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ENERGY EFFICIENCY VIA HETEROGENEOUS NETWORK

Master's Thesis for the degree of Master of Science in Technology, submitted for inspection,
Vaasa, 2 December ,2015.

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Acknowledgement

Firstly, my deepest gratitude goes to the God almighty for his goodness and mercies showered on me during the course of pursuing my master programme.

I would like to use this medium to express my sincere gratitude to my supervisor Prof. Mohammed Elmusrati, for his patience, insight, and guidance toward making this thesis a reality. My sincere appreciation goes to all members of the faculty of communication and system engineering of the University of Vaasa, most especially: Tobias Glocker, Timo Mantere, Caner Cuhae, and Duan Ruifeng of Aalto University. Their courses were valuable in laying a proper foundation for the completion of this thesis work.

Special thanks to the government of Finland for their commitment and continuous funding channeled towards providing quality education in Finland. I would also want to thank the international office of the University of Vaasa, all staff of Technobonia and all staff of Tritonia library, for creating an enabling environment for learning and carrying out research work.

Finally, I would like to thank my parents for the love, support, and prayers throughout the duration of my studies. I am heavily indebted to Mr. and Mrs. Emmanuel Oyakhilome, for all the financial assistance during the course of studies. I would like to acknowledge the support of my brothers David, Moses and little Jurrien. I would like to extend my appreciation to Bukola Fatile, Adeyina Omowunmi, and my colleagues Adesina Damilola and Ezeobi Chinonso for their unending support and keeping company during the course of studies.

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List of Abbreviations

3GPP	Third Generation Partnership Project
ABS	Almost Blank Subframe
AEE	Area Energy Efficiency
ATIS	Alliance for Telecommunications Industry Solutions
CA	Carrier Aggregation
CapEX	Capital Expenditure
CC	Components Carrier
CDF	Cumulative Density Function
COMP	Coordinated Multipoint
CRE	Cell Range Expansion
CRS	Common Reference Channel
CSG	Closed Subscriber Group
dB	Decibel
DeNB	Donor eNodeB
DL	Down Link
EARTH	Energy Aware Radio and neTwork tecHnologies
ECR	Energy Consumption Rate
EE	Energy Efficiency
eICIC	enhance Inter-cell Interference Coordination
eNodeB	Evolved Node B
EPC	Evolved Packet Core

ESTI	European Telecommunications Standard Institute
EU FP7	European Union Seventh Framework Programme
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
GaN-HEMT	Gallium nitride High Electron Mobility Transistor
GREEN	Globally Resource-optimized and Energy Efficient Network
GSM	Global System for Mobile Communications
HAT	High Accuracy Tracking
HetNets	Heterogeneous Networks
HO	Hand Over
ICIC	Inter-cell Interference Coordination
ICT	Information Communication and Technology
IE	Information Element
L1	Load Information
LPN	Low Power Node
LTE	Long Term Evolution
LTE-A	Long Term Evolution -Advanced
MBSFN	Multimedia Broadcast Multicast Service over Single Frequency Network
MIMO	Multiple Inputs Multiple Outputs
MME	Mobile Mobility Entity
NIPP	Network Interface, Power and Protection
OFDM	Orthogonal Frequency Division Modulation
OFDMA	Orthogonal Frequency Division Multiple Access

Opera-Net	Optimising Power Efficiency in mobile Radio Networks
OPEX	Operation Expenditure
OSG	Open Subscriber Group
PA	Power Amplifier
PDCCH	Physical Downlink Control Channel
PDN-GW	Packet Data Network Gateway
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RB	Resource Block
RN	Relay Nodes
RRH	Remote Radio Head
RRM	Radio Resource Management
RS	Resource Status
RSRP	Reference Signal Receive Power
S-GW	Serving Gateway
SC-FDMA	Single Carrier Frequency Division Multiple Access
SE	Spectral Efficiency
SIMO	Single Input Multiple Output
SINR	Signal-to-Noise plus Interference Ratio
TEER	Telecommunication Energy Efficient Ratio

TCO	Total Cost Ownership
UE	User Equipment
UL	Uplink
UTMS	Universal Mobile Telecommunication System
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access

List of Symbols

β_m	Indication function
Δe	Change in energy
Δt	Change in time
η_{SE}	Spectral Efficiency
$\eta_{EE}^{(r)}$	Energy Efficiency
θ	Tilt of the Elevation antenna response
θ_{etit}	Electrical angle Tilt
σ_i^2	Thermal Noise
∂	Impact of power amplifier, feeder loss
τ	ABS ratio
φ	Azimuth angle
φ_{3dB}	Half Power Beamwidth of the azimuth antenna
$A(\varphi, \theta)$	3 dimension antenna field pattern
$A_H(\varphi)$	Horizontal antenna pattern
$A_V(\theta)$	Vertical antenna pattern
A_m	Side lobe level suppression of combined antenna
A_{mh}	Side lobe level suppression of azimuth antenna
A_{mv}	Side lobe level suppression of elevation antenna

A_{EE}	Area Energy Efficiency
C	Channel capacity
$E\{R_i^{macro}\}$	Expected data rate of Macrocell
$E\{R_i^{pico}\}$	Expected data rate of Picocell
$E_{e,macro}$	Energy Efficiency of Macrocell
$E_{e,pico_i,n}$	Energy Efficiency of Picocell
$E_{e,cell}$	Overall Energy Efficiency
$h_{m,i}(n)$	Channel coefficient of Macro/cell
$h_{p,i}(n)$	Channel coefficient of Picocell at the subframe n
I	Interference
$I_i^{macro}(n)$	Interference of Macrocell
$I_i^{pico}(n)$	Interference of Picocell
j^*	Selection factor
NO	Noise Figure
N_t	Number of transmit antenna
P_f	Peak Power
P_{fixed}	Miscellaneous power consumed
$P_m(n)$	Transmit power of Macrocell
$P_p(n)$	Transmit power of Picocell

$P_{rf,out}$	RF Power output
P_{total}	Total power consumption by the Base Station
$P_{total,in}$	Total power in PA
P_{tx}	Radiated power per site
R	Cell capacity
R_{macro}	Average data rate for Macrocell
$R_{pico,in}$	Average data rate for Picocell
$RSRP_{j,i}$	Reference Signal Received Power
S	Area covered by certain base station with unit in Km^2
S_{macro}	Area covered by Macrocell with unit in Km^2
$S_{pico,in}$	Area of n number of Picocell
$SINR_{m,i}(n)$	Signal Interference plus Noise Ratio of Macrocell in subframe n
$SINR_{p,i}^{ABS}$	Signal Interference plus Noise Ratio of ABS Picocell in subframe n
$SINR_{p,i}^{nonABS}$	Signal Interference plus Noise Ratio of non-ABS Picocell in subframe n
$SINR_{p,i}(n)$	Signal Interference plus Noise Ratio of Macrocell in subframe n
$SNR_{p'}^i$	Signal to Noise Ratio of Picocell
$SNR_{m'}^i$	Signal to Noise Ratio of Macrocell
T_f	Maximum throughput
W	Bandwidth

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Topic of the Thesis: Energy Efficiency via Heterogeneous network
Supervisor: Professor Mohammed Elmusrati
Instructor: Professor Mohammed Elmusrati
Degree: Master of Science in Technology
Degree Programme: Degree in Communication and System Engineering
Major of Subject: Communication
Year of entering the university: 2013
Year of Completion of Thesis: 2015 **Pages:** 96

ABSTRACT

The mobile telecommunication industry is growing at a phenomenal rate. On a daily basis, there is a continuous inflow of mobile users and sophisticated devices into the mobile network. This has triggered a meteoric rise in mobile traffic; forcing network operators to embark on a series of projects to increase the capacity and coverage of mobile networks in line with growing traffic demands.

A corollary to this development is the momentous rise in energy bills for mobile operators and the emission of a significant amount of CO₂ into the atmosphere. This has become worrisome to the extent that regulatory bodies and environmentalist are calling for the adoption of more “green operation” to curtail these challenges. Green communication is an all-inclusive approach that champions the cause of overall network improvement, reduction in energy consumption and mitigation of carbon emission.

The emergence of Heterogeneous network came as a means of fulfilling the vision of Green communication. Heterogeneous network is a blend of low power node overlaid on Macrocell to offload traffic from the Macrocell and enhance quality of service of cell edge users. Heterogeneous network seeks to boost the performance of LTE-Advanced beyond its present limit, and at the same time, reduce energy consumption in mobile wireless network.

In this thesis, we explore the potential of heterogeneous network in enhancing the energy efficiency of mobile wireless network. Simulation process sees the use of a co-deployment of Macrocell and Picocell in cluster (Hot spot) and normal scenario. Finally, we compared the performance of each scenario using Cell Energy Efficiency and the Area Energy Efficiency as our performance metric

Keywords: Green communication, Heterogeneous Network, Energy Efficiency, and Area Energy Efficiency.

1.0. Introduction

The mobile wireless communication is a veritable tool for enhancing productivity and driving economic growth. Over the last few years, mobile services have spread its tentacle from an esoteric few in developed countries to a daily commodity in other remote parts of the world. In fact, it has effectively reduced the digital divide between continents of the world. Moreover, from an economic perspective, mobile wireless communication is one of the key enablers for economic growth. In 2010 alone, the total revenue accrued from mobile communication was €174 billion, which surpasses the revenue from aerospace and pharmaceutical sectors (GSMA, 2011). This highlights the pivotal role of mobile communication in our everyday existence.

The emergence of innovative products and services are responsible for the recent growth in the mobile wireless communication sector. Innovations such as smart phone and other mobile devices, online video gaming system, multiple social media platforms and a plethora of mobile applications are placing enormous pressure on the limited network resource. In response to this, telecommunication service provider resort to the deployment of more infrastructures and network resources to meet up with the pressing demands. However, this comes at a critical price of increasing in energy consumption and a significant rise in carbon emission.

On a global scale, Information Communication and Technology consumes about 2% to 10% of the total world energy (Global Action Plan, 2007), while the mobile communication networks alone consume about 60 billion kWh per annum (Fettweis & Zimmermann, 2008). Moreover, the cost of powering telecommunication infrastructures constitutes about 18% and 32% of the total operating expenditure of mobile operators in Europe and India, respectively (Lister, 2009). Expectedly, the continuous densification of mobile wireless infrastructure would lead to a significant rise in energy consumption and carbon emission.

From an environmental viewpoint, the ICT industry is culpable of about 2% of the world's carbon emission (Gartner, 2007) and by extrapolation, carbon emission is expected to increase to

4% in the year 2020. Moreover, on a yearly basis, over 120000 base stations are added to the mobile network, which culminates in an energy consumption of about 1400w and a carbon emission 11 tons per base station (Telecommunication Prediction, 2010). Taken together, if nothing is done to improve the operations of mobile wireless network, the environmental and financial implication would be colossal in the near future.

With this in mind, it is clear that conventional mobile cellular network consumes a lot of energy and is not environmentally friendly. Although cellular networks operate at full capacity, the densification of conventional base stations lead to a significant rise in energy consumption. This is because most base stations are lightly loaded and grossly under-utilized. In addition, the quest to support more data traffic and the need for ubiquitous wireless coverage makes it practically impossible to switch off lightly loaded base station. Scenarios were the same amount of energy is consumed by lightly loaded Base Station and heavily loaded Base station contravenes the essences of green communication.

From the foregoing, it is clear that the present mobile wireless network is not energy efficient. The need for mobile network operators to safeguard the environment and reduced energy consumption has become of utmost importance. To this end, there is a clarion call from governments and other regulatory bodies for the mobile telecommunication industry to restructure its activities toward a more energy efficient operation.

1.1.Motivation

The emergence of enormous data traffic on the radio link, coupled with the decoupling of the traffic demand and the expected revenue is critical to the sustainability of the mobile network. While the introduction of Carrier Aggregation in LTE-Advanced offers a wider bandwidth to users and a better performance, the combined capacity of the LTE-Advanced system is insufficient in handling the future traffic demands. More so, conventional means of improving

network capacity, such as the addition of more spectrum and densification of mobile infrastructure further heighten the OpEX and CapEX of mobile operators. As a last resort, improve network architecture seem to be the only viable solution to increasing the system capacity.

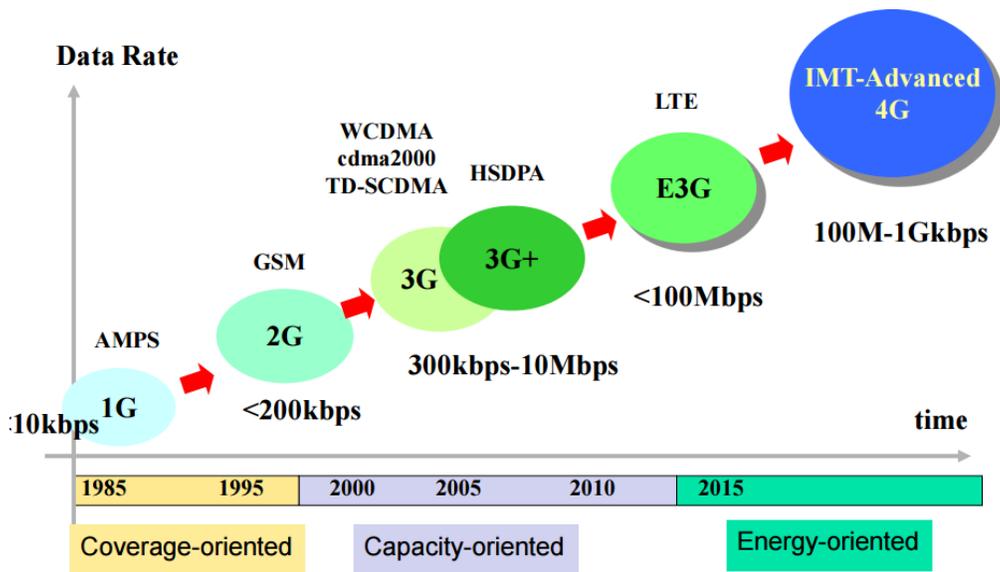


Figure 1. Transition of network development (Niu, 2011)

As shown in Figure 1, the mobile wireless network is making a transition from capacity-oriented improvements towards more energy-oriented operations. The introduction of Heterogeneous network is an intuitive way of enhancing the energy efficiency of wireless network. The overlaying of low power nodes over Macrocell fosters efficient use of spectrum, increase cell splitting gain and further reduce the transmit power between the Base Stations and the UE. The

use of HetNets further enhances the performance of LTE-Advanced with regards to increase in capacity, better Quality of Service and improve cell edge performance.

1.2. Scope of Thesis

This thesis addresses the issue of energy efficiency within the mobile wireless network. First, we shall analyze the current trends in green communication and examine key technique for optimizing the energy efficiency of the mobile network. Second, we consider the impact of heterogeneous network on the LTE-Advanced network and the underlying principles that enhances the performance of heterogeneous network. Third, we introduce three cell selection techniques for load balancing and resource allocation in the heterogeneous network. Finally, we evaluate the performance of the heterogeneous network using the cell Energy Efficiency and Area Energy Efficiency as our performance metric.

1.3. Thesis Outline

Chapter 2 reviews several papers on the current trends in green communication, with emphasis on energy efficiency metric, the fundamental trade-off in green communication and techniques for improving the energy efficiency of mobile wireless network.

Chapter 3 covers key radio interface technologies that support the operation of heterogeneous network. We introduce the concept of heterogeneous network and discuss key techniques such as Cell Range Expansion and Almost Blank Subframe.

Chapter 4 gives a brief introduction into the system level simulator use for our simulation. In addition, a detailed explanation of the equations, model and techniques used during the process of simulation is given in this chapter.

Chapter 5 presents the result of the simulations in a logical manner and examines the impact of heterogeneous network on the energy efficiency and area energy efficiency of the system.

Chapter 6 draws conclusions from the results obtained and give a detailed explanation for future works.

2.0. Current Research Trend in Green communication

Over the years, mobile wireless operators have committed a lot of manpower and capital towards expanding network capacity and improving customer quality of service by ensuring ubiquitous service wherever and whenever the need beckons. However, the dramatic rise in energy consumption and carbon emission has made the subject of green communication within the wireless cellular network of grave importance. So far, there have been intense collaborations between the academia and the industry to roll out initiatives in line with the goals of green communications. The following paragraphs highlight a few projects and ongoing research on green communications.

Green is an acronym for Globally Resource-optimized and Energy-Efficient Network (NIU, 2011). Green communication is not a cliché for reduced transmit power or a means of achieving higher energy efficiency. Green communication is an all-inclusive approach that champions the cause of overall network improvement, provision of more spectrums, reduction of energy consumption, and mitigation of carbon emission. Research focus on green communication targets improvement at the component level or an entire system level. Most notable ones are Earth Aware Radio and neTwork tecHnologies (EARTH), GreenTouch, Mobile VCE Green Radio and Optimizing Power Efficiency in mobile Radio Networks (Opera-Net), just to mention a few.

EARTH is a part of the EU FP7 project that was set up in January 2010 to tackle energy challenges in wireless network (Blume, Zeller, & Barth, 2010:3). EARTH project targets a 50 percent reduction in the overall energy consumption of 4G mobile network by overhauling individual radio component and changes in network topology. Opera-Net, on the other hand, arms itself with optimization of base station cooling and network component enhancement as a mean of achieving energy efficiency within the mobile framework.

