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Thème

Beyond 5G Wireless Networks (b5G)

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ABSTRACT

With 5G New Radio (NR) is finally being established reaching a data rate of 10 Gbps opening the door to advanced services to humanity such as the Internet of things (IoT), Virtual Reality (VR) and many other services. However, the extreme evolution of new services and applications demands for a higher data rates and ultra-lower latency. Taking this in consideration, our work is being concentrated on the development of what comes after the 5G era: Beyond 5G networks (b5G). Beginning with the requirements that are needed to be achieved in the future wireless networks as well as the visions that are expected from b5G systems. Then, moving to one of the most important characteristics which is the of need of higher frequency bands: the Terahertz bands. Next, we went more in depth concerning the signal processing techniques for b5G networks. And then focus on the full-stack protocol and the challenges facing it in b5G networks. Finally, a full scenario of b5G network was simulated using both of ns3's new module for THz communications: TeraSim and MATLAB.

Key words: 5G New Radio, b5G, THz bands, TeraSim, MATLAB.

ملخص

أخيرا، ومع انطلاق الجيل الخامس للشبكات اللاسلكية بسرعة لا تقل عن 10 جيغابيت في الثانية فاتحا الابواب امام خدمات عدة مثل أنترنت الأشياء و الواقع الافتراضي و عدة تكنولوجيات اخرى. ومع ذلك، فإن التطور الهائل في هانه التطبيقات يتطلب معدلات بيانات أعلى و وقت االستجابة أقل بكثير. مع أخذ هذا في الاعتبار، يتركز عملنا على التطور الذي سيحصل لشبكات مابعد الجيل الخامس. بدءا من المتطلبات التي يلزم تحقيقها في الشبكات اللاسلكية المستقبلية بالإضافة إلى الرؤى المتوقعة من أنظمة ما بعد الجيل الخامس. ثم ننتقل إلى واحدة من أهم الخصائص وهي الحاجة إلى نطاقات تردد أعلى: ترددات التيراهيرتز. ثم تعمقنا أكثر فيما يتعلق بتقنيات معالجة الإشارات لشبكات مابعد الجيل الخامس. بعد ذلك, تطرقنا الى كل طبقات الشبكات والتحديات التي تواجهها في شبكات ما بعد الجيل الخامس. أخيرا، تم محاكاة سيناريو كامل لشبكة مابعد الجيل الخامس باستخدام كل من برنامج محاكي الشبكات و الماتلاب.

الكلمات المفتاحية : الجيل الخامس ، ما بعد الجيل الخامس ، ترددات التيراهيرتز ، MATLAB

RESUME

Avec la 5G, une nouvelle radio (NR) est enfin établie avec une Débit de 10 Gbps ouvrant la porte à des services avancés à l'humanité tels que l'Internet des objets (IoT), la réalité virtuelle (VR) et de nombreux autres services. Cependant, l'évolution extrême des nouveaux services et applications nécessite des débits de données plus élevés et une latence ultra-faible. Compte tenu de cela, notre travail se concentre sur le développement de ce qui vient après l'ère 5G : Au-delà des réseaux 5G (b5G). À commencer par les exigences qui doivent être satisfaites dans les futurs réseaux sans fil ainsi que les visions attendues des systèmes b5G. Ensuite, passage à l'une des caractéristiques les plus importantes qui est le besoin de bandes de fréquences plus élevées : les bandes Térahertz. Ensuite, nous avons approfondi les techniques de traitement du signal pour les réseaux b5G. Après cela, nous avons discuté de toutes les couches de réseaux et des défis auxquels elles sont confrontées dans les réseaux b5G. Enfin, un scénario complet de réseau b5G a été simulé à l'aide des deux simulateurs pour la communication THz, MATLAB et le nouveau module de ns3 : TeraSim.

Mot clés : 5G nouvelle radio, b5G, les bandes Térahertz, TeraSim, MATLAB.

DEDICATION

This work is dedicated to:

My precious Parents. The raison of what I become today. Thanks for your great support and continuous love. May Allah protect you and bless you.

My beloved brothers: Tahar and Ilyess and sisters: Sarah and Douja, friends (a special thanks to a great friend: Selma hadbaoui) who shared their words of advice and encouragement to finish this study.

And lastly, this work could never be done without the help of my Bestie Jimy: 사랑행!

"이 논문을 내가 아는 사람들 중 가장 총명하고 상냥한 기연에게 바칩니다. 이런 힘든 시기에 날 지지해준 모두 고마워".

