ENERGY PERFORMANCE OF 5G WIRELESS SYSTEM UTILIZING CELL-DTX

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To my lovely family….

ABSTRACT

Due to the huge increase and continuous demands for wireless access networks, the energy consumption will increase more and more. This situation impels big challenges for mobile operators due to the cost of energy and increases worrying about sustainable development and global warning. This thesis focuses on the energy efficiency issues in the new access wireless system at 5G, and how to reduce the energy consumption .

First, the BSs load dependency with different BS types was studied, then the energy performance of 5G system was presented and the results are compared with traditional LTE system at the same network design with using Cell-DTX, which is a new feature that enables the BSs to deactivate some components when there is no traffic .

Finally, using MatLab application, the daily average area power consumption of 5G and LTE systems was evaluated with two cases of carrier aggregations at different traffic levels and the simulation results shows that the new 5G system provides much better energy performance compared to LTE system due to the longer duration and more efficient sleep mode in 5G network, and for the higher traffic level which is expected beyond 2020, 5G system decreases the network power consumption by more than 65% even with providing 10 times more capacity.

Keywords:5G;user centric network; SDN; mm-wave; Het-Nets; D2D; M2M; IoT; IoV;energy efficiency; Cell-DTX;wake-up time;power consumption model

ÖZET

Kablosuz erişim şebekelerinin sürekli artması ve kablosuz erişim talebinin de ayni şekilde artması nedeniyle enerji tüketimi gittikçe çoğalmaktadır. Bu durum, enerji maliyetinden ötürü mobil operatörler için büyük zorluklar yaratmakla birlikte sürdürülebilir kalkınma ve küresel sınmaya ilişkin endişeleri de artırmaktadır. Bu tez, yeni kablosuz erişim sistemi olan 5G'deki enerji verimliliği konularına ve enerji tüketiminin nasıl azaltılacağına odaklanmaktadır.

İlk olarak, farklı BS tipleri ile BSlerin yük bağımlılığı incelendikten sonra 5G sisteminin enerji performansı sunulmuştur. Çıkan sonuçlar, Cell DTX kullanılarak geleneksel LTE sistemi ile karşılaştırılmıştır. Cell-DTX hücrenin trafik (gidiş-geliş) olmadığında bazı BS'leri devre dışı bırakmasını sağlayan yeni bir özelliktir.

Son olarak, farklı trafik seviyelerinde iki taşıyıcı toplama vakası ile 5G ve LTE sistemlerinin günlük ortalama alan güç tüketimi değerlendirilmiştir. Simülasyon sonuçları, 5G şebekesinde daha uzun süre ve daha verimli uyku modu ve 2020'nin ötesinde beklenen daha yüksek trafik seviyesi nedeniyle yeni 5G sisteminin LTE sistemine kıyasla çok daha iyi enerji performansı sağladığını göstermektedir; 5G sistemi, 10 kat daha fazla kapasite sağlamakla birlikte şebeke güç tüketimini% 65 oranında düşürdüğü görülmüştür.

Anahtar Kelimeler: 5G; kullanıcı merkezli ağ; SDN; mm-dalga; Het-Ağlar; D2D; M2M; IoT; IoV; enerji verimliliği; Hücre-DTX; uyandırma süresi; güç tüketimi modeli

TABLE OF CONTENTS

CHAPTER 3: ENERGY PERFORMANCE OF 5G WIRELESS NETWORKS WITH Cell-DTX

CHAPTER 4: SIMULATION SETUP AND RESULTS

CHAPTER 5: CONCLUSION AND FUTURE WORK

LIST OF FIGURES

LIST OF TABLE

LIST OF ABBREVIATIONS

0.5G:	0.5 Generation
0G:	Zero Generation
1G:	First Generation
2.5G:	2.5 Generation
2.75G:	2.75 Generation
2G:	Second Generation
3.5G:	3.5 Generation
3.5G:	3.5 Generation
3G:	Third Generation
3GPP:	3rd Generation Partnership Project
4G:	Fourth Generation
5G:	Fifth Generation
A/D:	Analog to Digital
ABS:	Access Base Stations
AC:	Alternating Current
ACI:	Adjacent Channel Interference
ACK/NACK:	ACKnowledgement /Negative ACKnowledgement
AI:	Antenna Interface
AMTS:	Advanced Mobile Telephone System
AOA:	Angle of Arrival
ARP:	Autoradiopuhelin
AT&T:	American Telephone & Telegraph
BAN:	Body Area Network
BB:	Baseband
BBU:	Base Band Unit
BS:	Base Station
BSC:	Base Station Controller
BTS:	Base Tansever Station
CAPEX:	CAPital Expenditure

CDMA:	Code Division Multiple Access
CF:	Consumption Factor
CoMP:	Coordinated Multi Point
C-RAN:	Cloud Radio Access Network
CRS:	Carrier Routing System
D/A:	Digital to Analog
D2D:	Device to Device
DAS:	Distributed Antenna System
DC:	Direct Current
DHCP:	Dynamic Host Configuration Protocol
DMRS:	DeModulation Reference Signal
DNS:	Domain Name System
DSP:	Directional Self pursuing Protocol
DTX:	Cell Discontinuous Transmission
EDGE:	Enhanced Data Rates for GSM Evaluation
eNodeB:	Evolved Node B
EV-DO:	Evolution-Data Optimized
FD:	Full Duplex
FDD:	Frequency Division Duplexing
FDMA:	Frequency Division Multiple Access
GGSN:	Gateway GPRS Support Node
GPRS:	General Packet Radio Service
GSM:	Global System Mobile Communications
HBS:	Hub Base Stations
HetNets:	Heterogeneous Networks
HLR:	Home Location Register
HSDPA:	High-Speed Downlink Packet Access
HSPA:	High Speed Packet Access
HSPC+:	Evolution of High Speed Packet Access
HSS:	Hub Subscriber Stations
HSS:	Home Subscriber Server
HSUPA:	High Speed Uplink Packet Access

ICT:	Information And Communication Technology
iDEN:	Integrated Digital Enhanced Network
IF:	Intermediate Frequency
IIOVMS:	Intelligent Internet of Vehicles Management System
IMS:	Information Management System
IMT-2000:	International Mobile Telecommunications 2000
IMT-Advanced:	International Mobile Telecommunications Advanced
IMTS:	Improved Mobile Telephone Service
IoT:	Internet of Things
IoV:	Internet Of Vehicle
IP:	Internet Protocol
IS-95:	Internet Standard-95
ISD:	Inter-Site Distances
ITU:	International Telecommunication Union
ITU-R:	International Telecommunication Union-Radio Communication Sector
IWF:	Inter Working Function
LOS:	Line of Sight
LTE:	Long Term Evolution
M2M:	Machine To Machine
MAC:	Medium Access Control
MBSFN:	Multicast-Broadcast Single-Frequency Network
MDSFN:	Multi Service Data Network
MIMO:	Multi- Input Multi-Output
MME:	Mobility Management Entity
MMS:	Multimedia Messages
mm-wave:	Millimeter wave
MS:	Mobile Station
MSC:	Mobile Switching Center
MTD:	Swedish abbreviation for Mobile Telephony system D
MTS:	Mobile Telephone System
NLOS:	Non Line of NLOS Sight
NMT:	Nordic Mobile Telephone

NTT:	Nippon Telegraph and Telephone
OFDM:	orthogonal frequency-division multiplexing
OFDMA:	Orthogonal Frequency Division Multiple Access
OLT:	Norwegian Offentlig Landmobil Telefoni
OPEX:	OPerating EXpenditure
OSI:	Open Systems Interconnection
PA:	Power Amplifier
PCRF:	Policy and Charging Rules Function
PCU:	Power Control Unit
PDC:	Personal Digital Cellular
PDP:	Power Delay Profiles
P-GW:	Packet-Gateway
PRB:	Physical Resource Block
PSK:	Phase Shift Keying
PSS:	Primary Synchronization Signal
PSS:	Packet Switched Service
PSTN:	Public Switching Telephone Network
PTT:	Push to Talk
QAM:	Quadrature Amplitude Modulation
QoS:	Quality of Service
RAN:	Radio Access Network
RAT:	Radio Access Technology
RCCs:	Radio Common Carriers
RF:	Radio Frequency
RIT:	Radio Interference Technology
RMS:	Root Mean Square
RNC:	Radio Network Controller
RRH:	Remote Radio Heads
RRM:	Radio Resource Management
SCA:	Small-Cell Access
SCN:	Small Cell Networks
SCP:	Service Control Point

SDMA:	Space Division Multiple Access
SDN:	Software Design Network
SFN:	System Frame Number
SG:	Smart Grids
SG:	Scheduling Grant
SGSN:	Serving GPRS Support Node
S-GW:	Serving-Gateway
SI:	Self-Interference
SMS:	Short Message Service
SNR:	Signal-to-Noise Ratio
SON:	Self-Optimize Network
SR:	Scheduling Request
SSS:	Secondary Synchronization Signal
SVD:	Singular Value Decomposition
TDD:	Time Division Duplex
TDMA:	Time Division Multiple Access
TRU:	Transceiver Radio Unit
TRX:	Transceivers
TTI:	Transmission Time Interval
UE:	User Equipment
UL/DL:	Uplink/ Downlink
UMTS:	Universal Mobile Telecommunication System
UTRAN:	Universal Terrestrial Radio Access Network
VLR:	Visitor Location Register
WCCs:	Wireline Common Carriers
W-CDMA:	Wideband Code Division Multiple Access
WiMAX:	Worldwide Interoperability for Microwave Access
WPA:	Wireless Application Protocol
WWW:	World Wide Web

CHAPTER 1

INTRODUCTION

The ability of people communication has evolved uncommonly. The mobile wirelesses developed in very short time, in few last decades, the mobile wireless system development progressed from (0G) Pre cellular Generation or Zero-Generation, to First-Generation (1G), Second-Generation (2G), Third-Generation (3G), Fourth-Generation (4G), and now Fifth-Generation (5G).Each generation has replaced, developed, and add new technologies, not to mention the increasing in subscribers and their demands, as well as increasing and evolving of mobile devices.

Due to the huge increase and continuous demands for data services in wireless access networks, which is driven by the increase of the number of mobile devices (e.g., smart phones, tablets), Telecommunications operators became interested in finding a new generation to accommodate current demand for services. 5G wireless network will not be 4G networks, but faster. It may present a different kind of networks. Fifth-generation (5G) cellular networks are expected to overcome the challenges of existing cellular networks. Therefore, 5G networks purposed to combine essential solutions for more capacity, lower latency, and higher data rates, reduce energy consumption and high reliability. 5G networks are expected to be published around 2020; the number of connected devices is expected to reach 100 billion devices until 2020 according to Huawei Technologies (huawei, 2013). It will add the progress of existing standard and additional emerging technologies.Different sizes of network tiers, radio access technologies, backhaul connections, and transmission powers are expected to be a mixture of 5G wireless networks, which can be accessed by unexpected numbers of intelligent and heterogeneous wireless devices (Wang., 2012)**.**The main target of 5G is to design wireless systemwith best features, free from limitations, and without previous generation obstructions. This growth and expansion of the network will be a companion to increase the total energy consumption, which is a majorconcern for network operators.

1.1 Literature View

Too many researches have been done in order to reduce the power consumption of mobile wireless systems in 5G access network. In (O'Farrell, 2015) the authors compares between adding small cells with 3-sector RAN, and increasing sectorization order to 6-Sector RAN. They conclude that adding small cells is more energy efficient than increasing sectorization order on the same capacity density area. In (Klautau, 2015) the researchers proposed a sleep mode algorithm for small cells in 5G networks based on traffic patterns of the system, and the results indicated that the small cells energy consumption can be reduced by more than half. In (Sibel Tombaz, 2013) the area power consumption is presented utilizing indoor base stations and the result shows that the power consumption is decreased by half using small and low power BSs at the edge of macrocells. While in (Won, 2016) the effect of Beam-Forming (BF) and Cell-Discontinuous Transmission (cell-DTX) technology on the area power consumption are studied additionally with the desired density of base stations for a 5G network system in a rural environment, The results show that the beamforming reduces the number of required BSs by increases the signal strength and control the interference. The cell-DTX capability also effects by reducing the energy consumption of 5G networks by enabling sleep mode operations when the network is low-utilized. Cognitive green backhaul deployment scheme for 5G networks have proposed in (David, 2014), the backhaul link diversity utilized in the network, also RL based resource assignment algorithm have been used in order to reduce the power consumption, and they conclude that the power consumption decreased at low to medium traffic loads by focusing on distributed traffic of fewer backhaul links.

1.2 Evolution of Wireless Communication Systems

Since (1970), Mobile wireless manufacturer has been started the revolution and development of technologies, from the first beginning mobile wireless technologies introduces five generation from (0G) or Pre-Cellular technology to (4G) fourth-generation (Yi Liu, 2015). Cellular generation has four main different sides, bandwidth, data rate, radio access and switching scheme. The introduction of the cellular concept was in1G technology, mobile wireless communication was possible. 1G cellular systems is analog system and has a bandwidth range of (10 to 30 KHz) and that depends on the type of system and services offered, and data rates of 10 kbps, Radio access scheme is FDMA and switching was all circuit. 1G was only suitable for voice services.

In 2G technology, Digital-communication has been introduced instead of analog system, which improves the system quality. The first phase of the 2G system offered a data rate of (9.6 kbps) and increased in the second phase to more than (300 kbps) with bandwidth of (200 kHz), switching scheme was packet and circuit, and radio access was TDMA, as well as FDMA(Viswanathan, 2014), (Vajjiravelu, 2013).

In 3G technology, data communications are introduced additionally with the voice communication. The data rate peak began of 2 Mbps in the first phase and then it reached 50 Mbps in sequential phases at constant wide bandwidth of 5 MHz. the radio access scheme was CDMA, and switching scheme was persistent to be circuit with packet additionally. At the start of 3.5 G with HSDPA system, then it was concern on packet switching.

In 4G technology, advanced radio interface was used with OFDM, MIMO.4G wireless networks can offer data rates around 1 Gbps for low mobility, and 100 Mbps for high mobility (Vajjiravelu, 2013), (Albreem & Mahoud, 2015).That evaluation of wireless communication system is still continuous and the researchers are already investigated the next generation or the 5G wireless techniques.

1.2.1 0G

After World War-II, Wireless telephone with 0G became available. The mobile operator in those days is set up the calls with handful channels only, While the mobile phones does not support the handover feature, which means it cannot change the channel frequency. 0G appeared in 1970 and called pre cellular mobile telephony technology(Mohammad Meraj ud in Mir, 2015). Before cell phones advent, the Radio telephones used to be in cars. Then Mobile radio telephonic system created modern cellular mobile-telephone technology. There are a lot of technologies that used in 0G involved PTT, OLT, MTS, IMTS, AMTS, and MTD (Mohammad Meraj ud in Mir, 2015).

1.2.1.1 0.5 G

0.5 G is an improved version of 0G technology. 0.5 G is a group of many technologies of mobile telephone systems, which can be distinguished from earlier closed radiotelephone systems because they were available as a commercial service (Mohammad Meraj ud in Mir, 2015). These mobile telephones were ordinarily installed in cars and trunks, as the transceiver was putted in the vehicle trunk and connected to the top of the trunk, while the handset was mounted near to the driver seat.They were sold through WCCsand RCCs, as well as two-way radio dealers(Mohammad Meraj ud in Mir, 2015).the primary users of this generation were from realtors, celebrities, and upper class population. The examples of this generation were (Mohammad Meraj ud in Mir, 2015):

1. The Auto-radio-puhelin (ARP) found in (1971) in Finland as the country's first public commercial mobile phone network.
2. The B-Netz found in(1972) in Germany as the countries second public commercial mobile phone network.

1.2.2 First Generation Systems (1G)

First cellular network deployed commercially (1G) was started in Japan by NTT in (1979),the NTT network has been expanded to include all the country's population. In (1981) , it was followed by the simultaneous launch of the NMT system in Sweden, Denmark, Norway, and Finland(Albreem & Mahoud, 2015).NMT was from the first of mobile phone networks that offers international roaming. The 1G is analog system which is providing voice service only using FDMA as a radio scheme with bandwidth range of (10-30 KHz), frequency band was (824-894 MHz), and data rate of (10kbps)(Albreem & Mahoud, 2015).

1.2.3 Second Generation Systems (2G)

2G cellular system commercially started on the GSM in (1991), and the essential objective of 2G networks is the digital encryption of the conversations, In 2G data services are introduced for mobile also, starting with SMS ,and text messages (Albreem & Mahoud, 2015). Mobile phone networks are enabled to provide many services such as (SMS) text messages, (MMS) multimedia messages and picture messages. In 2G technology, digital encryption are presented so that the data of all text messages are encrypted in a way that only the purposed receiver can receive and read it. 2G technologies can be divided into TDMA-based and CDMA-based standards depending on the type of multiplexing used. The main 2G standards are:IS-95 (CDMA-based), iDEN (TDMA-based), GSM (TDMA-based), IS-136 (TDMA-based), and PDC(Albreem & Mahoud, 2015). The frequency band of GSM is 850-1900MHz. and it uses (8 channels/ carrier) with total data rate of (22.8kbps) in the full rate channel. And 2G technology extended to deploy the generation and these generations include 2.5 G (GPRS) and 2.75 G (EDGE).

1.2.3.1 General Packet Radio Service (GPRS) 2.5G

GPRS is a service provided by the GSM was commenced in 2001 providing mobile Internet access at worldwide.GPRS used to characterize 2G systems that have executed a packet-switched domain additionally with to the circuit-switched domain. The first pioneer step in the development of GSM networks is the GPRS. CDMA-2000 networks similarly improved through the introduction of 2.5G(Walke, 2013).Its approach focused on the use of packet data. Till this time all circuits has been devoted to a given user in a way known as circuit switched. Data rates of (56Kbps) up to (115Kbps) could be provided in GPRS.It could be used for services like:WPA, MMS, and for internet communication services like: emails and WWW(Meraj, 2015).

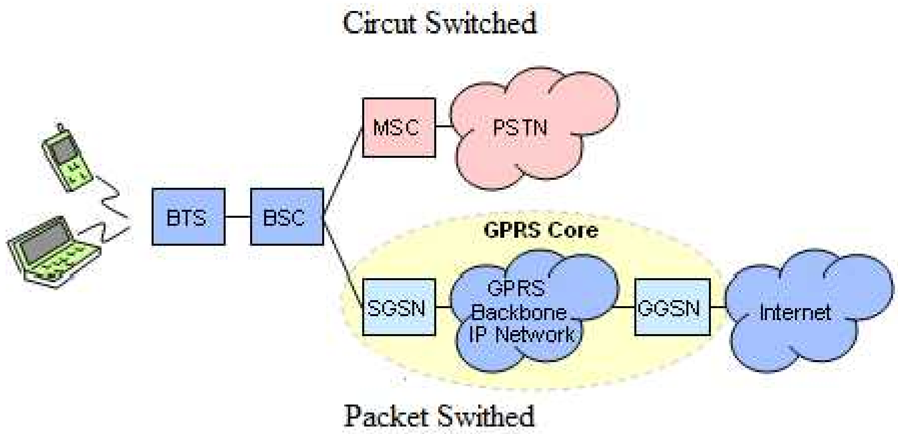


Figure 1.1:GPRS architecture

1.2.3.2 Enhanced Data Rates for GSM Evolution (EDGE) 2.75G

Enhanced Data Rates for GSM Evaluation (EDGE) is a new modulation techniques which would be considered a 3G radio technology and a part of ITU's 3G definition, but it most popular referred as 2.75G.EDGE was developed initially by AT&T in 2003 on GSM networks in the United States;itcharacterized of large amounts of data transmission peak rates up to 472 kbps (Patrick Traynor, 2008). EDGE is an upgrade technology that provides prospect increment in capacity of GSM/GPRS network(Ding, 2010).It depends on the TDMA time slot scheme, 8 Phase Shift Keying (8PSK) is the modulation technique that used in EDGE (Gratton, 2007). EDGE used for all packet switched applications, such as videos, internet and other multimedia. From EDGE networks UMTS networks and technology are introduced and referred as pure 3G.

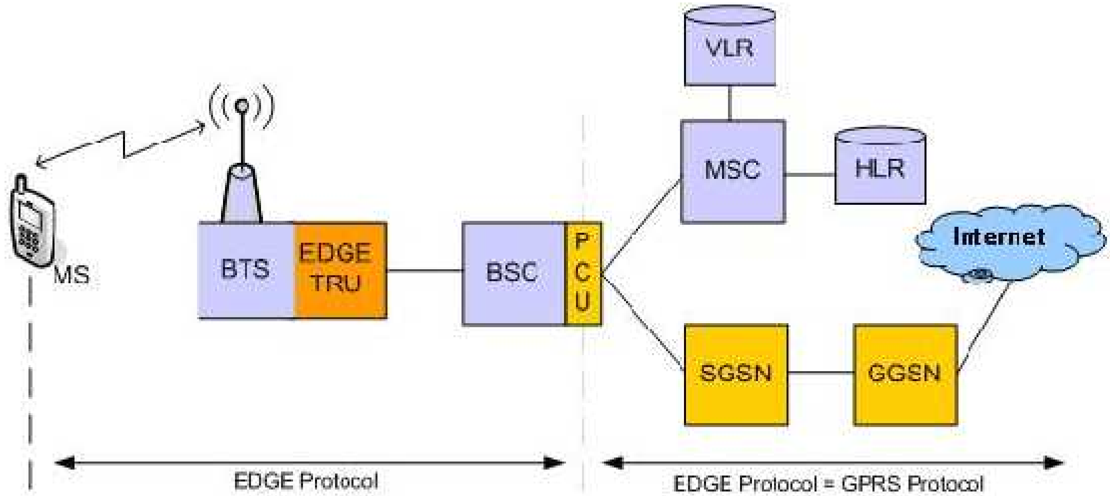


Figure 1.2: EDGE network architecture

1.2.4 Third Generation Systems (3G)

3G is the third generation of mobile phone standards and technology and it's considered one of the biggest opportunities in wireless communication world. 3G systems are established on IMT-2000 through ITU's project.it combines the Internet Protocol (IP) with high speed mobile access. 3G technologies characterized by faster data transmission, more capacity and advanced network services which include wireless web base access, email, video conference, and multimedia services (Chakraborty, 2013).The most important proposals introduced by the IMT-2000 are the UMTS or W-CDMA. 3G systems offer data rates of up to 2Mbps, over 5MHz channel-carrier widths, depending on mobility and velocity, with high spectrum efficiency.In 3G networks the data rates are varying according to the environment of the cell and it divided into three environments: 144kbps for satellite and rural outdoor, 384kbps for urban outdoor and 2Mbps for indoor and low range outdoor, with frequency band of 1.8-2.5GHz (Albreem & Mahoud, 2015).