Furthermore, MVCE Green Radio project pursues energy reduction within two major complementary streams (He et al. 2010:1). On one hand, it addresses energy consumption in the Radio Access Network (RAN) by efficient network architecture and component optimization. On the other hand, MVCE Green Radio harnesses improved radio technique to enhance base station and end user device operations. GreenTouch is an initiative sponsored by a group of concern individual and companies channeled towards fundamental research on energy reduction in mobile networks. Its research interest covers improvement in network architecture.

2.1. Energy Efficiency Metrics

The need to qualify the energy consumption within the mobile wireless framework led to the creation of energy efficiency metrics. Broadly speaking, there are numerous ways of evaluating the energy efficiency of a mobile network and as such, no singular definition is able to cover all approach. However, (Hamdoun, Loskot, O'Farrell, & He, 2012) defined Energy Efficient metric as the energy consumption normalized per some quantity or network entity. Energy efficiency metric serves as an index for assessing the energy consumption of various components of a mobile network.

According to (Tao, Haesik, & Yang, 2010:1.), energy efficiency metric is used for three main reasons. First, it serves as a yardstick for comparing energy consumption performance of different components and systems. Second, it enables the academia and the industry to set long-term goals targeted toward energy efficiency in wireless mobile networks. Lastly, it reflects the energy efficiency in a system and provides a means of adapting toward more energy efficient system configuration.

2.1.1. Types of Energy Efficient Metric

Energy efficiency metrics for telecommunication system are classified into three groups: facility level metric, equipment level metric and network level metrics. Explicitly, facility level metric computes the energy efficiency of large network systems such as a data center and ISP. Equipment level metrics are responsible for computing the energy efficiency metric for all network equipment, while network level metric evaluates the energy efficiency of network components in relation to the capacity and coverage of the network. We shall consider some equipment level metrics in subsequent paragraphs.

There are various bodies saddled with the responsibility of defining metrics used in evaluating the energy efficiency in telecommunication networks. However, the most basic form of quantifying energy efficiency is the Energy Consumption Rate (ECR) metric. ECR is an equipment level metric because it assesses the energy efficiency of network components. By definition, it is the ratio of the average energy consumed to the effective throughput of a network component. The ECR provides a proper assessment into the performance of various network components.

$$ECR = P_f / T_f \text{ (Watts/bps)} \quad (2.1)$$

Where P_f is the power in watt and T_f is the maximum throughput

As shown in Equation 2.1, ECR a veritable tool for evaluating the peak power consumed across the network against the maximum throughput across individual network components. Its unit is Watt/Gbps. Lower values of ECR signify that the network components are energy efficient while a high value of ECR is an indication that the component consumed a lot of energy. A major drawback of the ECR is the inability to gather relevant data related to the network load condition.

Moving ahead, the ATIS Network Interface, Power and Protection (NIPP) created the telecommunication, energy efficient ratio (TEER) metric (ATIS, 2009). It is a standardized method for measuring the energy and power consumption as well as the energy and power efficiency of telecommunication equipment. TEER is also an equipment level metric; however, it adopts painstaking approach towards calculating the energy efficiency metric than the ECR. The TEER is the ratio of the useful work done by equipment to the overall power consumed over a specific time.

$$TEER = \frac{\text{Useful work}}{\text{Power}} \text{ (?/watt)} \quad (2.2)$$

$$\text{switches, router} = \frac{\log(P_{total})}{\text{Forward capacity}} \text{ [dB/Gbps]} \quad (2.3)$$

$$\text{power Amplifier} = \frac{P_{rf,out}}{P_{total,in}} \quad (2.4)$$

As shown in Equation 2.2, the useful work can assume any dimension depending on the type and functionality of the equipment under consideration. On the other hand, the “Power” is the energy expended over a period of measurement. The TEER for telecommunication equipment such as routers, switches, and power amplifiers are derived as shown in Equation 2.3 and Equation 2.4, respectively. On a general note, network components and equipment with higher TEER values are considered more energy efficient than once with a lower value.

2.2. Fundamental Trade-off in Energy Efficiency

For an innovation to thrive, there is a need for a trade-off of one resource over another, and the telecommunication network is not an exception. The fact that certain network resources are approaching their limits warrants a trade-off of one network resource at the expense of another. For instance, under low load condition, it is possible to control the bandwidth of the network in order to increase the energy efficiency. Similarly, more transmit power might be required to support high spectral efficiency. In sum, fundamental trade-offs in green communication are performed on many platforms.

2.2.1. Spectral Efficiency-Energy Efficiency (SE-EE) Trade-off

For several years, the spectral efficiency metric has been a key parameter for planning and enhancing the performance of wireless network. The SE metric indicates the level of utilization of limit spectrum regardless of the amount of energy consumed in the network. However, the need to quantify the energy consumption in mobile wireless network prompted the development of Energy efficiency metric (EE). For a finite amount of bandwidth, the SE-EE trade-off addresses the compromise that plays out between the achievable data rate and the energy consumption in a system.

For the purpose of clarity, the SE is defined as the transmission rate per unit bandwidth while EE is the transmitted bit per unit energy. The Shannon capacity formula for a point-to-point AWGN channel enables us to grasp the relationship between the two entities.

$$C = W \log_2 \left(1 + \frac{P_t G}{W N_o} \right) \quad (2.5)$$

Equation 2.5 represents the channel capacity of an AWGN channel. Where C is the channel capacity, W = bandwidth, G is the channel gain, P_t is the transmit power and N_o denotes the power spectral noise density.

From observation, Equation 2.5 reveals that it is practically impossible to increase SE and EE at the same time. To be precise, the EE is always decreasing, while the SE rises. More so, more energy (or transmit power) boosts the spectral efficiency of the system while Bandwidth expansion is favored by increasing the EE of the network.

2.3. Techniques for Energy Saving in Wireless Access Network

Up until recently, a lot of research work has been dedicated to energy reduction in handheld devices and wireless sensor nodes. However, increasing energy bill and environmental concerns have broadened the scope of modern research activities toward energy consumption of the entire mobile wireless network. As Figure 2 depicts, Radio Access Network (RAN) consumes the most significant amount of energy in a cellular network. Moreover, the core and the base station consumed a significant amount of energy in their day-to-day operation. The rest of this section presents a modern approach of saving energy in telecommunication networks, with emphasis on the base station.

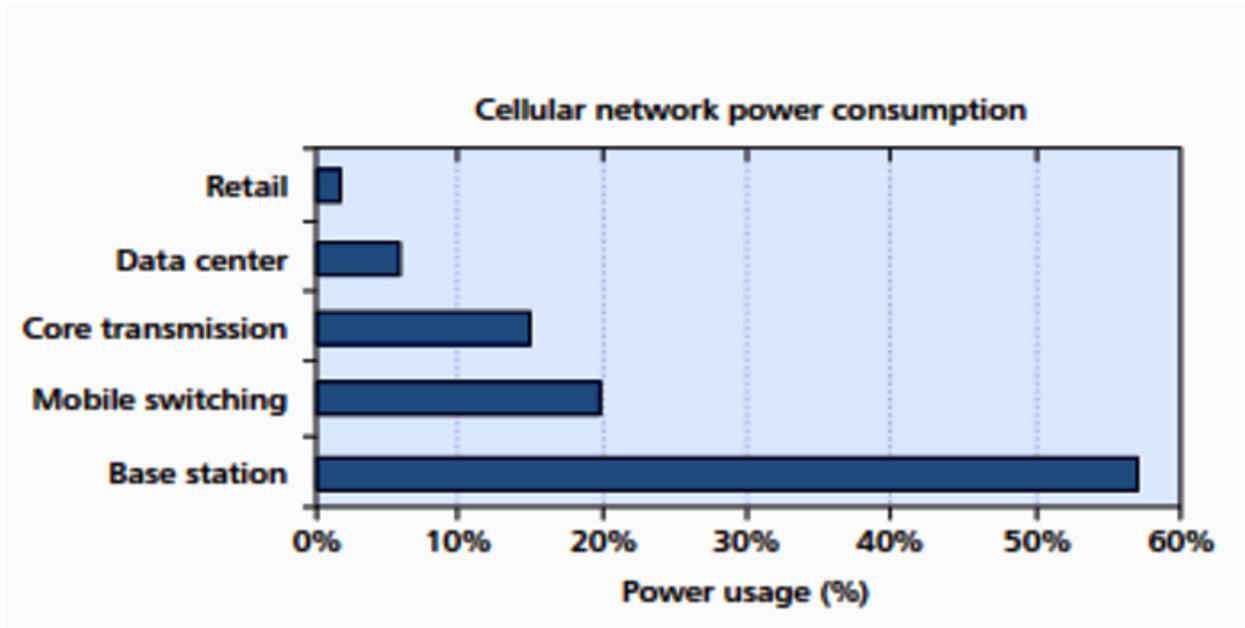


Figure 1. Power consumption of a typical wireless cellular network (Han, 2011)

2.3.1 Energy Efficient by Hardware Improvement

Figure 3 illustrates a breakdown of the overall energy consumption of a typical base station. Notably, the power amplifier dominates the energy consumption of conventional base stations. The power amplifier consumes about 60-70 percent of the overall energy usage in a base station and its operation lead to the generation of enormous amount of heat. This necessitates the need for a cooling system, which results in additional energy consumption. With this in mind, it is imperative to address the energy efficiency of the power amplifier (PA) in order to reduce energy consumption and improve network performance of the mobile base station.

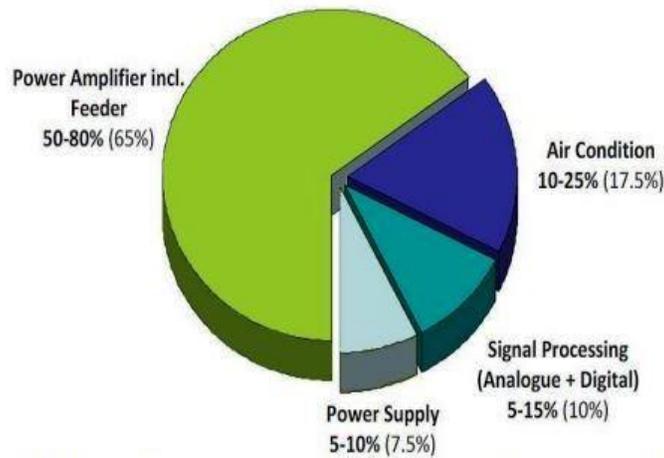


Figure 3. Breakdown of Power Consumption in radio base stations (Vodafone)

Energy efficient Power Amplifier (PA) plays a crucial role in making energy efficient communication a reality, particularly in LTE system. The frequency band, type of modulation used and the operating environment affects the operation of a power amplifier. The OFDM technique used in LTE downlink uses a non-constant envelope modulation technique, which result to a high Peak to Average Power Ratio (PAPR). Consequently, a large amount of energy is dissipated even when the signal quality is low. This emphasizes the need for more energy efficient power amplification in the LTE downlink system.

Furthermore, modern technology seeks to increase the efficiency of the PA, broaden the frequency range, and at the same time, increase its linearity. In fact, Energy efficient PA results to a lower OpEX and a more stable network. In light of this, the Doherty amplifier came as a replacement for the inefficient traditional amplifier. Doherty amplifier consists of a main amplifier and several peak amplifiers. Usually, the main amplifier is a biased class A or class B amplifier while the peak amplifiers are general class C amplifiers. From a technical perspective, Doherty amplifier enhances the operation of Power amplifier by 20-30% (Zhang, Nan, & Li, 2011). However, its major disadvantage is that it operates on a narrow bandwidth.

Furthermore, the deficiencies of Doherty technology led to the introduction of Gallium nitride High Electron Mobility Transistor (GAN-HEMT) amplifier and High Accuracy Tracking (HAT) amplifier. GAN-HEMT and HAT work on the principle of envelope tracking. Envelope tracking not only broadens the range of bandwidth of the PA but also tracks the signal envelope in such a way that the input power matches the RF output power. As a result, the power amplifier dissipates less heat. According to (Kaneko, Shiikuma, & Kunihiro, 2011), GA-HEMT PA can achieve a power efficiency of about 60%, which surpasses the performance of Doherty amplifier.

In the same vein, Table 1 summaries a research conducted using Traditional, Doherty and High accuracy tracking amplifiers. The research analyses the performance of three different types of Power amplifiers, with respect to their cost of deployment, energy efficiency, power consumption, and carbon emission. Based on results obtained from 20000 base stations, the use of the HAT power amplifier can save up to 35MW annually, which is equivalent to \$37 million reductions in energy bill for network operators (Mancuso & Alouf, 2011).

Table 1. Efficiency, costs and environmental impact of a 20,000-base-station network with different power amplifier technologies

Parameter	Traditional Technology	Doherty Technology	Envelope Tracking
Power amplifier efficiency	15%	25%	45%
Power Consumption	51.7MW	27.2MW	16.1MW
Power cost	\$54.3M	\$28.6M	\$17.0M
CO ₂ emission	194600 tons	102400 tons	60800 tons

2.3.2. Energy Efficiency by Renewal Energy

Renewable energy comes as a reliable alternative towards advancing the cause of energy efficiency in mobile networks. The clamour for renewable energy comes against the background of the drastic rise in carbon footprint and the accumulation of huge energy bills, especially for powering off-grid base station. In 2012 alone, off-grid base stations constitute about 40% of the total number of base stations deployed globally. According to (GSMA, 2014) an off-grid base station consumes about 13000 liters of diesel per annum, which translate to a total cost of \$21000 and emits about 35 metric tons of CO₂ annually. This is a wake-up call to telecommunication operator to consider the potentials and the benefits of using renewable resources in powering mobile base stations.

From an operator's standpoint, there has been a great awaken by network service providers towards the adoption of renewable energy as an alternative means of power mobile base station. For instance, Nokia-Siemens are championing the use of the latest innovation in fuel cell, deep circle battery technology combined with solar and wind energy in powering several off-grid base stations (E-Plus,2011). Another laudable project is the eco-smart innovation by Ericsson and Telecom Italia (Ericsson, 2009).By using a combination of flexible solar panels, the eco-smart solution is able to generate almost 100 % of the energy required to power a base station.

Unfortunately, several operational constraints limit the performance of renewable energy sources. For one reason, the intensity of sunlight and the velocity of wind power cannot be guaranteed at a consistent level at all times. For another reason, the limited capacity of storage batteries hinders the overall utilization of renewal energy. However, a viable solution comes from the incorporation of renewable supply into the smart grid system. Using adaptive power management control, renewable energy supply can power more base stations when supply is in excess or it can be restricted to standalone base stations where supply is at its minimum.

2.3.3. Energy Efficiency by Base Station Cooperation

Base Station cooperation is another innovative approach to improving the energy efficiency wireless communication. By exploiting the benefits of cell zooming, it is possible to save a significant amount of energy by dynamically adjusting the cell size. By definition, cell zooming is a network adaptation that dynamically modifies the coverage radius of a mobile Base Station to adapt to the location and QoS requirement of the mobile users.

Cell zooming thrives on the fact that the conventional Base Stations are usually designed and operated based on estimated traffic capacity. The high mobility of mobile user and a paradigm shift towards more data application, make mobile traffic susceptible to spatial and temporal variation. For instance, daytime traffic is higher in commercial areas during weekdays and working hours while it is lower during nighttime and weekends. This implies that at certain times, some of the Base Stations are under heavy load while others are serving few users. In sum, cell zooming is capable of addressing the problem of load imbalance as well as energy saving in mobile networks.

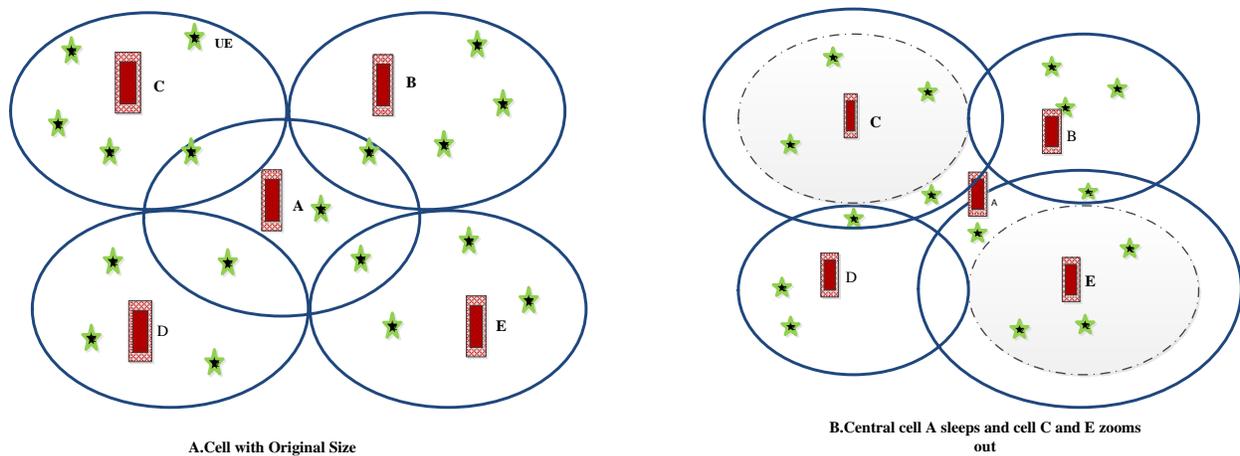


Figure 2. Cell zooming Mechanism for Energy Saving

Figure 4 illustrates the mechanism for energy saving via cell zooming. The cellular network consists of a centralized cell A, with four neighbouring cell B, C, D and E. The base stations are represented as a brown hollow rectangle while the UE is depicted by the dotted stars. In the event that UEs move in toward the central cell as shown in Figure 4a, this might result in network congestion and reduces the quality of service of the network. In order to save energy, the centralized call is Zooms in, thereby offloading some UEs to neighbouring cells. As shown in Figure 4b, Cell C and E Zooms out to accommodate the offloaded UE. In addition, should the neighbouring cells be configured with higher capacity, it is possible to completely sleep the centralized and save more energy within the network.