BENGUECHIA Nourelhouda

DEDICATION

My humble effort is dedicated:

To my sweet and loving father and mother. The source of inspiration and strength, whom continually provide their moral, spiritual, emotional, and financial support.

My treasured brother: Yahia and sisters specially Hanan, for all of their encouragements and prayers.

To my friends for their inspiring pieces of advices.

To my twinnie Dang for being with me through this work,

고생했어!

"지난 5년간 성실히 학업을 통해 논문을 완성하게 되었습니다. 옆에서 열렬한 응원을 보여준 가족에게 무한한 감사를 보냅니다. 마지막으로 수많은 시간동안 옆에서 격려해준 ㄴㅍ에게 고맙다는 말을 전하고싶습니다".

TALBI Djamila

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ABBREVIATION

3GPP	3rd Generation Partnership Project
5G	The Fifth Generation
AE	Antenna Element
APs	Access Points
b5G	Beyond 5G Networks
BBU	Baseband Unit
BSR	Blood Sample Reader
CD-NOMA	Code Domain NOMA
CFO	Carrier Frequency Offset
CMOS	Complementary Metal-Oxide Semiconductor
CN	Core Network
CoMP	Coordinated Multi-Point
CP	Cyclic Prefix
C-RAN	Cloud Radio Access Networks
CSI	Channel State Information
CSMA	Carrier Sense Multiple Access
CTS	Clear-To-Send
DD	Delay-Doppler
DFT	Discrete Fourier Transform
EH	Energy Harvesting
EHD	Extremely High-Definition
eMBB	Enhanced Mobile Broadband
FCC	Federal Communication Commission

FDE	Frequency Domain Equalization
FSPL	Free-Space Path Loss
GFDM	Generalized Frequency Division Multiplexing
H2H	Hospital to Home service
HCE	Hybrid Cross-Entropy
HEO	Highly-Elliptical-Orbit
HIH	Health Insurance at Hospital
HSR	Hyper-High-Speed Railway
HT	Holographic Telepresence
ICI	Inter-Carrier Interference
IGTHz	Interest Group on THz communications
IoE	Internet Of Everything
IoT	Internet of Things
IRS	Intelligent Reflecting Surfaces
ISI	Inter-Symbol Interference
ITU	International Telecommunication Union
IWD	Intelligent Wearable Devices
KPI	Key performance Indicators
LAA	Licensed-Assisted Access
LEO	Low-Earth-Orbit
LoS	Line of Sight
MAC	Medium Access Control
MC	Multi-Carrier
MEC	Mobile Edge Computing

mMTC	Massive Machine-Type-Communication
MRC	Maximal Ratio Combining
MUD	Multi-User Detection
mWET	Massive Wireless Energy Transfer
NLoS	Non-Line of Sight
NOMA	Non-Orthogonal Multiple Access
NR	New Radio
NSA	Non-Stand Alone
OBNOMA	OTFS Based NOMA
OTFS	Orthogonal Time Frequency Space
OFDMA	Orthogonal Frequency Division Multiple Access
OOB	Out of Band Radiation
P2P	point-to-point
PAPR	Peak-to average-Power-Ratio
PD-NOMA	Power Domain NOMA
PSD	Power Spectral Density
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RM	Receive Mode
RRC	Root raised cosine
RRU	Remote Radio Unit
SA	Stand-Alone
SC	Single-Carrier
SC-FDMA	Single carrier Frequency Division Multiple Access

SHD	Super-High Definition
SiGe	Silicon Germanium
SINR	Signal-to-interference-plus-noise ratio
SNR	Signal-to-Noise Ratio
TaNTIN	Terrestrial and Non-Terrestrial Integrated Networks
Tbps	Terabit-Per-Second
THz	Terahertz
TIBWB	Time Interleaved Block Windowed Burst
UAV	Unnamed Arial Vehicle
URLLC	Ultra-Reliable and Low-Latency Communications
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
WWWW	World-Wireless Wide Web

GENERAL INTRODUCTION

As the demand for wireless capacity is continuously growing in the recent years, a desperate need for ultra-higher rates is driving wireless network for the next evolution. Despite the fact that the fifth generation (5G) cellular system with millimiterWaves of frequencies ranging from 30GHz to 300GHz being a key enabler to many services such as the internet of things (IoT), Virtual Reality (VR) and many other extensive varieties of services as well as spanning the basic enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (uRLLC) and machine type communication (mMTC). However, as wireless markets are constantly developing leading the wireless data traffic and the magnitude of connected things to be unsupportable by 5G. Moreover, mmWave spectrum cannot support the new ultra-high data-hungry applications such as holographic communications that require larger bandwidth. Therefore, moving beyond 5G (b5G) with data rate of 1Tbps is highly requested for the next few years.

