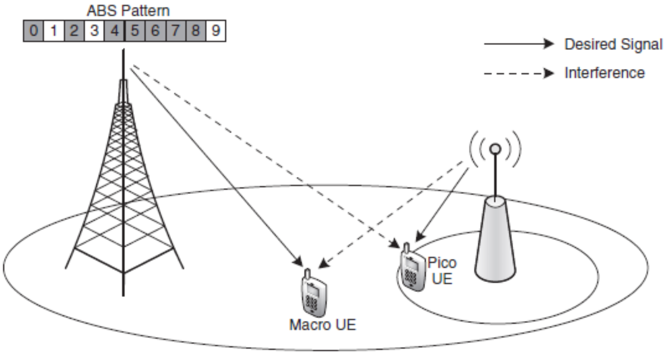


Figure 2.20: UE measurement and report in the macro–pico deployment scenario [32]

Without going in details of the above UE measurements, we first give an example to show how the configuration of ABSs affects UE interference measurements. Consider a typical macro–pico deployment scenario as shown in Figure 2.20, where the macrocell employs ABSs to reduce interference to the picocell. Obviously, the interference characteristics experienced by a pico UE in the protected subframes (i.e. subframes 1, 3, and 9) is different from that in the unprotected subframes. If the pico UE does not take such differences into account, it will perform interference averaging over some protected subframes together with some unprotected subframes, which leads to very inaccurate interference estimation. To solve the above-mentioned issue, the concept of restricted measurements was introduced in Release 10. This means that a UE can be configured to perform a certain measurement over a restricted set of subframes. In the interference measurement example, the subframes could be divided into two sets of subframes: one for the protected subframes and the other one for the unprotected subframes. The pico UE can perform independent interference measurement and estimation of these two measurement sets. Note that the configuration of ABSs does not affect the interference measurement of the macro UEs, since the interference characteristics from the picocell does not vary across subframes.

2.4 Literature Review

Landström et al. have first concept of HetNet and explained that HetNet can increase the cellular network capacity by adding low power network access nodes [26] . Currently, the integration of small cells in the infrastructure have been concerned in the latest 3G/4G cellular systems including long term evolution (LTE)/LTE-Advanced (LTE-A) [39] [40] [41] of 3rd generation partnership program(3GPP) and worldwide interoperability for microwave access (WiMAX) [42],respectively. Andrews in [43] explains seven major ways that small-cell oriented HetNet are different than traditional tower-based cellular networks. Dhillon et al.in [44] illustrate a K-tier network structure of HetNet and discussed on the associated research challenges in the network modeling and capacity analysis. Yun and Shin in [45] propose an adaptive interference management framework of OFDMA femtocells for co-channel deployment with macrocells. They loop resource management and power control in a way as the "onion rings" with respective time scales and control resolution. Furthermore, there are also active discussions on the other technical and research issues, such as interworking and mobility management, handoff, network selection and load balancing in HetNet. Andrews, Conti and Shen have compiled a list of best readings in multi-tier cellular on behalf of the IEEE Communications Society as a comprehensive survey on the state-to-art techniques and standardization efforts in HetNet [39]. The eICIC proposal is relatively new for LTE Heterogeneous networks. In [46] , the authors present a very good introduction to the concept of eICIC in LTE HetNets. In [47],the authors provide an excellent survey on eICIC and the motivation behind eICIC proposal in LTE standards. In a recent work [48], the authors present simulation studies to understand the dependence between network performance and eICIC parameters. However, the authors primarily consider uniform eICIC parameter in all the cells; clearly, the right choice of eICIC parameters should vary across cells and account for propagation map, cell-load etc. Also, the authors do not present a framework to optimize the eICIC parameters. In [49] [50] [51] , the impact of ICIC has been studied for LTE and LTE HetNets. The concept of soft-frequency reuse has been formally studied in [52] , where, the authors optimize downlink transmit power profiles in different frequency bands. The work closest to ours in principle is [53] that considers the problem of UE association and ICIC in a joint manner. Regarding the utilization of HetNets as a way to improve network capacity and performance in relation to traditional homogeneous network are discussed in [54] [55] . In [54], authors discuss a high-level overview of LTE heterogeneous network in terms of air interface, network nodes, spectrum allocation along with other mechanisms for HetNets deployments. In [46], the authors described the interference coordination schemes and technical challenges that arise in heterogeneous networks highlighting the impact of interference in deployments consisting of cells of different size. Also, authors in [46] described several techniques enabling the move from macro-only to HetNets including range extension and enhanced inter-cell interference management techniques over HetNets.

However, in context of ICIC management in HetNets, 3GPP Release 10 introduced ABS/ based eICIC which is an efficient way to enhance network performance, in particular for cell-edge/expansion area UEs. In addition, authors in [46], [56] , [57] addressed downlink co-channel interference in context of ABS-based eICIC at different deployment scenarios, where [46] and [58] deals with macro-pico approach and [57] studies both of the macro-pico and macro-femto approaches. The both studies have been evaluated in different network architectures, namely centralized and distributed architecture, and suggest a considerable performance gain by means of HetNets. On the other hand, interference management schemes based on FDM and scheduling algorithm are presented in [59] , [60]. In [59] authors proposed a dynamic interference coordination scheme based on the combination of soft frequency reuse and Graph-based resource allocation on macro-pico scenario. Authors in [60] discussed the key terms of scheduling through interference avoidance/coordination to mitigate interference in a multi-cell environment. Carrier Aggregation (CA) based radio resource allocation and inter-cell interference mitigation has been extensively described in [61] [57]. In [55] , multi-site CA has been introduced which effectively allows multiple uplink in support of Timing Advance (TA) enhanced uplink power control, and resulting avoid the interference by ensuring coordination among the transmission points. However, to the best of my knowledge, a holistic survey on inter-cell interference coordination in LTEAdvanced HetNets with particular focus on TDM based eICIC, FeICIC and carrier aggregation is not currently available.

2.4.1 SMALL CELL CHALLENGES AND RELATED LITERATURE REVIEW

After a brief introduction about LTE/LTE-A and small cell, now we are going to discuss about challenges in small cell/Heterogeneous networks deployment. Small cell are deployed on the same or different frequency layer as the macro network, which will result in different challenges in term of [62]

2.4.2 Intercell Interference

Intercell interference is the most significantly and widely- discussed challenged in small cell deployment. That is arising between the small cell (femto, pico and heterogeneous network cell) and macro cells. We are going to discuss the most commonly used femto small cell. Femto cell is control by HeNB that was described by 3GPP release 8/9/10. HeNB also called Femto Access Point (FAP). Major cause of interference between FAP and macro cell is, low power FAP is deployed in the cell range of macro cell. Two type interference described in literature [63], intercell (cross layer) and intra-cell (co layer). Intercell interference between the FAP and macro cell while intra cell interference is between two femto access points. Cross-tier and intra-tier interference problems are significantly challenging due to backhaul, restricted access control and self organizing nature described by, Lopez-Perez et al. [46]. To overcome the effect of interference, cancellation techniques have been proposed by Wiber et al., [64]. But this approach was discarded due to errors in the cancellation process. The simplest forms of inter-cell interference mitigation are Fractional frequency reuse (FFR) schemes because it is easy to implement in OFDA system such as LTE. Although these techniques do reduce the interference by partitioning the overall bandwidth among cells impairs the overall throughput. FFR used the static power allocation that is not applicable for dynamic nature of femto cells.

In addition to this, Lee et al., [65], proposed an interference management scheme in the LTE femtocell systems using Fractional Frequency Reuse (FFR), according to this approach frequency band is allocating Under the macro cell, the femtocell chooses sub-bands which are not used in the macro cell sub-area to avoid interference. This proposed scheme enhanced total/edge throughputs and reduces the outage probability in overall network, especially for the cell edge users. Enhanced frequency reuse schemes, such as Partial Frequency Reuse (PFR) proposed by Sternad et al., [66] and Soft Frequency Reuse (SFR) [67], have thus been introduced. The idea behind PFR is to partition the bandwidth so that only a limited amount of RBs can be used by all cells, while others are used with higher reuse factor. Cell-edge UEs can take advantage of lower interference in these sub-bands. Enhancement in PFR presented by Krasniqi et al., [68] a Flexible Bandwidth Allocation (FBA) scheme for Partial Frequency Reuse (PFR) depending on the network-load, which allocates bandwidth dynamically in the network. That presents general framework for intelligent frequency planning in wireless networks. In the SFR scheme, a cell can allocate the entire sub frame, but different power levels are employed in cell-center and cell-edge RBs. Semi-static Inter-Cell Interference Coordination (ICIC) schemes were then proposed, based on the above frequency reuse schemes. Fang et al., [69] and Yu et al., [70] authors proposed a novel load distribution aware soft frequency reuse (LDA-SFR) scheme for inter-cell interference mitigation and performance optimization in next generation wireless networks. The proposed scheme consists of two novel algorithms: edge bandwidth reuse and centre bandwidth compensation. Using the edge bandwidth reuse algorithm, cell-edge users can take advantage of uneven traffic load and user distributions within each cell to expand their resource allocations. Studied by Baktash et al., [71] dynamic intra-cell subcarrier reuse in cooperative OFDMA networks in which the users are allowed to share any subcarrier in the relay links provided that the resultant intra-cell interference is managed. Thomas et al., [72] compared the downlink throughput macro-cell interference scenario with a frequency reuse scheme. Bit accurate link level simulations are performed for the downlink physical shared channel (PDSCH). In addition, Ghosh et al., [73] and Damnjanovic et al., [40] discussed the advanced methods for intercell interference coordination (ICIC) specifically for femtocell network, it has been a major motivation for the 3GPP LTE-Advanced standardization effort. A new inter-cell interference coordination (ICIC) scheme based on adaptive sub-band avoidance on the inter-cell level is proposed by Xiao et al., [74] where for each cell a certain ratio of the subcarriers are avoided in the subcarriers group used for the center region. In the study by Lopez-Perez et al., [75], particular attention has been given to the avoidance of cross-tier interference due to its crucial role in proper operation of multi-tier networks. Furthermore, the main focused was on eICIC techniques. More advanced techniques for interference control including backhaul-based [76] , and cooperative communication between multiple base stations are also being researched Boudreau et al. [77] and Kulkarni et al. [78] . These all we will be discuss in resource allocation challenged.