Cell zooming shares some similarities with power control; however, both technique addresses different issues. Power control addresses link performance and transmit power consumption while cell zooming tackles network level performance and energy reduction of the entire network (Niu, Wu, Gong, & Yang, 2010:76). In other words, power control works on the transmit power of UE while cell zooming takes care of the power of the base station itself. In sum, successful implementation of cell zooming would require other techniques like BS cooperation, Physical adjustment of antenna and Relaying.

2.3.4. Energy Efficiency by Radio Resource management

Radio Resource Management (RRM) is also an alternative for promoting energy efficiency in mobile wireless networks. Although the objective of RRM seeks to optimize spectrum usage and at the same time, provide satisfactory Quality of Service (QoS) across all users, it can harness for energy saving. Energy efficiency by RRM is enhanced by the use of adaptive modulation and coding scheme.

$$C = W \log_2 \left(1 + \frac{P_{tr} G}{N_o + I} \right) \quad (2.8)$$

Where C = Channel capacity, W = Bandwidth, G =Channel Gain, I =Interference, N_o =additive noise power and P_{tr} is the transmit power.

From the Equation 2.8, the fact that the channel capacity C varies linearly with the bandwidth W and logarithmically with the transmit power P_{tr} enable the possibility of a trade-off between the spectral efficiency and energy efficiency in order to save energy. In (Han, et al., 2011:49), it was observed that a significant amount of energy can be saved by using wider bandwidth and less complicated modulation scheme such as QPSK over a narrow band and more sophisticated modulation scheme like QAM. This validates the trade-off between the spectral efficiency and the energy efficiency for saving energy.

2.3.5. Energy Efficiency by MIMO

The use of MIMO technique to improve network capacity and overall spectral efficiency comes at a price of an increase in energy consumption. While MIMO requires less power for transmission, its constituent components consumed a lot of energy. This is because more transmit and receive antenna are added to its circuitry. In fact, the circuitry power of MIMO is N_t times higher than that of SIMO, where N_t is equivalent to the number of transmitting antenna (Hongseok, Chan-Byoung, de Veciana, & Heath, 2009). High circuitry power has restricted the use of MIMO in the uplink system.

Furthermore, MIMO achieves more EE than SIMO owing to the spatial multiplexing gain (Gesbery, Shafi, Shiu, Smith, & Naguib, 2003). Besides, compared to a conventional system without multiple antennas, MIMO requires lesser energy per bit to reach a given distance. For MIMO system, the balance between circuitry energy consumption and the transmit power can be enhanced by the adaptive modulation scheme. In (Bougard, Lenoir, Dejonghe, Van der Perre, Catthoor, & Dehaene, 2006), several adaptive switching techniques were performed on MIMO

transmission scheme. It was observed that using a smart adaptation with MIMO not only offer better SE-EE trade-off, but also improve the EE by about 30% compared to a system without any adaptation.

3.0. Long Term Evolution and Heterogeneous Network

There are two emerging technologies developed for high-speed mobile broadband access: Long Term Evolution (LTE) and WiMAX, standardized by developed by 3rd Generation Partnership Project (3GPP) and the Institute of Electrical and Electronics Engineers (IEEE), respectively (Bao, 2013:1). The LTE system is an advanced version of the 3G network, simply because it evolved from the current WCDMA network. As far back as November 2004, 3GPP conceived the noble idea of developing an all-IP network. This led to the termination of the more expensive and less efficient circuit switching in favour of a more practical packet switching for real time and non-real time application.

The LTE system paves the way for higher spectral capacity and data throughput by using very efficient modulation technique at both the downlink and uplink system. The use of OFDM and SC-FDMA enhance the possibility of achieving a peak data rate of 100Mbps and 20Mbps at the DL and UL respectively. The LTE system also reduces the delay (latency) between the UE and the Base Station, which fosters steady connectivity between the UE and the core network during user mobility.

3.1. LTE Architecture

The LTE architecture or the Evolved Packet Switched System (EPS) consist of two main parts: the Evolved Packet Core (EPC) and the Evolved Universal Terrestrial Radio Access Network (E-UTRAN). In plain terms, they are referred to as the core and access network. As shown in Figure 5, the overall LTE architecture is composed of several network elements and standardized interfaces. Apart from enabling interconnectivity between network elements, LTE interfaces promote communication between nodes from multiple vendors. Concerning complexity, there are more elements on the core network than the access layer of the LTE system.

From the foregoing, EPC and E-UTRAN introduces some unique functionality to the LTE system. For instance, the core network established bearer and handle overall control of the UE while the access node allows the UE to access network resources. Notably network elements at the LTE core level are the Packet Data Network Gateway (PDN-GW), Serving Gateway (S-GW) and the Mobile Mobility Entity (MME). While the Access level consists of many evolved Node B (eNodeB). The absent of centralized controllers at the E-UTRAN implies that the architecture is Flat.

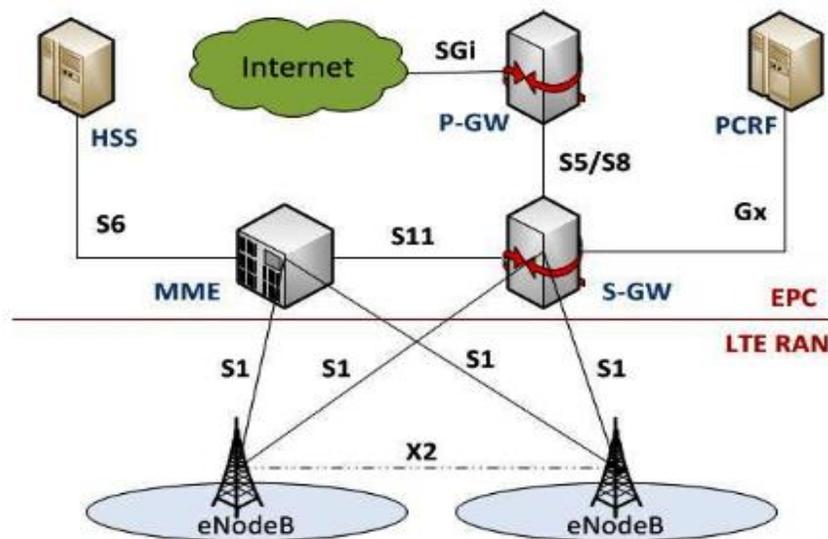


Figure 3. LTE Network Architecture (Joub, 2013)

Among other things, each network element and interface perform a definite function. The Serving-Gateway (S-GW) collates all information required for billing and it terminates interface connection towards the E-UTRAN. In the same light, the MME make the identification of UEs possible and it also capable of setting security parameter. The PDN-GW, on the other hand, performs lawful interception and allocates IP addresses to UE. Finally, eNodeB attend to all

radio interfaces related functions such as RRM, header compression and encryption of the user data stream.

3.1.1. LTE Frame Structure

LTE systems assign resources simultaneously to users in both frequency and time domain. The arrangement in the frequency domain sees the division of the entire bandwidth into sub-channels and subsequently into sub-carriers with a 15 kHz gap between each sub-carrier. Time domain works differently from the frequency domain. As shown in Figure 6, the structure of an LTE downlink is organized into frame, subframes and slots. Notably, the downlink transmissions are packaged into the frame of 10ms. Each frame consists of 10 subframes and each subframe consists of two slots of 0.5ms. Depending on the composition of the cyclic prefix deployed, each slot has 6 or 7 OFDM symbols.

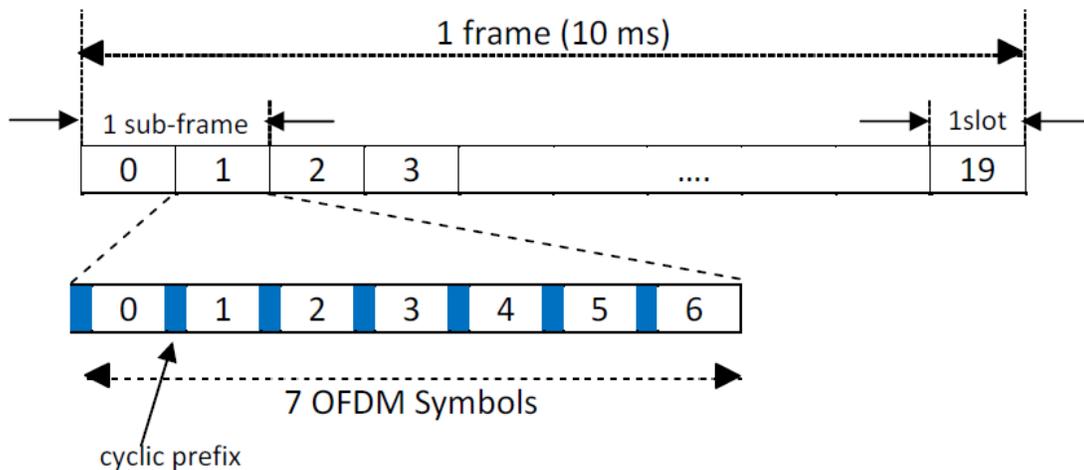


Figure 4. LTE generic frame structure (Martinez, 2013)

3.2. LTE-Advanced

LTE-Advanced fulfilled the requirement of IMT-Advanced for 4G network and it was standardized by 3GPP as a major improvement to the LTE standard. As part of the requirements for 4G networks, the LTE-Advanced network provides a superior bit rate in a cost-effective way while also striving to improve network capacity and performance on various frontiers. In addition, the provision of backward compatibility enhances the use of legacy devices from earlier LTE version (Release 8 and 9) on the LTE-Advanced network. However, the operations of Release 8 and 9 devices are restricted to only a few functions.

In spite of using a wider carrier bandwidth than the GSM and UTMS technology, LTE-Advanced introduces new features such as carrier aggregation, enhanced MIMO, relaying and coordinated multipoint (COMP) to further improve the overall spectral efficiency of the network and offer a better quality of service to its users. Even though some of the above-mentioned techniques were conceived in the previous version, LTE-Advanced brought the most of these techniques into full functionality. In the following section, we shall examine some key techniques that underline the performance of LTE-A.

3.2.1. Carrier Aggregation

Perhaps the most sophisticated and key enabling feature of LTE-A is Carrier Aggregation. As the name implies, carrier aggregation consist of grouping multiple carriers of the same or different frequency and jointly deployed to increase the overall transmission bandwidth. In LTE-A, each aggregated carrier is known as Component Carrier (CC). Each Components Carrier is capable of adopting a bandwidth ranging from 1.4MHz to 20MHz. From a theoretical viewpoint, there is provision for combining 5 (20MHz) component carriers (CC) to yield a total bandwidth of 100MHz. However, the combination of Components Carrier is restricted to only two CC in LTE Release 10.

Carrier Aggregation takes place on frequency domain as well as the time domain. Moreover, it is possible to enable backward compatibility by combining several LTE carriers to increase transmission bandwidth (Dehghani & Arshad, 2014:2). Carrier Aggregation enables the resourceful use of fragmented spectrum. Network operators with small and separated spectrum can combine one or two spectra to arrive at a greater bandwidth. This enables the possibility of offering better peak data rates to mobile subscribers.

Broadly speaking, there are two variants of carrier aggregation: Intra-band and Inter-band carrier aggregation. Intra-band Carrier Aggregation consists of contiguous and non-contiguous carrier aggregation. Figure 3 below depicts the various modes of carrier aggregation. An arrangement that combines two or more adjoining CCs of the same frequency is known as Intra-band contiguous aggregation. When Carrier Aggregation is performed using CC of the frequency band that are not adjacent to each other, the result is a non-contiguous carrier aggregation. Finally, performing aggregation of the component carrier along two entire different frequency bands is known as Inter-band carrier aggregation. Each of these modes has its own pros and cons.

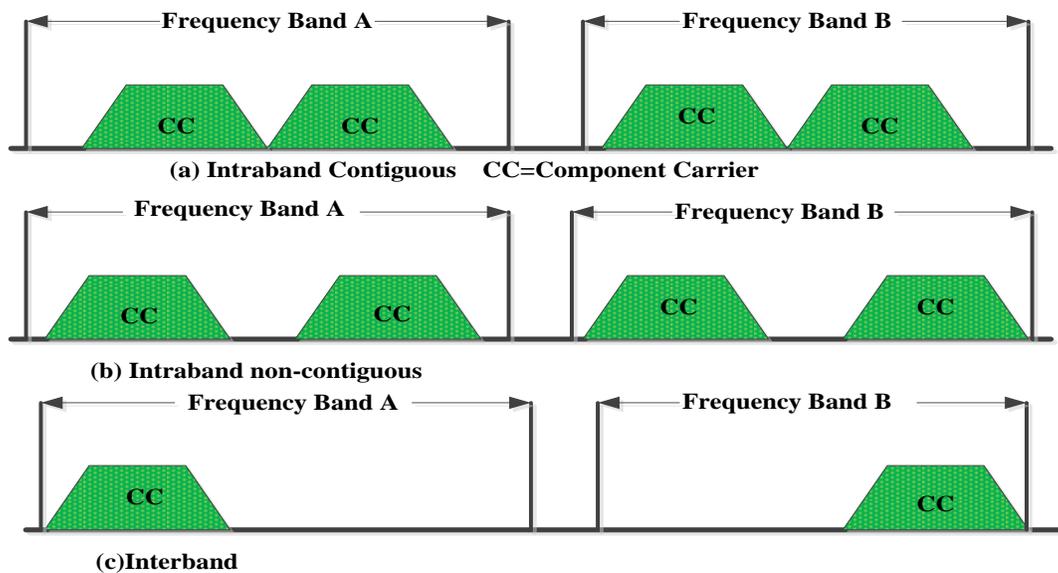


Figure 5. Modes of Carrier Aggregation

3.2.2. Enhanced MIMO

The usage of MIMO is not new to the LTE system. In fact, MIMO technique came into existence during the inception of LTE Release 8. Put simply, MIMO is an acronym for Multiple Input Multiple Output. A MIMO system utilizes multiple antennas at the transmitter and receiver side during propagation of RF through a communication channel. An intuitive way of ensuring the received signal strength reaches a UE is by the use of more antennas at both ends. Consonant with the requirements of LTE-A, MIMO uses a set of technique to achieve higher peak rate, cell-edge throughput, and overall cell average performance.

Although the Release 8 and 9 could accommodate close to four antennas on the downlink, the capacity of the uplink was restricted to one antenna only. As a result, 3GPP Release 10 came up with the idea of enhanced MIMO by using more antennas at the downlink and uplink, respectively. The arrangement sees the use of 8 transmitters and receivers at the downlink and 8 transmitters and 4 receivers at the uplink.

Furthermore, some of the MIMO algorithms used in LTE standard are receive diversity, transmit diversity, beamforming, and spatial multiplexing (Zarrinkoub, 2014:8). Receiver and transmitter diversity works in tandem to improve the overall network capacity. Beamforming is a technique that serves a specific cell and thereby improves coverage. In addition, spatial multiplexing takes care of the issue of handling more users. Taken together, the use of beamforming and transmit diversity generates stronger and more reliable communication link but do not improve the data rate. This is because their antennas transmit only redundant information. On the contrary, spatial multiplexing provides us the opportunity to increase the data rate by sending non-redundant information on several antennas. In sum, an increase in the number of antenna corresponds to a higher data rate.

3.2.3. Relaying

Relaying and COMP are the unique additions to the LTE-Advanced framework. Relaying is an innovative way of improving network coverage in a hotspot or dead zones without the additional cost of deployment. Similarly, relay nodes work independently without a backhaul link system and as such, it is suitable in places where backhauling is not required. According to (ESTI 3GPP, 2010), relaying facilitates a remarkable improvement in the provision of coverage to new areas, temporary network deployment, group mobility and cell edge throughput, just to mention a few. Similarly, the appropriate positioning of RN between eNodeB and UE reduces the path loss as well as the overall energy consumption of the wireless network.