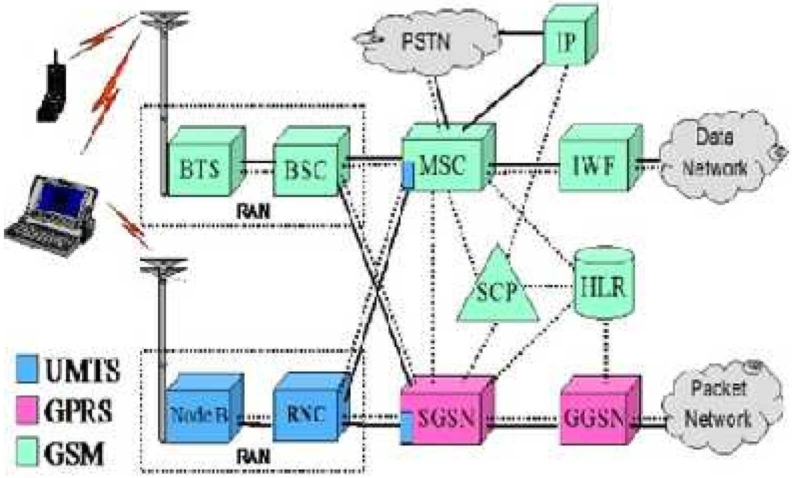


Figure 1.3: 3G network architecture

1.2.4.1 High Speed Packet Access (HSPA) 3.5G

The significant 3.5G standards are: HSPA) and EV-DO of Revision-R and Revision-C, HSPA is an expansion of UMTS, while EV-DO is a part of CDMA-2000 standards (Alexander, 2010). HSPA Enables faster data connection speeds, it includes High Speed Downlink and uplink Packet: High-Speed Downlink Packet Access (HSDPA) the enhancement of download speeds which could reach peaks of 14.4Mbps and it upgrades up to 42Mbps and beyond. And High Speed Uplink Packet Access (HSUPA) the enhancement of uploads speeds that enable speeds of around 5.76 Mbps and upgrades to 34.5 Mbps (GSMA-TM, 2014).

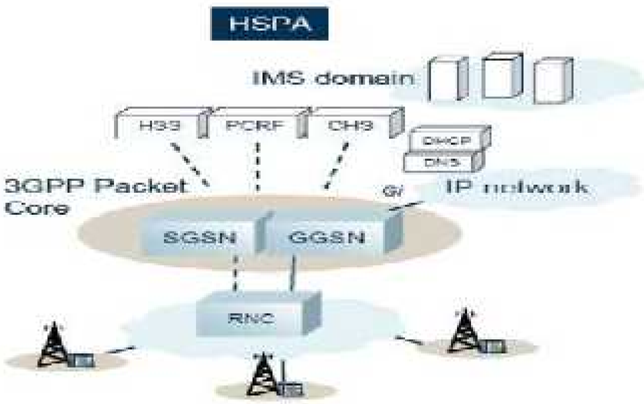


Figure 1.4: HSPA network architecture

1.2.4.2 Evolution of High Speed Packet Access (HSPC+)

HSPA Evolution, also known as HSPA+, it includes the downlink direction (HSDPA) and uplink direction (HSUPA). HSPA+ is a plane that addresses the enhancements and evolutions towards LTE. HSPA+ goals are to enhance the HSDPA - HSUPA and enhance the capabilities and performance of HSPA-based radio networks as well, and provides a migration path towards LTE (Santosh, 2013). HSPA+ was defined in the technical standard 3GPP release 7. In release 7 MIMO is defined by support higher-order modulation 16 QAM and 64 QAM for uplink and downlink respectively.16QAM modulation enables peak data rates of 12Mbit/s in uplink, while 64QAM modulation enables peak data rates of 21Mbit/s in the downlink (Wager, 2008).

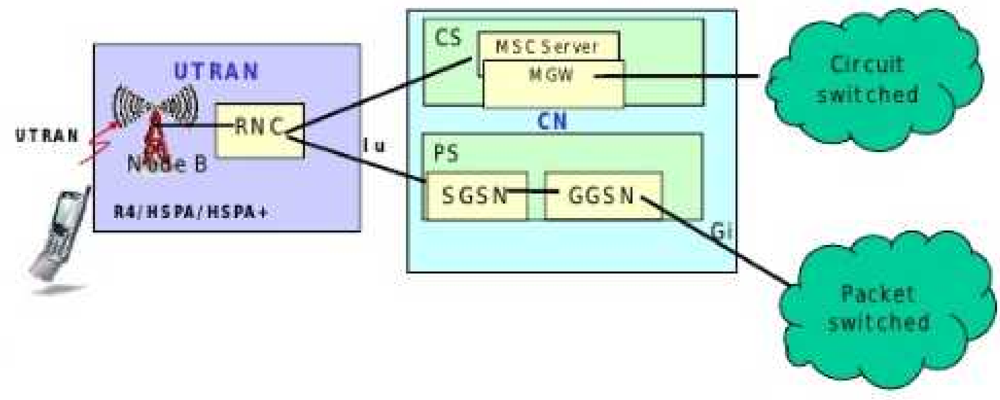


Figure 1.5: HSPA+ network architecture

1.2.5 Fourth Generation Systems (4G)

The fourth generationof wireless systems also known as Long Term Evolution (LTE) as a brand name which given to the effort of 3GPP 4th generation technology development (Subharthi , 2008). 4G systems include many services in addition to 3G services that providing mobile broadband internet access, for example: smartphones, wireless modems, with laptops, and other mobile device. 4G application include IP-telephony, high definition mobile TV, gaming services, 3D-TV, video conference, and cloud computing. Two systems are commercially deployed in 4G systems: the mobile WiMAX standardfirst used in South Korea in (2007), and the first release LTE standard first used in Sweden, Stockholm, and Norway since (2009) (Mehbodniya, 2013).

The 4G wireless known as the (IMT-Advanced) project was published in July-2008 by (ITU-R) through radio interference technology (RITs) (IYU-R, 2008).4G wireless network supports data rates of up to 1Gbps for low mobility, and up to 100 Mbps for high mobility (Albreem & Mahoud, 2015), it considers using a bandwidth of 100 MHz (Reyes, 2010).

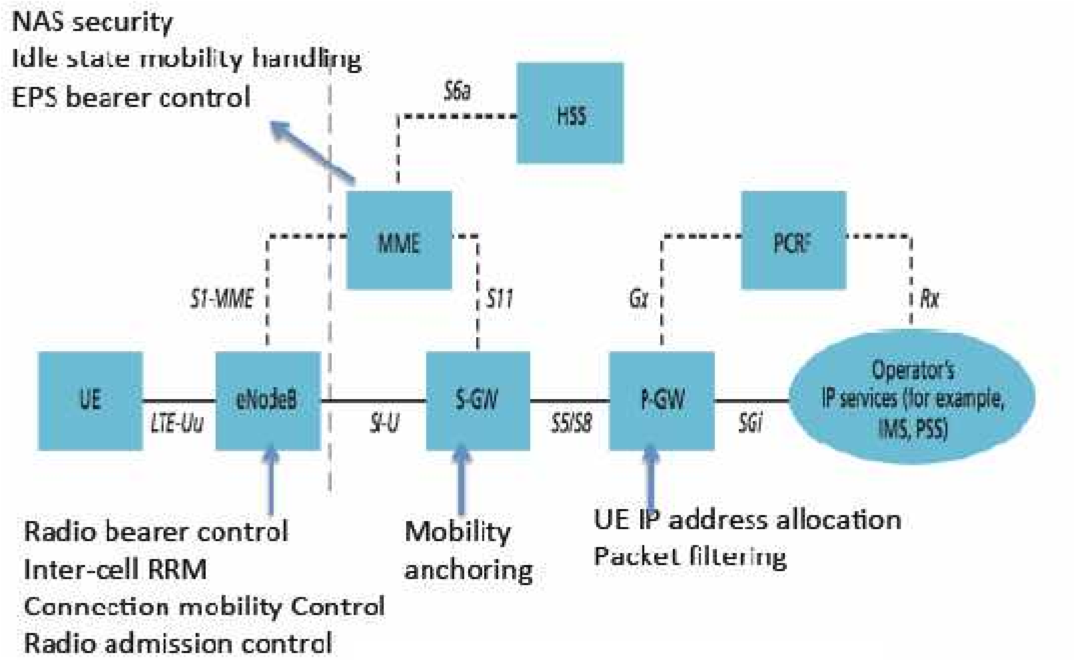


Figure 1.6: LTE architecture

1.2.5.1 LTE Advanced 4.5G

LTE advanced is the evolved version of LTE system; it exceeds the requirements of the International Telecommunication Union (ITU) for the fourth generation (4G) radio communication standard known as IMT-Advanced. It offers wider bandwidths, enabled by carrier aggregation, higher efficiency, enabled by enhanced uplink multiple access and enhanced multiple antenna transmission (advanced MIMO techniques).LTE advanced support data rates of 2048 kbps for indoor office, 384 kbps for outdoor to indoor and pedestrian, 144 kbps for vehicular, 9.6 kbps for satellite, it has a capability for interworking with other radio systems, high quality mobile services, user equipment suitable for worldwide use, user-friendly applications, services, and equipment, worldwide roaming capability, enhanced peak data rates to support advanced mobile services and applications (in the downlink, 100 Mbps for high mobility and 1 Gbps for low mobility)(Byonghyo, 2017).

Table 1.1: Comparison between 0G, 1G, 2G, 3G, and 4G systems

Technology/ Features	0G	1G	2G/2.5G/2.75G	3G	4G
Data Rate		2 kbps	14.4kbps/64 kbps/ 472 kbps	2 Mbps/12 Mbps for uplink- 21 Mbps for downlink	100 Mbps
Technology	Analog cellular	Analog cellular	Digital cellular	Broad Bandwidth/CDMA/ IP-technology	Unified IP and seamless combination of broadband LAN/WAN/PAN and WLAN
Service	Mobile Technology	Mobile Technology	Digital voice/ Short message	Integrated high quality audio, video, and data.	Dynamic information access, variable devices.
Multiplexing		FDMA	TDMA/CDMA	CDMA	CDMA
Switching	Circuit	Circuit	Circuit for access network and air interface	Packet expect for air interface	All packet
Core Network		PSTN	PSTN	Packet network	Internet
Handover	Not supported	Horizontal	Horizontal	Horizontal and vertical	Horizontal and vertical

CHAPTER 2

5G WIRELESS COMMUNICATION SYSTEMS

Mobile wireless communications started in the 0G and 1G with voice only system. After that it evolved steadily towards 2G, 3G, and 4G with Digital modulations, frequency ruse technique.Improvement and development the generations with (MIMO, WCDMA, OFDMA, etc.) have contributed towards 5G generation (Mamta Agiwal, 2016). The evolution of LTE continued to release 10-LTE advanced to moreover release, each with enhanced system performance with new applications and capabilities (Albreem & Mahoud, 2015). A quick look into recent wireless network statistics expose that global mobile data traffic grew 74% in 2015. Global mobile data traffic reached 3.7 Exabyte permonth at the end of 2015, up from 2.1 Exabyte per month at the end of 2014 (Cisco, 2016).

563 million connections and devices were increased in 2015. Smartphones are formed the largest proportion of this growth. Global mobile devices and connections in 2015 grew to 7.9 billion, up from 7.3 billion in 2014 (Cisco, 2016). Smart device represent 36% of the total mobile devices and connections in 2015; they are 89% of the mobile data traffic (Cisco, 2016).An average mobile user is expected to download around 1 Terabyte of data annually by 2020 (Cheun, 2014) , (Cisco, 2016).and to handle that the 5G wireless networks are aimed to offer 1000 times higher wireless capacity compared to current generation of wireless network developments (Li, 2014)

For users the difference between 5G and previous generations must be something more than increased maximum throughout, so 5G wireless networks expected to be characterized by low battery consumption, better coverage and high data rates available at cell edge, Higher system level spectral efficiency, amended and innovative modulation techniques and data coding, and Multiple concurrent data transfer paths (Albreem & Mahoud, 2015).

2.1 5G Architecture

Wireless users stay indoors for about 80% of time, while they stay only 20% of the time outdoors. In current cellular systems architecture there is only an outdoor BS in the middle of the cell which connected with mobiles (Albreem & Mahoud, 2015).Even if the users are existsoutdoor or indoor the buildings. For indoor users, they have to communicate with BS that located outside the building, so the signal will penetrate the building walls and that will cause a penetration loss, signal penetration loss changed according to the type of the building walls, and this affects the energy efficiency, spectral efficiency, and data rate of wireless transmission (AUER, 2011).

In 5G cellular network, the focus in the design of the network is to separate the indoor from outdoor scenario to avoid or decrease the penetration loss(AUER, 2011). This separation means that the current network architecture will be totally changed and it will be assisted by many technologies. At outdoor, BSs will be connected with many large antenna arrays by optical fiber distributed around the cell, using DAS and MIMO technologies, while at indoor the users only need to communicate with indoor wireless access point (without needing to communicate with outdoor BSs) with large antenna array installed outside the buildings. The wireless access point inside the buildings is connected with the large antenna arrays by cable (Albreem & Mahoud, 2015). This design has many advantages: cell average throughput improvement as well as improving spectral efficiency, data rate, and energy efficiency of the cellular system, but also it will increase the infrastructure cost (AUER, 2011). Heterogeneous network also introduced in 5G wireless architecture heterogeneous including macrocell, microcell, small cell, and relays, in order to serve the high mobility users (Intelligence., 2014).

2.1.1 User Centric Shift

The 5G wireless network as mentioned before separated to indoor and outdoor areas, and this needs to switch the BS centric network paradigm to user centric or device centric network. The requirement of latency and limitations in bandwidths in current wireless systems motivated to think about small cell, smaller than traditional macro hexagonal coverage(Saxena, 2015).Future networks are expected to contain different nodes in cell sizes: small, micro, and femtocell. In this manner 5G wireless network will have high co-channel interference, and to avoid this problem Space Division Multiple Access (SDMA) technology and effective antenna design are suggested to use(Saxena, 2015).

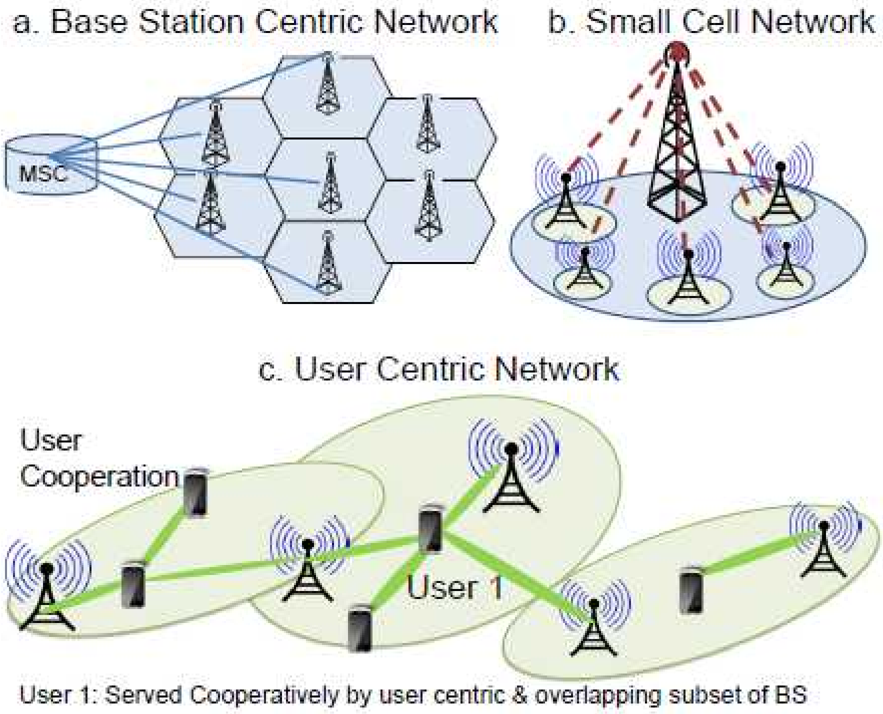


Figure 2.1: Difference between user centric architecture and BS centric network

2.1.2 Radio Access Network

5G wireless network proposed utilizing higher frequencies, high frequency signal propagation is limited in outdoor environment(Boccardi, 2014). As 5G networks use high data rates and high frequencies, it's necessary to change the node layout design, and densified the nodes. In crowded environments, LOS communication in preference over NLOS communication (Saxena, 2015).When LOS signal is completely down, its need to explore the diffracted, scattered, and reflected signals which might have adequate energy(Murdock, 2013).

The configuration of 5G network BSs cannot be applied instantly; it must be integrated gradually from legacy cellular networks. Thus it propose to design hybrid system of mm-wave (5G) and legacy 4G network, which is a dual-mode modem, it enables the user to switch between both of the networks in order to get better experience (Khan, 2011), (Saxena, 2015).

In this type mm-wave spectrum usually used for data communications, while traditional 4G spectrum used for transmitting control and system information(Khan, 2011). The second type is stand-alone 5G system as shown in Figure 2.2. In this one the same mm-wave spectrumused for both data and control signals, the narrow beam connotation allows acceptable spectrum overlap and also improves link quality between BS grids and large number of users (Saxena, 2015),(Farooq&Zhouyue, 2011). Thus, 5G communications are much different from legacy networks in the radio networking part.

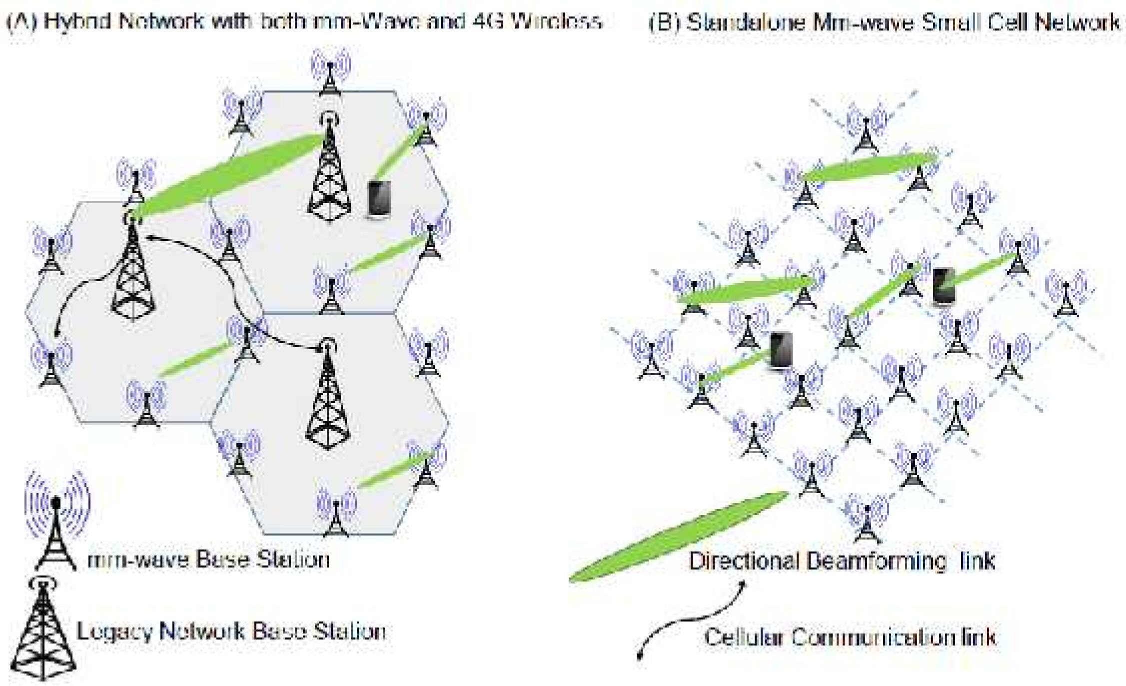


Figure 2.2: Mm-wave network architecture in standalone and hybrid networks

2.1.3 Air Interface

Mm-wavehas small wave length, so to propagate mm-wave signal large number of small antenna size demands. With this large number of antennas, it needs to use smart directional antennas in order to avoid the air interface, and enhance the electromagnetic waves in the desired direction; also it controls the phase and amplitude of signal by using array antenna. Figure 2.3 shows the difference between directional and Omni-directional antenna (Saxena, 2015). Highly directional radiation pattern could be secured by using adaptive beamforming technique, which is a signal processing technique used for directional signal transmission and reception. As mm-wave antennas allow a large number of antennas and high beamforming gain, SDMA can be implemented readily (Farooq&Zhouyue, 2011) also the frequency reuse for beamforming antennas are improved by SDMA for transmission and receiver (Bae, 2014) .

For this large number of antennas it might not be possible to connect every antenna to high rate Digital to Analog (D/A) and Analog to Digital (A/D) convertor(Boccardi, 2014). First alternative is a hybrid architecture where beamforming is performed in analog at RF, and the beamformers are connected to (A/D) or (D/A) convertor. In this case signal prepossessing is needed to lead the analog beamforming weight (Boccardi, 2014). Second alternative is connecting each RF chain to (A/D) and (D/A) converter, with very low power requirement. In this case, the beamforming is performed digitally but on very noisy data (Boccardi, 2014). This hybrid architecture with digital and analog beamforming can provide possible solutions (Khan., 2011).

The best configurations of antenna for beamforming techniques is: horn antenna in transmitter, patch antennas in receiver and special antenna arrays in high rise urban environment for vertical steering of the beam at allow for effective communication (Khan., 2011). Wide BS distribution and need of LOS communication could be relaxed by separation of uplink and downlink, multiple nodes can transmits from different communication paths at different channel conditions(Boccardi, 2014). These fundamental techniques of air interference may build a story foundation for 5G wireless network.

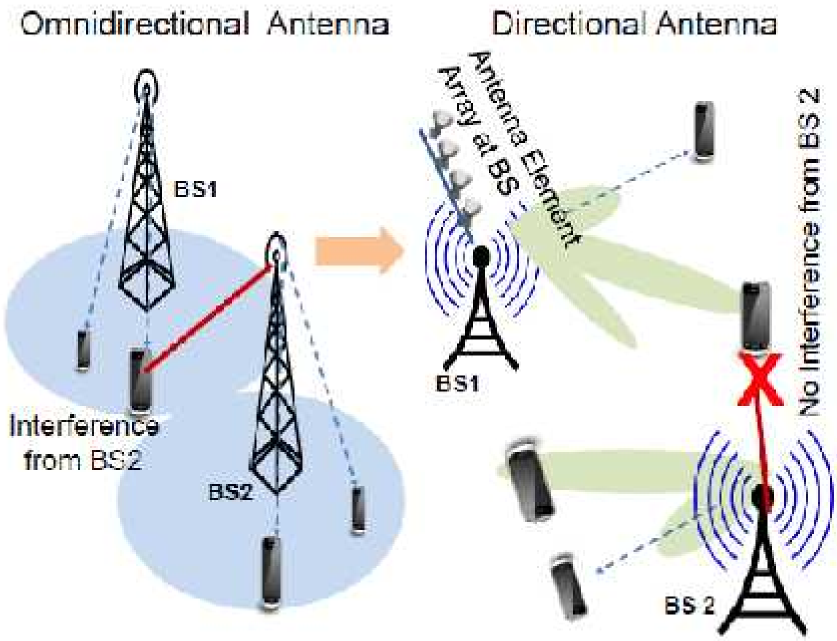


Figure 2.3: Comparison between smart beamforming directional antenna and Omni-directional antennas

2.1.4 Smart Antenna

Effective antenna array design is an important factor to succeed the deployment of 5G network. To realize SDMA capabilities, multi beam smart antenna array system should be used. Smart antennas mitigate interference with coverage the area properly and reduce energy consumption in each of the mobile phone and BSs (Saxena, 2015). More energy could be transmitted at higher frequencies for the same physical aperture size by using narrow beam (Roh, 2014). The implementation of smart antenna allow to different beams to use the same channel, which is solve or reduce a big problem of wireless communication (co-channel interference) (Cardieri, 2001).