2.4.2.1 Resource Allocation

The minimum time–frequency resource unit used for downlink transmission is resource element, which is defined as one sub carrier over one OFDM symbol. For both TDD and FDD duplex scheme, a group of 12 sub-carrier continuous in frequency over one slot in time from a PRB (physical resource block) a two dimension region corresponding to one slot in the time-domain and 180 KHZ (12 × 15 KHZ) in the frequency-domain. The transmissions are allocated in units of PRB. More specifically, the data or control signaling in each slot is transmitted via one or several resource elements of sub carrier over OFDM symbols. Small cell is most provisioning idea to improve the spectral efficiency, reduced cost and enhancement of the throughput. Resource allocation method is very important to improve such objectives. A lot recently research have been done in this area Parag KulKarni et al. [78] described two possible deployment path for operator, one approach is to set aside a chunk of the spectrum for deploying small cells and use the remaining for the macro network. This is well known as the dedicated channel deployment approach. The second approached deploy small cells on the same spectrum as existing macro cells. This is well known as co-channel deployment approach. Hatoum et al., [79] related works is the computation of efficient allocation of time-frequency resource blocks, while accounting for cross layer interference (interference between macro cell and small cells) and co-layer interference (interference between femtocells). Chang et al., [80] proposed graph theory to managed the inter cell interference coordination in multi-cell OFDMA downlink resource allocation. In the collaborative resource allocation scheme Lee et al., [81], cross-tier interference is approximated as additive white Gaussian noise (AWGN) for self healing and self optimization network. In the Lagrangian dual decomposition-based resource allocation scheme , constraints on cross-tier interference are used in power allocation, but channels are assigned randomly to femto users. Authors Sundaresan et al., [82] proposed a location-based resource management scheme to achieve efficient resource allocation and spatial reuse. In contrast Chandrasekhar et al., [83] proposed a decentralized resource allocation scheme that guarantees users a prescribed quality of service. Valcarce et al., [84], proposed and enhanced a hybrid limited access method that reduces cross-layer interference while guaranteeing subscribers a minimum performance. Zahir et al., [85], Quan et al. [86] and He et al., [87] described some works applying game theory and selfish characteristics in small cells networks were focused on signal-to-interference-ratio-based power control resource allocation.

Chapter Three
System Model and Design Approach

In this chapter, The Intercell Interference Problem Analyzed & Interference Management by using ABS is presented . implemented Macro–Pico Deployment Scenario system model. Propagation path loss models ,signal fading ,shadow fading , multipath fading , antenna gain , SINR , link performance model & traffic model used for macro cell and pico cell are described. performance metrics is explained analysis , assumption and the used parameters which are defined in some depth in table 3.2.

3.1 Intercell Interference Problem

When a UE moves away from the serving eNB and becomes closer to other eNBs, the strength of desired received signal decreases and the ICI increases. The impact of ICI in LTE downlink can be analysed according to the received signal to interference and noise ratio (SINR) of UEm on RBn. Three important factors have a great influence on the SINR of each UE including: (a) Channel gain from eNB to UE, (b)Transmission power of each RB, and (c) RB allocation scheme. Because of the larger transmission power of the macro eNB, the handover boundary becomes closer to the pico eNB which causes uplink interference challenges. When a UE closed to picocell is served by macro eNB, the strong interference will occur for UE located in the picocells. Consequently, picocells may become underutilized because of the large impacted interference. Moreover, it is clear that a mechanism is needed to allow flexible connection between a serving eNB and a UE and mitigate downlink and uplink interference beneficially [88]. Therefore, one of the important aspects of HetNets is interference management. The interference management should be able to support sufficiently the co-channel deployment of various traffic loads as well as using of different numbers of low power nodes at different geographical regions. In order to coordinate between macro eNB and pico eNB, some messages should be exchanged among them through X2 interface [89] . Inter-cell interference, on the other hand,becomes a performance-limiting factor. For this reason, interference mitigation has become an important topic in performance engineering of OFDMA networks. The simultaneous use of the same spectrum between different cell layers that run on different values of transmit power creates interference that will become more severe compared to homogeneous networks. For picocells, cell-edge user experience high level of intercell interference from macro eNodeB in downlink [90] [91].

3.2 Interference Management using ABS

ABS mechanism in HeTNet is the phenomenon by which a MeNB mutes some of its subframes in order to allow UEs in neighboring cells (specially UEs in CRE area) to do the data transmission in those silenced subframes, i.e. by transmitting their data in a different time range than the MeNB. Cell center UEs can do their data transmissions using all the subframes at any time, which makes the ABS method specially targeted for cell – edge UEs. Moreover, the usage of ABS for inter cell interference coordination, as time domain mechanism, also solves the cell edge interference problems that could not be addressed by using ICIC in frequency domain. And since ABS works in the time domain, all the neighboring eNBs which are in the same geographical area should be synchronized in time and phase to a small fraction of 1ms, as the duration of one sub – frame is 1ms. Figure 3.3 shows the steps or signalling done during an ABS setup and synchronization between a MeNB and aPeNB. In order to assist pico downlink transmissions, each macro remains silent for certain periods, termed Almost Blank Subframes (ABS periods), during which a Pico-eNB can transmit at reduced interference. These subframes are called ”almost blank” because a macro-eNB can still transmit some broadcast control signals over these subframes. Since these control signals only occupy a small fraction of the OFDMA subcarries, the overall interference caused by macro-eNB, in the picocell, is much less during these ABS periods. Thus, the pico-eNB can transmit to its UEs at a much higher data rate during ABS periods. It is important to note, a pico-eNB can transmit to its UEs during non-ABS periods, which can provide good enough performance to UEs very close to the it. The macrocell only need to stop transmission during ABS subframes to protect UEs connected to the picocells that located on its edge. Pico-eNBs sends data to the type 3 UE during ABS subframes and to the Type 2 UE using non-ABS subframes, as illustrated in Fig. 3.1.

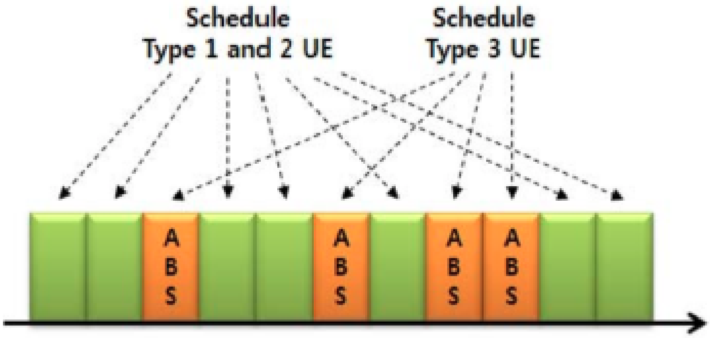


Figure 3.1: Interference management using ABS [92]

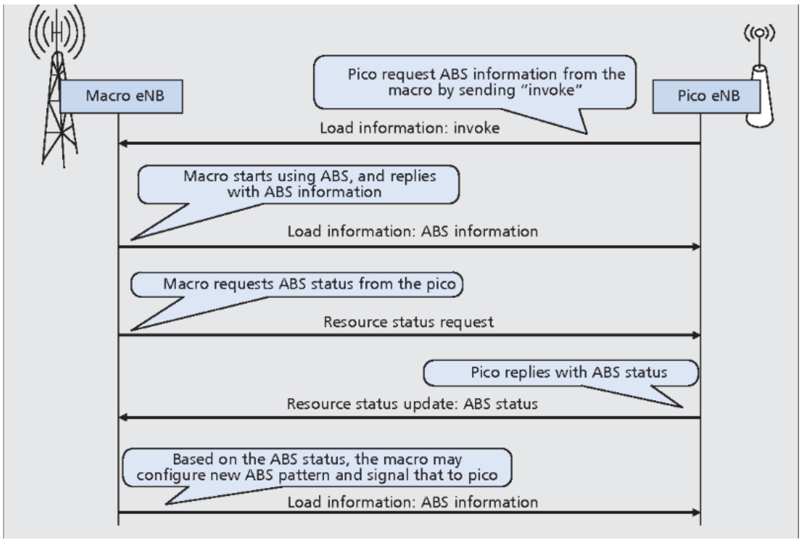


Figure 3.2: X2 signaling for Macro - Pico ABS coordination [93]

3.3 Typical Deployment Scenario

One of the most important features in LTE Release 10 is the support of heterogeneous network deployments, in which macrocells provide the basic coverage and small cells are deployed within the coverage area of macrocells to further enhance UE throughput. The following two typical small cell deployment scenarios are considered in Release 10: the macro–pico deployment.

3.3.1 Macro–Pico Deployment Scenario

In this section, the idea of integrating pico cells within the macro cell network is introduced . Study of the mutual interference between macro and pico cells as a result of sharing the same LTE frame.

In the macro–pico deployment scenario, picocells are deployed by the network operator in a planned way. For example, they can be placed on the edge of a macrocell or in a hotspot to enhance UE throughput. A Pico eNodeB (PeNodeB) that forms a picocell has the same protocol stack and functionalities as a Macro eNodeB (MeNodeB), but transmits with lower power. Both eNodeBs are connected to a Mobile Management Entity (MME) and a Serving Gateway (S-GW) via S1 interface. They are also connected to their neighboring MeNodeBs and PeNodeBs via X2-based backhaul. The X2 interface also facilitates the interference coordination between a macrocell and a picocell. In the macro–pico deployment scenario, a UE measures the downlink Reference Signal Received Power (RSRP) of its neighboring cells and chooses the one with the highest RSRP level as its serving cell. As a result, a picocell will serve a small number of UEs due to its low transmit power. In order to offload more data traffic to picocells, a logical bias can be added to the RSRP of the picocell before comparing it with the RSRP of another cell such as the macro. This biasing technique, called the Cell Range Expansion (CRE) bias, has been proposed to expand the serving area of a picocell without increasing its transmit power. An example is shown in figure 3.2 where PeNodeB 1 with positive CRE bias has a larger serving area than PeNodeB 2 which does not apply a CRE bias when the two PeNodeBs have the same transmit power.

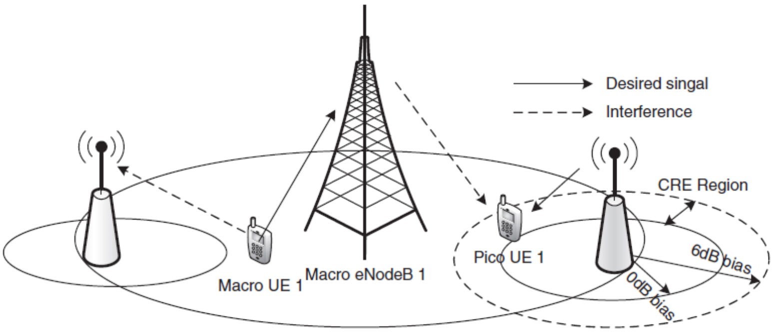


Figure 3.3: The interference situations in the macro-pico deployment scenario [32]

The MeNodeB decides whether to hand over the UE to other eNodeBs based on the received RSRP measurement report. If the RSRP of a neighboring PeNodeB becomes larger than that of the MeNodeB, the MeNodeB will initiate the handover process of the UE by sending a HANDOVER (HO) REQUEST message to the PeNodeB via the X2 interface. After receiving the HO REQUEST message, the PeNodeB prepares radio resources for the UE and replies back to the MeNodeB with a HO REQUEST ACK message. The MeNodeB then sends a HO COMMAND message to the UE in order to initiate the acquisition process of the picocell. Meanwhile, the MeNodeB starts data forwarding to avoid any data loss. When UE completes the cell acquisition process, it informs the PeNodeB by sending a HO COMPLETE message. After receiving the HO COMPLETE message, the PeNodeB sends a RESOURCE RELEASE message to the MeNodeB via the X2 interface, which completes the whole handover process. Consider the macro–pico deployment scenario, where the pico UEs in the CRE region of a picocell suffer strong interference from a macrocell. In the macro–pico deployment scenario, the expected behaviors of the macro and picocells are:

- Step 1: The macrocell predicts that the traffic demand may exceed its capacity and it has to offload some UEs to the picocell.
- Step 2: The macrocell hands over some UEs to the picocell by employing CRE.