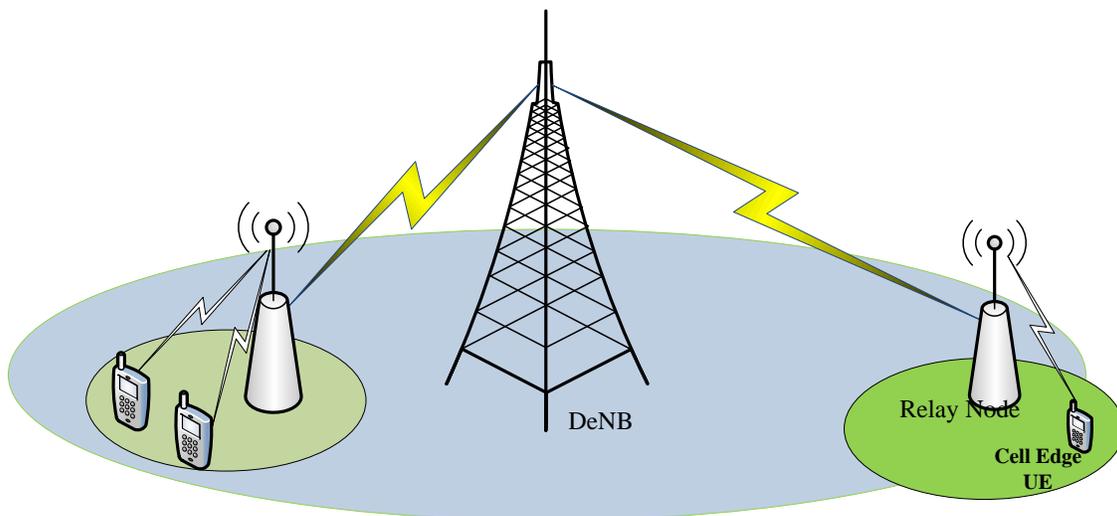


Figure 6. In channel Relay and Backhaul

Figure 8 depicts the arrangement and mode of operation of a typical RN. Relay nodes are deployed at cell-edges or in a multi-hop arrangement in order to extend coverage to areas with poor quality of service. As shown above, the main node or base station is referred to as the Donor eNodeB (DeNB). The DeNB transmits signal via its backhaul link (U_n) to the relay node. On one hand, the relay node demodulates and decodes the received signal from the DeNB. On

other hand, the relay node re-modulated and re-coded the process signal before onward transmission of an amplified signal to the UEs. This is done via the access link (Uu). In sum, the RN serves as an intermediary between the eNodeB and the UE.

The connection between eNodeB and RN (Un) and between the RN and UE may operate on the same or a different frequency band. In the event that the Un and Uu share the same spectrum, such relay is known as an Inband relay. On the contrary, where Un and Uu are on separate frequency band, the relay is called an Outband relay. Interference management on the access and backhaul link see the isolation of some frame in the frequency and time domain. Finally, the use of the separate frequency band on the access link (Uu), enhances the capacity of Outband relay over the Inband relay which uses the same frequency band on the access link.

3.3. Heterogeneous Network

The heterogeneous cellular network consists of several base stations and wireless nodes with varying size and transmits power. It consists of Macrocell with high capacity and extensive coverage, and low power nodes with low range and limited power. Whereas Macrocells provide capacity and support user mobility, small cells provide localized mobile service to cell edge users and offload traffic for congested Macrocell. This arrangement increases overall network performance and ensures a higher data for all subscribers. Figure 9 below shows a typical network topology with Macrocell overlaid with Picocell and Femtocell.

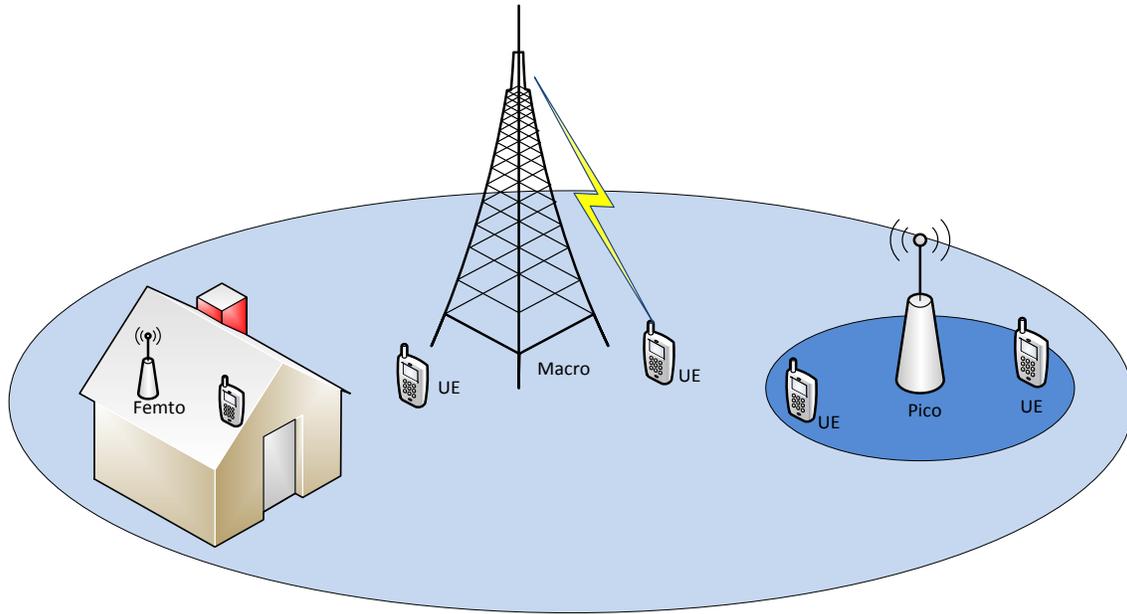


Figure 7. A typical Heterogeneous Network

Heterogeneous network is deeply challenging many time-honoured aspects of cellular system design and analysis (Ghosh, et al., 2012:1). First, heterogeneous network gives us the opportunity of designing and analyzing a mobile network system stochastically. This is a deviation from the traditionally held belief of representing mobile base station by hexagonal tessellation. There is also the possibility of using Poisson Point Process (PPP) to represent network nodes and perform analysis accordingly. Another interesting proposition of Hetnet is that cell selections by users are not entirely dependent on the base station with the strongest signal strength. There is provision for users to select base stations or low power nodes with weak signal strength.

3.3.1. Why Heterogeneous Network

The conventional Macrocell network is also known as a homogeneous cellular network. For many decades, homogeneous network deployment has widely been adopted by major cellular operators, as the default standard for designing cellular network. It comprises of Macro-centric base stations deployed in a well-planned manner to meet the mobile traffic demand and coverage capacity. A common challenge with the homogeneous Macro-cellular network is its inability to provide high data rate for all users. In addition, the cost of securing a suitable site for Macrocell is becoming enormous, especially in urban communities. Lastly, it is practically impossible to modify its network architecture or increase its capacity without a corresponding rise in energy consumption.

Furthermore, the reason for the migration from the traditional homogeneous network to heterogeneous network is not far-fetched. Figure 10 depicts the history of capacity gain in wireless network from 1950 to 2000 (Webb, 2007). From observation, voice coding and several modulation schemes were responsible for about 5% gain in spectral efficiency, respectively. Similarly, the addition of more spectrums to the network resulted to a 15% rise in spectral efficiency gain. Lastly, the use of small cell and universal frequency reuse gave the most significant gain of about 2700%. To this end, the use of small cells (LPN) remains the most efficient and cost effective way of increasing network capacity.



Figure 8. Source of Spectral efficiency gains of wireless communication systems from 1950 - 2000 (Webb, 2007)

For another reason, deployment of heterogeneous network is an auspicious opportunity to record an all-round gain for all parties concerned. Figure 11 below illustrates the Total Cost of Ownership (TCO) incurred by mobile operators in running the day-to-day operations of several base stations. From observation, the capital and operational cost of Picocell is 5 to 6 times lower than that of Macrocell and in the case of Femtocell deployment, it is infinitesimal. In addition, a joint deployment of Macrocell and Picocell reduces the energy bill of mobile operators by 60% compared to a network with Macrocell only (Claussen, Pivit, & Ho, 2008:4). Perhaps the most important benefit is at the user end. Heterogeneous network makes it possible for mobile users to enjoy longer battery life and superior downlink speed due to the proximity of the low power nodes to the mobile equipment.

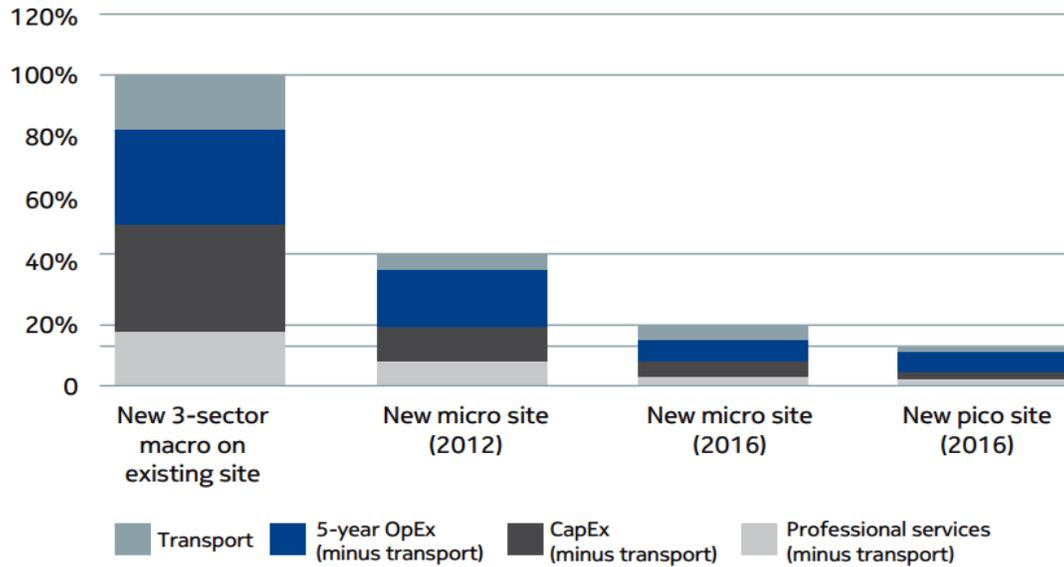


Figure 9. Example TCO values and predicted cost indicator development (Nokia, 2014)

3.3.2. Types of Heterogeneous network deployment.

There are three ways of deploying heterogeneous networks, namely: mobile-to-mobile, mobile to Wi-Fi and mobile to mobile/Wi-Fi deployment (Ascom, 2013). Mobile-to-mobile is the pioneer deployment standard for heterogeneous network. This arrangement ensures efficient spectrum reuse and improves the network capacity and coverage area. Nonetheless, the deployment of Mobile-to-Wi-Fi and Mobile-to-Mobile/Wi-Fi deployment is fast gaining ground within Hetnet framework. The introduction of WI-FI to the cellular network has immense benefit on network performance. The fact that Wi-Fi technology transmits on unlicensed band eliminates the need for serious interference management. Hence, it is possible to derive greater throughput over the radio interface and at the same time, improve the overall network performance. This is a key advantage of mobile-to-WI-FI deployment over mobile-to-mobile deployment where interference is a major issue.

3.3.3. Types of Small Cells

Some of the distinctive features of small cells are coverage area, physical size and transmit power. Generally, small cells are deployed either in residential homes, indoor settings or in an outdoor environment. While residential small cells are self-organizing network that serve a limit amount of users, indoor and outdoor small cells are deployed to provide localized traffic solution to a significant number of users. In the near future, small cells promise to be one of the key enablers for the 5G network.

3.3.3.1. Picocell

Picocell otherwise referred to as enterprise Femtocell, is a regular eNodeB with lower transmit power than conventional Macrocell. It is equipped with the same interface technology as Macrocell and its antenna radiation pattern is omnidirectional. By means of the X2 interface, Picocell coordinates its operations with that of the already established Macrocell base station. Picocell leverages on its proximity to the mobile station to provide better voice service and higher data rate to mobile subscribers. The deployment of Picocells follows a well-planned pattern either in outdoor site or in indoor (hotspot) environment. Finally, the transmit power of Picocell varies from 250mW to 2W.

3.3.3.2. Relay Nodes

Relay nodes are diminutive, low power transmitting node without a wired backhaul interface to the main network. The absence of a wired backhaul interface makes relay node economically and technically suitable in places where it is not feasible to deploy nodes with the wired backhauling interface. Relay node possesses an access link for connection to the mobile terminal and a backhaul link that connects to a main wireless network. Relay nodes use omnidirectional and directional antennas on access link and backhaul link respectively. Its transmit power is similar to that of a Picocell.

3.3.3.3. Femtocell

Strictly speaking, Femtocells are portable indoor devices with a transmitting power of about 100mW. It shares the same spectrum as the main wireless network. It is equipped with an omnidirectional antenna and it is capable of serving 6 to 8 mobile users. The utilisation of Femtocell with the heterogeneous network eliminates high penetration losses and reduces the distance between the user and the transmitter. This translates into elongated battery life for mobile users and a significant reduction in energy consumption of the entire network and

Femtocells are deployed in three operational modes, namely, Closed Subscriber Group (CSG) or Open Subscriber Group (OSG) and more recently, the Hybrid mode. In CSG mode, Femtocell resources are restricted to only registered users, while OSG mode gives all mobile subscribers accessibility to Femtocell resources barring any pre-registration. Finally, hybrid Femtocell prioritizes its operation. Although hybrid Femtocell admits all mobile users, it assigns a lower priority to non-registered users. Table 2 provides more insights into the key features of Picocells and Femtocells.

3.3.3.4. Remote Radio Head

A typical RRH is consists of an analog to digital converter which enhances the centralization of base band signal processing. The backhaul connection between the RRH site and the Macrocell Base station is established using a fiber optic connection. Remote Radio Head (RRH) is also referred to as a distributed antenna system.

Table 2. A comparison of home Femtocell and public Picocell key features (Hu & Quan, 2013:9)

Parameters	Femtocell	Picocell
TX Power	Low power <250mW	Higher Power,250mW -2W
Capacity	Low capacity,< 8 users	Higher capacity,16 – 32 users
Backhaul	Consumer grade, paid for by user	Carrier grade, paid for by the operator
Equipment	Owned by the consumer	Owned by the operator
Cell ‘site’	Consumer installation	Operator professional installation
Deployment	Unplanned, consumer deployment	Planned, deployment by operators
User access	Closed, restricted access	Open to all qualified subscribers
Handover	Loose coupling at network layer	Tight coupling, intra-network handover
Security	Not trusted by operators	Trusted by the operator
Enclosure	Consumer electronics	Often environmentally hardened

3.4. Cell Selection and Cell Range Expansion

HetNets uses advanced network topology improvement to achieve a tangible gain in the capacity of cellular networks. However, unplanned densification of small cells leads to a decline in the overall network performance. Mass deployment of small cells in an unplanned manner sees a greater portion of users being associated with the Macrocell while the small cells remain redundant. Consequently, it results to severe load imbalance, increases cross-tier interference,

and generally, forfeits the benefit of small cells in the first place. It is imperative to streamline the cell selection process in a manner that boosts the overall network performance.

There are several terminologies given to cell association in various literature such as cell selection, cell-site selection, cell assignment and user association (Chinipardaz, Rasti, & Noorhosseini, 2014:2). Cell association is a scheme that finds the most suitable base station for a mobile user using some predefined parameters. However, in LTE-Advanced, there are several factors that influence the cell association of mobile user, namely Reference Signal Receive Power (RSRP), Reference Signal Received Quality (RSRQ) and Signal-to-Noise plus Interference Ratio (SINR). Base stations with the strongest RSRP, RSRQ, or SINR, acts as the serving cell to the nearest mobile users.

Cell selection in heterogeneous network is critical on the downlink that the uplink. Cell selection on the uplink is based on signals transmitted for the mobile equipment to the different base stations. Thus, Macrocell and Picocell receives equal signal strength from all users at the uplink. On the contrary, cell selection on the downlink is based on the strongest RSRP of the base station. UE compares RSRP of all Base Stations within its vicinity and associates itself to the Base Station with the highest RSRP. Consequently, Picocells serves only a few UE because of its low transmit power.

The discrepancy between the transmit power of the Macrocell and Picocell led to the introduction of Cell Range Expansion in LTE Release 10. The Cell Range Expansion is an innovative technique geared towards extending the footprint of Picocell in order to offload more traffic from Macrocell to smaller cells. The addition of a logical bias to the Picocell not only extends the coverage of the Picocell but also compensate for the difference between Macrocell and Picocell transmit power. The resultant effect of introducing a bias sees more UEs offloaded to Picocell, regardless of its transmit power. The Cell Range Expansion is performed without increasing the transmit power of the Picocell.