As mention before horn antennas are used at transmitter, as it has higher gains over all other types of antennas. Thus an array of horn antenna provides high power output required for a BS(XLai, 2015). The power size and space are key points for mobile devices, thus simple patch antennas are more suitable for such devices (Khan., 2011).

2.1.5 Agility and Flexibility by Splitting of Plane-SDN

The new architecture of 5G network and changes in air interference confirms on small cells and large number of antennas. Thus there are many servers and routers have to be configured and conservation. A simplified solution for the complex challenges are introduced by Software Design Network (SDN) by splitting control and data plane(Agyapong, 2014),and thisseparation awards 5G network with high data rate at required places without preoccupation control plane overhead(Agyapong, 2014).SDN split the data and control planes by using the software components, which reduces the hardware constraints. Thus the management and control plane are responsible by these software components (Agyapong, 2014),(Cho, 2014).Figure 2.4can showthe separation of control and data plane.

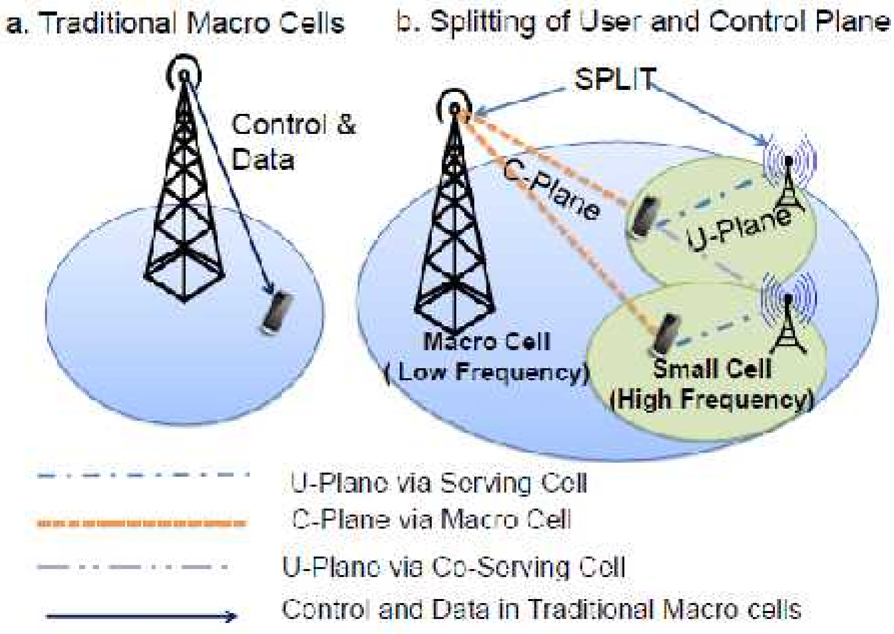


Figure 2.4: Separation explanation of user plane and control plane

SDN can step over OSI layer to remodel network as shown in figure 2.5 the OSI layer in 5G is different than in 4G network (Saxena, 2015),In order to run the mechanism completely. The controllers are reducing the excrescence interference, which assign to routes for monitoring functions(Arslan, 2015).SDNapplied to Radio Access Network (RAN) as Self-Optimize Network (SON) solution(Arslan, 2015).Although SON provides high gains. Multiple BSs are required for data transmission in order to improve the data plane(Saxena, 2015).Coordinated Multi point (CoMP) transmission smooth data transmission process in a good period of time (Arslan, 2015). Cloud RAN can also give an offer a solution by routing data and control signals through different nodes, spectrum and technology, in order to manage network density and variety (Saxena, 2015).

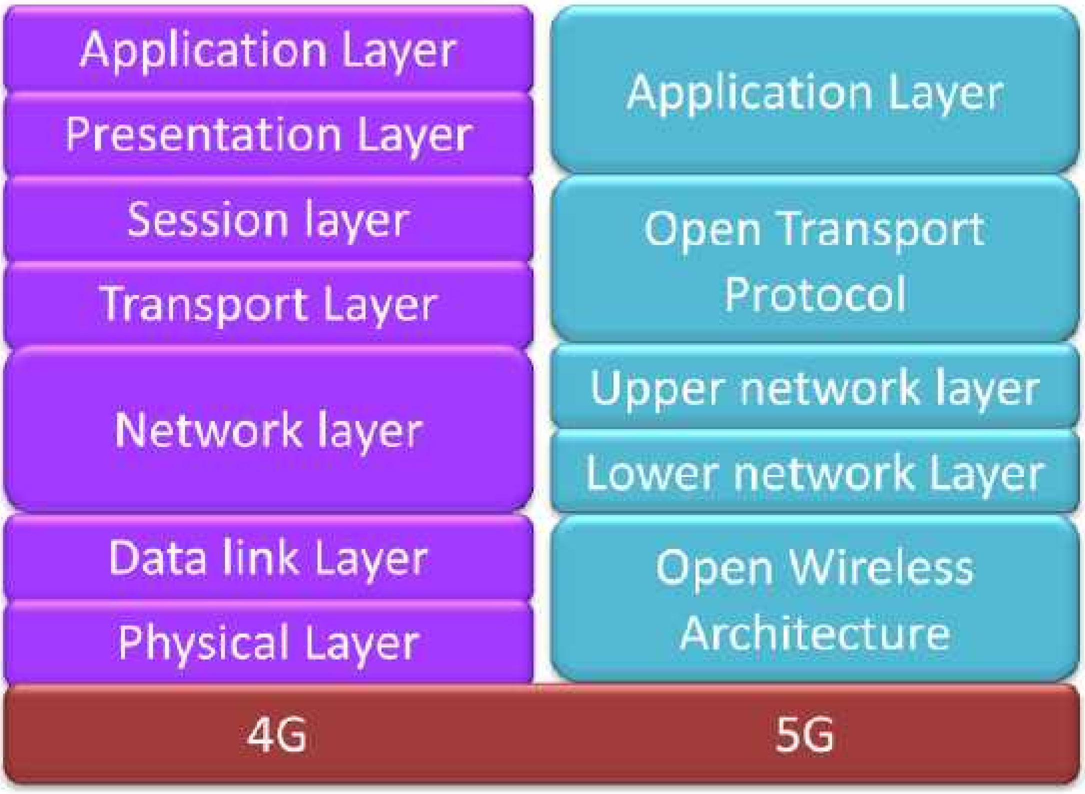


Figure 2.5: The difference between 4G and 5G in OSI layers

2.1.6 Cloud-RAN

Cloud Radio Access Network (C-RAN) solved some of problem related with high data rates demands (Checko, 2015). Wireless manufacture is depend on measurements to enhance the network capacity by increasing number of cells, achievement MIMO techniques, establishing complex construction of HetNets and small cell deployment.

C-RAN improves the system architecture by improving mobility, coverage performance, energy efficiency, and reducing the cost of deployment and operation of the network simultaneously(Checko, 2015). In conventional cellular networks, the multi-protocol functionality, Internet Protocoland Ethernet are extended to the remote cell sites (not at the cell sites) (Cvijetic, 2014). Figure 2.6 shows the C-RAN architecture.

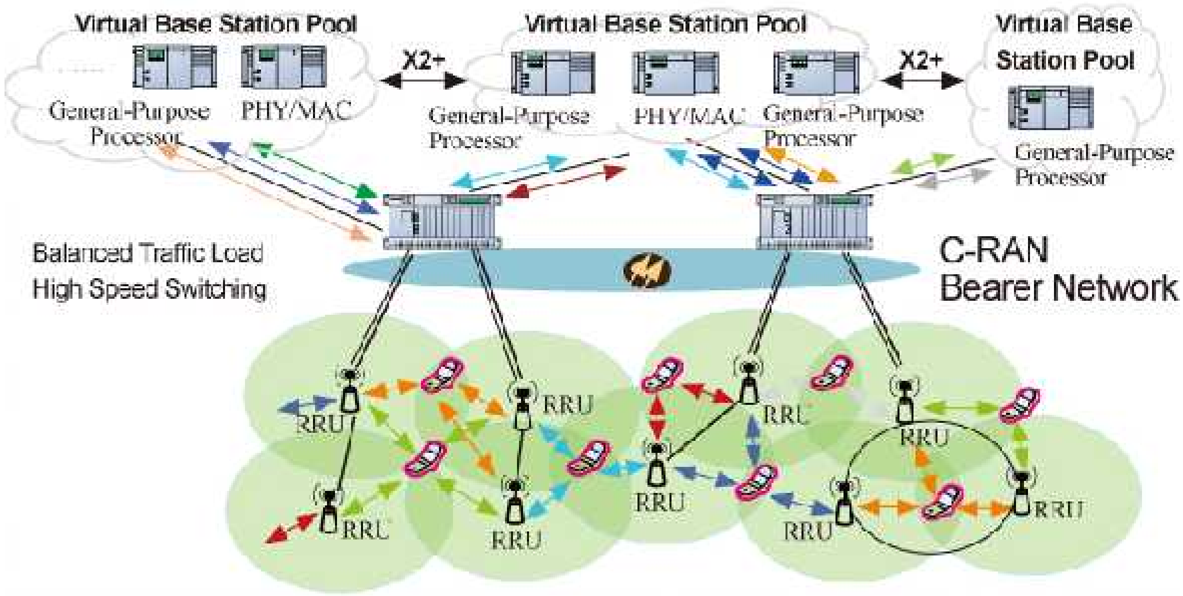


Figure 2.6: Cloud -RAN architecture

Remote Radio Heads (RRH) including tansever components, amplifiers and duplexer enable analog/digital conversions, digital processing,filtering, and power amplification (Saxena, 2015),(Cvijetic, 2014),(Checko, 2015). RRHs are connected to Base Band Unit (BBU) pool by single mode fiber of data rate higher than 1 Gbps(Saxena, 2015),(Cvijetic, 2014). The simplified BS architecture is alignments the way for dense 5G deployment by making it reasonably priced, flexible, and efficient(Agyapong, 2014). Complex control processes are handled easily by the cloud company(Cho, 2014).

2.1.7 Heterogeneous Network (HetNets)

A traffic explosion are expectedin 5G network, to handle the traffic Heterogeneous Networks (HetNets) arises (Shen, 2015), which is a large number of small cells with low transmission power. HetNets and legacyMacrocells together are improve the network Capacity and coverage(Abd El-atty, 2013), (Huq, 2013) as shows in Figure 2.7, micro, pico, and femtocells are standing within Macrocells which improves the frequency reuse efficiency(Wang, 2013).

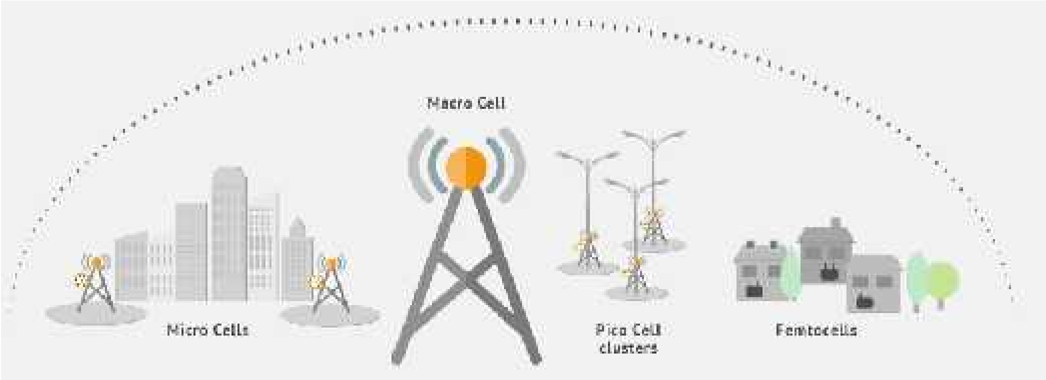
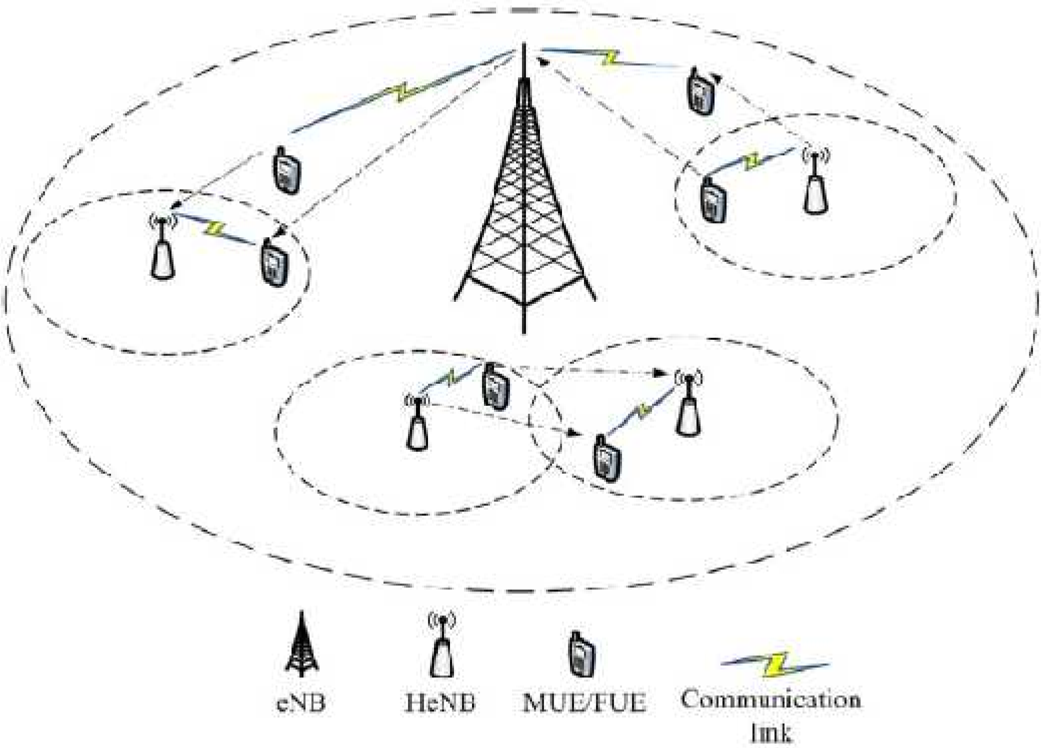


Figure 2.7: HetNets radio access network

TDD Reverse Time Division Duplex accrued in 5G HetNets between the macro and second tier cells (more distant one), In reverse TDD mode BS is in downlink operation while the Small-Cell Access (SCAs) is in uplink operation and vice versa(Sanguinetti, 2015). Inadvisable Radio Access Technology (RAT) causes unnecessary signaling overhead, so multi-RAN and efficient RAT are preferred to make RAT handover decisions and optimizations(Talwar, 2014). Toimprove the capacity and connectivity in HetNets multiple RATs are used. Two-tier heterogeneous network are proposed in (Lee, 2014) and there are two types of interference in a two-tier heterogeneous network: cross-tier interference and co-tier interference, Cross-tier which expected to be found when both the femtocells and macrocells share the same set of PRBs(Physical Resource Block), which is the smallest chunk of transmitted data and each PRB is comprised by 12 subcarriers along one time slot).While co-tier interference is a co-channel interference which occurs between femtocells, when the femtocells are violently deployed within a macrocell, which results coverage overlaps amongst the femtocells. Figure 2.8 shows different cross-tier and co-tier interference scenarios in both uplink and downlink(Lee, 2014).



Interference	Direction	Source	Victim	Symbol
Cross-tier	Downlink	eNB	FUE	←········
Cross-tier	Uplink	FUE	eNB	← — —
Cross-tier	Downlink	HeNB	MUE	←·-·-·-
Cross-tier	Uplink	MUE	HeNB	←———
Co-tier	Downlink	HeNB	FUE	←-----
Co-tier	Uplink	FUE	HeNB	←-·-·-

Figure 2.8: Two-tier femtocell networks architecture with their interference

Cloud based architecture introduced for HetNets in order to make the installation, monitoring, management, and upgrading the network easily(Shen, 2015). So the heterogeneous network connectivity of small cells is the main structure block oftheexpected 5G architecture with high coverage and data rates.

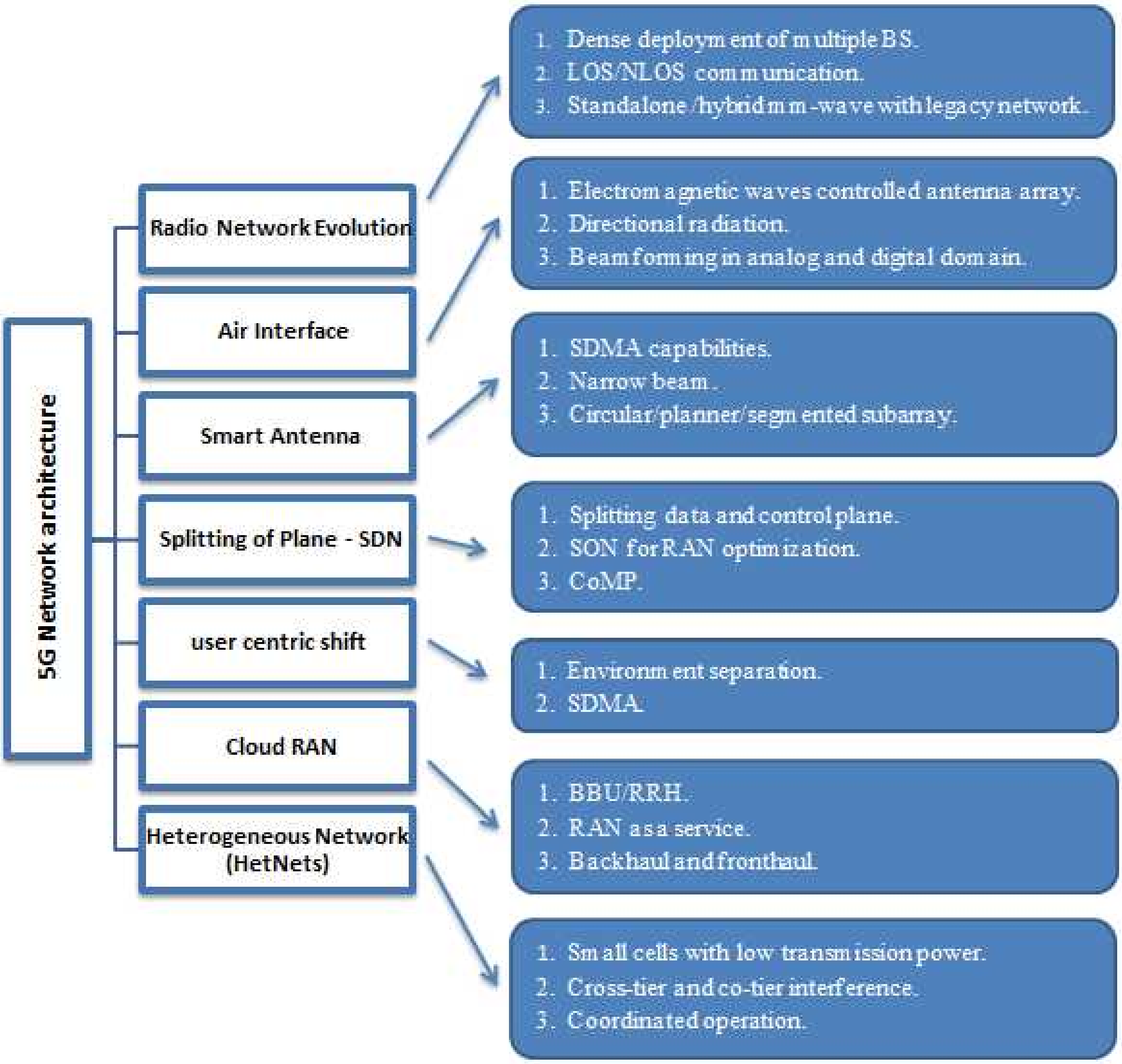


Figure 2.9: Key points of 5G network architecture

2.2 Physical Layer Design

Combining 5Gnetwork architecture with legacy wireless networksneeds a new scenario to make the process simple and speedily. So, it is necessary to understand the physical layerTechnologies and fuse them to decreasing the overhead and for better performance. In this section we present mm-wave wireless channel, adaptive beamforming, Sectorized antenna, Massive MIMO system, and full duplex radio technology.

2.2.1 Mm-wave Wireless Channel

The uses of mm-wave go up many challenges in wireless mobile system. The non-availability of any standard channel model is an essentialchallenge; understanding of channel model behavior could offer new techniques, different multiple access and new modes of interfaces(Murdock, 2013).Traditionally wireless channels characterized by propagation loss, multipath, signal penetration, andDoppler.

2.2.1.1 Propagation Loss

The free space loss is estimated by the equation:

$$L_{FSL} = 32.4 + 20 \log_{10} f + 20 \log_{10} \qquad (2.1)$$

Where (L_{FSL})accounts the mm-wave's transmission loss, (R) refers to the distance between transmitter and receiver,and (*f*)is the carrier frequency(Rajagopal., 2012). In high frequencies the losses are notable especially for isotropic antennas,dense small antennas needed for high frequencies and short wavelengths in a small area, mm-wave links are capable of casting very narrow beams comparing by microwave links (Adhikari, 2008). Transmitting with directional narrow beams increases spatial multiplexing capabilities and reduces interference. Performance of Mm-wave links may depends on link margin of the radios, multipath diversity, and distance between the nodes(Adhikari, 2008).