- Step 3: The macrocell mutes some subframes by configuring ABSs. These subframes are also called protected subframes from the context of the picocell.
- Step 4: The macrocell informs the picocell of the ABS pattern via the X2 interface.
- Step 5: The picocell schedules those UEs in the protected subframes based on the received ABS pattern.

The signal to interference and noise ratio received at a UE is being calculated under the following assumptions:

- Different path loss propagation models for the macro cell and pico cell
- Pico-eNB transmit power is much lower than the macro-eNB
- Placement of a pico cell is at the edge of the macro coverage area
- The pico and UE antennas are omni-directional

3.4 System Model

We consider a three-cell LTE based wireless communication system model, as mentioned in Figure 3.3 , a network consisting of one pico cell placed at the edge of the macro cell with radius of 1000 m & Pico eNodeBs (PeNodeB) with cell radius 50 m are planned in the coverage of Macro eNodeB A's (Macro Cell A) coverage area. The UE is located randomly between both base stations. The macro-eNB is carefully planned by the cellular operator considering the coverage demands and is located at the origin point $(0, 0)$ of the Cartesian plane (X, Y). Pico cell is associated to macro cell, placed in a hotspot where there is a denser population.

we are using Euclidean distance formula between two points in space, as indicated below

$$d_1 = \sqrt{(P_E\mathrm{NB}_x - \mathrm{UE}_x)^2 + (P_E\mathrm{NB}_y - \mathrm{UE}_y)^2}, \tag{3.1}$$

$$d_2 = \sqrt{(\mathrm{M}_E\mathrm{NB}_x - \mathrm{UE}_x)^2 + (\mathrm{M}_E\mathrm{NB}_y - \mathrm{UE}_y)^2}, \tag{3.2}$$

where d_1 and d_2 denote the distance from the user equipment from the picocell and the macrocell, respectively. The coordinates of the UE are

($\mathrm{UE}_x, \mathrm{UE}_y$), P_E is pico euclidean , M_E is macro euclidean, and finally NB_x and NB_y denote NodeB in X axis and NodeB in Y axis respectively .

3.4.1 Propagation Path Loss Model

In general, the path loss between a transmitter and receiver can be defined as the ratio of the transmitted power to the received power . However,most mobile networks operate in complex propagation environments that cannot be precisely modelled by free-space pathloss. Therefore, the pathloss model has been developed to predict path loss in wireless environments. In the area of wireless communications, pathloss is a function of distance, frequency and antenna height The system developed is based on the home eNodeB to UE path loss models. The considered models are mentioned in [3GP06b] and [3GP06c]. Path loss calculation for signals traveling from the serving eNodeB to the UE is given by:

3.4.1.1 Macro Cell Propagation Model

The propagation path loss (PL) between a macro eNodeB and outdoor macro UE (MUE) located in a point P in the 2-dimension, at distance R in km from macro eNodeB, the pathloss between a macro eNB and UE (L_m) and a pico eNB and UE (L_p) with distance R in urban area were modeled as follows when carrier frequency was set to 2 GHz is modeled as:

$$P_{\mathrm{L}}(R) = 128.1 + 37.6 \log_{10}(R), \tag{3.3}$$

where R is the Macro-eNB to UE separation distance in Kms. In an urban environment, radio wave propagation has two dominant paths which are over the rooftops and along the street. The first path dominants when the UE is far from the site, while the second path dominants when the UE is near to the site The macro cell propagation model is valid for Non Line of Sight (NLOS) case only. It gives the worst-case propagation scenario. The urban model is valid under the following conditions [94] :

- Frequency from 450 MHz up to 2200 MHz.
- Receiving antenna at distance to the base station antenna from 0 m up to (at least) 50 km.
- Base station antenna heights between 5 m and 60 m and antennas placed below as well as above rooftops.
-

The urban model consists of three wave propagation algorithms [94] :

- Half-screen model: calculates propagation above the rooftop and generates pathloss L_{above}.
- Recursive pico cell model: calculates propagation between buildings, i.e. along the street, and generates pathloss L_{below}.
- Building penetration model: calculates propagation from an outdoor base station antenna to an indoor UE and generates pathloss L_{inside}.

The urban model pathloss is expressed as:

$$L_{\text{urban}} = \text{m}in(L_{\text{above}}, L_{\text{below}}) \tag{3.4}$$

The building penetration model pathloss is determined by [94]:

$$L_{\text{inside}} = L_{outside} + L_w + d_s\alpha \tag{3.5}$$

in which L_{inside} is the pathloss from the base station antenna to a point just outside the external wall. L_w is the penetration loss through the external wall. d_s is the distance inside building [m]. α is the building penetration slope [dB/m].

After L is calculated, log-normally distributed shadowing factor ($\log F$) with standard deviation of 10 dB should be added [95].

$$P_{\text{Loss}-\text{Macro}} = L + \log F \tag{3.6}$$

3.4.1.2 Pico Cell Propagation Modell

ITU indoor propagation model is applied in pico sites placement algorithm.It is just used for rough estimation of the pathloss from the newly added pico site. After pico cell placement is done, the pathloss will be calculated.According to ITU indoor propagation model, the indoor propagation pathloss is [96]:

$$L_{\text{indoor}} = 20\log(f) + N\log(d) + P_f(\text{n}) - 28 \tag{3.7}$$

in which, f is the transmission frequency [MHz]. d is the transmission distance [m]. N is the distance power loss coefficient. $P_f(n)$ is the floor loss penetration factor. n is the number of floors via transmission.

Since only rough estimation is needed, the floor loss penetration factor $P_f(n)$ is ignored here. And the distance power loss coefficient N is chosen to be 28. Taking into account of the exterior wall loss $L_{wall} = 12$ since the pico sites will be placed outdoor, the total pathloss estimation can be expressed as:

$$L = L_{\text{indoor}} + L_{\text{wall}} = 20\log f + 28\log d - 16 \tag{3.8}$$

3.4.2 Signal Fading

In general, the fading term depicts the fluctuations in the envelope of a transmitted radio signal. In the wireless channel, large-scale fading is referred to as the slow varying envelop of signal over a long time duration while small scale fading characterizes the rapid fluctuation of the received signal strength over a very short time duration.

3.4.2.1 Shadow Fading

Large scale fading can be statistically represented in terms of path loss which is a function of distance and a log-normal distributed variation about the mean pathloss which is called shadow fading. Shadow fading is caused by shielding phenomenon from obstacles in the propagation path between the UE and the serving eNB. It arises due to irregularities of the geographical features of the territory [97]. The experimental result has shown that the autocorrelation function for the fluctuation of the shadow fading component is a reducing function over distance. The equations below are used to determine the shadow fading, φ, for UE_i at time t:

$$\varphi_i(t+1) = \psi_i(t) * \varphi_i(t) + \omega * \sqrt{1-\psi_i(t)^2} * G(t), \tag{3.9}$$

$$\psi(t) = \exp(\frac{-v(t)}{d_0}) \tag{3.10}$$

where $\psi_i(t)$ is the shadow fading autocorrelation function and G(t) is a Gaussian of UE_i at time t with zero mean.Moreover,$v_i(t)$ represent the speed of UE_i at time t and ω is the shadow fading standard deviation and d_0 is the shadow fading correlation distance.

3.4.2.2 Multipath Fading

The signal may arrive at receiver from multiple paths because of reflection and scattering of a radio signal. This effect is called multipath fading. The multipath fading gain in wireless channels with relatively small bandwidth can be characterized as the Rayleigh-fading channel. The Rayleigh fading is based on a statistical model and is considered as a reasonable model for signal propagation.It is representative of a case with a very large number of multipaths modeled as a time-dependent process [98] . In this thesis, the flat Rayleigh fading is approximated by a complex Gaussian random process [99]] as follows:

$$\mu - ap_i = \sum_{n=1}^{N} c_{i,n} \cos(2\mathit{\Pi} f_{i,n} t + \mathit{\Theta}_{i,n}) i = 1, 2, 3 \tag{3.11}$$

$$c_{i,n} = o_{k_0} \sqrt{\frac{2}{N_i}} \tag{3.12}$$

$$f_{i,n} = f_{max} \sin(\frac{\Pi}{2} k_n) \tag{3.13}$$

where $\mu - ap_i$ represents the approximated uncorrelated filtered white Gaussian noise with zero mean of process i at time t. Moreover,$c_{i,n}$ and $f_{i,n}$ are the Doppler coefficient and discrete Doppler frequency of process i of the n^{th} sinusoid, respectively.$\mathit{\Theta}_{i,n}$ is the Doppler phase of process i of the n^{th} sinusoid and N_i is the number of sinusoids of process i. In addition,$_n$ shows the uncorrelated filtered white Gaussian noise with zero mean of the n^{th} sinusoid o_{k_0} is the variance (mean power) and f_{max} is the maximum Doppler frequency.

3.4.3 Antenna Gain Model

Antenna pattern can be expressed as following:

$$A(\Theta) = -min(12(\frac{\Theta}{\Theta_{3dB}}), 20)[indB] \tag{3.14}$$

$$-180^o < 0 < 180^o \tag{3.15}$$

where $A(\Theta)$ is antenna gain, and Θ_{3dB} is the beamwidth, which is equal to 70^o.