For the purpose of illustration, Figure 12 depicts the different types of cell selection scenarios which are prevalent in the co-deployment of Macrocell and Picocell. For UE1 and UE2, the cell selection criteria are based on the strongest downlink RSRP of the neighbouring cell to the UEs. In both cases, Macrocell and Picocell with the strongest RSRP serve as the serving cell of both UE1 and UE2, respectively. UE3 depicts a mobile user being served by a biased Picocell. Equation 3.1 gives the mathematical representation of the bias process. Biasing is performed without increasing the transmit power of the Picocell.

$$\text{Cell id Serving} = \operatorname{argmax}_i (\text{RSRP}_i + \text{Bias}_i) \quad (3.1)$$

Where Bias_i = Positive bias in dB and RSRP_i = RSRP of Picocell

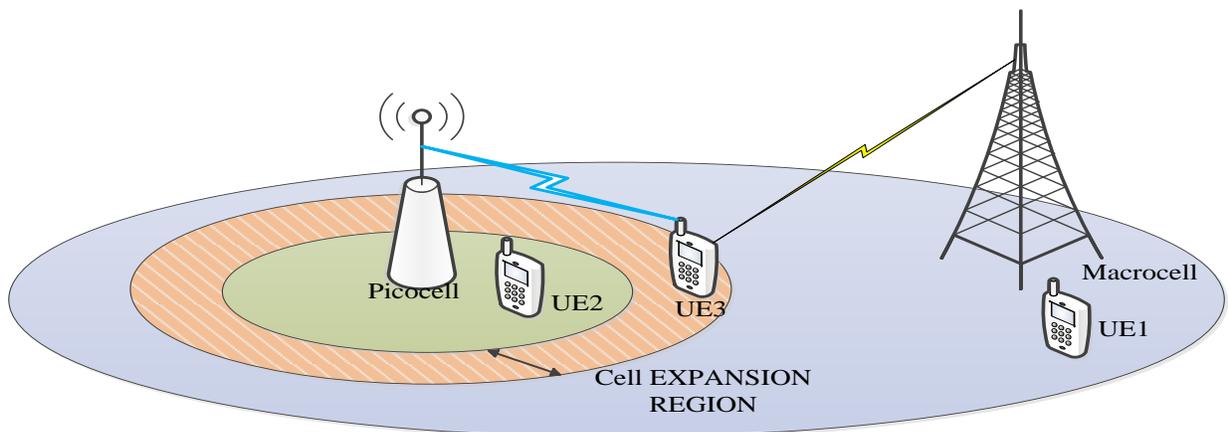


Figure 10. Cell selection with Cell Range Expansion in Heterogeneous network

Furthermore, the procedure of Cell Range Expansion is better understood by examining the handover procedure between a Macrocell and Picocell. As illustrated in Equation 3.1, a certain bias is added to the RSRP of the Picocell. It is summed and compared to the Macrocell RSRP before a handover decision is performed. UE 3 periodically measure the RSRP of the biased

Picocell and reports to the Macrocell. Subsequently, the Macrocell examines the report and checks if the RSRP of the biased Picocell is greater than its own RSRP.

In the event that the biased Picocell has a higher RSRP than the Macrocell, the Macrocell initiates the handover procedure by sending an HO (Hand Over) message via the X2 interface to the Picocell. The biased Picocell receives the HO message and reserves radio resources for the incoming UE, before sending an acknowledgment message via the X2 interface to the Macrocell. This activates the cell acquisition process and transfers UE 3 to the Picocell. Finally, a resource release message is sent from the Picocell to the Macrocell to end the handover process. In sum, the Macrocell handovers the UEs to Picocell with higher RSRP value, but this introduces severe interference into the network.

3.5. Interference Management in Heterogeneous Network

A critical challenge confronting the deployment of Heterogeneous network is interference between cells of the same tier and cells from different tiers. According to (Saqib, Hossain, Le, & Kim, 2012), there are two common types of interferences in Heterogeneous network. Co-tier interference occurs between LPNs (i.e. Picocell to Picocell) while Cross-tier interference occurs between a Macrocell and a Picocell. As UEs moves away from the center of the serving cell and leans towards the other neighbouring cell, the signal strength from the serving eNodeB decreases while the inter-cell interference increases, especially for cell edge UEs. Thus, proper handling of interference is critical to the performance of Heterogeneous network.

In GSM and UMTS network, interference management across base station is carried out by the Base Station Controller (BSC), which ensures fairness among a greater number of base stations. The advent of 4G network brings with it the possibility of base station cooperation. The X2 interface between an eNodeB and its neighbouring eNodeBs are harnessed to manage and control the inter-cell interference between both cells. Interference information is exchanged over

the X2 interface, making it possible for the eNodeBs to schedule radio resources in a manner that avoids inter-cell interference. Notably, interference management schemes are Inter-cell interference Coordination (ICIC) in LTE release 8 and enhance Inter-cell Interference Coordination (eICIC) in LTE release 10.

Furthermore, ICIC handles severe interference in cell edge user in homogeneous eNodeB deployment. The mode of operation of ICIC is simple. It assigns different Resource Block (RB) to the cell edge user in such a way that RBs of the serving cell and the adjacent eNodeBs do not overlap with each other. For two main reasons, ICIC fails to support interference management in LTE-Advanced. First, ICIC manages interference on the frequency domain, without paying any attention to interference on the time domain. Similarly, ICIC curtails interference within the traffic channel while leaving out interference on control channels. Therefore, eICIC replaces the use of ICIC in LTE Release 10.

The enhance Inter-Cell Interference Coordination was implemented in LTE Release 10 to support the operation of heterogeneous network and at the same time, overcome the limitations of the then ICIC in LTE Release 8. It uses power control, frequency, and time domain channel to cancel out the threat posed by interference across the multi-tier network. Unlike ICIC, eICIC performs interference management for both traffic channel and control channel of the LTE communication data channel. However, we shall restrict ourselves only to the interference management in the time domain.

3.5.1. Interference Management in Macrocell and Picocell deployment

Co-channel deployment of Macrocell and Picocell is a cost effective technique of achieving high spectral efficiency, especially in the spectrum-constrained network. In reality, bandwidth sharing between Macrocell and Picocell results in severe interference within the wireless network. For instance, in (Acharya, Gao, & Gaur, 2014:110), the authors describe the interference that occurs in a typical heterogeneous network. As in the case of a co-deployment of Macrocell and Picocell,

the cell causing the interference is known as the aggressor cell (Macrocell), the cell at the receiving end of the interference is known as the victim cell (Picocell) while the UEs experiencing the interference is called the victim UE. The severity of interference is felt when a large value of bias added to the Picocell.

Time-domain partitioning is a more efficient way of tackling interference in co-deployment of Macrocell and Picocell. Time domain partitioning is a subset of eICIC interference management. Its ability to adapt quickly to user distribution and variation in traffic load make it suitable for spectrum limit network (Brueck, 2011:1). Time domain partitioning of LTE resources between Macrocell and Picocell takes place over the X2 interface which enable backhaul coordination between cells of all tiers. The time partitioning adopts a technique known as Almost Blank Subframe introduced in eICIC in LTE release 10.

3.5.2. Almost Blank Subframe

By definition, Almost Blank Subframe is the minimum transmission subframe, where no data signal is transmitted from the Macrocell, except certain channel still working to guarantee backward compatibility to Release 8/9 UEs. In fact, ABS is regarded as a subframe with no activity. During an ABS, a cell transmits only the Common Reference Signals (CRS) and other signals necessary for channel condition monitoring. Consequently, this eliminates interference from PDCCHs of neighbouring cells.

Interestingly, ABSs are configured either as normal subframe or as Multicast Broadcast Single Frequency Network (MBSFN) subframe. They differ from each other in that, normal ABS still transmits CRS and PBCH signal, while the Subframe of MBSFN does not contain CRS signal. The fact that MBSFN generates less interference compared to normal Subframe makes it more effective in handling interference than normal ABS.



Figure 11. Basic eICIC principle showing Almost Blank Subframe

The concept of time domain eICIC (ABS) sees the muting of certain subframe of the aggressor cell in order to eliminate interference to the victim cell. Figure 13 illustrates the subframe pattern between an aggressor Macrocell and a victim Picocell. Normally, centralised UEs of Macrocell and Picocell are scheduled during normal subframe. However, the severity of interference from the Macrocell to the cell edge Picocell UE prevent the UE from being scheduled during normal subframe. In order to accommodate cell edge UEs, the Macrocell creates a protected (ABS) subframe which is exploited by the Picocell to schedule UE at the cell border region. In reality, the use of a large bias in heterogeneous network activates the need for more blank subframes to protect offloaded users.

Figure 14 illustrates the sequence for Almost Blank Subframe. The initiation process of ABS begins with the Picocell sending Load Information (L1) which contains Information Element (IE) to the Macrocell. Upon receiving the Load Information, the Macrocell respond accordingly by forwarding a similar L1 information embedded with the current ABS muting pattern to the Picocell. More so, by generating a Resource Status (RS) reporting initialization mechanism, the Macrocell inquire about the utilization of allocated ABS resources from the Picocell. In turn, an RS update with ABS status is sent from the Picocell to Macrocell. The Macrocell evaluates the received information and decides whether to deploy more subframes or reduce the number of

subframes before initiating a new ABS muting pattern. In the event of any change in the muting ABS pattern, the Macrocell notifies the Picocell via an ABS information message.

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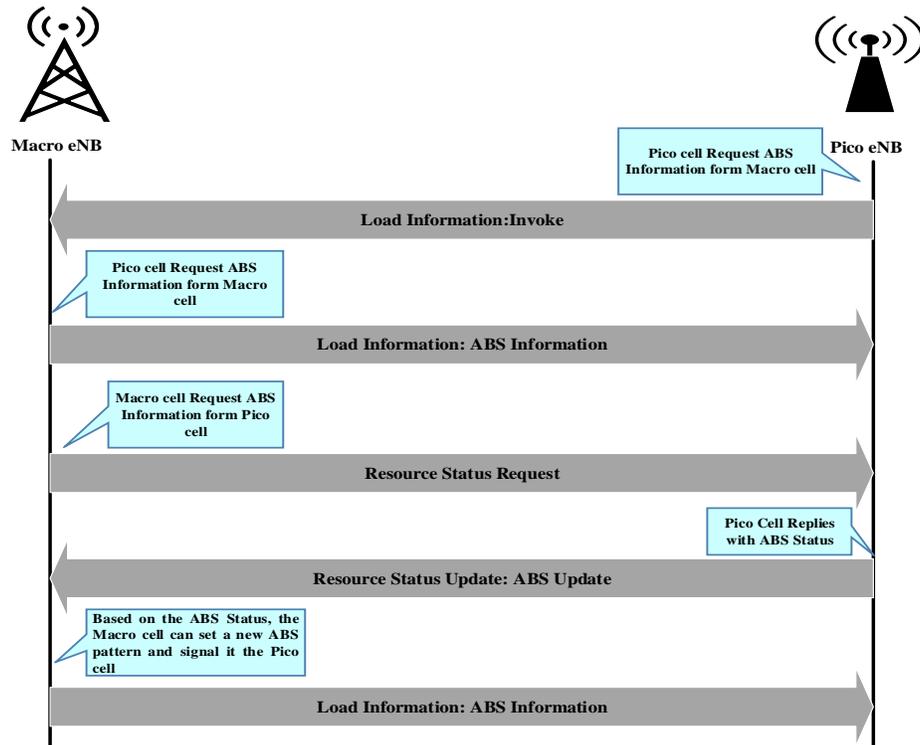


Figure 12. X2 signaling for distributed coordinated adaptation of an ABS muting pattern

4.0. System Level Simulator and Simulation Parameters

Simulations in wireless cellular networks are divided into two parts: link level simulation and system level simulation. The link level simulation narrows itself to studying the behaviour of the propagation channel between a single base station and a mobile user while a system level simulation studies the network performance of multiple cells and users. System level simulation offers a simplified and cost effective approach towards modeling network elements, operations and evaluating network performance than real life implementation. In addition, results from system level simulators are more precise and consistent than the analytical model.

For our simulation, we shall use an LTE-Advanced system level simulator developed by (Hitachi America Ltd, 2014) based on the parameters specified by 3GPP for homogeneous and heterogeneous cellular network. The simulator supports four scenarios: Urban Macro, Urban Micro, Hetnet conf1 and Hetnet conf4b. Whereas Urban Macro and Urban Micro models the typical LTE Macrocell and Microcell scenario, Hetnet conf1 and Hetnet conf4b are singularly designed to address simulation on heterogeneous network. The latter sees the overlaying of Picocells within the coverage area of Macrocell in a uniform and hot spot deployment scenario, respectively.

4.1. Network layout

The system level simulator uses a simplified cell layout. To this end, it consists of a centralized cell surrounded by 6 and 12 interfering cells at the first tier and second tier of the network, respectively. The overall description of the cell layout consists of 19 eNodeBs with 3 sector/cell site per eNodeBs. Likewise, for Hetnet conf1 and Hetnet conf4b configuration, Picocells are positioned at the cell edge region of each eNodeBs to enhance the network capacity and improve the data rate for cell edge users. UEs are evenly distributed over the entire network layout, except

for the Hetnet conf4b deployment. Hetnet conf4b uses a cluster arrangement of mobile user around the Picocell. Other factors taken into consideration during the preparation of the simulator are explained below.

4.1.1. Antenna Pattern

The antenna patterns are commensurate with the magnitude of the Macrocell and Picocell. Picocells, and UEs use an omnidirectional antenna pattern. However, following the guidelines stated in (ITU-R M.2135-1, 2010), the Macrocell antenna uses both horizontal and vertical radiation pattern. Equation 4.1 and 4.2 represent the horizontal and vertical antenna configuration for a Macrocell

$$A_H(\varphi) = -\min \left[12 \left(\frac{\varphi}{\varphi_{3dB}} \right)^2, A_{mh} \right] \quad (4.1)$$

$$A_V(\theta) = -\min \left[12 \left(\frac{\theta - \theta_{stilt}}{\varphi_{3dB}} \right)^2, A_{mv} \right] \quad (4.2)$$

Where $A_H(\varphi)$ and $A_V(\theta)$ are the attenuation offsets introduced by the horizontal and vertical antenna pattern with respect to the maximum antenna gain. As shown in Equation 4.3, the combined effect of using both horizontal and vertical antenna results in a 3-dimension antenna field pattern for a single Macrocell.

$$A(\varphi, \theta) = -\min [-[A_H(\varphi) + A_V(\theta)], A_M] \quad (4.3)$$

4.1.2. Path loss Model

The path loss model for Macrocell and Picocell are model according to the guideline of ITU-R M2135 standard. The complexity of the path loss varies with the geographical location of the UE to the base station, breaking point and the line of sight (LOS) probability. For UE located outdoors, the computational process is straightforward. Path loss for outdoor UEs is dependent on the LOS probability and the Euclidean distance between the base station and the mobile user. Conversely, path loss for indoor UEs requires more computational steps. This is because the path loss model considers other parameters such as the penetration loss and indoor path loss during the computation process. Penetration loss refers to losses generated when RF signal makes a transition for the outdoor environment to an indoor environment. While the indoor loss represents the losses within the building, the UE is located.

4.1.3. Channel Model and Simulation Metric

The channel mode is built on a Spatial Channel Model (SCM). An SCM uses the concept of “drops” to collate the network properties over a period. With exception to fast fading, a drop is a simulation interval with fixed channel properties. For instance, during a drop, the UE moves randomly from one node to another due to fast fading. Furthermore, the SCM uses three simple steps for generating the channel matrix for each scenario. First, the simulation environment is specified. This initiates the acquisition of all associated parameters related to the specified environment. Finally, the channel matrix is generated based on the input parameter.

Mathematically, we can represent the channel model by the constituent elements. The first simulation metric generated is the Coupling Loss (or the Link gain).

$$P_{RX} - P_{TX} = P_L + SF + AG + L_{misc} \quad (4.4)$$

Where P_{RX} and P_{TX} are transmitting power of the receiver and transmitter, respectively. The path loss, shadow fading, and antenna gain are given as P_L , SF and AG . All values in Equation 4.4 are in dB. The path loss and shadow fading vary with the carrier frequency and whether the UE is within the LOS and NLOS region. L_{misc} is the miscellaneous loss, such as feeder loss in Macrocell. Another metric is the Signal Interference Noise Ratio (SINR). The SINR is an indication of the overall performance of the cellular network.

$$SINR = \frac{Signal}{Interference + Noise} \quad (4.5)$$

The noise is constant while the interference is an aggregate of all interfering base stations apart from the serving base station.