2.2.1.2 Penetration and LOS Communication

Between indoor and outdoor environments the characteristics of signal propagation are changed (Pozar, 2005). Understanding the mm-wave in different environments with different cases such as diffraction, penetration, scattering and reflection form the 5G system foundation (Anderson, 2004). In indoor environments the behavior of high frequency waves are affected by shadowing effects of people movement, and this could be decreased by using angular diversity and larger antenna beam width (Collonge, 2004). According to the separation of indoor and outdoor environment, still very little outdoor mm-wave signals pass through (glass doors- open doors- open windows) indoor building even if it's bounded to outdoor environment. Thus, different nodes are needed to servedifferent coverage sites. However, theseparationkeeps the energy in the intended area(Schulz&Samimi&Gutierrez, 2013). Also this separation could relax the overhead associated with radio traffic. Small cell architecture is already under deployment in intensive areas. In Japan the inter-BS distance is around 200 meters only(Andrews, 2014). In small cell environment,LOS propagation appears hopeful for mm-wave communications. Because LOS needs huge antenna deployment without any limited Pattern. The antenna deployment is expected to change according to the situation. According to the challenges that associated with LOS communications, NLOS propagation investigates the network requirement.

2.2.1.3 NLOS and Multipath

When an antenna receives signals from more than one path, this would be called multipath effect in wireless communication (Saxena, 2015), (Kyro, 2012). LOS is not always possible in outdoor environment, thus Understanding of multipathwill reduce the NLOS problems. Thus, it is significant to search for the obstructing LOS and NLOS links possibilities like short-term signal levels in rain, rain attenuation, attenuation through vegetation, etc.(Schulz&Samimi&Gutierrez, 2013). LOS link may not attenuated always by building edges, corners and human activities, but it may causesshadowing, Reflection coefficients for different surfaces(Dillard, 2004). By combining the beam widening techniques it observed that wide beam-width antennas give a true assessment of received signal. In NLOS paths the Communication process needs equalizers, which gives new challenges by increasing the power consumption, requiring high latency, and low data rates(Qiao, 2012). Thus designing equalizers and selecting modulation techniques are depends properly on multipath statistics.

2.2.1.4 Doppler

The Doppler affected by carrier frequency and mobility, Doppler shift resulting when received incoming waves have different shift values. Doppler encourages time-selective fading, which relieved by suitable coding and packet size over coherence time of the channel(Murdock, 2013). Moreover, Doppler spread reduces by reducing angular spread in narrow beam transmissions inseparable to mm-wave propagation(Rajagopal., 2012). Thus Doppler may not raise 5G network challenges.

2.2.2 Adaptive Beamforming

In this section, we discussed how beams are created; trained, controlled, steered, and measuredby using smart antenna design and discussing how these are an integral part of emerging 5G networks will be produced.

2.2.2.1 Creating and Controlling the Beam

An antenna array and sub-array configurations with specific beamforming lead and controls the beam. Beamforming weights are applied in digital or analog domain to create directive beams. Thus, mm-wave beamforming algorithm understanding is substantial to put the energy in wanted trend(Roh, 2014). There are three types of beamforming: digital and analog beamforming, in digital beamforming, better performance are offered while the complexity of the system is increased as well as the cost. On the other hand, there is analog beamforming which is simple and effective method but it has less flexibility. The last type is hybrid beamforming which combines the sharp beams with phase shifters from analog beamforming and flexibility from digital beamforming (Roh, 2014). For antenna arrays, component cost and power consumption should take into account, the larger antenna arrays the greater power consumption and rise in component cost, as every antenna element use separate transceivers(Vook, 2014).

2.2.2.2 Antenna Training Protocols

As mentioned before highly directional antennas are considerable for future 5G development. As shown in Figure 2.10 (a) users are aligned with the transmitter, while in Figure 2.10 (b) users are not beam aligned with the transmitter. Thus, transmitting and receiving antennas cannot communicate (Saxena, 2015). Mobile hand set can use steerable beams as well as BSs for backhaul coordination and RF communication. Antenna directions could be efficiently determined with multipath angular spreads and narrowband signals and by using pseudo noise sequences on mm-wave antenna pointing protocols(Murdock, 2013).

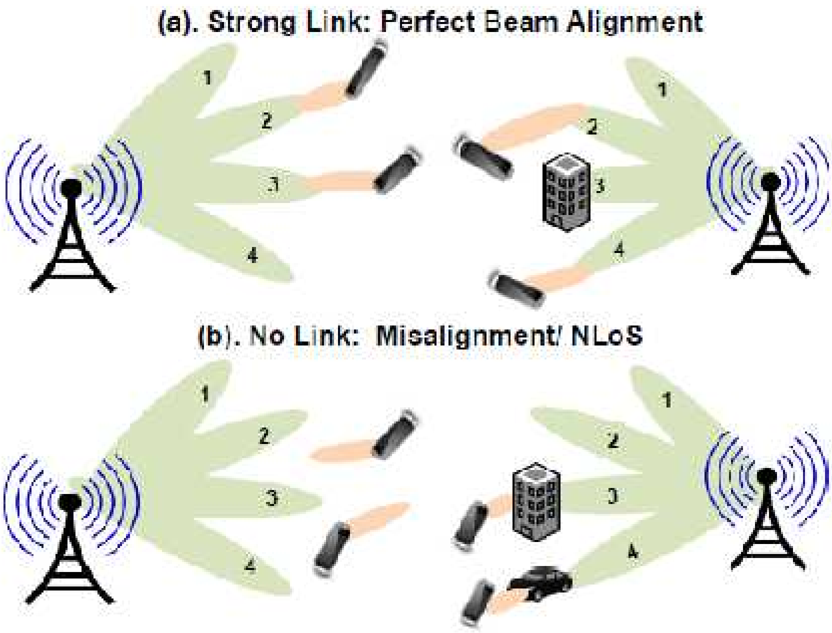


Figure 2.10: Link alignment with beam steering

SVD Singular Value Decomposition has proposed to transmit and receive precoding and combining method. It is utilized for training antenna coefficients in multistage repeated fashion. This training method is effective with large number of antennas and lower number of RF chains (Xia, 2008).For future mm-wave communication, the NLOS technique needs to be robust and crucial. The idea is based on gaining high received signal by moving the axis in small step, as the SNR and the step size are dependent by precision and performance (Tserenlkham, 2013).

2.2.2.3 Angle of Arrival Estimations

Comparing to LOS, In NLOS the antenna pointing makes multipath delay spread and higher path loss. Thus, for outdoor mobile channels, it is necessary to know the characteristics of Doppler spread and time-varying (AOA)(Ben-Dor, 2011). Understanding AOA is useful to find alternative paths of NLOS.For instance in blockage case, switching the device to the next alternate path is needed. The traditional method is to recognize alternate paths by classify signal strengths of all training beam pairs(Tsang, 2011).Directional Self-pursuing Protocol (DSP) use AOA information to achieve energy and bandwidth conservation, with lower redundancy.

2.2.3 Sectorized Antenna

It's difficult to get channel information from each single antenna element in MIMO integrated mm-wave system, so using switched narrow beams for both transmitter and receiver could solve or relieve this problem (Thomas, 2014). Fixed antenna patterns are used for transmitting and receiving from specified directions. Thus, Sectorized antenna model is considered to be the best choice for this system. (Saxena, 2015). The range is divided into overlapping sectors for each transmitting node, and these nodes are designed to switch on one or more than one sectors,which covered transmission range together. Also it decreases the hardware requirements. Furthermore, to increase spectrum capacity with frequency reuse SDMA and beam combining protocol could be used with TDMA or FDMA (Schulz&Samimi&Gutierrez, 2013), (Saxena, 2015).

2.2.4 Massive MIMO System

Massive MIMO provides BS with a huge number of antennas as shown in Figure 2.11, the grid of antennas is able to direct the beams horizontally and vertically. Massive MIMO significantly improves the energy efficiency(Swindlehurst, 2014).The design of massive MIMO system model needs efficient algorithms with advance modulation techniques. Increasing the number of antennas cannot recognize the highly correlated channel vectors as orthogonal. Thus, user scheduling algorithms are suggested to be critical to massive MIMO systems. The new massive MIMO designed by combine large antenna array with electromagnetic lens to obtain better energy focus as well as reduces spatial interference (Zeng, 2014). Comparing massive MIMO with SCN found that the energy efficiency of SCN is larger than massive MIMO(Liu, 2013).

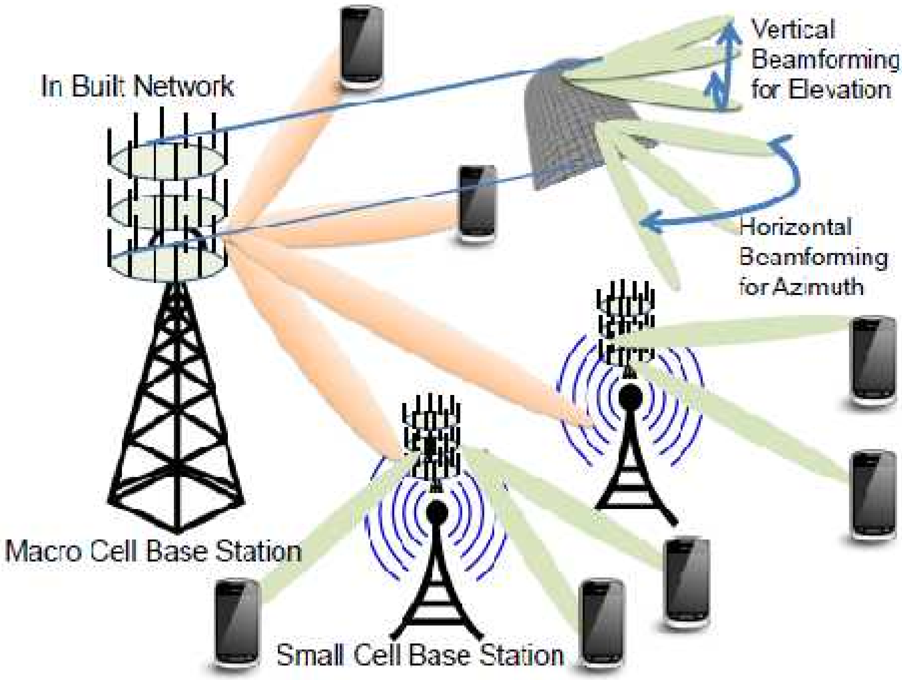


Figure 2.11: Massive MIMO and beamforming

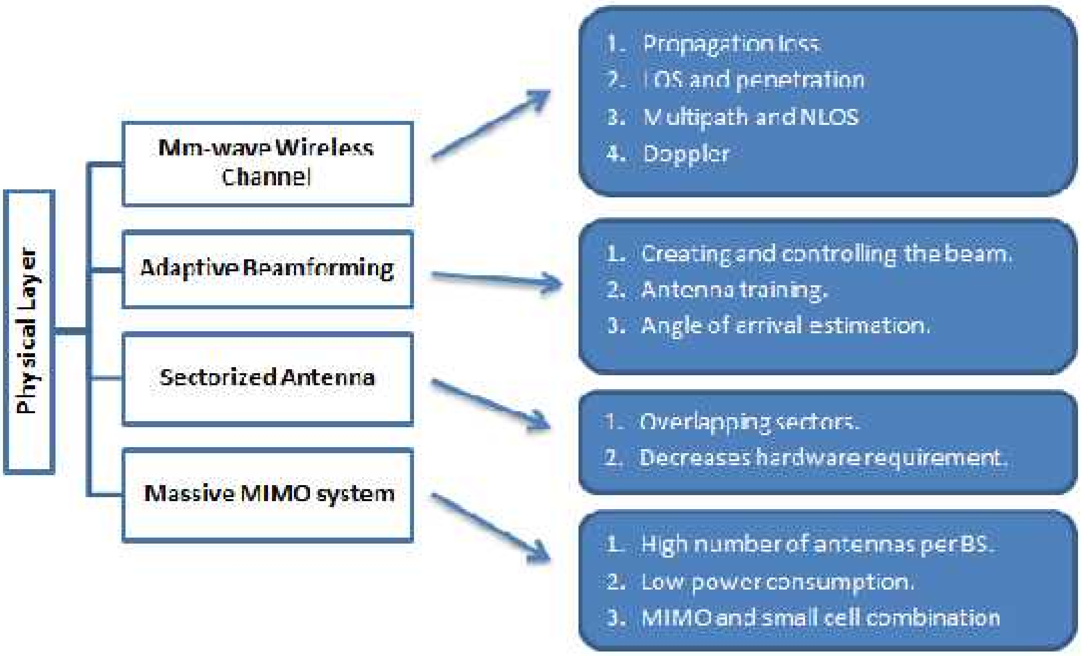


Figure 2.12: Physical layer research in 5G wireless networks

2.3 5G Applications

Expected 5G wireless networks makes the life more excited and provide a solutions for many challenges like city management ,energy, health care, transport, and manufacturing, as well as improved software services.the development in 5G network make it support various devices and service requirement accordingly, this support does not exist in 4G wireless, original 4G LTE standards, 3GPP LTE Release 8.0 in spite of the possibility of the existing applications(Placeholder2). Indeed, these applications increase in wireless data usage, additionally with enormous number of connections which formed a significant burden on 4G wireless networks. 5G network application is represented in this section like: M2M communications, IoT, D2D communications, Healthcare, and IoV.

2.3.1 D2D Communication

As mentioned before 5G wireless network is a device centric nature which enables the devices in closeness to communicate through the cellular BS directly (Asadi, 2014).Figure 2.13 shows different D2D communication scenarios.In ad-hoc D2D network of 5G wireless devices, Routing control process proposed to be used (Jung, 2014). End-users are one of the special advantages foreseeable from D2D communications(Yilmaz, 2014). Energy efficiency, scalability, and low latency are Pivotal to 5G networks. Therefore, decreasing the control signaling and end to end latency is necessary in network support D2D communications (Yilmaz, 2014).

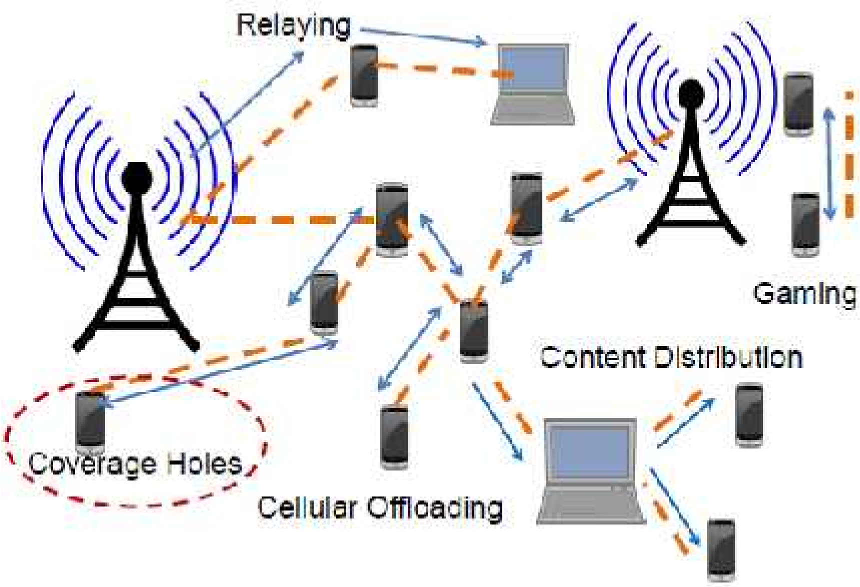


Figure 2.13: D2D communication in 5G network

2.3.2 M2M Communication

Machine-to-Machine (M2M) communications comprises machines communicating with each other and exchanging information with remote servers.M2M communications main characteristics include automated data generation, exchange, processing, and transfer between intelligent machines, with minimum human intervention. Thus, it's expected to be supported in 5G systems like D2D communications (Zhang, 2012). Figure 2.14 shows huge number of devices connected by M2M communications like sensors, smart grid, smart meteringequipment's(Asadi, 2014).M2M communications used with countless devices with small data, high reliability, intermittent transmissions, and low latency(Maksymyuk, 2014).

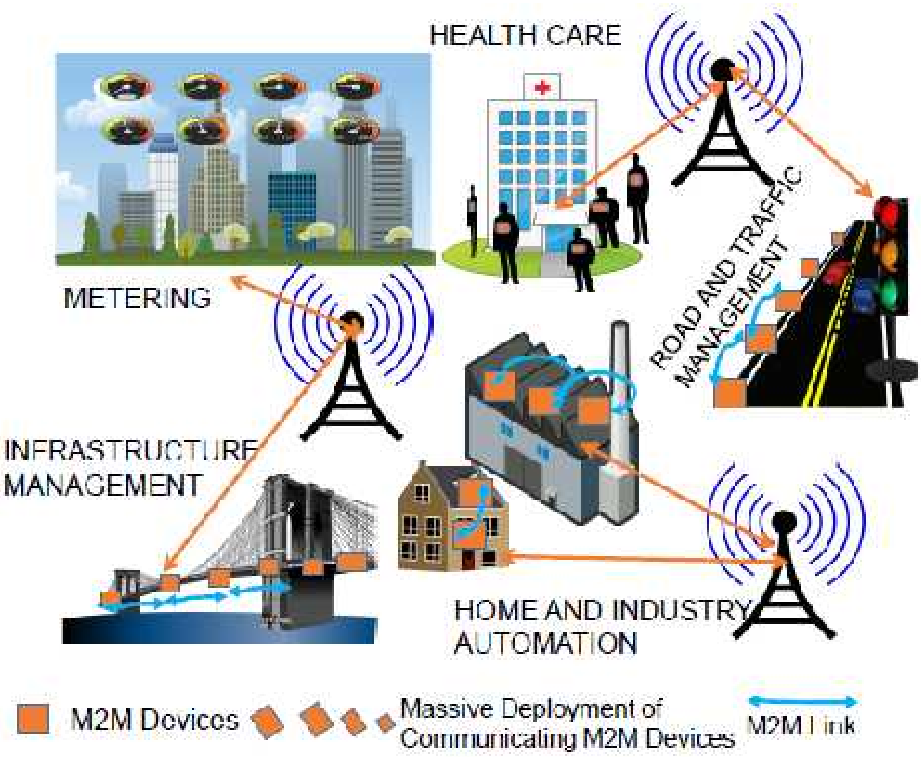


Figure 2.14: Application of M2M communication

2.3.3 Internet of Things (IoT)

Internet of things is the new age of the Internet; IoT refers to the networked interconnection of everyday objects, which will increase the use of the internet by integrating every object with internet systems(Feng Xia& Laurence, 2012).IoT has millions of simultaneous connections including smart homes, smart cities, smart health care, smart transportation systems, and smart grids. Thisdevelopment could be recognized only with high bandwidth 5G systems. The achievement of IoT includes cooperation among huge, distributed, independent and heterogeneous components (Fortino, 2014). IoT includes many challenges like automated sensor configuration, context discovery, context sharing, security, and privacy (Perera, 2014). IOT needs a large storage which is offered by cloud system, it also offers capabilities of networking and computing, which could be integrated with various IoT enabled devices(Nastic, 1014).

2.3.4 Advanced Vehicular Communications

IoV (Internet of Vehicles)is an interconnected vehicle networks for reduced collision probabilities and robust traffic management, which is evaluated from the development of IoT(Intelligence, 2014). Vehicular cloud Features are High bandwidth, diffuse availability, and low latency. IoV include very huge spatial temporary data, which needs high safety and security to be processed and delivered. (Kumar, 2015).IIOVMS and cloud assisted data processing helps in traffic management over a wide number of vehicles (Leng, 2011).

2.3.5 Health Care and Wearable

Developments of communications technology have opened new horizons for the world, and the health field has attended in this developments. In last 30 years world strained increased by ballooning ageing population(Rutherford, 2010). BAN and 5G wireless system have simplified a shift in real time remote patients' health monitoring. Bandwidth limitation considered to be a big constraint in real-time data collection.5G wireless systems are expected to solve the bandwidth constraints with higher bandwidth and data rates(Oleshchuk, 2011).The capabilities that introduced in 5G network require huge data processing, storage, and real-time communications. 5G wireless expected to offer a big data challenges solution of real-time healthcare applications (Xu, 2014).

2.3.6 Miscellaneous Applications

In addition to other applications that mentioned above, strong computing and data processing are also required for increased customers and businesses (Lingzhen, 2009).Future 5G mobile networks have a possibility to transform different financial services, like banking, personal finance management, peer to peer transaction and local commerce, social payments, local commerce, and peer to peer transaction. Wireless networks used for energy data collection, protection, demand/response management, and power line monitoring(Erol-Kantarci, 2015).Smart grids are integrated from smart communication subsystem and smart information (Fang, 2012).SGs are anticipated to solve many challenges, Similarly, Smart homes, smart cities and smart grids increases dense and diverse connectivity this prompt increase in connectivity and data usage supposed to be solving with low latency and high bandwidth and that are offered with 5G systems.