3.4.4 Signal to Interference plus Noise Ratio (SINR)

The Signal to Interference plus Noise Ratio (SINR) is is a key parameter that can describe the performance of a resource block allocation technique. As a general rule, the received signal power level at a UE decreases as it moves away from the centre of the serving cell. Thus, the SINR level of received signal decreases as the distance from the cell centre increases. Furthermore, as a UE moves towards the cell edge from the centre of the cell, the strength of the interference signals from the adjacent cells rises. Since, ICI levels are stronger at the edge of the cell, the SINR values of the actual transmitted signal is further reduced as the distance from the cell centre increases.Similarly the received signal strength (RSS) can be computed using the formula:

$$P_{Rx}eNodeB = P_{Tx}eNodeB + GeNodeB + GUE - PL(R) \tag{3.16}$$

Where, $P_{Rx}eNodeB$ denotes the eNodeB transmit power in dB, GeNodeB denotes the eNodeB antenna gain in dBi, GUE denotes UE antenna gain in dBi. The UEs of pico-cell can be interfered by macro-cell only during non-ABS subframes .The SINR at any point in a cell can be calculated by taking the ratio of actual signal strength and the strength of interferences from neighboring cells and noise (thermal noise) at that point:

$$\mathrm{S}INR = \frac{P_{Rx}(eNodeB)}{\sum InterferersP_{Rx}(eNodeB) + P_{them}} \tag{3.17}$$

3.4.5 Link Performance Model

In LTE, the UE sends a Channel Quality Indicator (CQI) report to its serving eNB to help eNB select an appropriate Modulation and Coding Scheme (MCS). The CQI reports are obtained from the downlink received signal quality, typically based on measurement of downlink reference signal. In order to enable the UE to measure the channel quality on a PRB, the reference signals are transmitted in each PRB. In each PRB, four RE, out of the 84 REs, are deployed to transmit reference symbols (in case of single antenna transmission). In LTE, 15 different MCSs are defined by 15 CQI values. The CQIs use Quadrature Phase Shift Keying (QPSK), 16- Quadrature Amplitude Modulation (QAM), and 64- QAM modulations as shown in Table 3.1. Although a lower order modulation (e.g. QPSK) is more robust against noise and can tolerate higher levels of interference, it provides a lower transmission bit rate. A higher order modulation (e.g. 64 QAM) offers a higher bit rate. However, it is more susceptible to errors because it is more sensitive to interference, noise and channel estimation errors and hence this case can be suitable for the high SINR [9]. . Table 3.1 shows CQI index with corresponding parameters [100]. A set of Additive White Gaussian Noise (AWGN) link-level performance curves are deployed to

Table 3.1: SINR-CQI mapping table [**?**]

CQI	Modulation	Coding Rate	Spectral Efficiency (bps/Hz)	SINR (dB)
1	QPSK	0.0762	0.1523	-6.7
2	QPSK	0.1172	0.2344	-4.7
3	QPSK	0.1885	0.377	-2.3
4	QPSK	0.3008	0.6016	0.2
5	QPSK	0.4385	0.877	2.4
6	QPSK	0.5879	1.1758	4.3
7	16 QAM	0.3691	1.4766	5.9
8	16 QAM	0.4785	1.9141	8.1
9	16 QAM	0.6016	2.4063	10.3
10	64 QAM	0.4551	2.7305	11.7
11	64 QAM	0.5537	3.3223	14.1
12	64 QAM	0.6504	3.9023	16.3
13	64 QAM	0.7539	4.5234	18.7
14	64 QAM	0.8525	5.1152	21
15	64 QAM	0.9258	5.5547	22.7

assess the Block Error Rate (BLER) of the received Transport Blocks (TBs). Note that a TB refers to a group of RBs with a common MCS. Then to a SINR to-BLER mapping function is required to obtain an effective SINR value. It is achieved by mapping a set of sub-carrier-SINRs assigned to the TB to an AWGN-equivalent SINR [97]. BLER threshold approach is the simple method to select an appropriate CQI value by UE. The UE would report the CQI value corresponding to MSC that ensures $BLER\, 10-1$. Therefore, the CQI can be used to adapt MSC to the channel conditions and optimize the time/frequency selective scheduling [97].

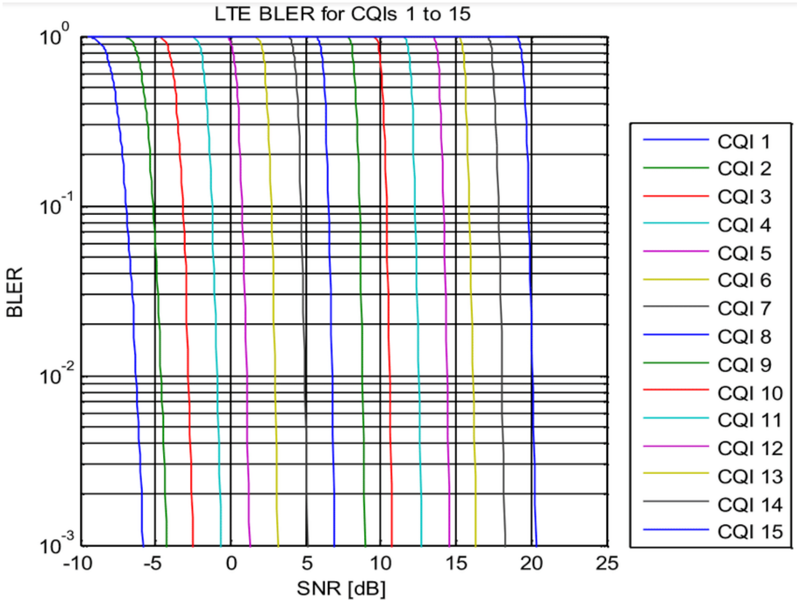


Figure 3.4: SNR–BLER curves for CQI from 1 to 15 [**?**]

3.4.6 Packet Scheduling

The aim of packet scheduling is to allocate PRBs to UEs such that the system throughput is maximized while the fairness is maintained. In the downlink, the decision about PRB allocation is performed every TTI through the eNB and then sent to the UE using the Physical Downlink Control Channel (PDCCH). A PRB is allocated to a UE for each TTI but a UE can be assigned several numbers of PRBs in each TTI. This thesis assumed that the buffer capacity of each UE at the eNB is infinite. The packet scheduler used in this thesis was round robin (RR) because RR is simple for using in a theoretical model to ensure that all UEs have the same chance to being scheduled. In this algorithm, all UEs are placed in a queue and if a UE has data for transmission, the PRB are allocated to it otherwise the next UE is served. This thesis used RR scheduling to minimize the effect of scheduling on system performance and then investigate the impact of interference management technique in more detail.

3.4.7 Traffic Models

The different types of traffic models as well as call arrivals have been used so that different types of results can be provided. Firstly, two different UEs call arrival modes have been considered: full buffer UEs and finite buffer UEs:

- Full buffer: these simulations consist of a certain number of N_{RUN} runs of T_{FULL} seconds each. In each run, a fixed amount of N_{UE} UEs is dropped per cell, with a total of N_{TOT} UEs in the simulated network. These UEs have a ”full buffer” (aka infinite buffer) in the eNB to download. Hence, these UEs last in the system from the beginning of the simulation until the run ends. Even though this case is not very realistic, it is useful to understand the main operation of the algorithms used and can be taken as starting point in the study. Since both the number of UEs and the time of each UE in the network are fixed, an easy analysis and interpretation of the results can be done.
- Finite Buffer: these simulations consist of only one run of T_{FIN} seconds. A number of N_{UE} UEs is dropped in the beginning of the simulation, and each UE has a f_{fnite} payload of B_{FIN} Mb for each call. Once the payload has been successfully delivered to the UE, the call is terminated. Moreover, Poisson call arrival is used for this type of UEs. In that case, new arrivals of UEs at each cell follow a Poisson distribution.

Furthermore, two different traffic models have been tested so as to evaluate the performance of the system: Best Effort (BE) traffic and Guaranteed Bit Rate (GBR) traffic:

- BE traffic: this type of traffic model uses as many resources as available, trying to obtain the highest throughput and complete its transmission as fast as possible. Hence, users having good radio conditions and suffering from low interference will achieve higher throughput and will be served faster than those with poor conditions. Both full and

  finite buffer UEs have been used as BE traffic.
- GBR traffic: for this traffic model users have a certain GBR requirement to be fulled. Therefore, higher priority should be given to achieve the minimum required throughput for all UEs rather than to exploit the channel conditions, even though it will also be an important factor for the scheduling decision. In this case, only full buffer UEs have been analysed.

3.4.7.1 Full Buffer UEs

Firstly, UEs with an infinite buffer to be downloaded are considered for the study. In this case, a fixed quantity of UEs remains in the system during the whole simulation time. Therefore, since the number of macro and RE UEs (i.e. those in the coverage extended area) within the macro-cell area is constant, the muting ratio (i.e. number of mandatory ABS) at the macro eNB is also constant. The settings of the chosen number of mandatory ABS, normal and optional subframes as well as the RE for both strategies.the best configuration that maximizes the 5^{th} percentile UE throughput through simulations. Furthermore, such a remarkable improvement in the UE throughput is appreciated when using eICIC techniques compared to the case without eICIC. When RE and eICIC techniques are not enabled, once the number of UEs in the network increases (under medium or high load conditions) and both macro and pico eNBs start to have higher probability of transmitting, more interference is also generated for other cells, resulting in an important decadence in the UE performance. Enabling RE and eICIC techniques, relevant gains in the overall performance are achieved, especially with high offered load in the system and,therefore, more interference has to be managed.

3.4.8 Performance Metrics

Since the ICI problem can restrict the 4G system performance in terms of throughput, the main purpose of ICI mitigation schemes is to improve throughput. Moreover, the implementation requirements for real environment should be taken into account. Here, the most common metrics which were used to evaluate the performance of ICI management techniques are described

- User throughput: the user throughput is defined as the amount of data sent successfully to a UE in the downlink divided by the simulation time. It is calculated as follows:
    - Find number of PRB allocated to each UE (N_{PRB}).
    - Obtain the efficiency rate based on the allocated MCS.
    - Calculate the number of REs for normal cyclic prefix :

$$N_{RE} = 12(subcarriers) \times 7(OFDMASymbols) \times N_{PRB} \times 2(slots) = 168N_{PRB} \quad (3.18)$$

    - Compute the Throughput :

$$Thr = N_{RE} \times E_{fficiencyrate} \quad (3.19)$$

- Cell edge throughput: it equals as the 5^{th} percentile point of the Cumulative Distribution Function (CDF) of the user throughput which indicates the minimum throughput achieved by 95% of UEs.
- Average macrocell throughput: it is defined as the throughput of macrocell without considering picocells.
- Average picocell throughput: it equals the sum of throughputs of picocells distributed in each macrocell.
- Average cell throughput: it is achieved by dividing the total bits correctly delivered over all the active sessions in the system to simulation time. For HetNet, cell throughput is defined as the cell throughput for one macrocell and equals the sum of one macrocell and related picocells.
- RE UE throughput: it equals the 5% of CDF of the user throughput of pico UEs.

- Average macro UE throughput: it equals the average user throughput of UEs connected to macro eNB.
- Average UE throughput: it represents the average user throughput of all UEs in the network.
- Percentage of the offloaded UEs: it indicates the ratio of UEs which are offloaded to picocells to total number of UEs
- Outage probability: it indicates the number of UEs with average SINR smaller than a SINR threshold . It means the rate supported by the random fading channel is less than the target value for the UEs to function appropriately

Sometimes, however, it can be appreciated how the algorithm self-adapts and uses a higher muting ratio, meaning that for those cases the percentage of RE RRH UEs is higher than the percentage of macro UEs in the macro-cell area. This way, an efficient manner to allocate resources and schedule RE pico UEs or macro/center pico UEs only when needed is possible, bringing a remarkable improvement as a consequence.