With all that been said, it is time to wonder about what relies beyond 5G networks? Is there a need to move to higher frequencies? what are the visions and requirements of b5G networks? And what services and applications that will be achieved from such networks? What are the technologies and techniques that will be used in b5G networks to achieve such requirements?

In our end of the year project, we tried to answer these questions through a detailed study of b5G network. The main aim of our work, is to simulate the future b5G network based on macroscale scenario mentioned earlier, in order to investigate the performance of higher layers on the transmission of packets in THz frequencies, the simulation is done using the new ns-3 extension for Terahertz communications, namely TeraSim, where a full end-to-end scenario was created and derived from a full-stack layers perspective. We have also used MATLAB software to create point-to-point scenario in order to analyze the impact of directionality and beamforming during data transmission.

As for the first chapter, we started by stating the releases of 5G networks moving toward b5G networks as we talked about the visions and requirements of b5G networks that will be achieved by using one of the key factors of b5G networks: THz communications, we investigated the most promised spectrum bands that will be utilized in b5G networks as well as the challenges facing it. Then we moved to services and applications that will be provided by b5G networks.

For the second chapter, we had a deep analysis of the signal processing techniques that are expected to be applied in b5G networks, for multiple antenna technologies, new techniques

were observed, cell-free massive MIMO, beamspace massive MIMO and Intelligent Reflecting Surfaces. For multiplexing techniques, several techniques based on OFDMA and NOMA has been discussed, then the new OTFS modulation was mentioned for the next future mobility for b5G networks. In the third chapter, we gave a full overview of the layers starting from the physical layer up to the network layer from the protocol stack perspective based on two main scenarios namely macroscale scenario and nanoscale scenario.

CHAPTER I: THE ROAD BEYOND 5G

I. INTRODUCTION

Mobile Wireless communication systems has witnessed a huge evolution during the past few decades, the change in the technology used as well as frequency, speed and the nature of the system has created the cellular wireless Generations through time, each generation is defined by its standard, capacities, techniques and the new services that it provides, the road of mobile wireless communication has started from the 2nd generation and is still on-going as the wireless device users increases every year. nowadays, we have reached the fifth generation (5G) networks with its first release been launched in the end of 2019, although the 5G specification and development work is still on the progress with a great deal of imperfection remains yet the research for beyond 5G networks is a trending subject in the wireless network community. in this chapter, we will start by addressing the different phases of 5G networks while moving beyond 5G as we introduce the future wireless Terabit-per-second (Tbps) communication network system that is known as beyond 5G networks (b5G), the visions of b5G will be then presented. moreover, the requirements in order to reach the ultra-high data rate for b5G network will be listed. in addition, we will provide a full study of the future promising Terahertz communications as we address the spectrum opportunities and constraints, then we will give the promised services expected from b5G networks. Finally, a detailed description of b5G potential applications and use cases will be discussed.

II. THE ROAD BEYOND 5G

Due to the limitation of the bandwidth in 4G that can no longer handle the high-quality-new services demanded by mobile users. moving to the fifth generation was highly needed, focusing on the world-wireless wide web (WWWW) that will connect everything [1] (including objects the 4G couldn't fully connect), knowing that, 5G has reached data rate up to 10Gbps by using different kind of services such Coordinated Multi-Point (CoMP), Single carrier multiple access (SC-FDMA), Orthogonal frequency multiple access (OFDMA) and non-orthogonal Multiple access (NOMA) techniques as well as Massive-MIMO and small cells [2]. even though 5G is still in its first release, we still need to have a full comprehensive on what is beyond it as we investigate the road through 5G releases starting from release 15.

II.1. Release 15

Release 15 is the first full release of 5G wireless network standards by 3rd Generation Partnership Project (3GPP) that provides outstanding results in its Key performance Indicators (KPI) essential for extreme mobile broadband service, data rate, spectral and latency, surpassing what 4G is capable of [3]. we can distinguish two important events: December 2018 the release of Non-stand Alone (NSA) specifications, and June 2019 the release of Stand-Alone specifications, Devices used today are all based on these specifications.