4.1.4. Simulation Result

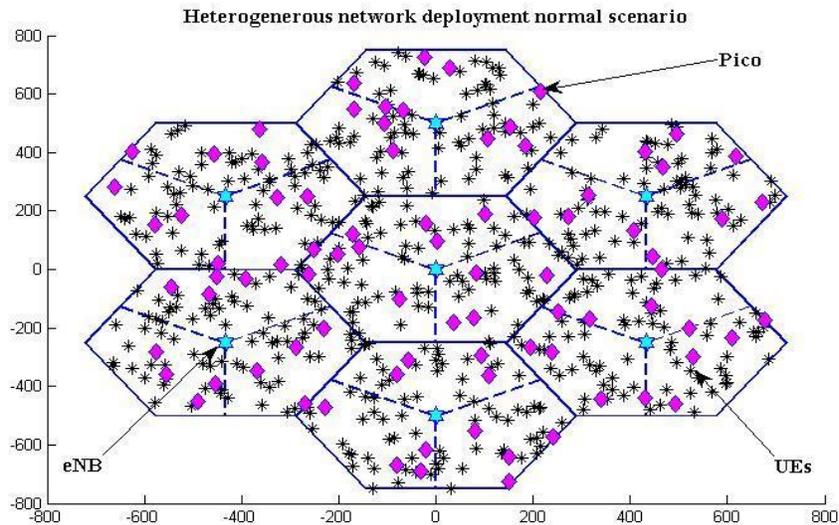


Figure 13. Heterogeneous network deployment normal scenario

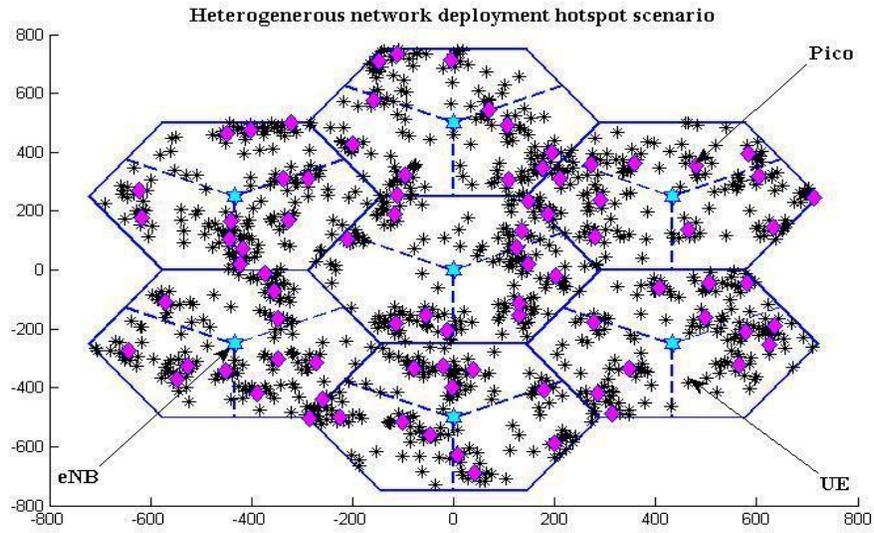


Figure 14. Heterogeneous network deployment Hot-spot scenario

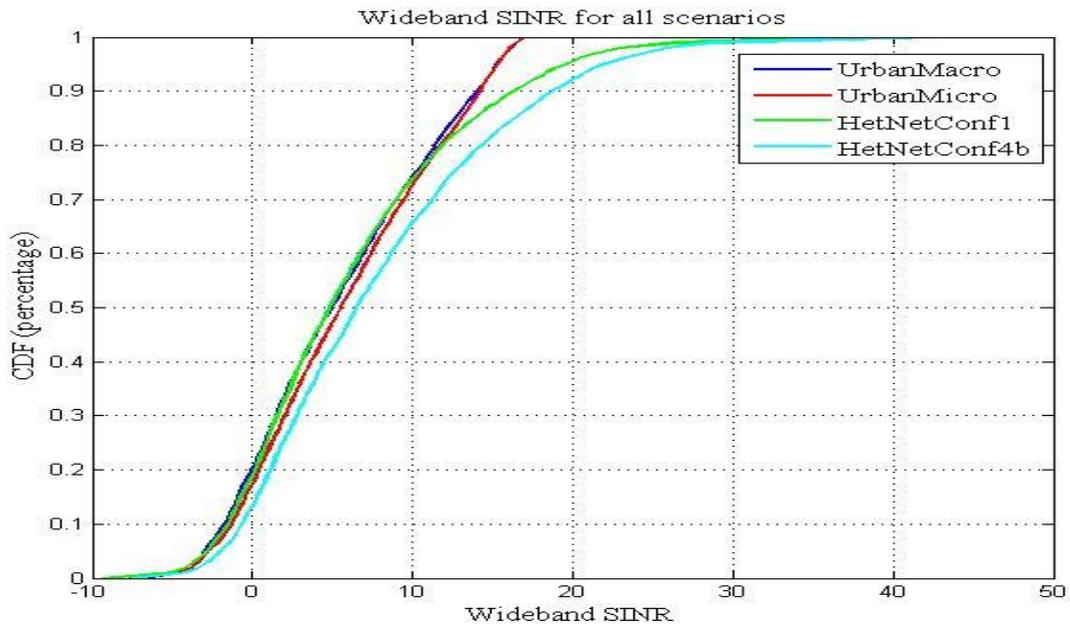


Figure 15. Wideband SINR for all scenarios

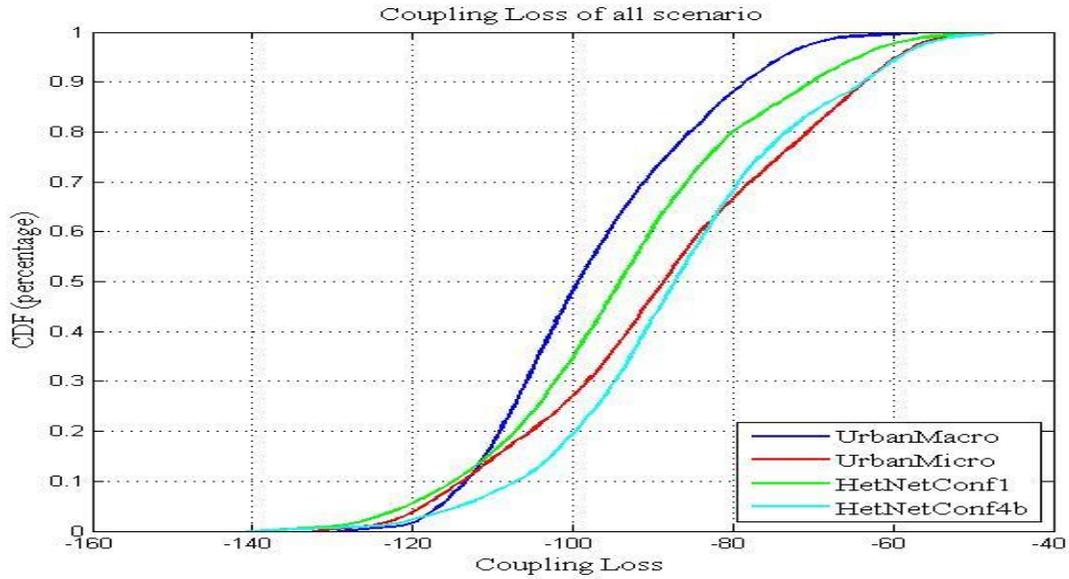


Figure 16. Coupling Loss for all scenarios

4.2. System Model

In this thesis, we shall examine the benefit of deploying Picocell in Macrocell environment in order to boost the overall energy efficiency of the LTE-Advanced system. In this regards, we introduced the concept of cell range expansion and almost blank subframe in the previous chapter, to optimize the performance of the Picocell and ensures a high data rate for cell edge users. The novelty of this thesis sees the introduction of three cell selection criteria for assessing the performance of heterogeneous network.

4.2.1. Cell Selection Criteria

As part of the simulation process, we shall consider three cell selection criteria that influence user association and the overall system performance. The first cell selection criterion is based on conventional cell selection process. As expected, a UE is inclined to choose the base station with the strongest Reference Signal Received Power (RSRP) as its serving cell. This criterion favours the selection of Macrocell by a sizeable amount of UE due to its higher transmit power. Equation 4.6 illustrates cell selection criteria using the highest RSRP.

$$j^* = \arg \max_{j \in M \cup P} RSRP_{j,i} \quad (4.6)$$

Moving on, in order to exploit the benefit of cell splitting and offload more users to Picocell, a second cell selection criterion based on the biased cell selection was introduced. As shown in Equation 4.7.

$$j^* = \arg \max_{j \in M \cup P} \{RSRP_{j,i} + bias_j\} \quad (4.7)$$

Where $bias_j$, a positive bias added to the Picocell

The biased cell selection criterion facilitates offloading of more UEs from the Macrocell to the Picocell, even if the Macrocell has a better signal strength. Consequently, the SINR of cell edge users attached to Picocell decreases because of strong interference from neighbouring Macrocell.

Finally, the last cell selection criterion is based on the ABS ratio. This is based on research work done by (Oh & Han, 2012). Since the data rate of each user is proportional to the scheduling opportunities of the target cell, the cell with highest expected data rate is selected as the serving cell. With this in mind, the cell selection process is explained as follows.

In the event of a UE selecting a Macrocell at a subframe n , the computation of the SINR of that UE is given as shown in Equation 4.8.

$$SINR_{m,i}(n) = \frac{h_{m,i}(n)P_m(n)}{I_i^{macro}(n) - h_{m,i}(n)P_m + I_i^{pico}(n) + \sigma_i^2} \quad (4.8)$$

$$I_i^{macro}(n) = \sum_{m=1}^M h_{m,i}(n)P_m(n) \quad (4.9)$$

$$I_i^{pico}(n) = \sum_{p=1}^P h_{p,i}(n)P_p(n) \quad (4.10)$$

Where the $h_{m,i}(n)$ and $h_{p,i}(n)$ denotes the channel coefficient at the subframe n from the Macrocell m and Picocell p to the i^{th} user. The transmit power of the Macrocell and Picocell at subframe n is denoted as $P_m(n)$ and $P_p(n)$. $I_i^{macro}(n)$ and $I_i^{pico}(n)$ represent the sum of the interference of the Macrocells and Picocells, respectively. The noise power of the i^{th} user is given as σ_i^2 . In a similar vein, when i^{th} user selects a Picocell at subframe n , the SINR is given as shown in Equation 4.11

$$SINR_{p,i}(n) = \frac{h_{p,i}(n)P_p(n)}{I_i^{macro}(n) \cdot \beta_m + I_i^{pico}(n) - h_{p,i}(n)P_p(n) + \sigma_i^2} \quad (4.11)$$

Where β_m represents an indication function. When the subframe n is an ABS, a value of 0 is assigned to β_m . Conversely, should subframe n be a non-ABS subframe, a value of 1 is assigned to β_m . Consequently, Picocells has separate SINR value for ABS and Non-ABS subframe.

$$SINR_{p,i}(n) = \begin{cases} SINR_{p,i}^{ABS} & \text{if } n \text{ is ABS} \\ SINR_{p,i}^{nonABS}, & \text{otherwise} \end{cases} \quad (4.12)$$

Moving on, the expected data rate of when a user selects a Macrocell is given as

$$E\{R_i^{macro}\} = (1 - \tau) \log_2(1 + SINR_{m,i}) \quad (4.13)$$

Where τ is the ABS ratio. It indicates the ratio of the almost blank subframe to the number of the non-ABS subframe. Similarly, the expected data rate when a user selects a Picocell is given as:

$$E\{R_i^{pico}\} = (1 - \tau) \log_2(1 + SINR_{p,i}^{nonABS}) + \tau \log_2(1 + SINR_{p,i}^{ABS}) \quad (4.14)$$

For a small value of τ the probability that a user selects a Picocell as its serving cell is low. Expectedly, an increase in the value of τ corresponds to an increase in the number of users selecting the Picocells as their serving cell. Finally, the user compares the data rates of the Macrocell and the Picocell and chooses the cell with the highest data rate as it serving cell.

$$j^* = \underset{j \in M \cup P}{\operatorname{argmax}} E\{R_i^j\} \quad (4.15)$$

Finally, the cell selection after much mathematical manipulation is given as

$$SNR_{p,i} > (SNR_{m,i} + 1)^{1-\tau} - 1 \quad (4.16)$$

Where $SNR_{m',i}$ and $SNR_{p',i}$ are the maximum signal to noise ratio of the Macrocell and Picocell, respectively.

4.2.2. Power model

For the purpose of simulation, we shall adopt a power model developed by (Richter, Fehske, & Fettweis, 2009). The power model establishes a direct relationship between the average total power consumption of the base station and the average radiated power per site.

$$P_{total} = \partial \cdot P_{tx} + P_{fixed} \quad (4.17)$$

Where P_{total} and P_{tx} stand for the total power consumed and the radiated power per site, respectively. The impact of the power amplifier, feeder loss and other power consumed during transmitting are factored into the model by the coefficient ∂ . More so, P_{fixed} represents power consumed regardless of whether the Base Station is transmitting or not. Equation 4.17 would be used in the latter part of our simulation to compute the total power consumed by Macrocell and Picocell as a function of their transmit power.

4.2.3. Energy Efficiency Metric

From the foregoing, our focus has been on the energy efficiency of wireless systems. We intend to exploit the amount of data transmitted using a minimal amount of energy. Accordingly, for a Base Station transmitting with transmit power P during a time interval, the energy consumed is modelled as

$$\Delta e = \Delta t \cdot P \quad (4.18)$$

Therefore, the energy efficiency in bit per joule is formulated as

$$E_s = \frac{R}{\Delta e / \Delta t} \quad (4.19)$$

Which is equivalent to

$$E_s = \frac{R}{P} \quad (4.20)$$

Where R is equivalent to the data rate and P is the average total power. The unit of E_s is given as bits/s/Joule.

Finally, considering a heterogeneous network with N number of Picocell per Macrocell, the overall cell energy efficiency is given as

$$E_{s,cell} = \frac{R_{macro} + \sum_{n=1}^N R_{pico_{i,n}}}{P_{macro} + \sum_{n=1}^N P_{pico_{i,n}}} \quad (4.20)$$

Where R_{macro} and $R_{pico_{i,n}}$ represent the average data rate of the Macrocell and n^{th} Picocell respectively. The corresponding power consumed by Macrocell and n^{th} Picocell is given as P_{macro} and $P_{pico_{i,n}}$, respectively. Finally, we proceed to compute the area energy efficiency.

4.2.4. Area Energy Efficiency

Another key metric for quantifying the energy efficiency of the heterogeneous network is the Area Energy Efficiency. The Area Energy efficiency computes the overall network efficiency with respect to the entire coverage area of the wireless network. Its unit is given in bit /Joule/unit area supported by each cell. After initial user association, each base station serves a specific

number of UE within a particular area with respect to the UE proximity and the transmit power of the wireless nodes.

Mathematically, the Area Energy Efficiency of a network, regardless of its composition is given as

$$A_{EE} = \frac{E_e}{S} \quad (4.21)$$

Where E_e and S represent the cell Energy Efficiency and the area covered by a certain Base Station with unit in Km^2 . Now the overall Area Energy Efficiency for the co-deployment of Macrocell and Picocell is given as:

$$A_{EE,cell} = \frac{E_{e,macro} + \sum_n^N E_{e,pico_{in}}}{S_{macro} + \sum_{n=1}^N S_{pico_{in}}} \quad (4.22)$$

Where $E_{e,macro}$ denotes for the energy efficiency of the Macrocell with a coverage area of S_{macro} . Similarly, $E_{e,pico_{in}}$ denotes the energy efficiency of n^{th} Picocell with coverage area of $S_{pico_{in}}$.

Table 3. Simulation Parameters

Parameter	Values
Carrier Frequency	2.4GHz
Bandwidth	10MHz
Channel model	Fast fading model disable
Max macro station power	46dBm
Max pico station power	30dBm
Number of UE per sector	25
Shadowing standard deviation	Macro-to-UE = 8dB Pico-to-UE = 10dB
Penetration loss	Macro-to-UE = 20dB Pico-to-UE = 20dB
Antenna pattern	$A(\varphi, \theta) = -\min[-[A_H(\varphi) + A_V(\theta)], A_M]$
Antenna gain	Macro=17dBi, Pico= 5dBi
Thermal noise	-174dBm/Hz
Noise figure	7dB
ABS ratio	0.5
Bias value for Cell Range Expansion	12 dB
Scheduling	Proportional fair scheduling

5.0. Simulations and Results

5.1. Simulation stages

In previous chapters, we discussed the challenges, identify the problems, and proffer solutions to enhancing the energy efficiency of the mobile wireless network. In the same vein, we highlighted the potential and benefits of altering the network architecture from the conventional homogeneous network deployment to more energy-efficient heterogeneous network. We concluded by explaining key concepts related to heterogeneous network and how they can be utilized to optimize the performance of the wireless system.

In this chapter, we shall perform simulation on the LTE-Advanced Downlink system. There are three stages of simulations. The first stage covers the computation of basic concepts such as Coupling Loss (or Link gain), Signal-to-Interference plus Noise Ratio (SINR), User throughput and cell range expansion. Similarly, the second stage present results from cell selection criteria and resource allocation. While the third stage of our simulation is wholly dedicated to the performance analysis of heterogeneous network with respect to two metric, namely, Energy Efficiency (EE) and Area Energy Efficiency (AEE). The simulations would be performed in the normal and hot-spot deployment scenario.

5.2. Performance Evaluation of Macrocell versus Macrocell plus Picocell

In this section, we examine the impact of adding Picocell to conventional Macrocell. In this regards, we compare the performance of using Macrocell only and a combination of Macrocell plus Picocell (Heterogeneous network) using an LTE-Advanced downlink system level simulator. The simulation result covers the Coupling Loss, SINR, UE throughput and the Biased SINR of both homogeneous and heterogeneous networks.

5.2.1. Coupling Loss

The coupling loss indicates the minimum distance loss measured between the transmitter and the receiver. Figure 19 compares the Coupling Loss of the Macrocell only and Macrocell plus Picocell. Macrocell plus Picocell has a higher Coupling Loss of than that of the Macrocell only. This is due to the fact that Picocell has a better link gain and brings the base station closer to the UE.