3.4.9 Pico Layer

LPNs deployment (pico cells) requires a new layer to embed them into the macro layer. The approach that has been used to deploy outdoor pico cells is illustrated in figure 3.15 , where one pico cell is modeled as a 2-dimensional rectangular block (100 x 100 meters) and placed randomly in each site sector with a minimum distance between macro cell and pico cell.Using this approach may allow to place two pico cells that belong to adjacent macro cells very close, to avoid that a minimum separation between pico cells

The antenna radiation pattern for LPNs is assumed to be omnidirectional & adaptive antenna with constant gain. The other remaining assumptions for pico layer are located in the table 3.2.

3.4.10 Model Assumptions

The model under study satisfies the following assumptions:

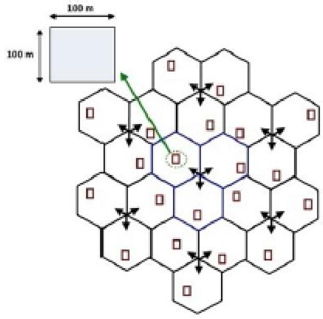


Figure 3.5: Outdoor Pico cells deployment within macro layout [34]

- All the UEs are statistically identical
- All UEs assumed to be LTE Release-10 compliant, which mean they individually report their CQI for ABS and regular sub-frames to their serving base station.
- The UEs distribution within the pico cell is uniform with a user density of α_p UE/unit area, different (larger) than the user density in the rest of the macro cell coverage area.
- Users are uniformly distributed within the macro coverage area with a user density of α_m UE/unit area.
- The macro cell and pico cell share the same frequency channel (frequency reuse factor is unity).
- The macro and pico have two different radio propagation models
- Packets are scheduled on the basis of Round Robin protocol. Round robin is a straightforward method to schedule users by assigning them the radio resources in turn, one after another.
- Packets are delivered on best effort basis.
- The simulation is performed at loading level near saturation for both macro-eNB and pico-eNB.
- Each active macro UE as well as pico UE is assumed to have an infinite buffer and that it is always loaded with data and can use any number of radio blocks allocated to it.
- The simulation is performed on a frame-by-frame basis.
- Traffic not sent during a frame will stay at the top of the queue for the next frame. Although, failure to be allocated any radio block

Table 3.2: Simulation Parameters

Parameter	Value
Network Layout	Macro cell size 1Km
	Pico cell size 40 meters
Transmit Power	Macro eNB 49 dBm
	Pico eNB 30 dBm
LTE Radio Frame	10 msec.
Sub-Frame Duration	1 msec.
Bandwidth	10MHz
Traffic model	”Full buffer,Infinite buffer, Video streaming”
Radio Blocks	1000 Radio blocks
TTI	1 msec.
Antenna Pattern	Omni and Adaptive
Antenna Gain	Macro eNB =NW input data
	Pico eNB Variable from 1 to 5 dBi
Path Loss	Macro eNB to UE 128.1+37.6log10(R[km])
	Pico eNB to UE 140.7+36.7log10(R[km])
Macro and pico antenna patterns	As mentioned in section 3.4.3
Thermal noise density	-174 dBm/Hz
Fast fading	ITU Rayleigh
eNB Packet Scheduling	Round Robin
CQI reporting	1 msec.
$CQI_{threshold}$	1 <= CQI <= 15
Number of UEs	200 in the whole network per radio frame
UE Distribution	Macro eNB 150 per radio frame uniformly distributed
	Pico eNB 100 per radio frame in hotspot

in the frame doesn’t increase the chance for the UE to be allocated radio blocks in subsequent frames.

- Macro and pico are synchronized in time, i.e., the radio frame of 10 msec. begins at the same time for both macro-eNB and pico-eNB.

3.4.11 Simulation assumptions

The network layout used in this study was described in the previous section. Table 3.2 shows a summary of the main network elements and contains an overview of the general simulation assumptions.

All the elements of the operator-specific scenario described throughout this chapter were imported into a system-level simulator. This simulator follows the LTE specifications, including detailed modeling of major functionalities such as packet scheduling, hybrid ARQ and link adaptation.The simulation methodology follows the 3GPP guidelines: every TTI, the packet scheduler entity decides how to distribute the available resources (i.e. PRBs) among the active users. For the selected set of PRBs, the link adaptation functionality decides an appropriate modulation and coding scheme for the transmission which is determined by the frequency-selective CQI measurement reported by the UE.

Chapter Four
Results and Discussion

This chapter discusses in details the simulation output, assumption and the used parameters which are defined in some depth in table 3.1. The used scenario Macro–Pico Deployment Scenario contains three macrocell site and one pico site.

4.1 Simulation to find Optimal ABS Ratio

The main principle consists of checking the load at the macro and pico layer at each optional ABS, and based on those measures decide whether the optional ABS shall be used as normal subframe or protected subframe.First, the ABS offered to picos not only depends on traffic load but also depends on the number of interferers. The load in the pico layer is defined as the percentage of users in the range extension area as compared to the total number of users in the cluster, and analogously in the macro layer with the percentage of macro users Notice that the load measure in the pico layer refers only to RE users, since those are the ones benefiting more from ABS resources. It has been verified through simulations that this option (not using center users) is giving the best performance results We expect the muting algorithm to use a small muting ratio most of the time: for low load, because both layers are empty most of the time, and for high load due to the higher amount of users in the macro layer. This expected behavior is plotted in Figure 4.1 where the muting ratio is plotted for different values of arrival rate λ. as the load increases, the number of users in both layers grows at a similar rate, and the average muting ratio slighty increases the ABS ratio for which Macro is muted is found out that maximizes the overall cell throughput. For high values of load the number of macro users significantly increases, and the algorithm will try to reduce the muting ratio as much as possible to serve the macro layer. the figure

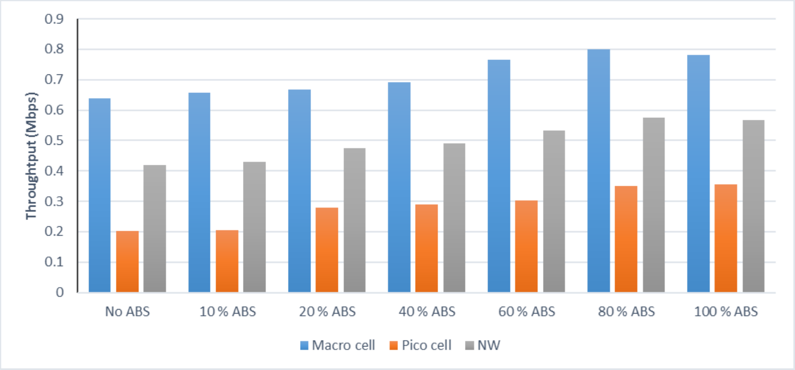


Figure 4.1: ABS muting Ratio

4.1 illustrated optimal ABS ration value based on optimizing a system utility function which is defined as a function of the all UEs ,a utility function using the throughput of macrocell, edge and centre throughput of picocells, number of picocell and macrocells, and the number of UEs. By derivative from the utility function, the required number of ABS is obtained.

4.2 Atoll with Monte Carlo Simulation and Analysis

Advanced LTE Monte Carlo simulator including RRM power control, interference control, inter-cell coordination, aggregation, and backhaul (S1) capacity constraints. Generation of prediction plots, based on simulation results or on cell load figures from the live network including:

- Cell and network coverage analysis
- Downlink and uplink interference analysis
- Downlink and uplink service areas
- Effective service areas
- Downlink and uplink throughputs
- Downlink and uplink quality indicator analyses
- PCI, PSS ID, SSS ID, and PRACH RSI collisions.

Atoll uses Monte Carlo simulations to generate realistic network scenarios (snapshots) using a Monte Carlo statistical engine for scheduling and resource allocation. Realistic user distributions can be generated using different types of traffic maps or subscriber data.Atoll calculates the cumulated peak RLC, effective RLC, and application cell throughputs during Monte Carlo simulations.

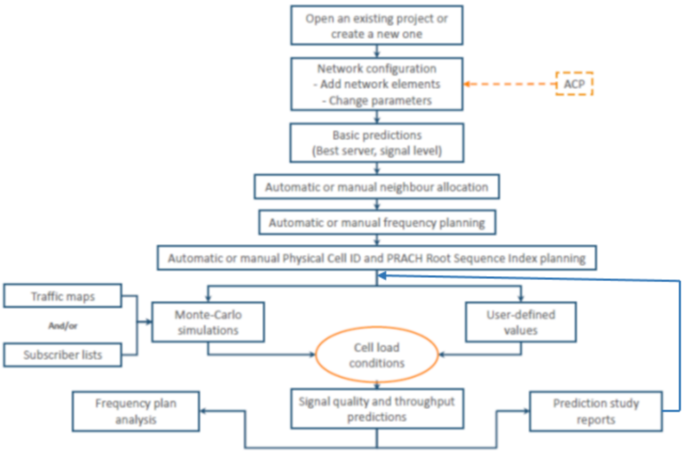


Figure 4.2: LTE Planning Workflow in Atoll

4.3 System layout

The investigated area consists of four sites three macro sites and one pico sites as shown below , pico eNBs within an existing macro cell network provides coverage improvements by offloading users from the macro to the pico eNB, taking advantage of the RE. This, however, added to the difference in the transmission power of the macro and the pico eNBs, will bring some inter-cell interference problems for users on the whole extended area of the pico eNB. These problems have to be solved in order to not suffer degradation in the overall system performance. In this first approach, interference is managed through the eICIC techniques.

4.3.1 Co-channel Interference

The pico co-channel interference probability is described in figure 4.4 and noticed high improvement after activation eICIC .Enhanced Inter-

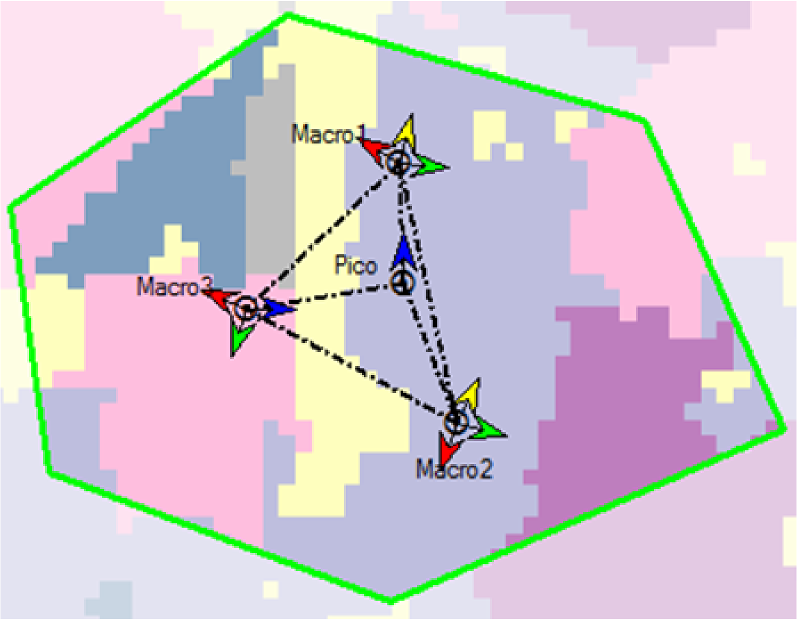


Figure 4.3: Network Layout for Macro-Pico layer

Cell Interference Coordination (eICIC) is introduced to mitigate interference and improve the system as well as the cell-edge throughput. Almost Blank Subframe (ABS) is an important time-domain techniques in the eICIC proposal. Macro BS reduces its transmission power on certain subframes to relief the interference to the CRE UEs. The macro BS can either stop data transmission or simply reduce the transmission power in ABS. These two options are referred to as zero-ABS and Low Power ABS (LP-ABS), respectively.