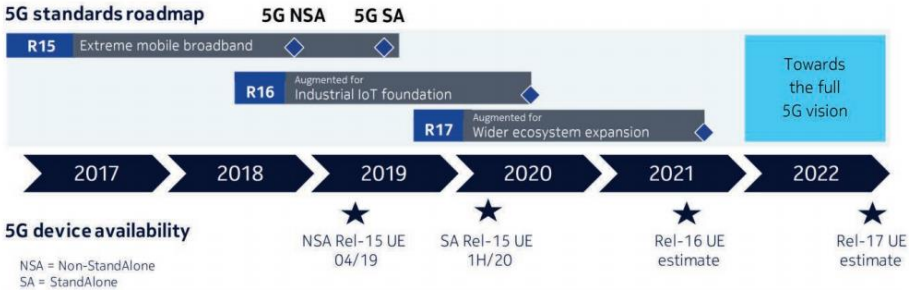

Figure I-1 5G standards Evolution [3]

As for the architecture of 5G, according to 3GPP Releases 14, it is going to reuse the 4G LTE core network (CN) being deployed in non-stand-alone (NSA) and stand-alone (SA) modes with some modifications, the figure below describes 5G architecture in a simple NSA mode [4]:

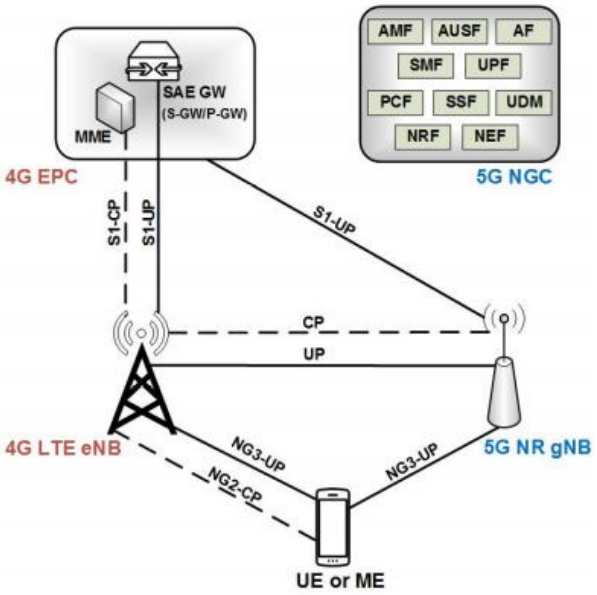

Figure I-2 5G NSA Architecture [4]

As for the Physical layer the table below summarizes the protocols applied for each layer, 5G will also be using virtual multi-wireless network [1]:

Table I-1 OSI layers for 5G Mobile Terminal Design

Application Layer	Application (Service)
Presentation Layer	
Session Layer	Open Transport Protocol (OTP)
Transport Layer	
Network Layer	Upper Network Layer
	Lower Network Layer
Data Link Layer	Open Wireless Architecture (OWA)
Physical Layer	

5G was able to achieve the following requirements [2]:

- high speed and high capacity.
- Large broadcast of data in Gbps.
- Large phone memory, dialing speed, clarity audio/video.

II.2. Release 16

Release 16 has been finalized by 3GPP of the 5G New Radio (NR) radio access specifications, which can be the first step of 5G evolution, the main goal of Release 16 is to enhance the NR performance by supporting unlicensed spectrum focusing on 5GHz and 6GHz unlicensed frequency bands [5], working in unlicensed bands will allow traffic and capacity to extend and therefore achieve high data rate in many scenarios.

NR supports both licensed-assisted access (LAA) and Stand-alone operation unlicensed spectrum using certain features that are introduced in NR Release 16 such as Dynamic channel access that relies on listen before talk where the transmitter listens to potential transmission activity on the channel.

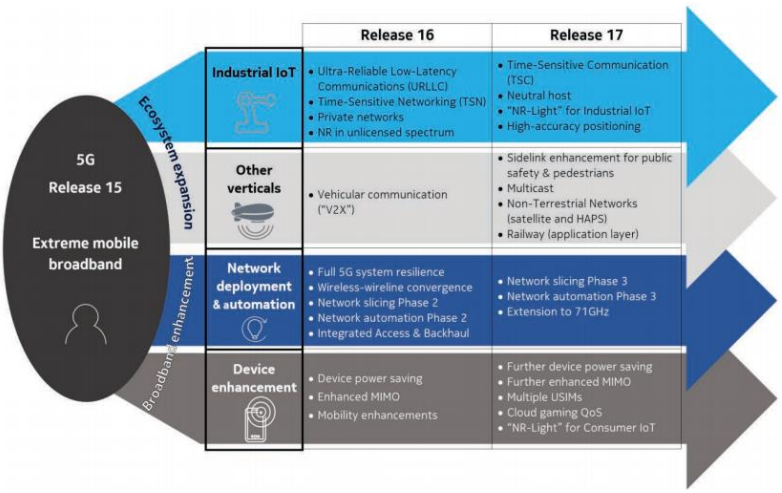

Figure I-3 Key elements of 5G releases 16 & 17 [3]