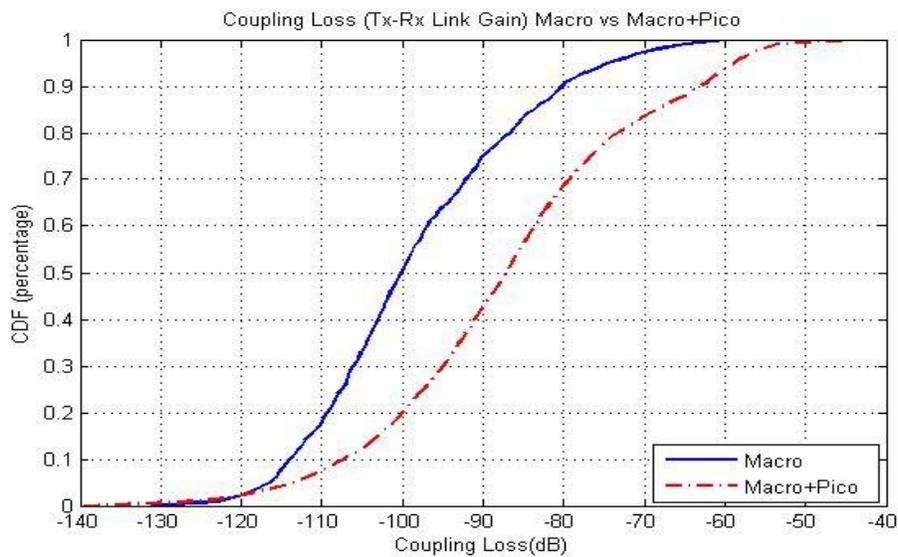


Figure 17. Coupling Loss between Macrocell versus Macro+Picocell

5.2.2. SINR

The SINR is a means of estimating the spectral efficiency of any wireless communication system. Accordingly, low SINR and high SINR correspond to lower and higher spectral efficiency respectively. Figure 20 depicts the CDF curve of the average UE SINR for Macrocell and Macrocell plus Picocell scenarios. Barring any use of interference management, the deployment of Macrocell plus Picocell has a better SINR performance compared to Macrocell

deployment only. The improvement in the performance of Macrocell plus Picocell is credited to the deployment of Picocell at the cell edge of the Macrocell. The proximity of the Picocell to the cell edge user offers a better link gain to the cell edge UEs, while at the same time, the cell splitting gain of Picocell, is used to provide a higher data rate to the User connected to the Picocell.



Figure 18. Wideband SINR between Macrocell and Macro+Picocell

5.2.3. UE throughput

The benefit attached by offloading mobile user dynamically from Macrocell to Picocell enhances the overall UE throughput. Figure 21 illustrates the CDF curve of the average UE throughput between Macrocell and Macrocell plus Picocell. It is clear that UEs are able to attain a higher throughput under the Macrocell plus Picocell deployment than the case of Macrocell deployment only.

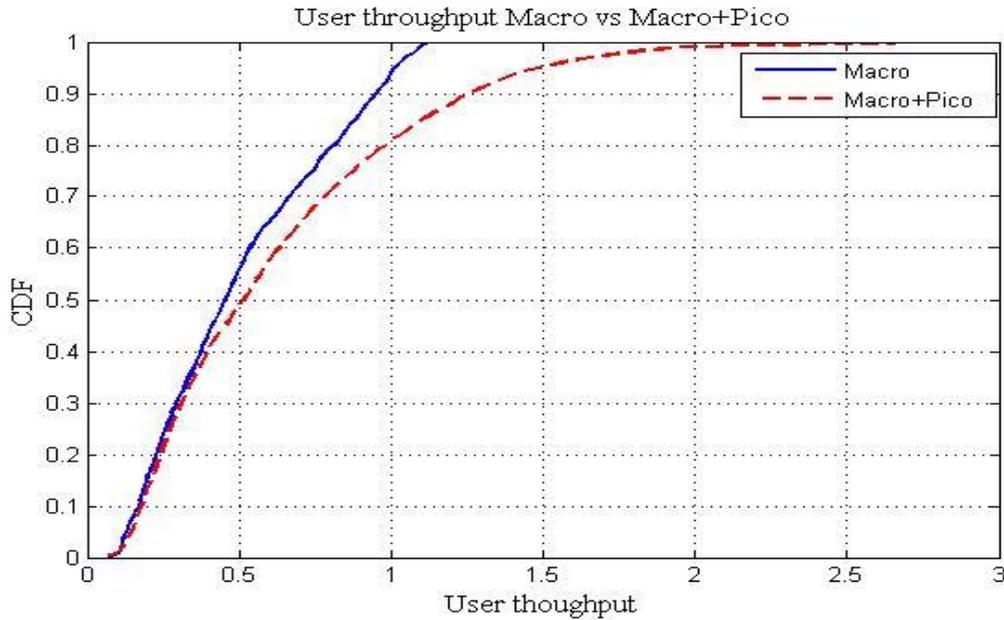


Figure 19. User throughput Macro vs. Macro+Picocell

5.2.4. Cell Range Expansion

The discrepancy in the transmit power of Macrocell and Picocell, coupled with the strong interference from Macrocell to the Picocell, renders most Picocells redundant. Despite the limited resources Macrocell and traffic overloading, most UEs are inclined to select the Macrocell as their serving cell. In the light of this, it cancels out the benefit of adding Picocell to Macrocell. As a mean of resolving this issue, cell range expansion was introduced.

Furthermore, in Figure 22 and Figure 23, we observe the impact of cell range expansion on the UEs in the co-deployment of Macrocell and Picocell. Using a total of 1425 users and a biased of 6dB to Picocells, the simulation was run for both normal and hot-spot deployment. As shown in

Figure 22, the number of UE offloaded from the Macrocell to the Picocell increases with the bias and the number of Picocell per sector.

Figure 23 shows the CDF for average UE SINR with a bias value of 0, 6, 12, and 15 dB. The footprint of the Picocell and the number of UEs offloaded from Macrocell to Picocell increases as the value of bias increases. As shown in Figure 23, the value of the SINR decreases as the value of the bias increases. For two reasons, the performance of the system declines with an increase in bias. Firstly, base stations with lower RSRP serve as the serving cell of offloaded UEs. Consequently, increasing bias result in the UEs having SINR values lower than zero. Secondly, cell edge users attached to bias Picocell experience severe interference from neighbouring Macrocell. This emphasizes the need for an efficient interference management technique when a large value of bias is used.

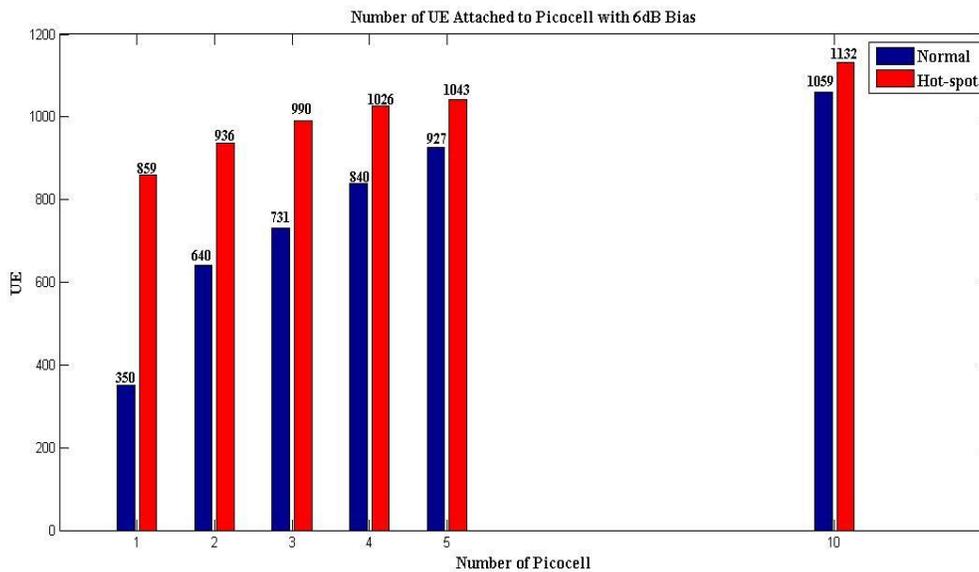


Figure 20. Bar charts showing UEs associated to Picocell under normal and hotspot scenarios

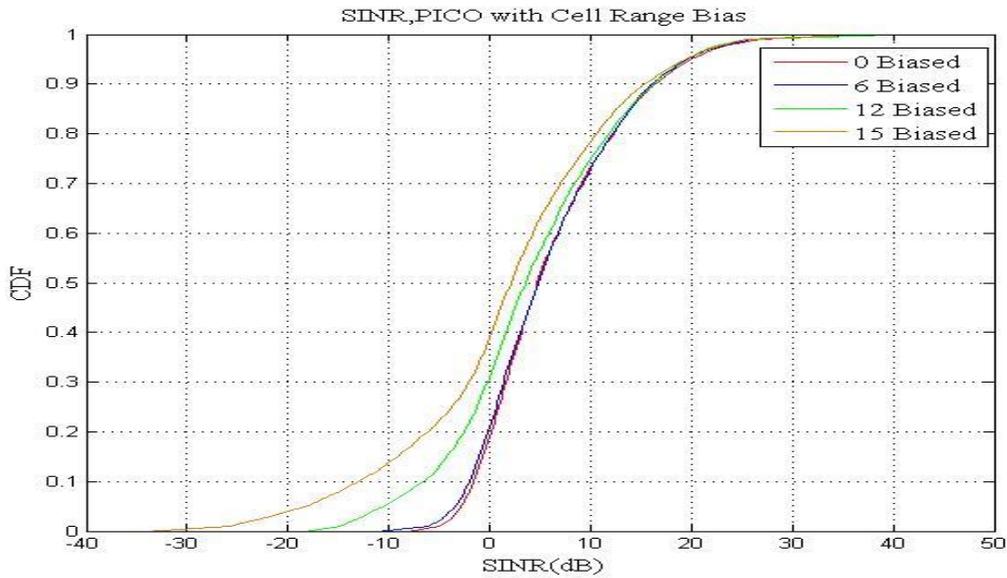


Figure 21. The CDF for average UE SINR with various biased values

5.3 Cell Selection Criteria and Resource Allocation

Earlier in chapter 4, we discussed three types of cell selection techniques for choosing the serving cell in heterogeneous wireless network. We mentioned the conventional method, using the maximum RSRP (Equation 4.6); the biased method, using the combination of the maximum RSRP+Biased (Equation 4.7) and finally, the cell selection based on the higher data rate (Equation 4.15). In this section, we evaluate the performance of each cell selection technique to find the best in term of performance.

The parameters for evaluation is based on the cell average spectrum efficiency and Macrocell selection ratio. The cell average spectrum efficiency denotes the average cell throughput per 1Hz for all nodes in the network while the Macrocell selection ratio represents the number of UE who select the Macrocell as their serving cell. The simulator uses a varying amount of bias value and subframe ratio.

From a technical perspective, the bias and ABS ratio dictate the performance of the average data, SINR, and Macrocell selection ratio. Regardless of the bias, low level of ABS corresponds to lower data rate, SINR, and lower selection of Picocell. This is because only 20 percent of Macrocell subframes are restricted from transmitting while the remaining subframes are transmitting in synchronism with Picocell. As shown in Figure 24, an increase in the subframe ratio results in a lower Macrocell selection ratio, especially for the high data rate selection technique. This translates to better performance of the network with regards to the SINR, average UE throughput, and cell edge capacity.

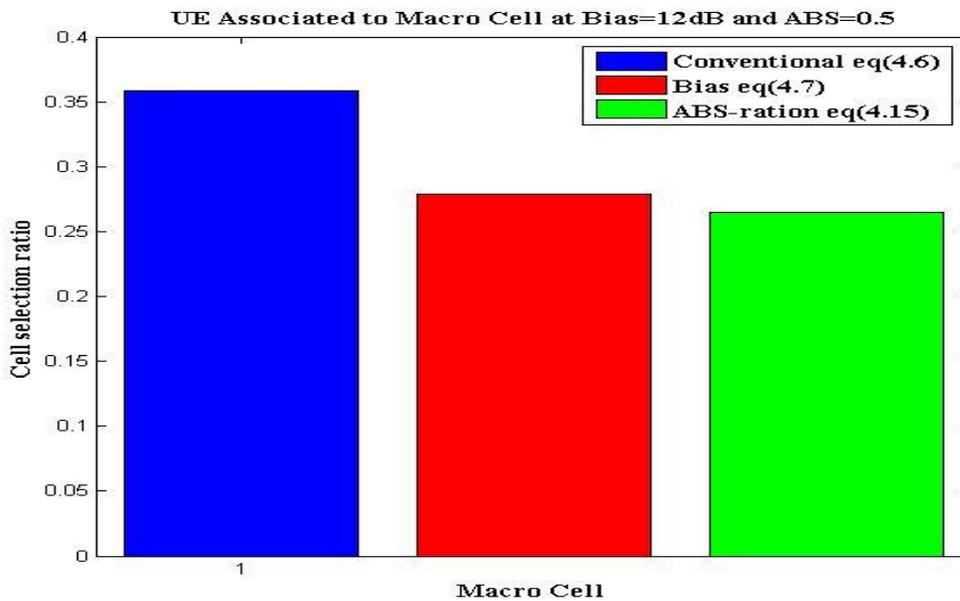


Figure 22. Comparison Of Macrocell Selection Ratio of the three cell selection criteria with Bias=12db And Abs=0.5

Similarly, a low ABS ratio is an indication that UE offloaded from the Macrocell to the Picocell will experience lower data rate for all cell selection techniques. However, increasing the ABS ratio results in more offloaded UE having higher data rate and a slight improvement in the average user throughput (as shown in Figure 25), especially for the expected data rate cell

selection scheme. Table IV summarises the performance of each cell selection criteria, using different values of bias and ABS ratio. For the third part of our simulation, we shall use the expected data rate technique as our choice for cell selection and resource allocation.

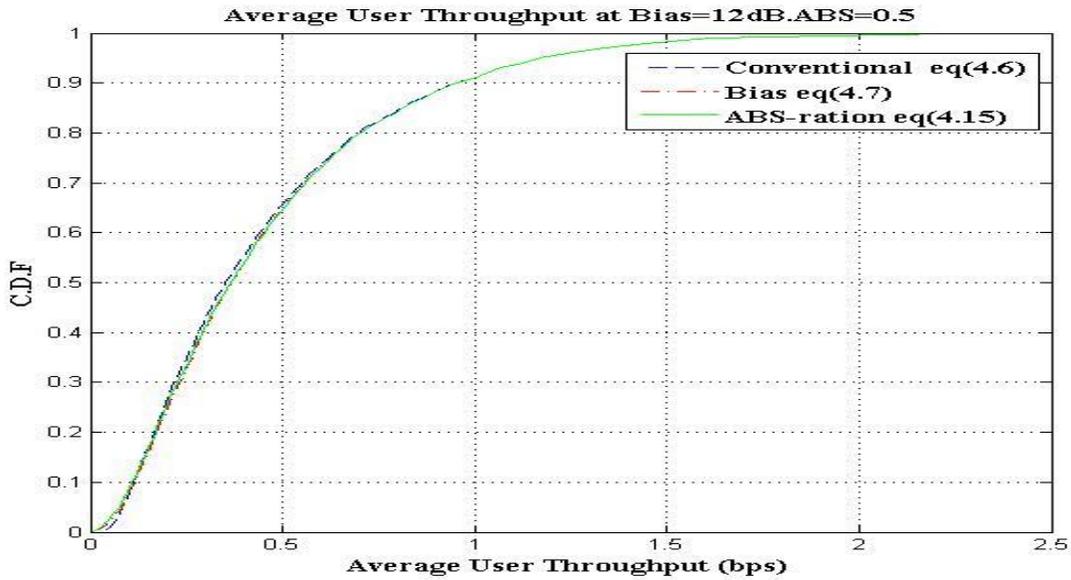


Figure 23. Comparison of CDF of Average User Throughput of the three cell selection criteria with bias=12dB and ABS=0.5

Table 4. Simulation Result for Cell Selection Criteria

Parameter	Max RSRP	Biased	Max data rate	Max RSRP	Biased	Max data rate
	Biased=6dB,ABS=0.2			Biased=12dB,ABS=0.5		

Cell average Spectrum efficiency (bps/Hz/cell)	7.555	7.9749	8.0060	7.9959	8.1177	8.1348
UE associated to Macrocell(%)	36.93%	31.27%	31.24%	36.07%	32.86%	29.59%
	Biased=12dB,ABS=0.2			Biased=12dB,ABS=0.5		
Cell average Spectrum efficiency (bps/Hz/cell)	7.6596	8.1017	8.1689	8.0606	8.1338	8.2320
UE associated to Macrocell(%)	35.68%	28.00%	26.44%	36.28%	27.71%	26.22%

5.4. Energy Efficiency and Area Energy Efficiency Metrics

In this section of our simulation, we compare the performance of normal deployed Picocell against cluster deployed Picocell, using the average cell capacity, Energy Efficiency (EE) and Area Energy Efficiency (AEE) as our performance metric. For cluster (hot-spot) cell deployment, the UEs cluster around the Picocell with some minimum distance constraint. The simulator uses a Spatial Channel Model (SCM) without fast fading. For both scenarios, the arrangement of the Picocell changes as the number of Picocell increases. Whereas Picocell 1,2,3,4 are arranged at the cell edge of the Macrocell, Picocell 5 and above, are randomly deployed within the Macrocell.