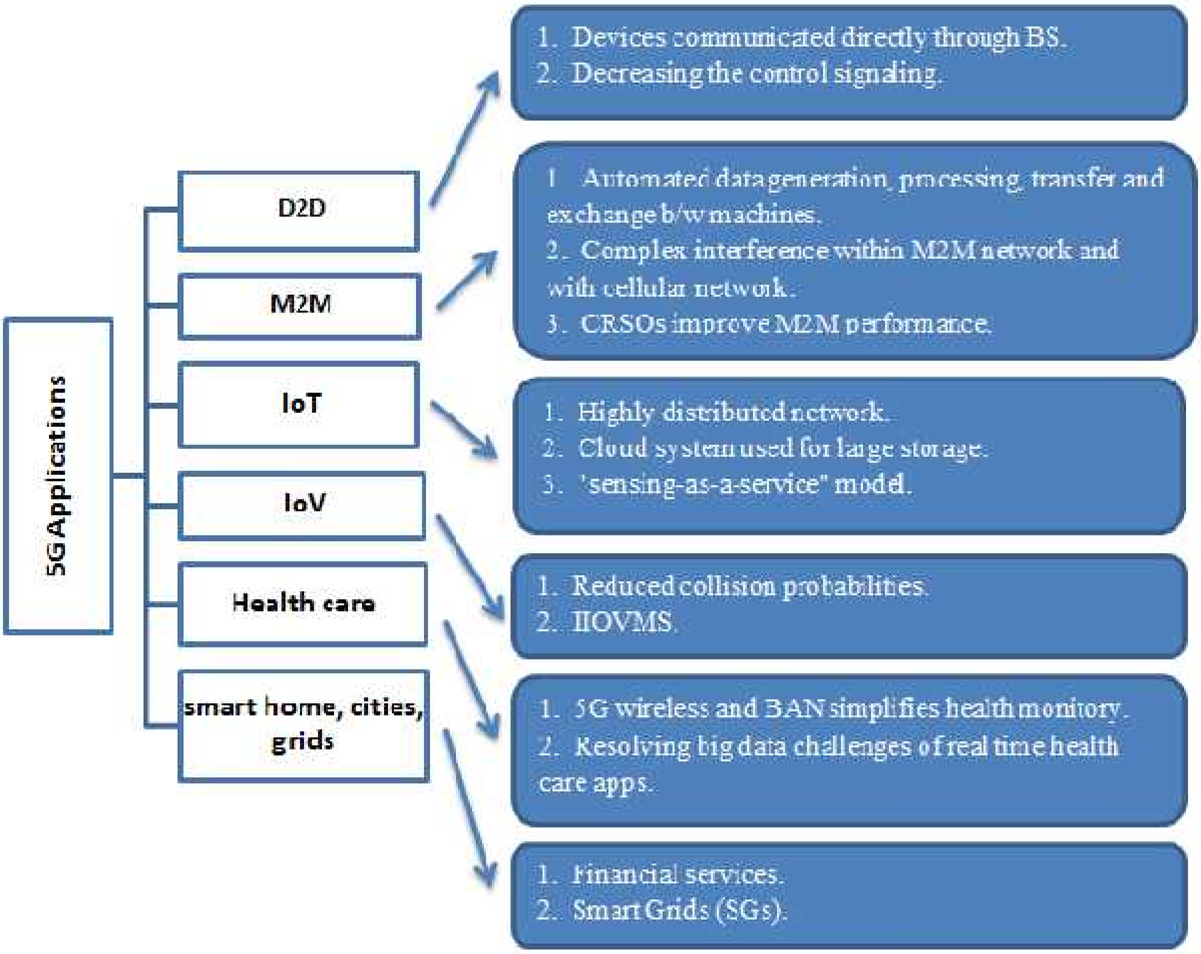


Figure 2.15: Key points of 5G Applications

2.4 5G Challenges

Challenges are the deep-rooted part of the new development, and like all technologies, 5G has also big challenges to deal with. Now if we compare it with legacy networks, next generation represents different features with more rigorous requirements and performances.Moreover, there are a lot of promises that made by 5G wireless network which are related with their challenges like anywhere anytime coverage, Ultra high data rates, huge energy saving and extremely low latency(Saxena, 2015) . And the most research issues that are raised by 5G wireless system are mention below:

a) In 5G system mm-wave spectrum (3 _ 300 GHz) is expected to introduce, and the Propagation features of mm-waves of for wireless communication are a little less useful (Andrews, 2014) . However, with the massive bandwidth that offered by the system,it offers a very compelling long term solution in order to satisfy massive capacity demands, (Adhikari, 2008). Thus, the first challenge is to study all cases associated with signal propagation like diffraction, atmospheric absorption, scattering, refraction, Doppler, reflection, attenuation multipath and multipath(Saxena, 2015).

b) Understanding of indoor, outdoor, and fixed mm-wave communication's radio channel models are required in order to develop the 5G mm-wave mobile communication (Schulz&Samimi&Gutierrez, 2013). According to the separation between indoor and outdoor environments, there is such a need to investigate the outdoor environment referenced by the effects of NLOS beamforming, path loss, delay spread, angular spread, and blocking issues(Khan., 2011), besides the Rx and Tx locations. Thus, the cell design could be a characteristic of 5G deployment(Schulz&Samimi&Gutierrez, 2013).

c) As the mm-wave frequencies have small wave length, it will utilize many numbers of antenna elements in an array over the small physical surface(Schulz&Samimi&Gutierrez, 2013). The advantages of these large number of antenna array elements are the capability of steering and cohesively collect the energy beam (Andrews, 2014). Thus, the challenges in this concept are the desired directivity in BS and mobile devices design.

d) In 5G wireless systems, there is a completely different BS architecture with millions of small antennas with low power amplifiers, and this could make a serious challenge with MIMO system. Effective massive MIMO algorithms adoption for 5G execution could represent a major leap in future communications (Schulz&Samimi&Gutierrez, 2013). Moreover, the researchers are concerned with theoretical studies and simulations.

e) Heterogeneous network and diverse applications like (D2D, M2M, IoT, IoV, financial technology, health monitoring, smart grids etc.) would make a challenge of synchronism and orthogonalityin future mobile scenarios (Wunder, 2014).

f) Direct conversion to 5G network architecture would face a big challenge according to the enormous requirements. Thus, integration of 5G network 3G/4G network could be useful with along with standalone 5G systems gradually(Schulz&Samimi&Gutierrez, 2013).

CHAPTER 3

ENERGY PERFORMANCE OF 5G WIRELESS NETWORKS WITH Cell-DTX

Due to the continuous increasing in mobile communication industry, there are billions of subscribers of mobile phones in these days, and network operators have been adding more and more base stations (BSs) to meet a higher service demand.By 2020 It is forecast that there will be more than 50 billion connected devices, which means there will be more than 6 connected devices per person, and the communication will not be only between human devices, but also between machines, that's make it more complicated (Stefano Buzzi, 2016). Thus, the energy consumption of mobile networks is increased significantly. Also Rising attention for the environment requires special focus on the energy efficiency of these systems. 5G network needs to have an ultra- broadband network infrastructure to be associated with the development of mobile communication to serve everyone and everything in everywhere. Energy efficiency is considered to be one of the evolution metrics in wireless communications (Sun Zhennian, 2016). Therefor in 5G network it's important to make the subscribers satisfied in energy efficient manner.Energy consumption includes BSs, mobile terminals, and the core network. Andit is worth mentioning that the BSs are consumed around 80% of the total energy that used to operate the network (Fehske, 2011). This huge increment in number of devices and in energy consumption will generate other concerns such as Economic and Environmental concerns. Economically, we need to maximize the capacity to cover the subscribers, which needs more and moreenergy to increase the communication capacity and this in turn would result in significant costs(Sun Zhennian, 2016). Environmentally,information and communication technology (ICT) systems are responsible for 5% of the world's CO_2 emissions, because the carbon is based energy sources for Current wireless communication systems(AUER, 2011),(Fettweis, 2011). This percentage is expected increase by 2020 and beyond,which means the ICT will be responsible to reduce the CO_2 emissions by that time.In this chapter we discuss the energy efficiency in 5G wireless network with exploring the new Techniques that could serve the system.

3.1 Power model

The formation of the BS power model considersbeing equilibrium amidst the components and system-level, and that will quantify the energy saving on specific components and boost the energy efficiency at the network level. The BS type also has a big role on the implemented components due to constraints in output power, cost, and size(AUER, 2011).

3.2 Base station power consumption

BSs type in general are consists of multiple transceivers (TRXs), each one of theme serves one transmit antenna element. A TRX involves a power amplifier (PA),a radio frequency (RF) small-signal TRX module, a baseband engine including a receiver (uplink) and transmitter (downlink) section, a DC-DC power supply, an active cooling system, and an AC-DC unit (mains supply) for connection to the electrical power grid (AUER, 2011). This structure could be generalized to all BS types, including macro, micro, pico and femto BSs. Figure 3.1 shows a s block diagram of BS components.

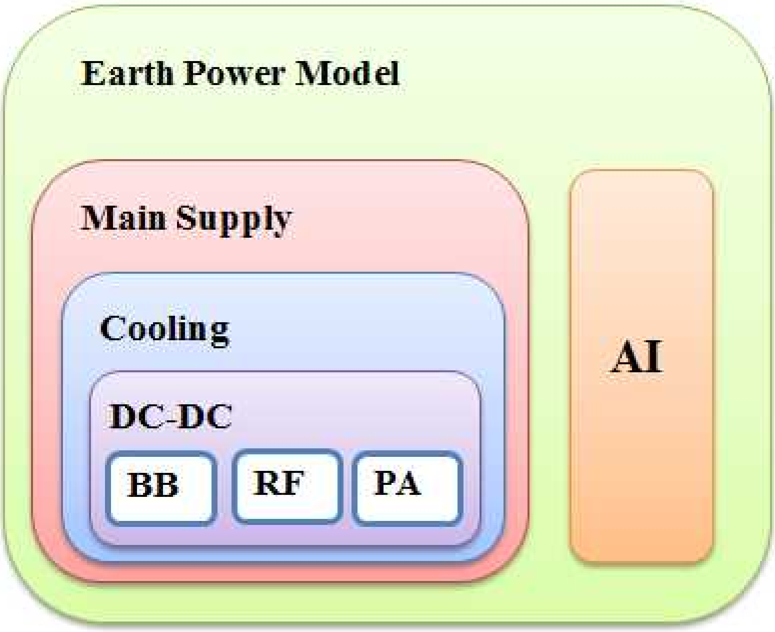


Figure 3.1: A block diagram of base station components

3.2.1 Antenna Interface (AI)

The impact of power efficiency in antenna typesare modeled by a certain amount of losses, including the feeder, antenna bandpass filters, duplexers, and matching-components

(AUER, 2011). introducing a remote radio head (RRH) may relieve the feeder loss in macro BS, RRH is a remote radio transceiver, which connects by electrical or wireless interface to the operator radio control panel (AUER, 2011). The feeder losses are almost negligible for smaller BS types.

3.2.2 Power Amplifier (PA)

Maximum output power is the most effective PA operating point. Unluckily, nonlinear effects and orthogonal frequency-division multiplexing (OFDM) modulation with non-constant envelope signals imposes the power amplifier to operate in a more linear region (Cripps, 2006). Due to the nonlinear deformity this will deny adjacent channel interference (ACI), which also averts performance degradation at the receiver. But this high operating will leads to poor power efficiency η_{PA}, which translates to increased power consumption (AUER, 2011).

$$P_{\mathrm{PA}} = \frac{P_{out}}{\eta_{PA}\,(1-\sigma_{feed})} \qquad (3.1)$$

The required extra feedback for pre-distortion and additional signal processing are consider as a necessary part of macro and micro BSs (Cripps, 2006). in smaller BS type, the PA are careless due to increased operating back-off; moreover, considering that the PA is consume a small percentage of the total BS power consumption excuse a lower PA efficiency(AUER, 2011).

3.2.3 RF Transceiver (RF-TRX)

This part is involved uplink and downlink communication for the receiver/transmitter. The requirements of linearity and blocking in RF module would be different according to the BS type, which is in turn influent the RF architecture: for macro/micro BSs, super-heterodyne architectures orlow-intermediate frequency (IF) are preferred(AUER, 2011).

3.2.4 Basebandunit (BB)

The BB engine implements the digital-signal-processing, filtering,modulation-demodulation, digital pre-distortion (only for large BS types), signal-detection (synchronization, channel estimation, equalization, compensation of RF non-idealities), and channel coding/decoding (AUER, 2011). Finally, platform control and medium access control (MAC) operation add a further power consumer (control processor) (AUER, 2011). Beside the technology, signal bandwidth, number of antennas and the applied signal processing algorithms also involved in the effective of the BB power consumption(Wajda, 2012).

3.2.5 Power consumption and loss factors

The losses that afforded by (DC-DC) power supply, main-supply and active-cooling are linearly related with the power consumption, also there are other components may approximated like loss factors σ_{DC}, σ_{MS}, and σ_{cool}, respectively(Wajda, 2012).Moreover, the active cooling is only viable for macro BSs, and neglected for other smaller BSs. The BS power consumption grows respectively with the number of transceivers N_{TRX}, the breakdown of the BS power consumption at maximum load, where $P_{out} = P_{max}$, yields(Wajda, 2012):

$$P_{in} = N_{TRX} \frac{\frac{P_{out}}{\eta_{PA}(1-\sigma_{feed})}+P_{RF}+P_{BB}}{(1-\sigma_{DC})(1-\sigma_{MS})(1-\sigma_{cool})} \tag{3.2}$$

(Pout) which is the output power (RF) per transmit antenna is measured at the input of the antenna element. Therefore, the losses due to the antenna interface with feeder losses are not involved in the power breakdown, and the supply power Pin scales linearly to the number of TRX chains N_{TRX}(AUER, 2011).

3.3 Cell Discontinuous Transmission (Cell-DTX)

To operate a typical cellular network, around 80% of the energy is consumed by BSs. (Pål Frenger, 2011). Cell-DTX is a new feature that operates during the transmission time intervals (TTIs) when there is no traffic, which enables sleep mode operations at BS. Thus, it transmits only when it’s needed to transmit;while it puts the transmitter in low power mode(Jens, 2014).At the network side this technique is hardware component based deactivation feature which expedite low power states. Figure 3.2 shows simple model for power consumption per cell, with noticing that a site can serve many cells. The cell power use increases linearly with PA use. The fixed energy consumption part (C) is typically in same order as the variable part (V). A cell can be put into sleep mode or discontinuous transmission (DTX) mode when the energy consumption is reduced to a lower value (D) (Pål Frenger, 2011).

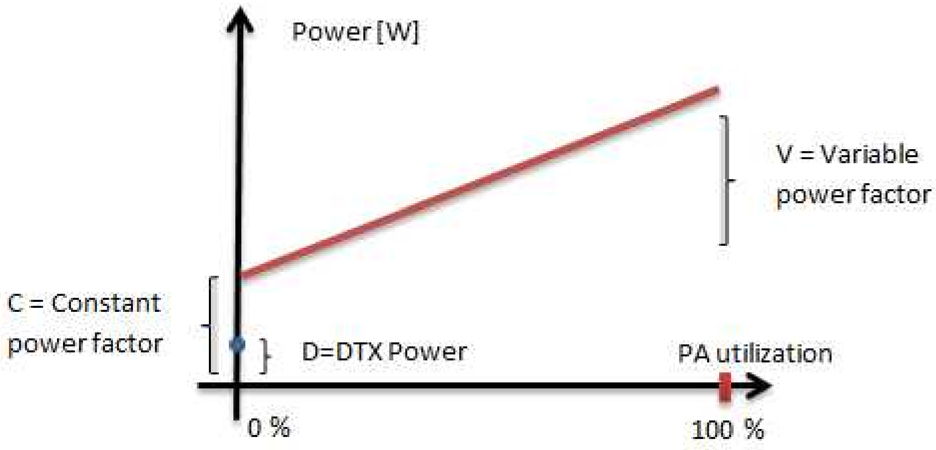


Figure 3.2: Simple model for power consumption per cell

There are two types of cell DTX: fast cell DTX and long cell DTX.Fast cell DTX or short cell DTX acts on slot/subframe level and occurs in some different versions: cell micro DTX, and MBSFN-based DTX(Rapone, 2015) .The cell micro DTX are also known as micro sleep, in this version the radio is put into DTX among transmissions of Cell-specific Reference Signal (CRS) when there is not any user data to transmit. The other oneis MBSFN-based DTX (Multicast Broadcast-Single Frequency Network), in this case the subframes are used to make room for longer sleep periods,as CRS are not transmitted in MBSFN subframes. Thus, both cell micro DTX and MBSFN-based DTX are possible in LTE Release-8 networks (Rapone, 2015).

Long cell DTX is the inversion of fast cell DTX, as it works on slower time scale, as it refers to putting the cell into low-activity mode. Thus, it can be seen as a cell sleep, and it is based on a deeper sleep state, means lower power consumption than the low power state considered in the fast cell DTX (Rapone, 2015). Traditionally, long cell DTX could be activated in low traffic terms, where the cells are low load and traffic guidance techniques are easily viable without many “ping-pong” effects during the day.(Rapone, 2015).

3.4 Wireless Standard and UE Wake up Time

The power consumption of network devices may affected by physical layer latency, which is reduced by using reduced physical layer latency. For instance to prolong the battery life of UEs, it is fundamental to maximize UE's sleep time. The sleep and wake up procedure can be divided into five different states (sleeping-waking up (wup)-synchronizing, transferring data-powering down (pd)).The states are explained in Figure 3.3(Eeva Lahetkangas, 2014).Changing the status from sleep to active mode and vice versa is device dependent and not influenced by wireless standard. Otherwise the time duration of the synchronization and transfer states are depends on the wireless standard. Thus, the total power consumption is related directly to the latency and frame length of the wireless standard(Eeva Lahetkangas, 2014).For LTE-UE being out of sleep mode it has to receive and decode (PSS-SSS) the primary and secondary synchronization signals with the Physical Broadcast Channel also, including the System Frame Number (SFN)(Eeva Lahetkangas, 2014). The synchronization time (t_{sync}) supposed to be (16 ms) when the UE has been in deep sleep mode (Lauridsen, 2014).

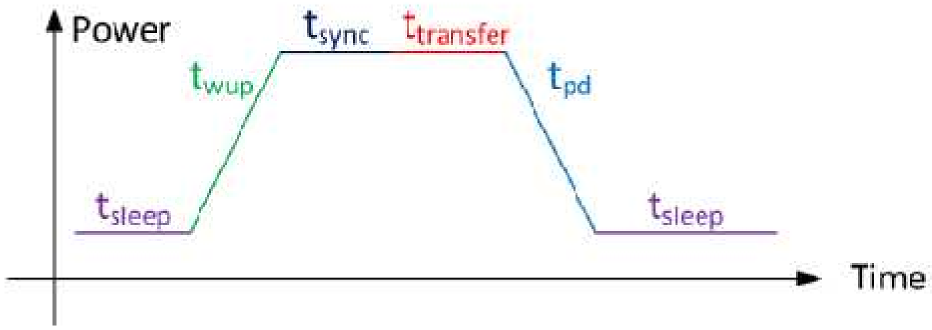


Figure 3.3: UE power states

With 5G UE the synchronization will be much faster because the frames will be shorter, which enables the synchronization signals to be existing in every frame. Therefore, the ON time of the system will be reduced and saves more energy. Comparing data transfer time between LTE and 5G show that the time in 5G will be shorter. Moreover, in 5G wireless network the short frame length reduces the transmission of scheduling request (SR) and scheduling grant (SG) (Eeva Lahetkangas, 2014). In LTE system the time between UE sending and receiving time is not specified. Thus, in LTE physical frame structure the minimum required time is limited and depends on the configurationof UL/DL procedure, and the frame numbersare specified to be around 4-7 frames.The data transmission time is predestined to be (10 ms), andthe specified time for processing the data before it transmits the(ACK/NACK) in BS is at least (4 ms). (Eeva Lahetkangas, 2014).While in 5G system in each frame, bidirectional control plane are exists, The UE started data transmission/reception can be accomplished within 5 frames + 1 symbol as clarified in Figure 3.4(Eeva Lahetkangas, 2014). According to 5G short frame length, which is almost ~1.27 ms (0.25ms for each frame or shorter) (Eeva Lahetkangas, 2014).

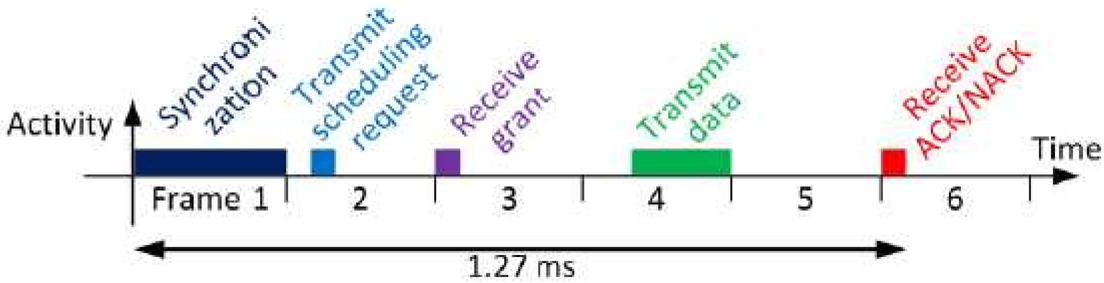


Figure 3.4: UE-initiated transmission in 5G

3.5 Sleep Mode Drawback Solutions

As sleep mode introduces a big challenges to save energy, it's also has a drawbacks have to be solve. One of the solutions is a self-organizing backhaul links. Figure 3.5 could show the future of 5G architecture. There are Hub Base Stations (HBSs), Access Base Stations (ABSs) and their associated Hub Subscriber Stations (HSSs)(Lun, 2014).ABSs acting as relays from HBSs to Mobile Stations (MSs).There are two backhaul wireless connections: the connection between homes HBS and the associated HSS called the main link, while the connection between an available HBS from another cell to the HSS   called an alternative link.Figure 3.6 shows an example of an alternative link, as the HSS render alternative link (second choice) and then the main link will be deactivated (Lun, 2014). Addition to wireless backhaul connection there is a mix of efficient technologies like Fiber, microwave or copper, which could be selected according to the available infrastructure, cost, spectrum, operators, business model and QoS requirements (Saxena, 2015). By comparing wired and wireless backhaul it seems that in wired backhaul higher reliability and capacity are offered, but it is neither a flexible nor an economical solution to dense 5G deployments.

Otherwise, the wireless backhaul may suffer from unreliability issues.Moreover, the power requirements by dense wireless backhauls are yet to be emulated (Saxena, 2015).

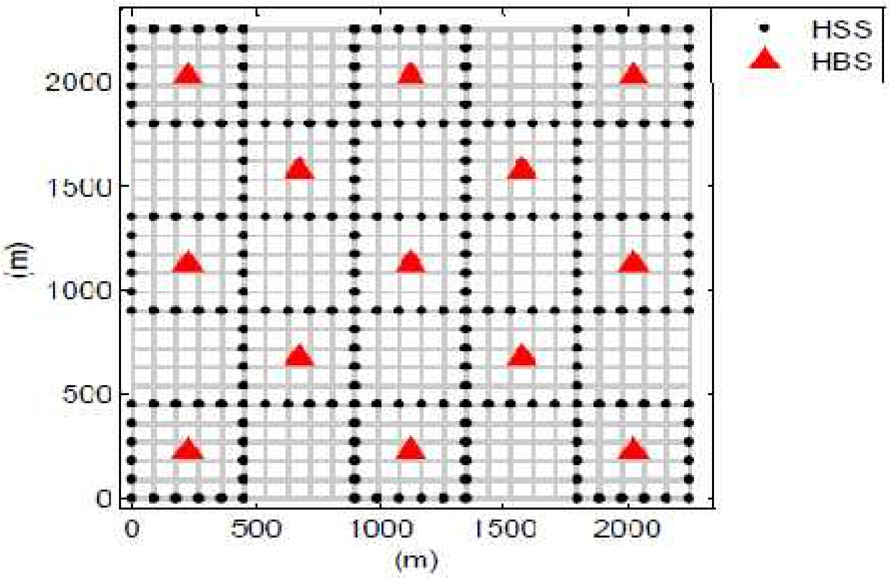


Figure 3.5: Premise network architecture

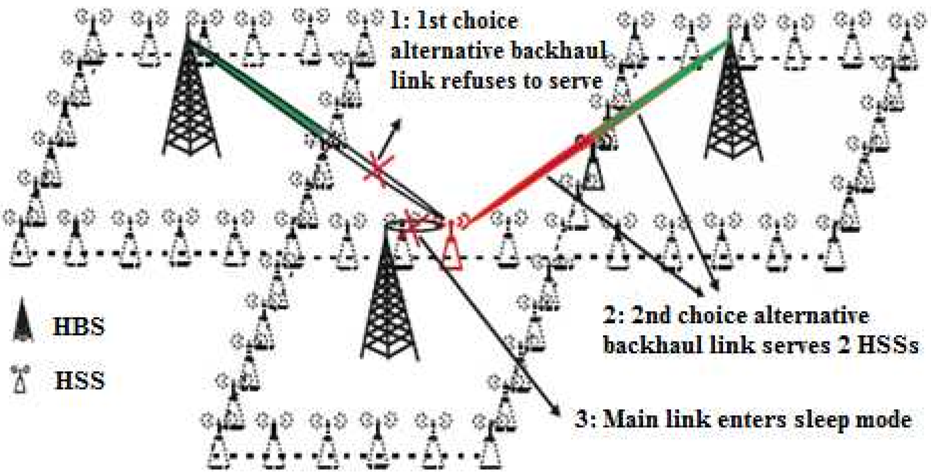


Figure 3.6: Alternative link usage examples with HSS

CHAPTER 4

SIMULATION SETUP AND RESULTS

The target of this thesis is to reduce the energy consumption in the new 5G wireless access technology using Cell-DTX. In this chapter we discuss the power consumption for various BS Type including Macro, Micro, Femto and Pico cell and how much it effected according to the type of BS. Also we discuss the difference of power consumption model for 5Gand LTE and how to reduce the consumption rate with Cell-DTX, as well as calculating the daily average area power consumption with different traffic levels.