II.3. Release 17: Next Step of the 5G Evolution [6]

The content of release 17 was meant to be on December 2019. But, due to covid-19 and its effect on 3GPP, the etude on release 17 was delayed on fall of 2020 and is expected to be launched on spring 2021, the features of this release are mentioned below briefly:

- Spectrum beyond 52,6GHz.
- More general side-link: since release 16 introduced the possibility of device-to-device communication, release 17 will focus on v2X use cases.
- Reducing energy consumption in the devices.

III. MOVING BEYOND 5G

The research and the development of 5G networks is still on going with its first phase been released in late of 2020, 5G has managed to achieve a massive data rate connection that is slandered for 10Gbps using mmwaves, that helped to provide a thrilling services and applications with a seamless connection and low latency such as Virtual and Augments Realities. However, this much of data rate is not enough for higher applications and services such as holographic communications. also, with the increasing number of mobile users as well as the limitations of carrier frequency that are being used currently, it is difficult to achieve the demanded higher and seamless connection with even lower latency and more secured connection. Therefore, THz frequencies has caught the attention and the interest of the research field as the nominated frequencies that will be used for the next generation which is Beyond 5G (b5G). In this Part of the Chapter, we will go through the visions of b5G and discuss its requirements, applications and the challenges facing it.

III.1. Visions

Beyond 5G networks are been studied in order to satisfy the requirements for the expected intelligent information society moving to a structure based on cloud native data network, many countries are currently on the road to move beyond 5G. China for example, has launched the project “broadband communication and new networks” for 2030 and beyond, Several b5G projects has been planned in the European commission’s horizon for 2030 as well with the hope of 6G to connect everything with a full coverage using two main cases; the mobile internet and internet of everything (IoE) are the key scenarios for b5G. Furthermore, b5G will support [7,8]:

- Super-High Definition (SHD) and extremely High-Definition (EHD) videos with a super-High throughput.
- Extremely low-latency communications (10us).
- support the Internet of Nano-Things and Internet of Bodies through smart wearable devices and intrabody communications achieved by implantable nanodevices and nano sensors with extremely low power consumption.
- support underwater and space communications to significantly expand the boundaries of human activity, such as deep-sea sightseeing and space travel
- provide consistent service experiences in emerging scenarios, such as hyper-high-speed railway (HSR)
- enhance 5G vertical applications, such as the Massive Internet of Things (IoT) and fully autonomous vehicles [9].

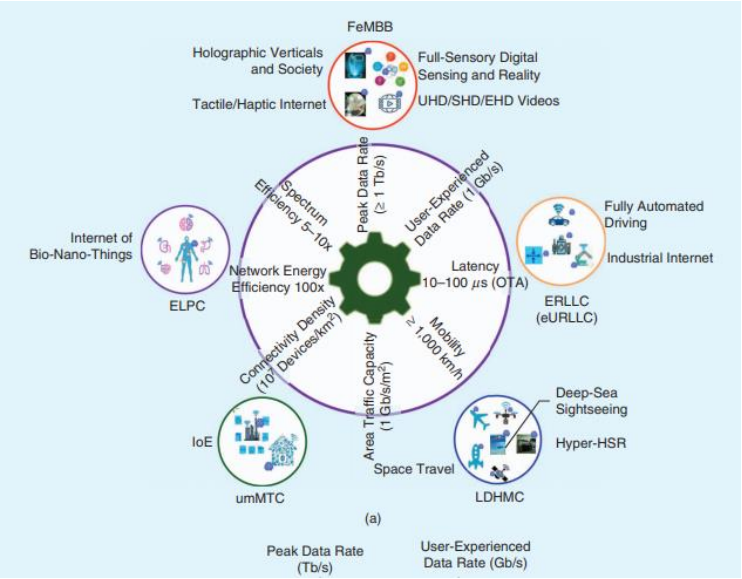

Figure I-4 typical scenarios of b5G networks [9]

III.2. Requirements

In order to achieve these promising applications, b5G needs to achieve certain requirements, the table below summarize the main key performance indicators that are needed to be applied in order to apply b5G networks and achieve the promising Applications and services.