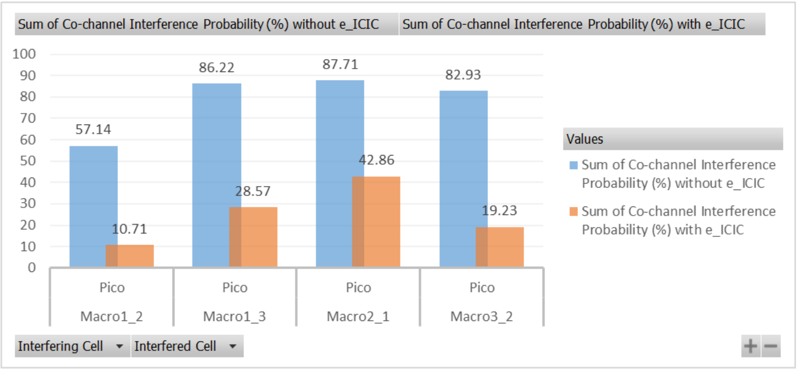


Figure 4.4: pico Co-channel Interference

4.4 Pico-eNB with Smart Antenna

In adaptive beamforming the antenna pattern is adapted in order to provide optimal reception for the scheduled user. This optimisation can be done according to different criteria. The adaptation is based on channel knowledge, typically long term CSI in the form of a spatial transmit covariance matrix. In the following we will briefly describe how adaptive beamforming can be achieved. In this thesis additional to used eICIC is having pico-eNB with adaptive array antenna installed . The adaptive antenna will provide a higher antenna gain in the direction of the macro site such that this will improve the SINR values of the victim UEs closer to the macro site and allow them to be scheduled on the regular sub-frames as well. The delay associated with waiting for an ABS to be served for the pico cell edge UEs will be significantly reduced, as the UEs with better SINR and CQI are eligible to be served on a non-ABS sub-frame. The overall network performance improves.

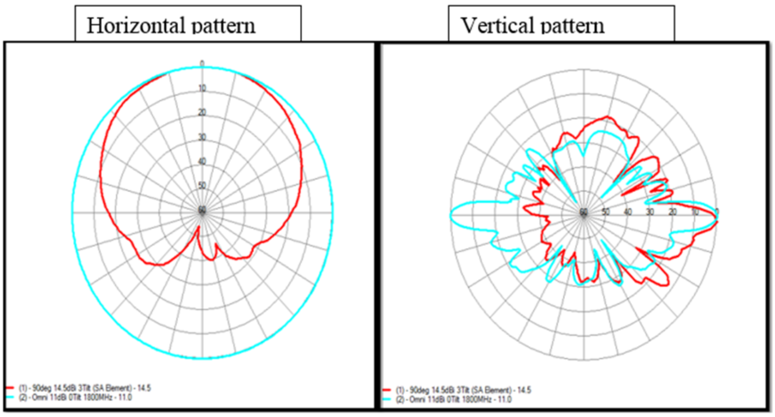


Figure 4.5: Omni Vs Smart antenna gain pattern

The figure 4.5 describes omni radiation pattern compared with smart antenna radiation pattern we noticed omni antenna has circular coverage but in other side smart antenna has more directive pattern This means that more gain will be placed at directions where the interference is coming from and less gain in directions where there is little interference. and this will improve SINR and CQI for pico cell edge UE.

4.5 load balance

The main objective of heterogeneous networks is to increase capacity. They offer solutions for efficient use of spectrum, load balancing and improvement of cell edge coverage amongst others.cell association scheme for heterogeneous network aiming to maximize the network capacity figure 4.6 explains simulation results show that the load balance between macro and pico BS is achieved and network capacity is improved significantly after used eICIC scheme.

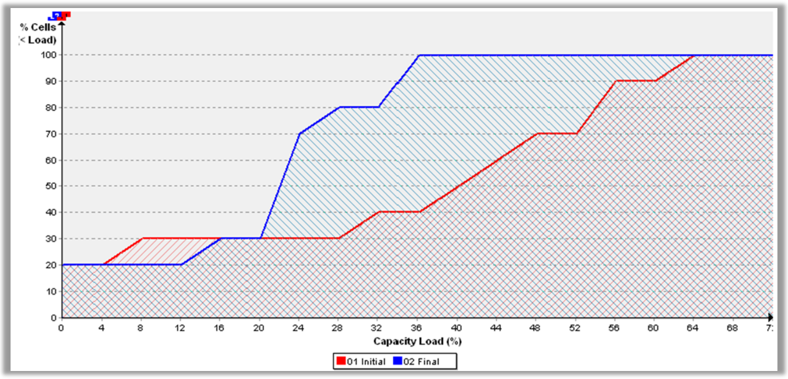


Figure 4.6: Network load balance

4.6 System Level Performance Evaluation for eICIC Scheme

Figure 4.7 shows situation of RSRQ (reference signal received quality) distribution , there is noticeable improvement of quality after using eICIC scheme mainly in pico severing area.Reference Signal Received Quality (RSRQ) measurement is a cell-specific signal quality metric. this metric is used mainly to provide ranking among different candidate cells in accordance with their signal quality,RSRQ considers the combined effect of signal strength and interference. In addition to this, if SNR is higher, channel quality is better i.e. RSRQ will be better , lesser interference which in turn leads to better received signal quality.

Figure 4.8 demonstrates Comparison of Coverage prediction by PDSCH C/(I+N) Level in downlink there is a noteworthy gain in overall network.C/(I+N) in the downlink is calculated for different channels using

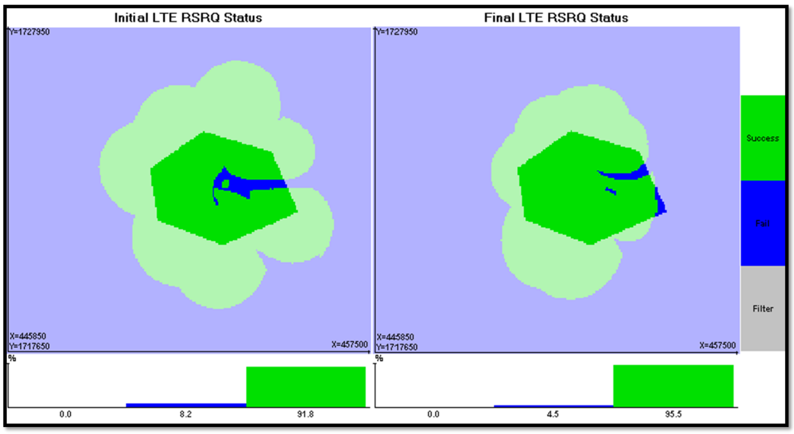
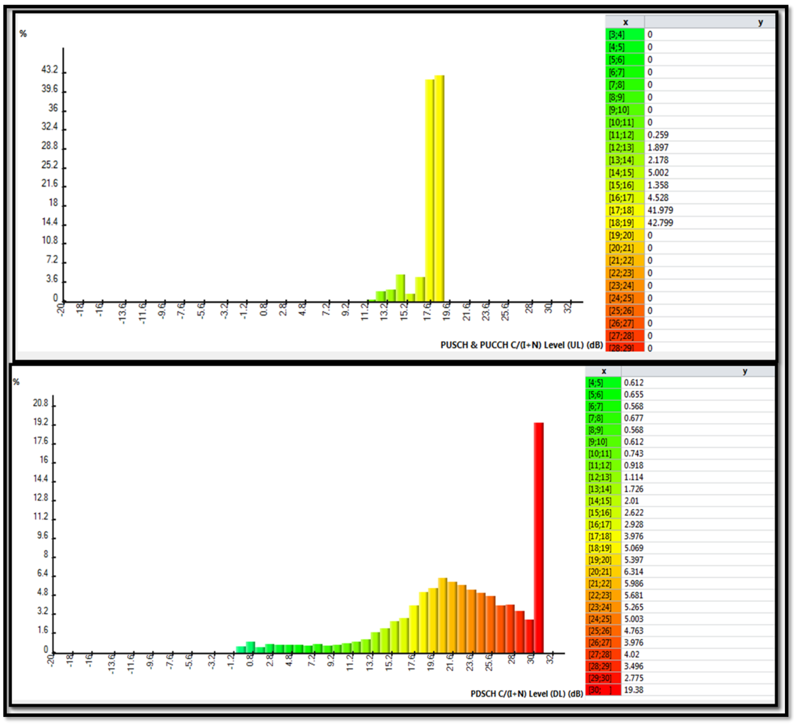


Figure 4.7: Received RSRQ distribution without eICIC & with eICIC

their respective transmission powers and by calculating the interference received by the resource elements corresponding to these channels from interfering cells.

Figure 4.9 demonstrates The overall cell downlink throughput levels determined by Monte Carlo simulation for both macro and pico throughput combined , throughput has been improved by %15 which is a large gain increment comparable with the accumulated throughput before the deployment the eICIC which lead to pico users on the high interference side can have a fair chance to be scheduled on a regular sub-frame with their SINR values made equal or greater than the threshold SINR that can support the lowest modulation and coding scheme in LTE.

Figure 4.10 explains the pico cell throughput for eICIC and adaptive array antenna. the adaptive antenna is where digital beam forming techniques are used to adjust the gain using N degrees of freedom, where N is the number of antenna elements. The beam forming strategy would be a long-term gain adjustment to fit the Pico cell into the specific environment. Initially, the adaptive beam would be an Omni-directional pattern but as interference is sensed from different directions, the antenna elements adjust to increase the gain in high interference direction and lower the gain in low interference directions to equalize the SINR around the Pico cell center. This improved the SINR values of the victim UEs closer to the Macro site and allow them to be scheduled on the regular sub-frames as well.The delay associated with waiting for an ABS to be served for the Pico cell edge UEs will be significantly re-



x	y
[3;4]	0
[4;5]	0
[5;6]	0
[6;7]	0
[7;8]	0
[8;9]	0
[9;10]	0
[10;11]	0
[11;12]	0.259
[12;13]	1.897
[13;14]	2.178
[14;15]	5.002
[15;16]	1.358
[16;17]	4.528
[17;18]	41.979
[18;19]	42.799
[19;20]	0
[20;21]	0
[21;22]	0
[22;23]	0
[23;24]	0
[24;25]	0
[25;26]	0
[26;27]	0
[27;28]	0
[28;29]	0

x	y
[4;5]	0.612
[5;6]	0.655
[6;7]	0.568
[7;8]	0.677
[8;9]	0.568
[9;10]	0.612
[10;11]	0.743
[11;12]	0.918
[12;13]	1.114
[13;14]	1.726
[14;15]	2.01
[15;16]	2.622
[16;17]	2.928
[17;18]	3.976
[18;19]	5.069
[19;20]	5.397
[20;21]	6.314
[21;22]	5.986
[22;23]	5.681
[23;24]	5.265
[24;25]	5.003
[25;26]	4.763
[26;27]	3.976
[27;28]	4.02
[28;29]	3.496
[29;30]	2.775
[30;]	19.38

Figure 4.8: Comparison of PDSCH C/(I+N) Level (DL) without/with eICIC

duced, as the UEs with better SINR and CQI are eligible to be served on a non-ABS sub-frame.