4.1 Power Consumption for Various BS Types discussion and results

In this section we calculate the power consumption with deferent BS types and deferent parameter values for each BS and for that we choose a real available wireless system like LTE system with bandwidth of 10 MHz and 2×2 MIMO configuration. The linear power model is represented below(AUER, 2011):

$$P_{in} = \begin{array}{ll} N_{TRX}.\,P_0 + \Delta_p P_{out}, & 0 < P_{out} \leq P_{max} \\ N_{TRX}.\,P_{sleep}, & P_{out=0} \end{array} \qquad (4.1)$$

Where P_0 is the power consumption at the minimum not-zero output power,Δ_p is the slope of the load dependent power consumption, and N_{TRX} is the number of transvers within each BS. The parameters of the linear power model eq.4.1 are listed in Table 4.1. P_{sleep} is fast deactivation of component, means it put them in sleep mode when there is no data to transmit, which is considered an important solution to save energy(Frenger, 2011). P_{in} is the power consumption which is varies depending on BSs type. Figure 4.1shows the relation between relative RF output power P_{out} and BS power consumption Pin are nearly linear. For each BS type, the power consumption P_{in} also varies with the verification of parameter values.

Table 4.1: Parameters of power model for differnt BS types

BS Type	N_{TRX}	P_{MAX}	P_0	Δ_p	P_{sleep}
Macro	6	20	130	4.7	75
	2	20	130	5.9	75
	6	40	130	2.8	75
	6	20	110	4.2	75
Micro	2	6.3	56	2.6	39
	6	6.3	56	2.27	39
	2	11.2	56	2.1	39
	2	6.3	47	2.8	39
Pico	2	0.13	6.8	4.0	4.3
	6	0.13	6.8	1.6	4.3
	2	0.4	6.8	3.3	4.3
	2	0.13	4.6	2.15	4.3
Femto	2	0.05	4.8	8.0	2.9
	6	0.05	4.8	2.88	2.9
	2	0.1	4.8	7.35	2.9
	2	0.05	3.1	5.0	2.9

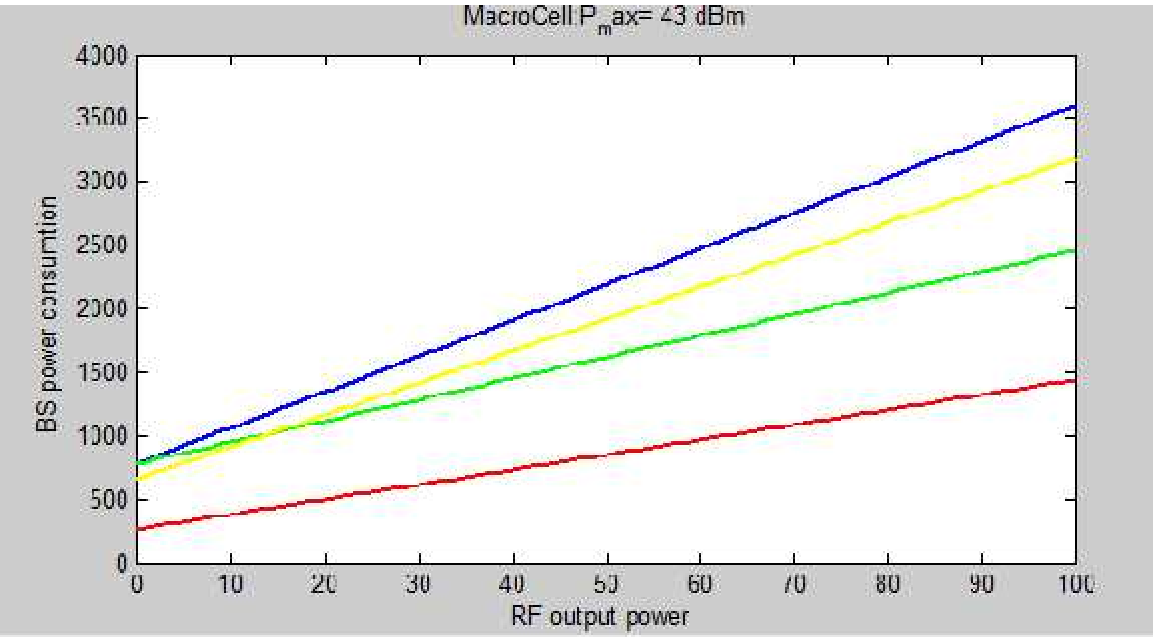


Figure 4.1: Power consumption for Macro cell BS

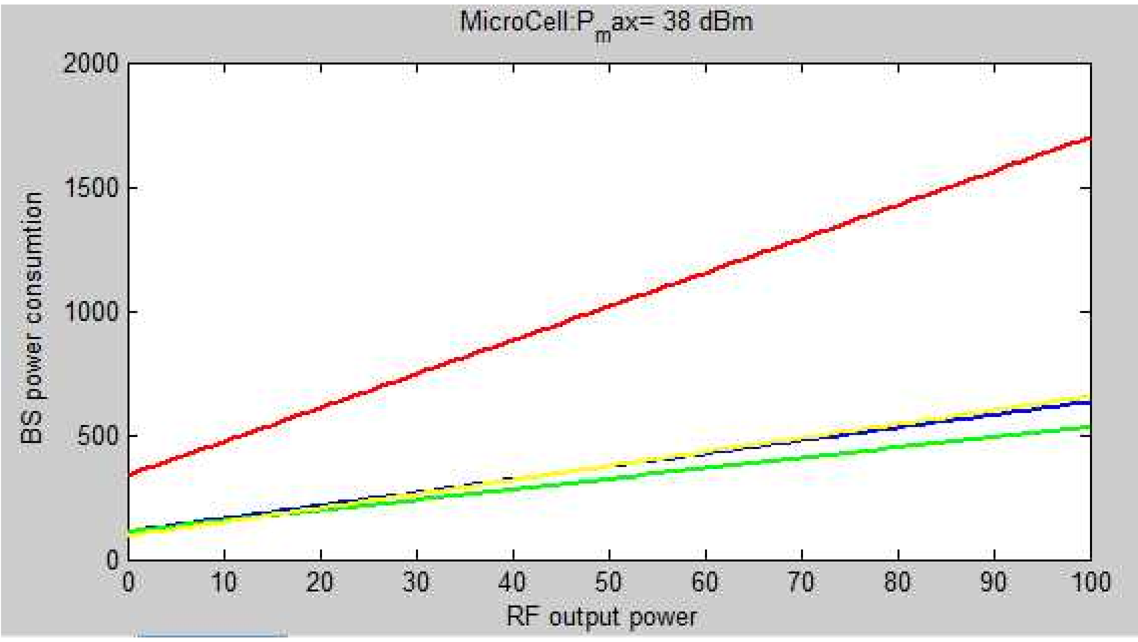


Figure 4.2: Power consumption for Micro cell BS

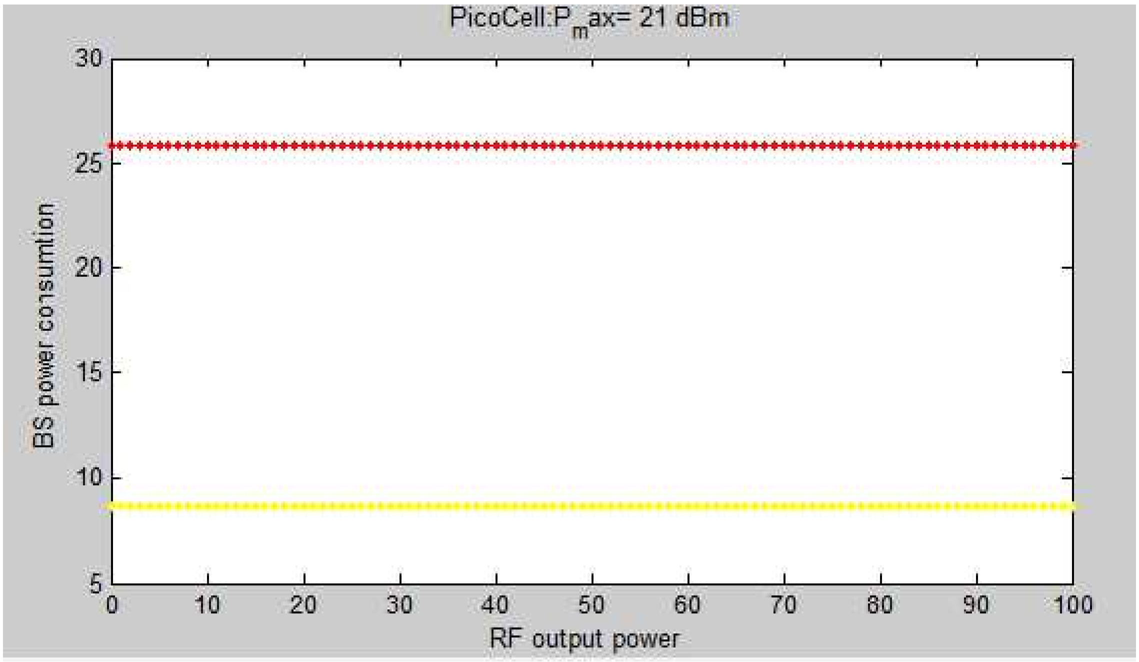


Figure 4.3: Power consumption for Pico cell BS

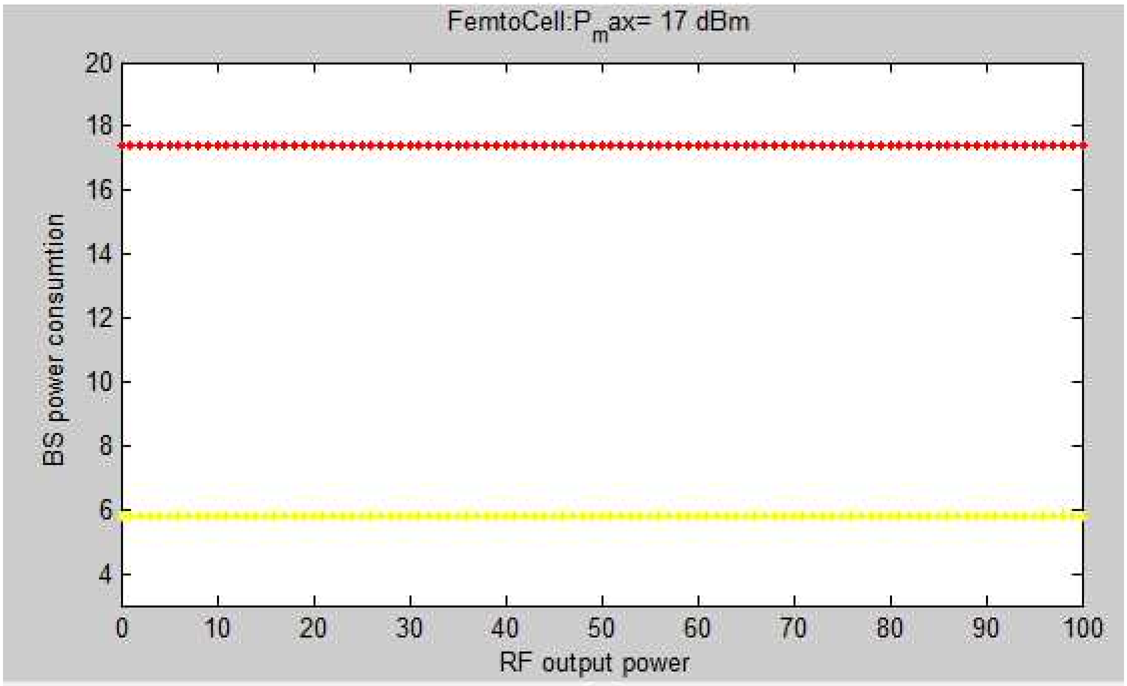


Figure 4.4: Power consumption for Femto cell BS

The macro/micro/pico/femto scenarios are not the basis of the models, but in general manner these models can serve the actual traffic demands in next generation. From the results that shown in the figures above, it's clear that the power consumption (Pin) is load dependent for macro BSs and less effect for micro BS and almost negligible for pico and femto BSs.Thus, densifying pico and femto cells in next generation will decreases the power consumption rate.

4.2 Power Consumption Models discussion and results

In this section, power consumption models are introduced for LTE systems and 5G systems in order to appraisal the energy performance.

4.2.1 Power Consumption Model for LTE:

In LTE, the model of total power consumption of a BS divided into two cases, first case: The idle power consumption (the power consumed in the BS even when there is no transmission P_{tx}= 0); Second case: The traffic load dependent power consumption, as expressed below:

$$P_{BS}^{LTE} = N_{TRX} \times \begin{cases} \Delta_p P_{tx} + P_0 & if\ P_{tx} > 0 \\ P_0 & if\ P_{tx} = 0 (without\ cell\ DTX) \\ \delta P_0 & if\ P_{tx} = 0 (with\ cell\ DTX) \end{cases} \quad (4.2)$$

Where P_{tx} is denote to the transmit power and N_{TRX} is the number of transceivers. On the other hand, Δp represents the portion of the transmit power dependent power consumption due to feeder losses and power amplifier, whereas P_0 accounts for the power consumption because of the active site cooling and the signal processing (Furuskär, 2015).Even when there is no user in the cell, the Traditional BS consumes a large amount of power. Cell-DTX enables the BSs during the empty Transmission Time Interval (TTIs) to deactivate some components of the BS. Which reduce the idle power consumption (Psleep $=N_{TRX}\ \delta$ P0, where $0 < \delta < 1$) (Jading, 2011), (Furuskär, 2015).In LTE cells, it considered to prevent a shortsleep according to the cell DTX period which is (max 0.2 ms). Table (2) shows parameter values of eq. 4.2.

4.2.2 Power Consumption Model for 5G:

Power consumption model in 5G in this thesis is based on(Furuskär, 2015). As given bellow:

$$\mathbf{P_{BS}^{5G-NX}} = \mathbf{N_s} \times \begin{cases} \frac{\mathbf{P_{tx}^{x}}}{\epsilon} + \mathbf{NP_c} + \mathbf{P_B} & \mathbf{if\ P_{tx}^{s} > 0} \\ \mathbf{P_B} & \mathbf{if\ P_{tx}^{s} = 0 (without\ cell\ DTX)} \\ \mathbf{\delta P_B} & \mathbf{if\ P_{tx}^{s} = 0 (with\ cell\ DTX)} \end{cases} \quad (4.3)$$

Where N_s is denotes to the number of sectors in each site, N is the number of RF chains and ε is the power amplifier (PA) efficiency. P_c represents the additional digital and RF processing needed for each antenna branch, whereas $P_B$is the baseline power consumption for each sector. P^s_{tx} denotes to the transmit power per sector. The number of RF chains (N) is twice the number of dual-polarized antenna elements. Sleep mode power consumption of a 5G BS is longer compared to an LTE BS due to consecutive DTX periods, which is up to 99.6 ms. Table 4.2 shows parameter values of (4.2) and (4.3).

Table 4.2: Power consumption models parameter

LTE	
Parameter	Value
Number of transceivers for LTE (N_{TRX})	6
Power slope (Δp)	4.7
Transmit power per transceivers for LTE (P_{tx})	20 W
Baseline power consumption for LTE (P_0)	130 W
Cell DTX performance for LTE (δ)	0.84
5G	
Parameter	Value
Number of sectors is a site (N_s)	6
Transmit power per sector for 5G (P^s_{tx})	20 W
Power amplifier efficiency for 5G (ε)	20%
Number of RF chains (N)	24
Circuit power per RF branch 5G (P_c)	1 W
Baseline power consumption for 5G (P_B)	260 W
Cell DTX performance for 5G (δ)	0.29

According to table 4.2 values using MatLab application, it is noticed that adding Cell-DTX to the network will reduce the power consumption of the network during cell idle mode, as it decreases by 16% in LTE network system and 71%for 5G network system, the results shows that 5G systems provide much better energy performance as it saves more energy comparing to LTE system. Thus, it concluded that the effect of Cell-DTX is uprated in 5G systems which areconsidered to be one of advantagesof power harvesting during idle mode. Otherwise 5G system consumes more power in active mode.

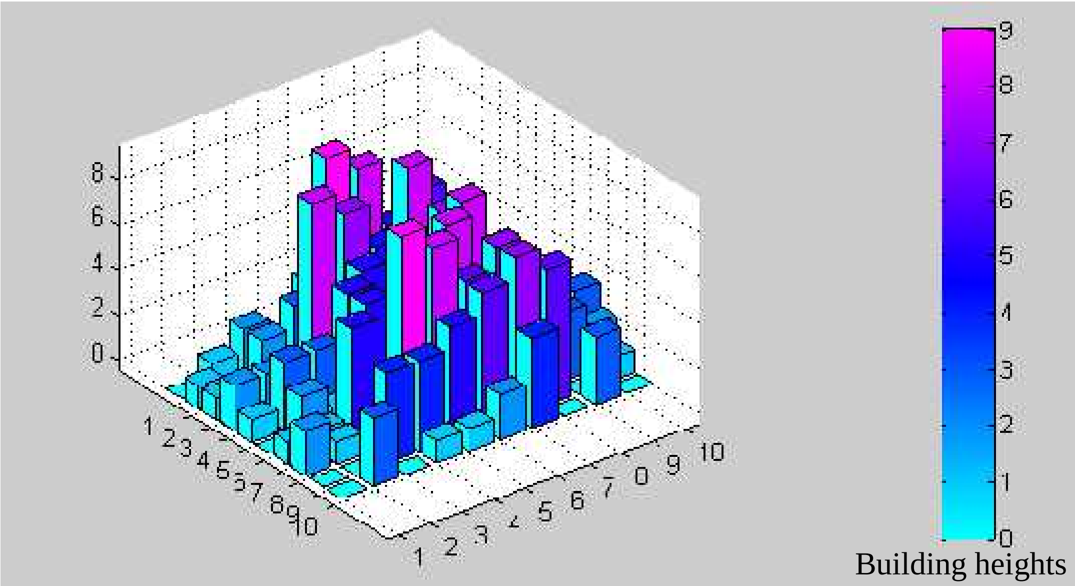
4.3 Daily Average Area Power Consumptiondiscussion and results

Daily average area power consumption is used as the index of energy performance which makes a relation between the total power consumption in the network along a day and theassumption network area *A*, which is measured in W/km2 as below:

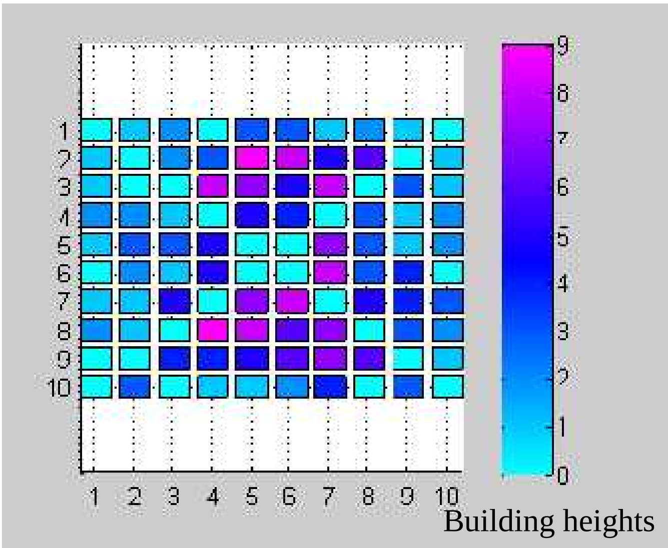
$$\rho_{area} = \frac{1}{24} \frac{\sum_{t=1}^{24} \sum_{i=1}^{N_{BS}} P_{active}\,\eta_i^t + P_{sleep}(1-\eta_i^t)}{A}$$

Where $N_{BS}$is the number of total BSs in the network, Pactiveand Psleepare the power consumption of each BS in transition and sleep mode respectively.The power consumption values in Eq. 4.4 will be different for LTE and 5G systems. Also $\eta^t_i$is represents the resource utilization of the BS i during given hour t.It alsorepresents the probability of that BS *i* is transmitting (Furuskär, 2015).

To access 5G system energy performances we simulate a city model with area of 2×2 km and nearly 250 multi-floorbuildings with different heights between (3 to 148m) as shown in Figure 4.5 the small scale of a city model. With different antenna heights and different inter-site distances (ISD), assuming we have 35 macro sites distributed on this area.



(a) 3D sketch



(b) Top view

Figure 4.5: Small scale sample of city model in the evaluation

Considering we have four different cases to evaluate the system:

Case #01: LTE with 2.6 GHz

Case #02: LTE at 2.6 GHz + LTE at 15 GHz

Case #03: 5G at 15 GHZ

Case #04: LTE at 2.6 GHz + 5G at 15 GHz

Case # 01: the traffic is assumed to be LTE system with 2×2 MIMO configuration with 2.6 GHz, which is representing current network deployment. The other cases are representing the futuristic systems which are expected for year 2020and beyond.

Case #02 : The traffic is an LTE with total bandwidth of about 140 MHz, 40 MHz at 2.6 GHz and 100MHz for 15 GHz using time division duplex (TDD) each with 2×2 MIMO configurations .The reason for choosing TDD for the 15 GHz carrier is that spectrum around 15 GHz will probably be unpaired. Additionally, TDD simplifies beamforming since channel reciprocity can be utilized. This case might represent a transition scenario where LTE has been evolved to allow higher bitrates and carrier frequencies.

Case #03: The 5G standalone system is deployed at 15 GHz using 5×20 antenna arrayto overcome the network traffic demand with 100 MHz Bandwidth.

Case # 04: In this case, we assume that 5G at 15 GHz is deployed together with the existing LTE at 2.6 GHz using carrier aggregation with total bandwidth of 140 MHz.
We consider that all systems are using the same frequency and time resources in each cell for transmission. The assumptions that used in simulation setup and power consumption parameters are listed in the table below (Furuskär, 2015).