In order to curtail interference and at the same time, conserve excess energy consumption, we resort to a gradual reduction of the Macrocell transmit power to keenly observe the overall Energy Efficiency (EE) and Area energy Efficiency (AEE) of the network.

5.4.1. Cell Capacity

Figure 26; depict the average cell capacity against the number of Picocell for the normal scenario. From our observation, the cell splitting gain of Picocell enhances the performance of the network. Thus, the cell capacity increases with the number of Picocell. However, as the number of Picocell certain overlap are introduced into the system, which cause the system to a slight glitch in performance due to co-channel interference.

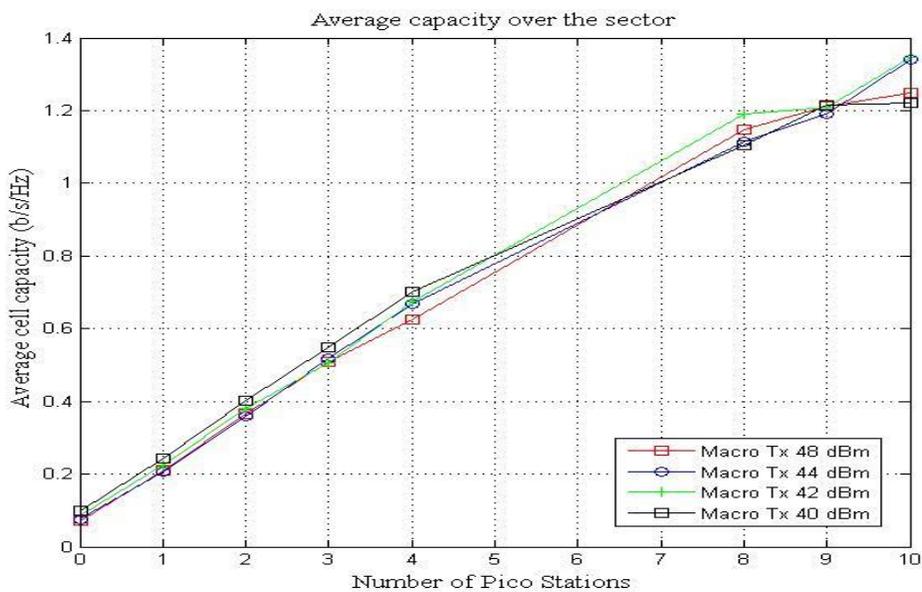


Figure 24. Average capacity comparison under normal scenario

As shown in Figure 27, the cluster deployment of Picocell achieves higher cell capacity with an increase in Macrocell transmit power. Besides the improvement of the performance with the increase in transmits power, for the same number of Picocell, the cell capacity of the cluster deployment is two times higher than that of the normal deployment. This is because the UEs are

closer to the Picocell in hot-spot scenario than in normal scenario. The anomaly observed at nine Picocells, is due to severe interference within the cell.

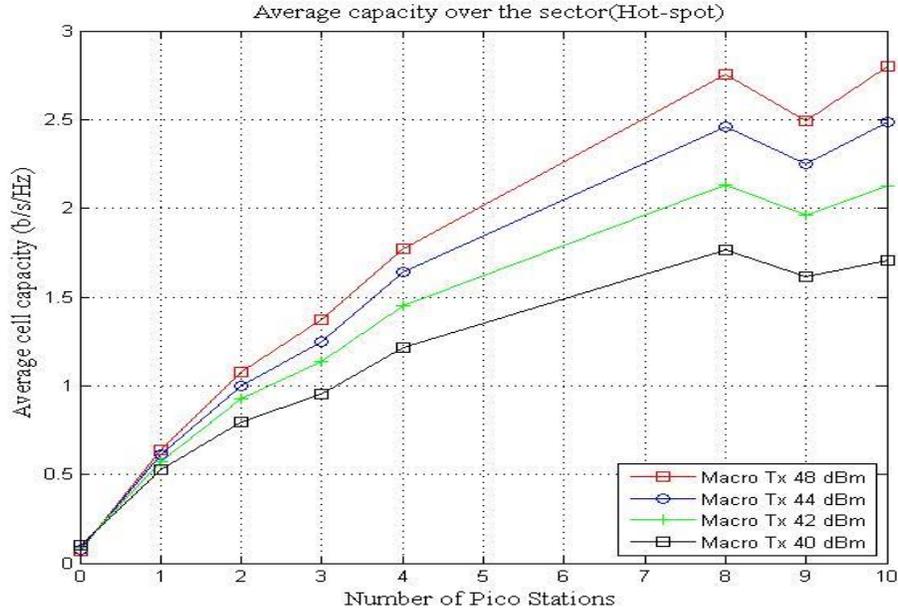


Figure 25. Average capacity comparison under cluster (Hot-spot) scenario

5.4.2. Energy Efficiency

Furthermore, we move on to compare the Energy Efficiency of both normal and cluster scenarios. We evaluate the performance of the average cell capacity against the overall power consumption of the network. As proposed in chapter 4, we adopted a unified power model for both Macrocell and Picocell. The aggregate power for each Macrocell is: $\alpha_{macro} = 3.8$, multiplied by the transmit power of the Macrocell, plus $P_{fixed_macro} = 68.8w$. While that of the Picocell is: $\alpha_{pico} = 5.5$ multiplied by the transmit power of the Picocell, plus $P_{fixed_pico} = 38w$

Figure 28 illustrates the performance of the normal deployment of Picocell with respect to the cell energy efficiency. At zero Picocell (i.e. Homogeneous Macrocell network), the Energy Efficiency is far lower than that of the heterogeneous network. More so, the value of the EE rises steadily from 1 Picocell per sector to 4 Picocell per sector before a steady decline set in as the number of Picocell increases. In fact, at 4 Picocell and 44 dBm; Energy Efficiency of about 111.4% can be achieved. In addition, Figure 29 shows the energy efficiency of cluster Picocell. Although the hot-spot scenario attains a higher EE in of than normal scenario, the performance is unstable. The EE fluctuates for Picocell 1 to 4, but it steadily decreases as the number of Picocell increases.

A notable feature common to both scenarios is that the energy efficiency reaches its peak at small number Picocell per cell and diminishes as the number of Picocell increases. This calls for a trade-off between system capacity and overall energy consumption. The densification of small cells should be commensurate to the ratio of system capacity to the overall energy consumption of the system.

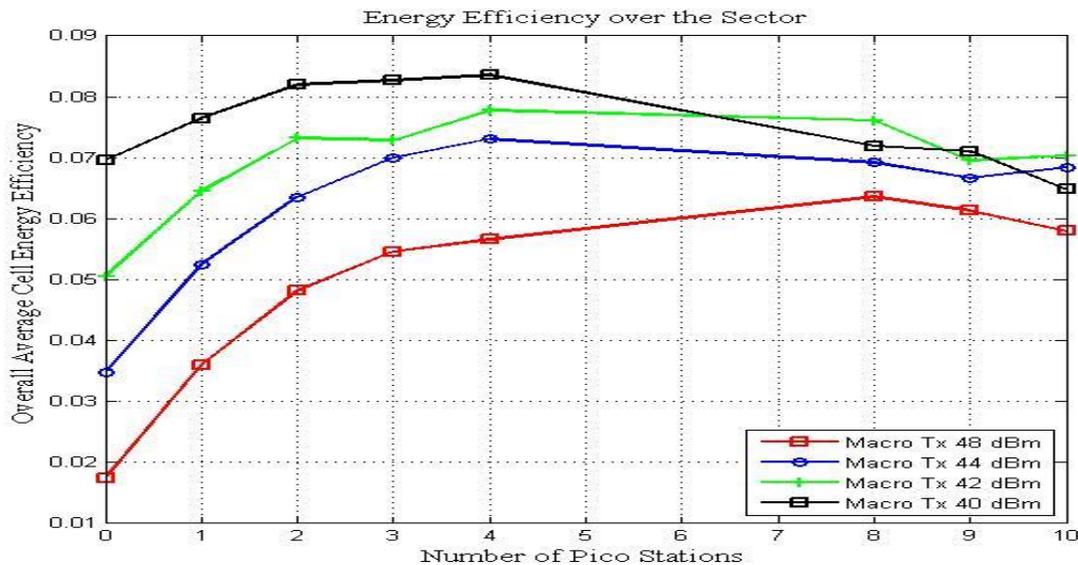


Figure 26. Energy Efficiency comparison under normal scenario

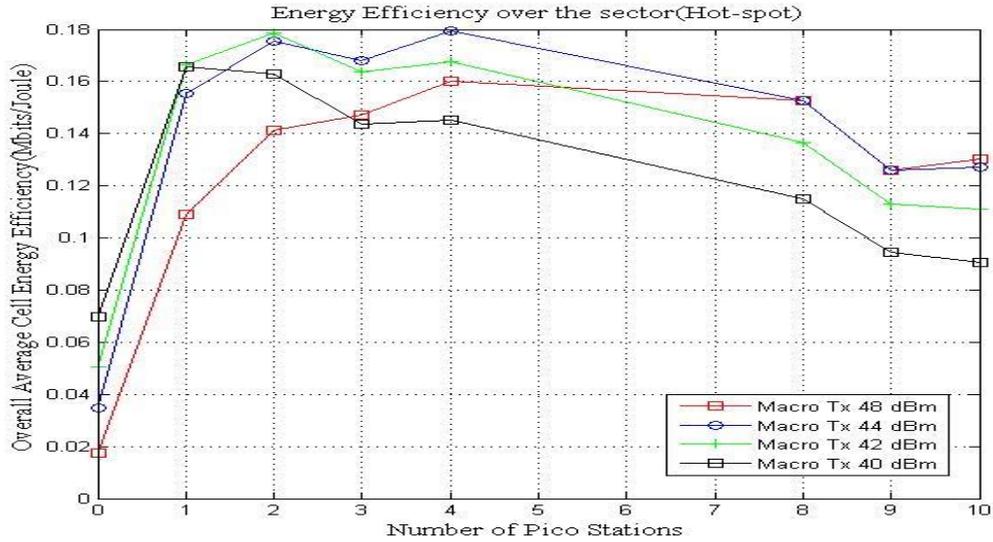


Figure 27. Energy Efficiency comparison under cluster (Hot-spot) scenario

5.4.3. Area Energy Efficiency

The AEE is a metric that assesses the energy efficiency with respect to the overall cell site. The AEE is measured under different inter-site distance. Table 5 depicts the transmit power of Macrocell where a large proportion of area covered by Macrocell is above a pre-defined SINR value of -4dB.

Table 5. Macro TX power for different cell sizes

Inter site distance(m)	600	900	1200	1500	1800
TX power(dBm)	38	40	41	44	48

A notable observation in Figure 30 and Figure 31, the AEE of heterogeneous network outperforms that of a conventional Macrocell network. This validates the use of Picocell in extending network coverage and increase capacity of wireless networks. Additionally, we also

observe that the hot-spot arrangement performs better than the normal scenario at all stages of increasing cell size. In conclusion, the overall performance of the AEE depreciates as the cell size becomes larger; this is because the Energy Efficiency of the entire cell decreases with increasing cell area and power consumption.

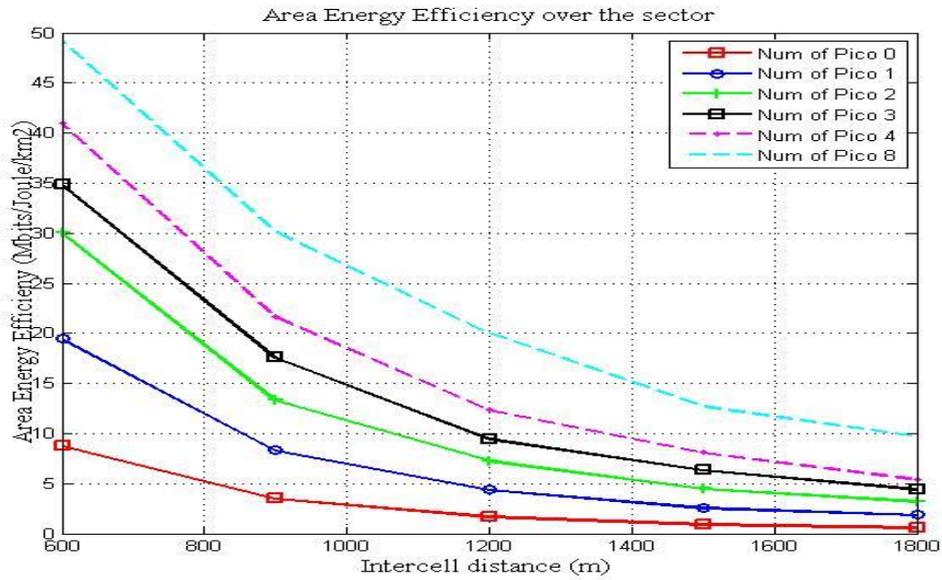


Figure 28. Area energy efficiency under normal scenario

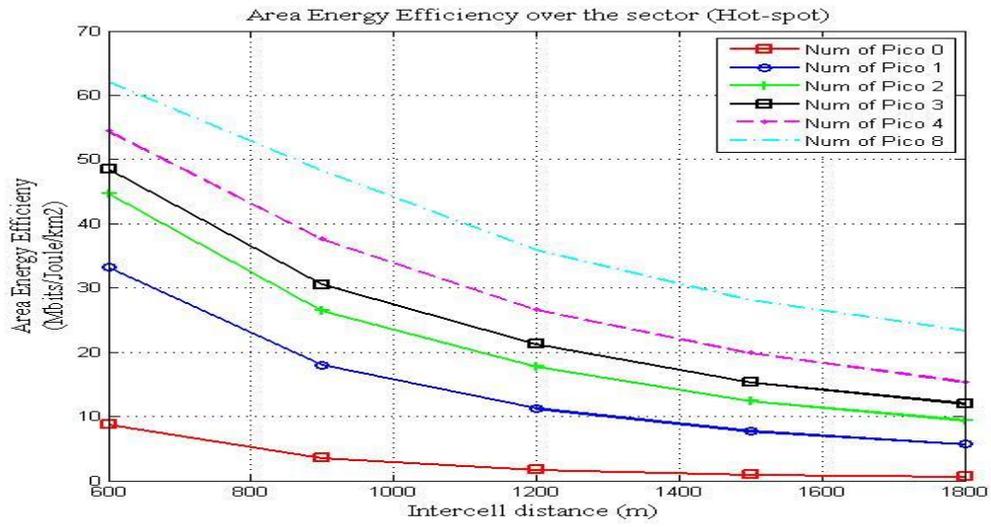


Figure 29. Area energy efficiency under hot-spot scenario

6.0. Conclusion and Future Work

6.1. Conclusion

We have examined the pressing issue of energy efficiency in wireless mobile networks. We started by evaluating the current state of energy consumption in wireless network and its severe implication to mobile wireless operators in terms of OpEX and carbon emission. More so, we introduced the concept of Heterogeneous network as a mean of improving the energy efficiency and the overall performance of the mobile network. We performed several simulations to assess the impact of heterogeneous network on the wireless mobile network using techniques like cell range expansion and Almost Blank Subframe. Finally, we assessed the cell capacity, energy efficiency, and area energy efficiency of the heterogeneous network using a normal and cluster scenario.

As shown in our simulations, heterogeneous network remains the simplest and the most cost-effective means of increasing spectral efficiency per unit area of mobile wireless network. Besides reducing the transmit distance between the base station and UEs, heterogeneous network offers better QoS and efficient spectrum reuse. Taken together, the above-mentioned quality results in a better link gain, SINR and user throughput for heterogeneous network compared to homogeneous network. More so, the introduction of cell range expansion and Almost Blank Subframe plays a vital role in influence cell selection process and resource allocation. From our observation, network performance improves with a large bias value and a significant Almost Blank Subframe ratio.

In summary, heterogeneous network has a higher average cell capacity, Energy Efficiency (EE), and Area Energy Efficiency (AEE) than homogeneous Macro-centric network. For both normal and cluster (hot-spot) scenario, a higher Energy Efficiency and Area Energy Efficiency were obtained. However, cluster deployment of Picocells performs better in all ramifications than a normal deployed Picocell. Finally, Heterogeneous network validates our claim as a means of

reducing the energy consumption of wireless mobile network and enhancing overall system performance.

6.2. Future Work

For future work, the following areas should be considered. It is necessary to find an appropriate bias value that results in the optimum network performance. Similarly, the use of adaptive biasing would be a great idea. This would enable the addition of bias to a specific Picocell at a particular time. Furthermore, it is useful to analyze the impact of using separate bandwidth at the Macrocell and Picocell against a co-deployment of Macrocell and Picocell. For the Purpose of validation and gaining meaningful insight into the operation of Heterogeneous network, we recommend analysis of the simulation using stochastic Process. The use of Poisson Point Process to evaluate system performance and in particular, the energy efficiency of the network would be a great idea. The fact that eICIC fails to eliminate all interference emanating from the control channel, calls for the introduction of a better interference management scheme. As a proposition, we recommend the use MSBFN instead of an Almost Blank Subframe.

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