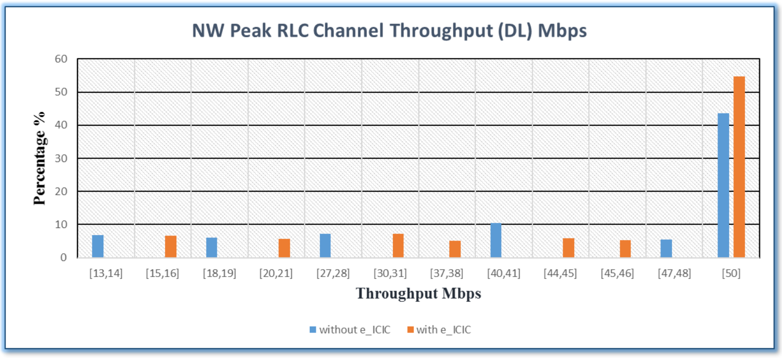


Figure 4.9: Network throughput levels without/with eICIC

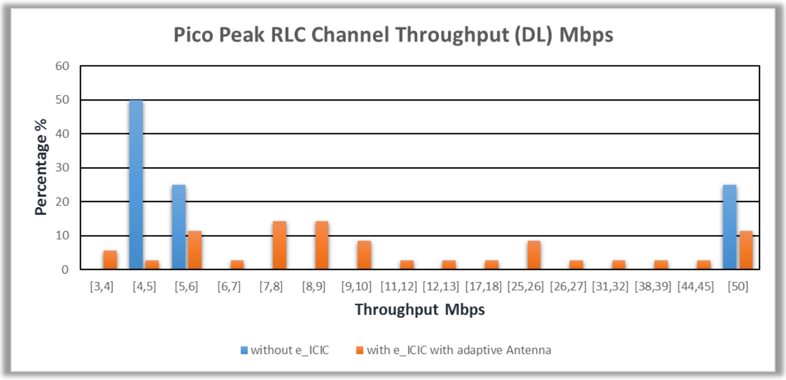


Figure 4.10: Pico throughput with adaptive array antenna

Chapter Five
Conclusions and Recommendations

5.1 Conclusions

In spite of the significant benefits of deploying LTE-Advanced HetNets to increase the network capacity or to extend the coverage in a cost-effective way, Inter-cell interference is one of the largest challenges in such networks when utilising co channel deployment. Concretely, co-channel inter-cell interference from the macro eNB to the users connected to the small cell has been addressed in this thesis through the use of eICIC techniques.also work a study about htereogeneous networks has been presented with a special focus on the optimization of the Almost Blank Subframes (ABS) allocation ratio in heterogeneous LTE-Advanced networks . The optimization criterion was improve the cell edge users throughput while keeping a moderate level of normal user throughput , studied intercell interference challenges in LTE and LTE-A systems and a number of contributions were provided to improve downlink system performance by mitigating the intercell interference in macrocell-picocell scenarios. an extensive survey on inter-cell interference management in LTE-Advanced HetNets has been performed. The survey has covered all possible techniques of ICIC in LTE-Advanced HetNets. It has clearly identified the benefits as well as drawbacks of each the techniques with all possible modifications picocell is one of the important low power nodes in HetNet that can be used to enhance the overall system capacity and coverage. However, the transmission power difference between macro eNB and pico eNB results in new challenges in cell selection technique and intercell interference management. In addition to ABS mechanism, the CRE method would make the PeNBs or other small cells to extend their coverage area so that the UEs which are closer to the small - cells would get a better received signal strength while also helping to offload the macro - cell traffic. The CQI feedback that is experienced by each UE for each cell is used in selecting the best cell to which it is best to connect to. New dynamic ABS scheme was suggested to mitigate interference without reducing the throughput of macro UEs when the radio resources were shared between macrocell and picocell. after proposed dynamic ABS value scheme for further improvements of the system performance as described in Chapter 4. In this scheme, each macrocell could simultaneously change the ABS and CRE offset values of all picocells under its control to reach the expected system performance. The proposed eICIC scheme was simulated for different membership functions and picocell densities. The simulation result showed the average throughput of the MeNBs with one PeNB. We can see that the throughput is better when the simulation is run with ABS mechanism applied. this study focuses specifically on the computation of the suitable Almost Blank Sub-frames (ABS) allocation ratio and dynamic distributed configurations of ABS based on the network traffic in LTE-Advanced heterogeneous networks. It is concluded that the ABS pattern is dependent on both the number of macro users and pico users in the network. Thus, the objective of this thesis of achieving pico cell edge user throughput performance improvement is achieved successfully.

5.2 Recommendations

Despite the significant work done in interference coordination for various types of wireless network deployments, there are a number of limitations that have been identified and need to be considered before the above techniques become implementable for real-life mobile networks and By growing the demand for 4G technology, new features are added to LTE/LTE-A systems to enhance the system performance. However, new challenges could arise by adding new features and hence, new research areas will be open which can be taken into account by researchers. Based on the study of inter cell interference challenges in mobile cellular networks, a number of important issues have been identified for future research work. CRS interference cancellation is an important challenge in the use of Almost Blank Subframes as CRS is considered to be a big source of interference in a HetNet scenario. Some solutions are being studied to combat CRS interference such as successive interference cancellation or the puncturing of CRS resource elements, these solutions are still being tested and will be included in the Further Enhanced Inter-Cell Interference Coordination (FEICIC) in LTE release 11.

In HetNet, different types of nodes with different transmission power are deployed and when the number of low power nodes increases, the manual operations may be costly. Therefore, one optimal solution for the radio resource allocation (in same or different bands) can be the autonomous interference management technique which does not need synchronization. Moreover, the amount of information which is exchanged will be minimized by autonomous technique.

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Appendix A

A.1 LTE Air Interface Procedures

The overall LTE air interface procedures are illustrated in Figure A.1 and discussed in the following sections.

A.1.1 Frequency Scan and Cell Identification

When the LTE device powers on, it needs to perform an LTE attach procedure to connect to the EPC. The EPS attach procedure takes place after the UE accesses a suitable cell from the surrounding LTE eNBs deployed in a network. In order for the UE to identify the cell and synchronize with the radio frame timing, the eNB sends synchronization signals (SCH) over the center 72 sub-carriers. The SCH is comprised of the PSS (primary synchronization signal) and the SSS (secondary synchronization signal). Together they enable the UE to identify the physical cell identity (PCI) and then synchronize any further transmissions. There are 504 unique PCIs, divided into 168 cell identity groups, each containing three cell identities (sectors). Once a PCI is identified and both slot and frame synchronization is done through the PSS and

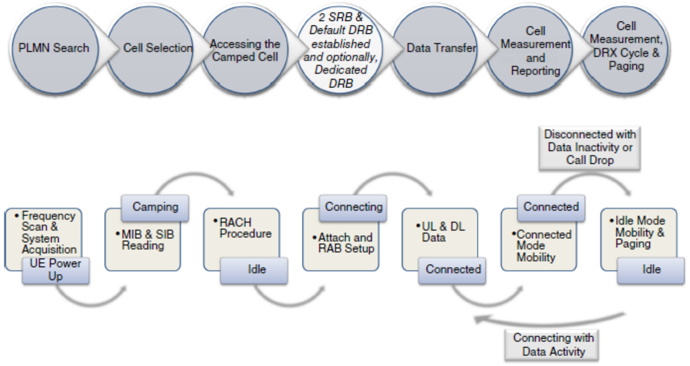


Figure A.1: LTE air interface procedures overview

SSS, the UE acquires the strongest cell measured during this cell search stage, known as the acquisition Stage.

A.1.2 Reception of Master and System Information Blocks (MIB and SIB)

The downlink in LTE is based on scalable OFDMA with channels ranging from 1.4 to 20 MHz.Initially the UE is unaware of the downlink configuration of the cell. To retrieve the cell configuration,the UE needs to monitor the PBCH PHY channel right after cell acquisition. The PBCH carries the MIB. The MIB repeats every 40 ms and uses a 40ms TTI. It carries system configuration parameters:

- The downlink bandwidth – 6, 15, 25, 50, 75, or 100 resource blocks.
- The PHICH configuration parameter and cyclic prefix information
- The SFN (system frame number) is used by the UE to know the subframe number for synchronization of all PHY channels transmitted.

Additional SIB messages which carry the system parameters the UE uses in idle mode need to be decoded. SIBs are carried in system information (SI) messages which are then transmitted on the DL-SCH based on various system parameters. Other than SIB1, the UE uses the SI-RNTI to decode the SIBs carried on the PDSCH. SIB1 on the other hand, is broadcast with 80 ms periodicity. Scheduling of all other SIBs is specified in SIB1, except for SIB2 which is always contained in the first SI.

A.1.3 Random Access Procedures (RACH)

At the end of a successful cell selection, the UE performs a random access (RACH) procedure on the PRACH/RACH. This is used to access the cell and establish the RRC connection where the SRBs are assigned to the UE. In LTE, the RACH procedure can also be performed in different parts of the call, during handover, or after unsuccessful uplink grant request by the UE. This is different than UMTS. Therefore, LTE defines two different RACH procedures: contention-based RACH, or contention-free RACH. In LTE, the RACH procedure can also be performed in different parts of the call, during handover, or after unsuccessful uplink grant request by the UE.