Table 4.3: Simulation assumption values

System and Path Loss Parameters				
Parameters	**Value**			
	Case#01	**Case#02**	**Case#03**	**Case#04**
Carrier frequency	2.6	2.6+15	15	2.6+15/GHz
Bandwidth	40	40+100	100	40+100/MHz
Duplex scheme	FDD	FDD+TDD	TDD	FDD+TDD
UE antenna gain	-8	-8 + -8	3	-8 + 3 dBi
Beamforming at BS	None	None + None	UE specific BF	None + UE specific BF
Maximun BS antenna gain	18dBi	18 + 18 dBi	Antenna Array	18 dBi +Antenna Array
Number of UE Rx/Tx branches	2/1			
TDD configuration	5			
Noise figure of UE	9 dB			
Noise figure of BS	2.3 dB			
Traffic Model	Packet download, equal buffer			
Indoor traffic	80%			
Distance between two indoor walls	D_w=4 m			
Indoor threshold distance	d_{break}=10 m			

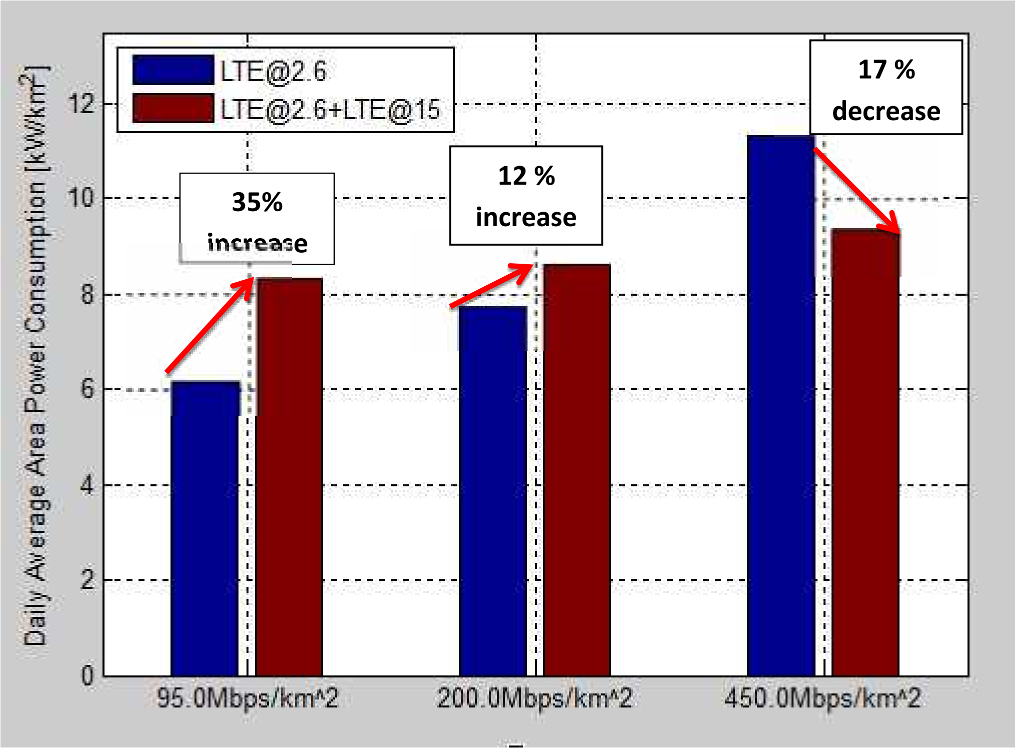


Figure 4.6: Energy performance comparison of LTE@2.6 and LTE@2.6+LTE@15

Considering that we have same traffic conditions and different performance for the evaluated system and by using the methodology that mentioned before, and by comparing the average daily power consumption of LTE system with 2.6 GHz (Case#1) and LTE at 2.6 GHz + LTE at 15 GHz (Case#2), it's clarified that the power consumption increased by 30 % when as shown in Figure 4.6 because of additional RF components and PA power consumption that LTE system at 15 GHz has.

For all traffic levels the power consumption rate changed as we observed on (95 Mbps/km^2) the power consumption increased by 35 % and on (200 Mbps/km^2) it increased by 12 %, while at higher traffic level (450 Mbps/km^2) it decreases by 17 %. Thus, it's seeded that the LTE system with 2.6 GHz is highly utilize the (450 Mbps/km^2) traffic level.

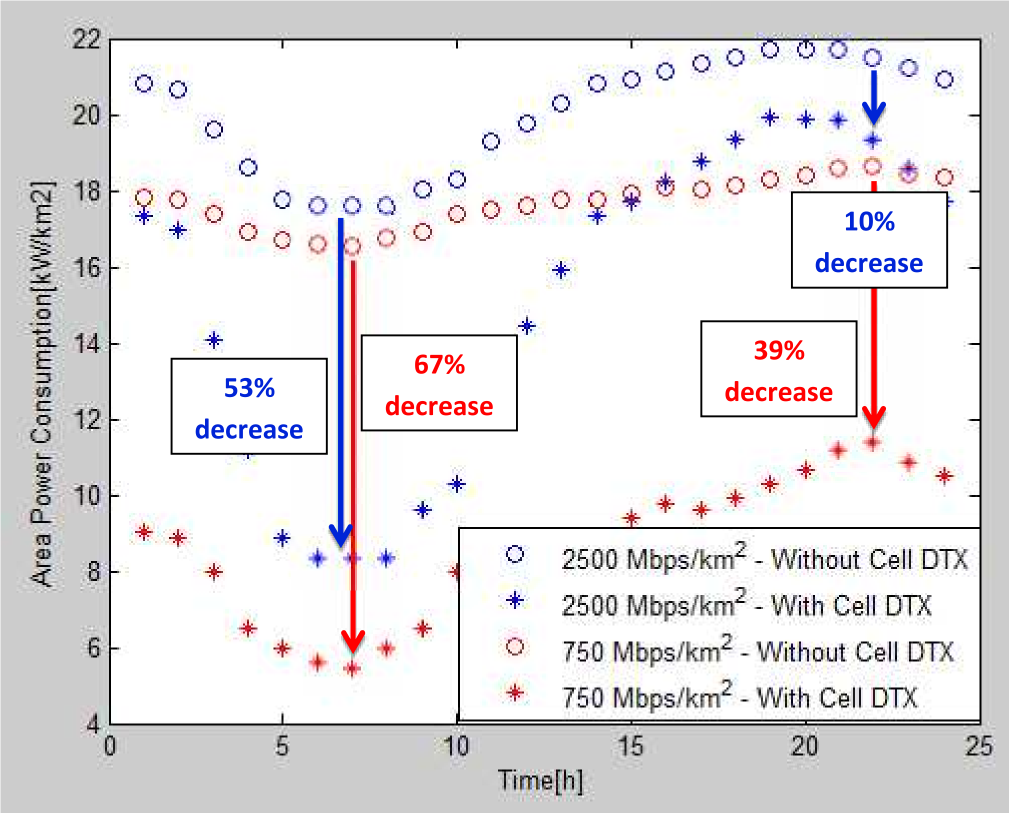


Figure 4.7: Daily variation of area power consumption for traffic levels for 5G @15 GHz

Figure4.7 shows the daily variation of area power consumption for two different traffic levels for 5G systems with 15 GHz, and at each level there are two cases. First: BS with Cell-DTX capability (where parts of BS could be deactivated when there is no traffic). Second: BSs without Cell-DTX capability (where the BS stay active even if there is no traffic). The two different area traffics are (750 Mbps/km^2) the red curve and (2500 Mbps/km^2) the blue curve. It’s clear that there is a high difference between day and night traffics as the power consumption varies along the day. In other hand, it’s remarkable that the Cell-DTX have a significant effect on energy savings. For least busy hours the power consumption decreases 53% at (750 Mbps/km^2) and about 67% at (2500 Mbps/km^2), and for most active hour the power consumption decreases 10% at (750 Mbps/km^2) and around 39 % at (2500 Mbps/km^2), it’s clear that Cell-DTX effect is much better at least busy hours.

Comparingthe power consumption for the four different cases at various area traffic demands with and without Cell-DTX capability gives different result asin Figure 4.8when the traffic level is low (95 Mbps/km2), we observe that 5G wireless system (case #3) decreases the power consumption for about 68% comparing with LTE system (case #1). This shows that the 5G wireless system also has better energy focusing on efficient Cell-DTX capability. We should also observe (case#2) and (case#4), as the power consumption is increased about 35% and 15% respectively. The power consumption for the two cases is increased additionally with hardware cost especially for (case#4) by comparing two different systems with two different scenarios. From this assumption, its seem that this traffic level is not quite benefit from carrier aggregation in (case#2) nor (case#4) in order to reduce the power consumption.

At (450 Mbps/km2) as shown on Figure 4.9 the moderate traffic level, it's clear that LTE system at 2.6 GHz is highly utilized comparing with the low traffic level, which means the user performance is deteriorated and the power consumption increased even with Cell-DTX capability. In this traffic, we observe that the 5G system could save about 72% of the energy comparing to LTE system, while at carrier aggregation cases the power consumption decreases about 17% for (case#2) and 36% for (case#4). From this traffic level, we conclude that the power consumption in (case#2) and (case#4) is effected to the high power consumption in LTE system and this due to the short Cell-DTX duration in LTE system.

For high traffic level (1200 Mbps/km2) which expected beyond 2020, In this traffic 5G system provide 64% of power consumption as shown in Figure 4.10, while it's expected to provide around 10 times more capacity, which is quite difficult for LTE system to handle such a traffic as it utilizes the full system. With no much difference in (case #2), in (case#4) the power consumption reduces for about 34% and this power consumption is due to the 5G system.

The main reason of power consumption decrement is enabling the deep sleep mode in 5G wireless system which is about 99.6 ms, and that's quit better than LTE system which has 0.2 ms for maximum sleep time. That means 5G system increases Cell-DTX duration for about 500 times.

Finally, we should illuminate on the other benefits in 5G system in addition to Cell-DTX capability to reduce the energy consumption which is the high BF gain, higher BW, user-centric shift, etc.).

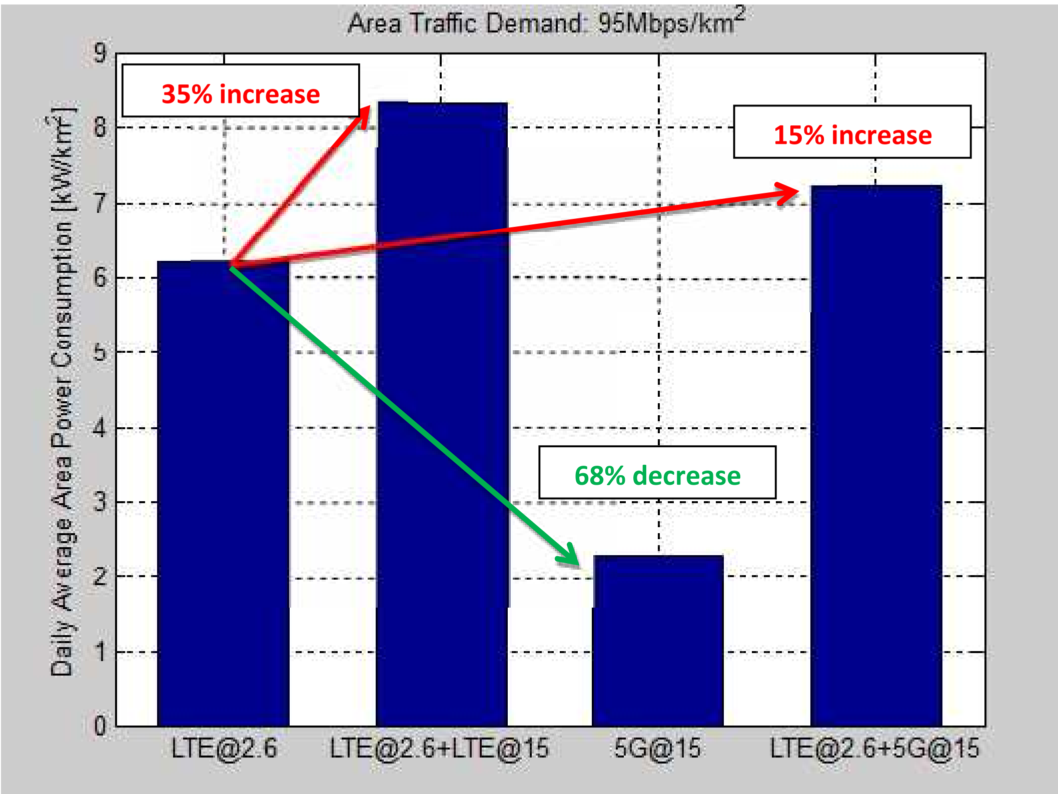


Figure 4.8: Daily average area power consumption at 95 Mbps/km^2

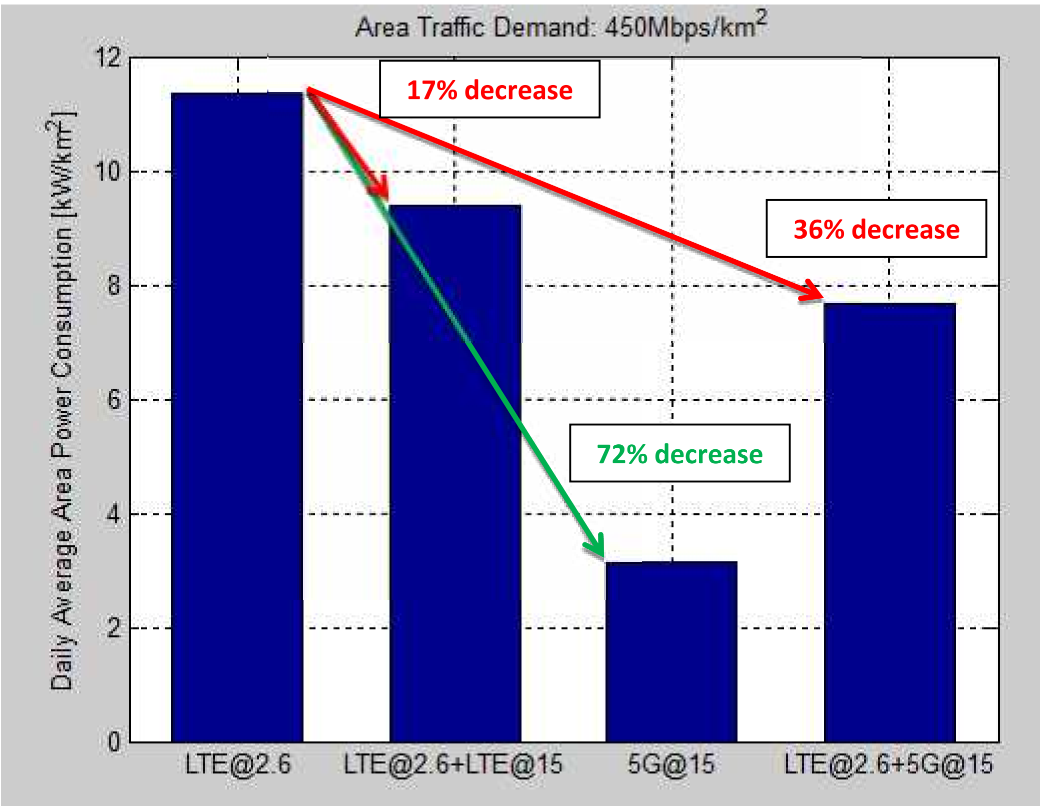


Figure 4.9: Daily average area power consumption at 450 Mbps/km^2

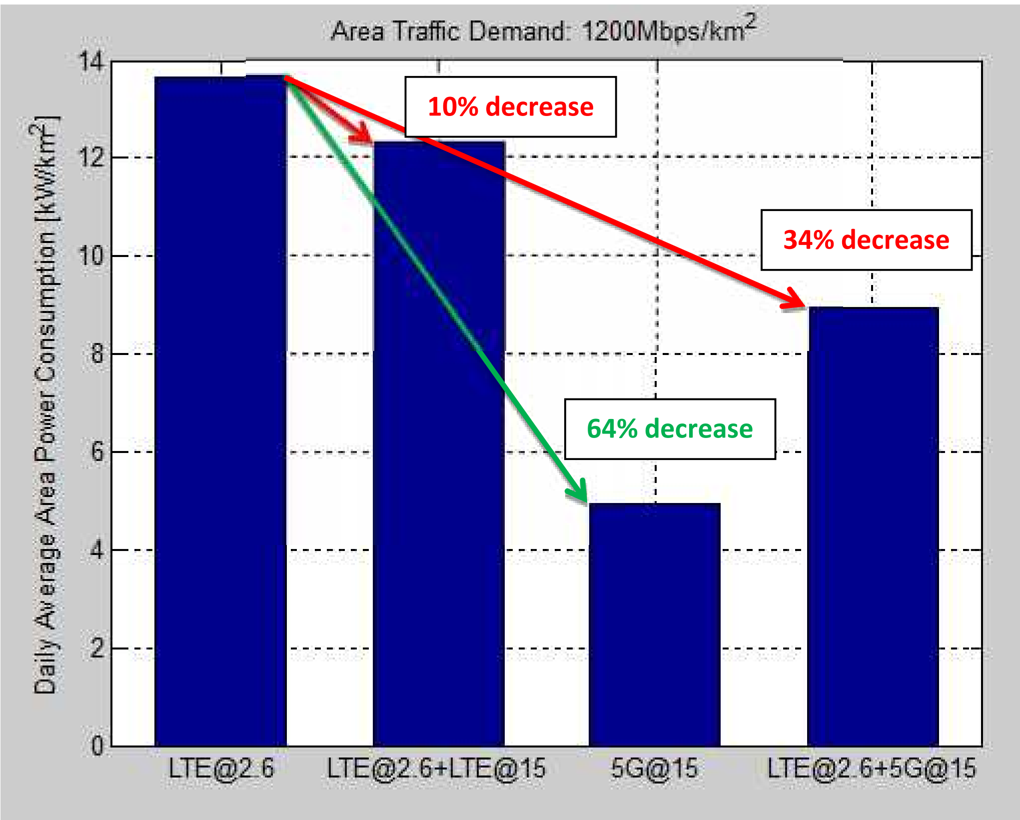


Figure 4.10: Daily average area power consumption at 1200 Mbps/km^2

CAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion and Future Work

In this thesis we aimed to study the architecture, applications, and challenges of the new 5G wireless system and focusing on the energy performance of the system in specific manner to reduce power consumption of the new 5G wireless system, and as the BSs are consumed around 80% of the total energy of the network we try to see the power consumption for various BS types including:(macro, micro, pico, and femto BSs) as they considered to serve the actual traffic demands in the next generation, and we conclude that the power consumption for macro BSs is load dependent, and less dependent for micro BSs, while it's almost negligible for pico and femto BSs .Thus, densifying pico and femto cells in next generation will decreases the power consumption rate.

To evaluate the energy performance of 5G wireless system we compare it with LTE system in dense urban area by presenting Cell-DTX capability for each system. From the results, we infer that 5G systems provide much better energy performance than LTE system by providing longer duration and more efficient sleep mode. Comparing the daily average area power consumption for different traffic demands shows that 5G system saves for about 68% to 72% at low and medium area traffic demands respectively. At high traffic level which expected beyond 2020, 5G system decreases the energy consumption for 69% even with providing 10 times more capacity. The carrier aggregation was presented in order to offer a solution for gradual evolution towards 5G, which combines the benefits of high bandwidth at 15 GHz and better propagation conditions at 2.6 GHz; it's providing a quite energy saving by reducing the power consumption at medium and high traffic demands .

The future work will be on model system of energy harvesting from ambient radio signals in 5G wireless networks, this will improves the energy efficiency of wireless devices, as well as prolonging the lifetime of battery-equipped wireless devices.