A.1.4 Attach and Registration

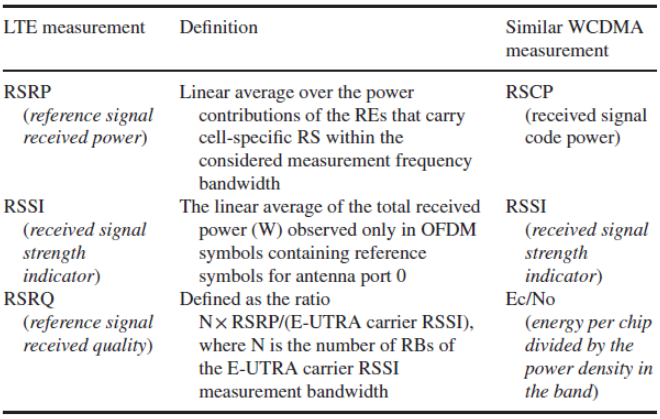
Once theUE completes the RACH procedure, it begins to establish the RRC connection, SRBs, followed by DRBs, with the EPS. This stage is part of the UE's attach and registration with the EPS. Upon a successful attach procedure in the NAS and RRC layer, the UE gains access to the user plane where the IP packets can flow on uplink or downlink. Devices with voice-centric or data-centric capabilities typically attach with EPS differently.The data-centric device attaches to EPS services only whilst the voice-centric UE is required to attach to the EPS as well as the non-EPS (i.e., the legacy 3GPP core) for circuit-switch fallback voice calls (CSFB).

A.1.5 Downlink and Uplink Data Transfer

Both the user and control planes downlink and uplink packets can flow on the entire E-UTRAN protocol stack after the attach procedure is completed.LTE requires a power control procedure. It manages the eNB interference levels in the serving and, possibly, across neighboring cells. Uplink power control determines the average power over an SC-FDMA symbol in which the PHY channel is transmitted. All uplink channels can be power controlled: PUSCH, PUCCH, PRACH, and SRS (sounding reference signal). The power calculations for these channels are performed by the UE, based on configured parameters from the eNB in RRC messages.

A.1.6 Connected Mode Mobility

When theUE is in amobility state around the different eNBs in the network, handover becomes handy in ensuring call continuity. For the handover to be performed, the UE needs to measure the downlink signal level and report the values back to the eNB. The eNB then sends the handover commands on the RRC layer to change the LTE serving cell. The mobility procedures are normally controlled by downlink level measurements.The measurements listed in the table are derived from the DL-RS. The reference signals are spread over the entire bandwidth with REs' assignments depending on the number of antennas configured.



LTE measurement	Definition	Similar WCDMA measurement
RSRP (*reference signal received power*)	Linear average over the power contributions of the REs that carry cell-specific RS within the considered measurement frequency bandwidth	RSCP (received signal code power)
RSSI (*received signal strength indicator*)	The linear average of the total received power (W) observed only in OFDM symbols containing reference symbols for antenna port 0	RSSI (*received signal strength indicator*)
RSRQ (*reference signal received quality*)	Defined as the ratio N × RSRP/(E-UTRA carrier RSSI), where N is the number of RBs of the E-UTRA carrier RSSI measurement bandwidth	Ec/No (*energy per chip divided by the power density in the band*)

Figure A.2: UE measurements

A.1.7 Handover

The eNBexecutes the handover based on theUEmeasurements. The eNB's RRC layer requests the UE to measure either intra-frequency cells, inter-Frequency cells, or IRAT cells belonging to other 3GPP or non-3GPP systems.The reporting by the UE is controlled by the eNB through periodic or event-based measurements.

A.1.8 Idle Mode Mobility and Paging

When the eNB releases the RRC connection for the UE, it transitions from connected mode into idle mode. The idle mode is used when there is no uplink or downlink activity for the UE. This state provides the UE with a battery saving option where it is only required to perform measurements or monitor the paging message.

matlab code

```
%%%%%%%%%%%% RF Miniproject %%%%%%%%%%%%%
clc;
clear all;
close all;


%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Defining Parameter ...
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% given data ...
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
P=1;           % set of Picos
M=1;           % set of macros
U=100;          % numberer of user equipment
ru_macro = randi([(80) (100)],1,U); % macro user ...
    datarate 100KBPS
r_pu_ABS= randi([(300) (500)],1,U);  % Pico user ...
    datarate in ABS Period 500KBPS
r_pu_NABS= randi([(100) (200)],1,U);  % macro user ...
    datarate in NABS Period 40KBPS

% ru_macro=[0 0 20 300 400 0 0 200 0 40];
% r_pu_ABS=[10 100 0 0 0 0 0 0 0 800];
% r_pu_NABS=[0 0 0 0 0 100 70 0 30 10];

Ip=1;                  % Set of the interfrering macro ...
    with pico
Nsf=40;                % Total No. of subframe
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% To compute ...
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% number of ABS Subframes Ap that each pico p can use
% number of NABS Subframes Nm left for macro usage
```

```
% Binary decision on wheather UE u associated with its ...
    candidate pico or macro
% Throughput Ru of each User equipment

%% Initializing the variable %%

gamma=0.1;                          %step size
t=20;                               % No of iteration
% Wu=rand(1,U);                        % weight for UE
Wu=randi([1 100],1,U);
prio=Wu;
% Wu=[0.10 0.2 0.4 0.005 0 0.09 0 0 0 0.10];


%initial value of the Otimization (Primal variable)
x{1}=rand(1,U);         %air time for micro
y_a{1}=rand(1,U);       %air time for pico in ABS
y_na{1}=rand(1,U);      %air time for pico in NABS
Ap{1}=rand(1,P);                    %Number of Subframes ...
    associate(used by) with pico
Nm{1}=rand(1,M);                   %Number of Subframes ...
    associate(used by) with Macro

Ru{1}=ru_macro.*x{1}+y_a{1}.*r_pu_ABS+y_na{1}.*r_pu_NABS;
%initial value of the lagrangian multiplier(Dual Variable)
lemda{1}=rand(1,U);     %lagrangian multiplier
mu{1}=rand(P,M);        %lagrangian multiplier
beta_m{1}=rand(1,M);    %lagrangian multiplier
beta_p{1}=rand(1,P);    %lagrangian multiplier
alfa_p{1}=rand(1,P);    %lagrangian multiplier

B=100*10^6;              %bandwidth in HZ

%%
Prx=rand(1,U);                              %Recieved ...
    average power
Ppico=randi([2 4],1,P);                     %Pico UE ...
    recieved power in interference with pico
Pmacro=randi([4 10],1,M);                   %Macro UE ...
    recieved power in interference with pico
no=2;                                       %noise
%% Data rate for UE

```

```


%% Greedy Primal update %%%%%%%%%%

 for i=1:t
    %% Dual update of variable %%%%%%%%%%

         lemda{i+1}=(lemda{i}+gamma.*(Ru{i}-(ru_macro.*x{i})-(r_pu_

         beta_m{i+1}=(beta_m{i}+gamma*sum(x{i}-Nm{i}));

    for j=1:P
         mu{i+1}(j,1)=(mu{i}(j,1)+ ...
             gamma*(Ap{i}(1,j)+Nm{i}-Nsf));
    end
    for j=1:P
         beta_p{i+1}=(beta_p{i}+gamma*sum(y_a{i})- ...
             Ap{i}(1,j));
    end
         alfa_p{i+1}=(alfa_p{i}+gamma*(sum(y_a{i}+y_na{i})-Nsf));




    %% 1) user primal update

    Ru{i+1}= Wu./lemda{i+1};

    %% 2) Macro Primal update

    if ((beta_m{i+1}-sum(mu{i+1}))>0)
         Nm{i+1}=Nsf;
    else
         Nm{i+1}=0;
    end

    ttp=((lemda{i+1}.*ru_macro)-beta_m{i+1});
    um=max(ttp);
    for j=1:U
         if (um==ttp(j))
              x{i+1}(j)= Nsf;
         else
```

```
            x{i+1}(j)=0;
        end
    end

    %% 3) Pico Primal update

    for j=1:P
        if (beta_p{i+1}(1,j) - mu{i+1}(j,1)>0)
            Ap{i+1}(j)=Nsf;
        else
            Ap{i+1}(j)=0;
        end
    end
    %%%%%%%%%%%%%%%%%%%%%%%% for ABS
    for j=1:P
        ttp1{j}= (lemda{i+1}.*r_pu_ABS)- ...
           beta_p{i+1}(j)-alfa_p{i+1}(j);
        up_a{j}=max(ttp1{j});
    end

    y_a{i+1}=zeros(1,U);

    for j=1:P
        for k=1:U
            if up_a{j}==ttp1{j}(k)
                y_a{i+1}(k)= Nsf;
            end
        end
    end


    %%%%%%%%%%%%%%%%%%%%%%%% for NABS

    for j=1:P
        ttp2{j}= (lemda{i+1}.*r_pu_NABS)-alfa_p{i+1}(j);
        up_na{j}=max(ttp2{j});
    end

    y_na{i+1}=zeros(1,U);

    for j=1:P
        for k=1:U
            if up_na{j}==ttp2{j}(k)
```

```
                y_na{i+1}(k)= Nsf;
            end
        end
    end



end

xsum=zeros(1,U);
y_asum=zeros(1,U);
y_nasum=zeros(1,U);
Apsum=zeros(1,P);
Nmsum=zeros(1,M);

for i=1:t
    xsum=xsum+x{i};
    y_asum=y_asum+y_a{t};
    y_nasum=y_nasum+y_na{t};
    Apsum=Apsum+Ap{t};
    Nmsum=Nmsum+Nm{t};
end

x_T=xsum/t;              %final Airtime For macro
y_a_T=y_asum/t         %final Airtime For pico in abs period
y_na_T=y_nasum/t       %final Airtime for pico in nonabs ...
    period
Ap_T=Apsum/t           %Final Number of abs subframes ...
    used by pico
Nm_T=Nmsum/t           %Final number of Nonabs subframes ...
    used by macro 1

FinalRu=(ru_macro.*x_T)+(y_a_T.*r_pu_ABS)+(y_na_T.*r_pu_NABS);
utility=0;
for j=1:U
    utility=utility+ Wu(j)*log(FinalRu(j));
end

Ru_macro=ru_macro.*x_T; %%throughput of macro user ...
    equipment
Ru_pico=(y_a_T.*r_pu_ABS)+(y_na_T.*r_pu_NABS);%%throughput ...
    of Pico user equipment

```

```
userm=0;
userp=0;
tm=0;
tp=0;
%b=bar(prio,'face color','flat');
%set(gca, 'xticklabel',{'macro','pico'})
for j=1:U

    if Ru_macro(j)>Ru_pico(j)
        tm=tm+1;
        userm=userm+1;
        usermacro(tm)=j;
        fprintf('Priority of user %d equipment is %d ...
           \n',j,prio(j));
        fprintf('Macro user %d equipment datarate in ...
           KBPS :',j)
        disp(Ru_macro(j));
    else
        tp=tp+1;
        userp=userp+1;
        userpico(tp)=j;
        fprintf('Priority of user %d equipment is %d ...
           \n',j,prio(j));
        fprintf('Pico user %d equipment datarate in ...
           KBPS :',j)
        disp(Ru_pico(j));
    end
end
THP=xlsread('test.xlsx','sheet1','A1:I5');
[¬, ¬, everything]=xlsread('test.xlsx');

cell1=findgroups(everything.cell);
 [cell1,cellnames]=findgroups(everything.cell);
userm;
usermacro;

userp;
userpico;
```