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APPENDICES

APPENDIX A

POWER CONSUMPTION FOR VARIOUS BS TYPE

```
clc
clear
% MacroCell
P_out = 0:100;    % RF output power
Po_macro= 130 ;% Power consumption at the minimum non-zero output power
dP_macro= 4.7 ;% slop of the load-dependent power consumption
N_TRX_macro=6;
P_max_macro= 20;
p_sleep_macro= 75;

if 0<P_out<= P_max_macro
P_in_macro= N_TRX_macro*Po_macro+N_TRX_macro*dP_macro*P_out;
else
P_in_macro=N_TRX_macro* p_sleep_macro;
end

%%%%%

Po_macro= 130 ;
dP_macro= 2.8 ;
N_TRX_macro=6;
P_max_macro= 40;

if 0<P_out<= P_max_macro
    P_in_macro1= N_TRX_macro*Po_macro+N_TRX_macro*dP_macro*P_out;
else
   P_in_macro1=N_TRX_macro* p_sleep_macro;
end
```

```
%%%%%

Po_macro= 130 ;
dP_macro= 5.9 ;
N_TRX_macro=2;
P_max_macro= 20;

if 0<P_out<= P_max_macro
    P_in_macro2= N_TRX_macro*Po_macro+N_TRX_macro*dP_macro*P_out;
else
   P_in_macro2=N_TRX_macro* p_sleep_macro;
end

%%%%%

Po_macro= 110 ;
dP_macro= 4.2;
N_TRX_macro=6;
P_max_macro= 20;

if 0<P_out<= P_max_macro
    P_in_macro3= N_TRX_macro*Po_macro+N_TRX_macro*dP_macro*P_out;
else
   P_in_macro3=N_TRX_macro* p_sleep_macro;
end

figure,plot(P_out,P_in_macro,'b',P_out,P_in_macro1,'g',P_out,P_in_macro2,'r',P_out,P_in_
macro3,'y')
title('MacroCell:P_max= 43 dBm')
xlabel ('RF output power ')
ylabel ('BS power consumtion ')

% Microcall
```

```
P_out = 0:100;
Po_micro= 56 ;
dP_micro= 2.6 ;
N_TRX_micro=2;
P_max_micro= 6.3;
p_sleep_micro= 39;

if 0<P_out<= P_max_micro
P_in_micro= N_TRX_micro*Po_micro+N_TRX_micro*dP_micro*P_out;
else
P_in_micro=N_TRX_micro* p_sleep_micro;
end
%%%%%%%

Po_micro= 56 ;
dP_micro= 2.27 ;
N_TRX_micro=6;
P_max_micro= 6.3;

if 0<P_out<= P_max_micro
    P_in_micro1= N_TRX_micro*Po_micro+N_TRX_micro*dP_micro*P_out;
else
   P_in_micro1=N_TRX_micro* p_sleep_micro;
end

%%%%%%

Po_micro= 56 ;
dP_micro= 2.1 ;
N_TRX_micro=2;
P_max_micro= 11.2;

if 0<P_out<= P_max_micro
```

```
    P_in_micro2= N_TRX_micro*Po_micro+N_TRX_micro*dP_micro*P_out;
else
   P_in_micro2=N_TRX_micro* p_sleep_micro;
end

%%%%%

Po_micro= 47 ;
dP_micro= 2.8 ;
N_TRX_micro=2;
P_max_micro= 6.3;

if 0<P_out<= P_max_micro
    P_in_micro3= N_TRX_micro*Po_micro+N_TRX_micro*dP_micro*P_out;
else
   P_in_micro3=N_TRX_micro* p_sleep_micro;
end

figure,plot(P_out,P_in_micro,'b',P_out,P_in_micro1,'r',P_out,P_in_micro2,'g',P_out,P_in_
micro3,'y')
title('MicroCell:P_max= 38 dBm')
xlabel ('RF output power ')
ylabel ('BS power consumtion ')

% PicoCell
P_out = 0:100;
Po_pico= 6.8 ;
dP_pico= 4 ;
N_TRX_pico=2;
P_max_pico=0.13;
p_sleep_pico= 4.3;

if 0<P_out<= P_max_pico
```

```
P_in_pico= N_TRX_pico*Po_pico+ N_TRX_pico*dP_pico*P_out;
else
P_in_pico= N_TRX_pico* p_sleep_pico;
end

%%%%%%

Po_pico= 6.8 ;
dP_pico= 1.6 ;
N_TRX_pico=6;
P_max_pico=0.13;

if 0<P_out<= P_max_pico
    P_in_pico1= N_TRX_pico*Po_pico+ N_TRX_pico*dP_pico*P_out;
else
   P_in_pico1= N_TRX_pico* p_sleep_pico;
end

%%%%%%

Po_pico= 6.8 ;
dP_pico=3.3 ;
N_TRX_pico=2;
P_max_pico=0.4;

if 0<P_out<= P_max_pico
    P_in_pico2= N_TRX_pico*Po_pico+ N_TRX_pico*dP_pico*P_out;
else
   P_in_pico2= N_TRX_pico* p_sleep_pico;
end

%%%%%%%%
```

```
Po_pico= 4.6 ;
dP_pico= 2.15 ;
N_TRX_pico=2;
P_max_pico=0.13;

if 0<P_out<= P_max_pico
    P_in_pico3= N_TRX_pico*Po_pico+ N_TRX_pico*dP_pico*P_out;
else
   P_in_pico3= N_TRX_pico* p_sleep_pico;
end

figure,plot(P_out,P_in_pico,'.b',P_out,P_in_pico1,'.r',P_out,P_in_pico2,'.g',P_out,P_in_pic
o3,'.y')
title('PicoCell:P_max= 21 dBm')
xlabel ('RF output power ')
ylabel ('BS power consumtion ')

%FemtoCell
P_out = 0:100;
Po_femto= 4.8 ;
dP_femto= 8 ;
N_TRX_femto=2;
P_max_femto= 0.05;
p_sleep_femto= 2.9;

if 0<P_out<= P_max_femto
P_in_femto= N_TRX_femto*Po_femto+ N_TRX_pico*dP_femto*P_out;
else
P_in_femto=N_TRX_femto* p_sleep_femto;
end

%%%%%%
```

```
Po_femto= 4.8 ;
dP_femto= 2.88 ;
N_TRX_femto=6;
P_max_femto= 0.05;

if 0<P_out<= P_max_femto
    P_in_femto1= N_TRX_femto*Po_femto+ N_TRX_pico*dP_femto*P_out;
else
   P_in_femto1=N_TRX_femto* p_sleep_femto;
end

%%%%%%%

Po_femto= 4.8 ;
dP_femto= 7.35 ;
N_TRX_femto=2;
P_max_femto= 0.1;


if 0<P_out<= P_max_femto
    P_in_femto2= N_TRX_femto*Po_femto+ N_TRX_pico*dP_femto*P_out;
else
   P_in_femto2=N_TRX_femto* p_sleep_femto;
end

%%%%%%%

Po_femto= 3.1 ;
dP_femto= 5.0 ;
N_TRX_femto=2;
P_max_femto= 0.05;

if 0<P_out<= P_max_femto
```

```
  P_in_femto3= N_TRX_femto*Po_femto+ N_TRX_pico*dP_femto*P_out;
else
  P_in_femto3=N_TRX_femto* p_sleep_femto;
end

figure,plot(P_out,P_in_femto,'.b',P_out,P_in_femto1,'.r',P_out,P_in_femto2,'.g',P_out,P_in
_femto,'.y')
title('FemtooCell:P_max= 17 dBm')
xlabel ('RF output power ')
ylabel ('BS power consumtion ')
```

APPENDIX B

POWER CONSUMPTION MODEL FOR LTE AND 5G SYSTEMS

```
clear
clc
%%% Power Consumption model for LTE

 N_TRX=6;    % number of transceivers for LTE
dp=4.7;     % power slop
 Po=130;     % Baseline power consumption for LTE
 d=0.84;     % Cell DTX performance for LTE

 P_TX=input('enter the value of  P_TX for LTE= ')    % transmit power per transceivers for
LTE

% without cell-DTX

if P_TX>0
P_active_LTE=  N_TRX*(dp*P_TX+Po)
else
P_sleep_LTE = N_TRX*Po
end

% with cell-DTX

if  P_TX>0
P_active_LTE=  N_TRX*(dp*P_TX+Po)
else
P_sleep_DTX_LTE = N_TRX*d*Po
end
```

```
%%% Power Consumption model for 5G

 Ns=6;        % Number of sectors in a site
 N=24;        % Number of RF chains
 e=0.25;      % power amplifier efficiency
 Pc=1;        % additional digital and RF processing needed for each antenna branch
 P_B=260;     % baseline power consumption for each sector
 d=0.29;      % Cell DTX performance for 5G
  P_TX=input('enter the value of  P_TX for 5G = ')      % transmit power per sector

% without cell-DTX

if P_TX>0
  P_active_5G = Ns*((P_TX/e)+N*Pc+P_B)
else
  P_sleep_5G = Ns*P_B
end

% with cell-DTX

if P_TX>0
  P_active_5G = Ns*((P_TX/e)+N*Pc+P_B)
else
  P_sleep_5G_DTX = Ns*d*P_B
end
```

APPENDIX C

SMALL SCALE SAMPLE OF CITY MODEL IN THE EVALUATION

```
clear
clc
% create some data
x=[0 1 2 0 3 3 1 2 1 0 ; 1 0 2 3 9 8 5 6 0 1 ; 1 0 0 8 7 5 8 0 3 1 ; 2 2 1 0 5 4 0 3 1 2 ; 1 3 3 5
0 0 7 3 1 2; 0 2 1 5 0 0 8 3 4 0 ; 1 1 5 0 7 8 0 5 4 3 ; 2 1 0 9 8 6 7 0 3 2 ; 0 0 4 4 5 6 7 6 0 1
; 0 3 0 1 1 2 4 0 3 0];

bh=bar3(x);
for i=1:length(bh)
set(bh(i),'cdata',...
get(bh(i),'zdata'));
end
colormap(winter(256))
colorbar;
```

APPENDIX D

DAILY AVERAGE AREA POWER CONSUMPTION SIMULATION

```
function comparison5G()
closeall;
totalArea = 4;
numberOfSector = 6;        % Number of sectors in a site
numberOfRFChain = 24;        % Number of RF chains
amplifierEfficiency = 0.25;      % power amplifier efficiency
Pc = 1;        % additional digital and RF processing needed for each antenna branch
baselinePower = 260;     % baseline power consumption for each sector
d5_G = 0.29;      % Cell DTX performance for 5G
transmitPower = 20;     % transmit power per sector

n75 = [0.24 0.23 0.18 0.10 0.07 0.05 0.04 0.07 0.10 0.18 0.19 0.21 0.23 0.23 0.26 0.28
0.27 0.29 0.31 0.33 0.36 0.37 0.34 0.32];
n25 = [0.7 0.68 0.52 0.36 0.23 0.2 0.2 0.2 0.27 0.31 0.47 0.54 0.62 0.7 0.72 0.75 0.78 0.81
0.8423 0.841 0.84 0.81 0.77 0.72];

P_active_5G = numberOfSector*((transmitPower/amplifierEfficiency)
+numberOfRFChain*Pc+baselinePower);
P_sleep_5G = numberOfSector * baselinePower;
P_sleep_5G_DTX = numberOfSector * d5_G * baselinePower;

P_area_5G_25 = (1/24)*( P_active_5G * n25 + P_sleep_5G*(1-n25))/totalArea;
P_area_5G_DTX_25 = (1/24)*( P_active_5G *n25 + P_sleep_5G_DTX*(1-
n25))/totalArea;

P_area_5G75 = (1/24)*( P_active_5G * n75 + P_sleep_5G*(1-n75))/totalArea;
P_area_5G_DTX_75 = (1/24)*( P_active_5G * n75 + P_sleep_5G_DTX*(1-
n75))/totalArea;
```

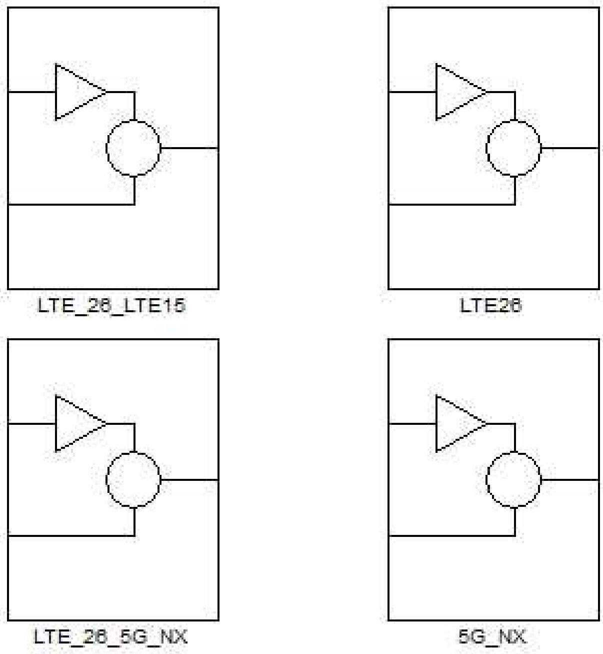
```
figure('Name','Area Power Consumption'), plot (P_area_5G_25,'bo')
holdon ,plot (P_area_5G_DTX_25,'b*')
holdon ,plot (P_area_5G75,'ro')
holdon ,plot (P_area_5G_DTX_75,'r*')
xlabel('Time[h]')
ylabel('Area Power Consumption[kW/km2]')
legend('2500 Mbps/km^2 - Without Cell DTX','2500 Mbps/km^2 - With Cell DTX','750
Mbps/km^2 - Without Cell DTX','750 Mbps/km^2 - With Cell DTX')

simResults = sim('Implementation');
Lte_26_95 = Lte_26(:,1);
Lte_26_95 = mean(Lte_26_95);

Lte_26_450 = Lte_26(:,2);
Lte_26_450 = mean(Lte_26_450);

Lte_26_1200 = Lte_26(:,3);
Lte_26_1200 = mean(Lte_26_1200);

Lte_26_200 = Lte_26(:,4);
Lte_26_200 = mean(Lte_26_200);

Lte_26_Lte_15_95 = Lte_26_Lte_15(:,1);
Lte_26_Lte_15_95 = mean(Lte_26_Lte_15_95);

Lte_26_Lte_15_450 = Lte_26_Lte_15(:,2);
Lte_26_Lte_15_450 = mean(Lte_26_Lte_15_450);

Lte_26_Lte_15_1200 = Lte_26_Lte_15(:,3);
Lte_26_Lte_15_1200 = mean(Lte_26_Lte_15_1200);

Lte_26_Lte_15_200 = Lte_26_Lte_15(:,4);
Lte_26_Lte_15_200 = mean(Lte_26_Lte_15_200);
```

```
Lte_2_6_5G_95 = Lte_2_6_5G(:,1);
Lte_2_6_5G_95 = mean(Lte_2_6_5G_95);

Lte_2_6_5G_450 = Lte_2_6_5G(:,2);
Lte_2_6_5G_450 = mean(Lte_2_6_5G_450);

Lte_2_6_5G_1200 = Lte_2_6_5G(:,3);
Lte_2_6_5G_1200 = mean(Lte_2_6_5G_1200);



NX_5G_15_95 = NX_5G_15(:,1);
NX_5G_15_95 = mean(NX_5G_15_95);

NX_5G_15_450 = NX_5G_15(:,2);
NX_5G_15_450 = mean(NX_5G_15_450);

NX_5G_15_1200 = NX_5G_15(:,3);
NX_5G_15_1200 = mean(NX_5G_15_1200);

labelX = {'LTE@2.6', 'LTE@2.6+LTE@15', '5G@15', 'LTE@2.6+5G@15'};

bar95 = [Lte_26_95; Lte_26_Lte_15_95; NX_5G_15_95;Lte_2_6_5G_95];
newFig = figure('Name','95Mbps/km^2');
plot95 = bar(bar95);
set(gca,'XTickLabel',labelX);
set(plot95,'BarWidth',0.6);
gridon;
ylabel('Daily Average Area Power Consumption [kW/km^2]');
title(gca,'Area Traffic Demand: 95Mbps/km^2');



bar450 = [Lte_26_450; Lte_26_Lte_15_450; NX_5G_15_450;Lte_2_6_5G_450];
newFig = figure('Name','450Mbps/km^2');
```

```
plot450 = bar(bar450);
set(gca,'XTickLabel',labelX);
set(plot450,'BarWidth',0.6);
gridon;
ylabel('Daily Average Area Power Consumption [kW/km^2]');
title(gca,'Area Traffic Demand: 450Mbps/km^2');

bar1200 = [Lte_26_1200; Lte_26_Lte_15_1200; NX_5G_15_1200;Lte_2_6_5G_1200];
newFig = figure('Name','1200Mbps/km^2');
plot1200 = bar(bar1200);
set(gca,'XTickLabel',labelX);
set(plot1200,'BarWidth',0.6);
gridon;
ylabel('Daily Average Area Power Consumption [kW/km^2]');
title(gca,'Area Traffic Demand: 1200Mbps/km^2');

labelX1 = {'95.0Mbps/km^2','200.0Mbps/km^2','450.0Mbps/km^2'};
barcomparison = [Lte_26_95 Lte_26_Lte_15_95; Lte_26_200
Lte_26_Lte_15_200;Lte_26_450 Lte_26_Lte_15_450];
newFig = figure('Name','Comparison');
plotcomparison = bar(barcomparison);
set(gca,'XTickLabel',labelX1);
set(plotcomparison,'BarWidth',0.8);
gridon;
ylabel('Daily Average Area Power Consumption [kW/km^2]');
legend('LTE@2.6','LTE@2.6+LTE@15','Location','northwest');

end
```

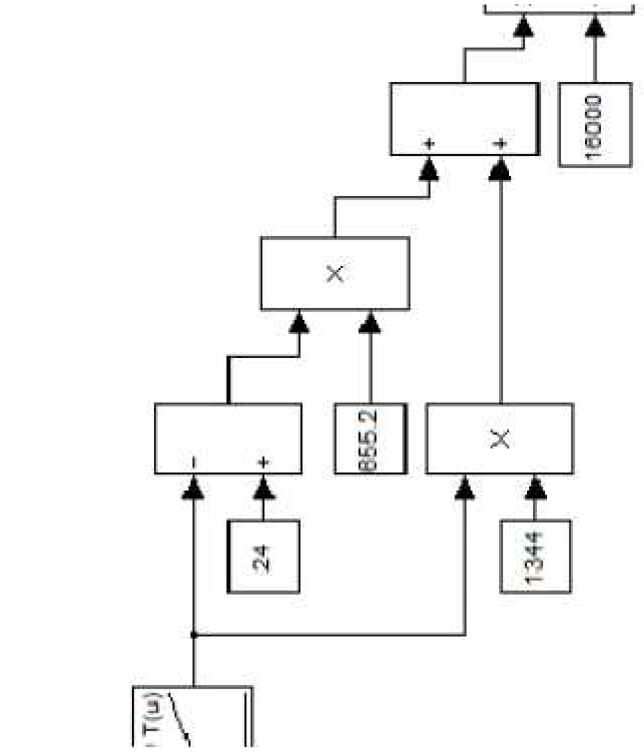
APPENDIX E

SIMULINK MODEL OF DAILY AVERAGE AREA POWER CONSUMPTION



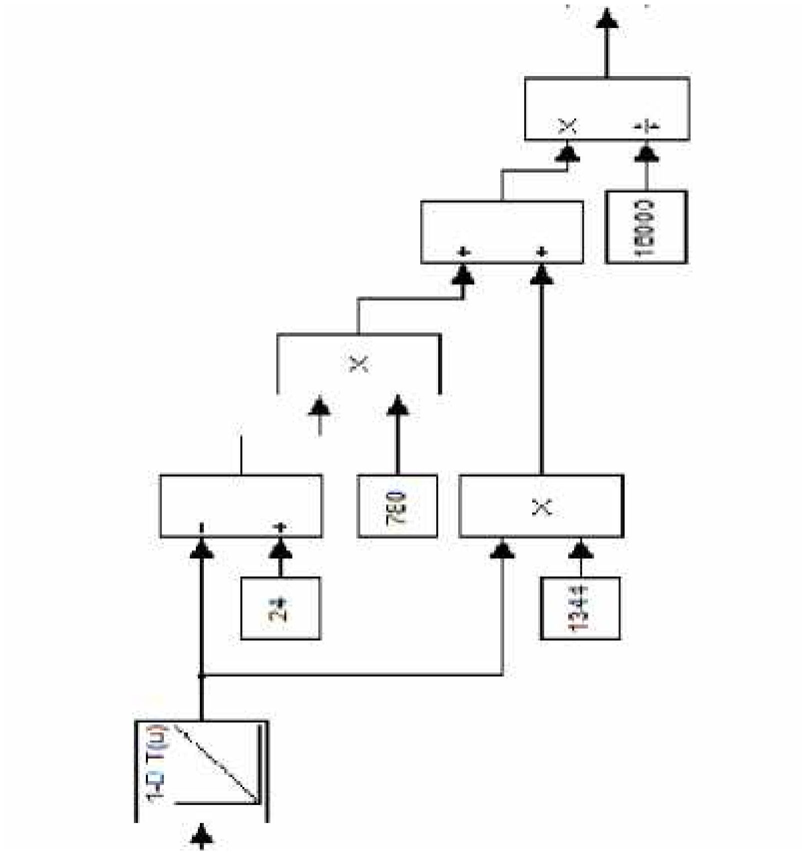
APPENDIX F

SIMULINK MODEL OF CASE #01: LTE WITH 2.6 GHZ



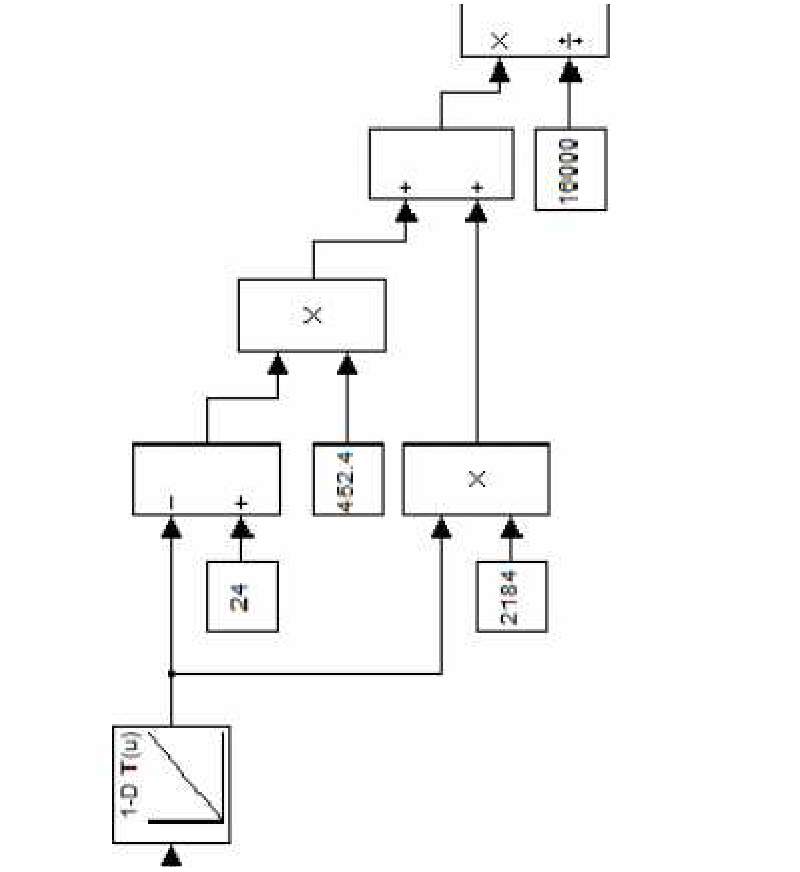
APPENDIX G

SIMULINK MODEL OF CASE #02: LTE AT 2.6 GHZ + LTE AT 15 GHZ



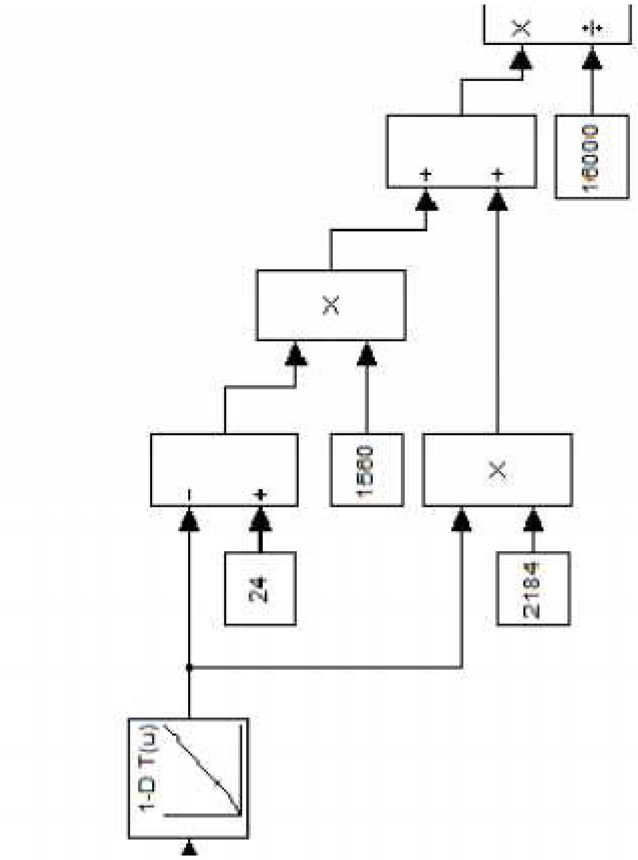
APPENDIX H

SIMULINK MODEL OF CASE #03: 5G AT 15 GHZ



APPENDIX I

SIMULINK MODEL OF CASE #04: 5G AT 15 GHZ + LTE AT 2.6


1-D T(u)
24
1560
2184
16000