Table I-2 b5G Requirements

B5G REQUIRMENTS [9,10]	
Peak Data Rate	A peak data rate of at least 1 Tb/s, which is 100 times that of 5G. For some special scenarios, such as THz wireless backhaul and fronthaul (x-haul), the peak data rate is expected to reach up to 10 Tb/s.
Experienced Data Rate	A user-experienced data rate of 1 Gb/s, which is 10 times that of 5G. It is also expected to provide a user experienced data rate of up to 10 Gb/s for some scenarios, such as indoor hotspots.
Latency	An over-the-air latency of 10–100 μs and high mobility 1,000 km/h . This will provide acceptable QoE for such scenarios as hyper-HSR and airline systems
Connectivity Density	Ten times the connectivity density of 5G. This will reach up to 10 devices/k 7 2 m and area traffic capacity of up to 1 / Gb/s m2 for scenarios such as hotspots.
Energy Efficiency	An energy efficiency of 10–100 times and a spectrum efficiency of 5–10 times those of 5G.

IV. TERAHERTZ COMMUNICATIONS

IV.1. Spectrum Allocation for Beyond 5G

The limited spectrum bands can no longer keep up with the massive increasing in connected applicants with their applications, which make it urgent for the radio access network to move toward the unutilized unlicensed spectrum in order to expand band resources beyond the

already used charts, moving to such frequencies is one of the key solutions to improve resources availability in beyond 5G wireless networks. This has been the focus of the main leading bodies; 3GPP and WIFI to debate licensed and unlicensed spectrum for future Beyond 5G networks [11].

The current usable capacity of the radio spectrum for 5G are the millimeter bands of frequencies ranging from 30GHz up to 60GHz. As recent research are aiming to test millimeter bands spectrum at 60GHz to be able to support 2GHz wide channels, however the number of such channels is very limited, for example between 60GHz and 70GHz, only 7GHz is available. Therefore, in order to widen the channels bands usage and access a lot more frequencies we need to go beyond 5G and look beyond Millimeter waves to the Terahertz (THz) spectrum [12].

Table I-3 A summary of the electromagnetic spectrum and its designated frequency bands

Electromagnetic Spectrum	Designate Band Name	Frequency Range
Radio Frequency	VLF (Very Low Frequency)	3KHz-30KHz
	LF (Low Frequency)	30KHz-300KHz
	MF (Medium Frequency)	300KHz-3MHz
	HF (High Frequency)	3MHz-30MHz
	VHF (Very High Frequency)	30MHz-300MHz
Microwave	UHF (Ultra High Frequency)	300MHZ-3GHz
	Centimeter Wave	3GHz-30GHz
	Millimeter Wave	30GHz-300GHz
Infrared	Sub-Millimeter Wave	300GHz-3THz
	IR-C	300Ghz-100THz
	IR-B	100THz-215THz
	IR-A	215THz-430THz
Visible Light	-	430THz-970THz
Proposed THz Band		95GHz-10THz

Standardization of THz bands has begun in early 2008 with establishing of an Interest Group on THz communications (IGTHz) under IEEE 802.15 standard umbrella. Later on, IEEE 802.15.3d Task group was introduced in order to facilitate the standardization of THz bands [12].

Table I-4 Available bandwidth for different THz carrier frequency ranges [13,14]

Frequency Range (THz)	0.1-0.2	0.2-0.27	0.27-0.32	0.33-0.37	0.38-0.44	0.44-0.49	0.49-0.52	0.52-0.66	0.66-0.72
Contiguous bandwidth (GHz)	100	70	50	35	65	56	40	123	60
Frequency Range (THz)	0.84 - 0.94	0.66-0.84	0.94-1.03	1.03-1.3	1.3-1.35	1.35-1.49	1.49-1.56	1.56-1.83	1.83-1.98
Contiguous Bandwidth (GHz)	143	47	58	38	51	92	29	25	65

THz wave also known as submillimeter radiation are the spectrum between 95GHz-3THz which Both of Federal Communication Commission (FCC) and International Telecommunication Union (ITU) has been focusing on these bands as a promised spectrum for beyond 5G networks (THz bands), other research has been focusing at THz bands from 100GHz-10THz corresponding to wavelengths of 3mm – 0.03mm. other suggested band is ranging from 100GHz-30THz for future discussion.

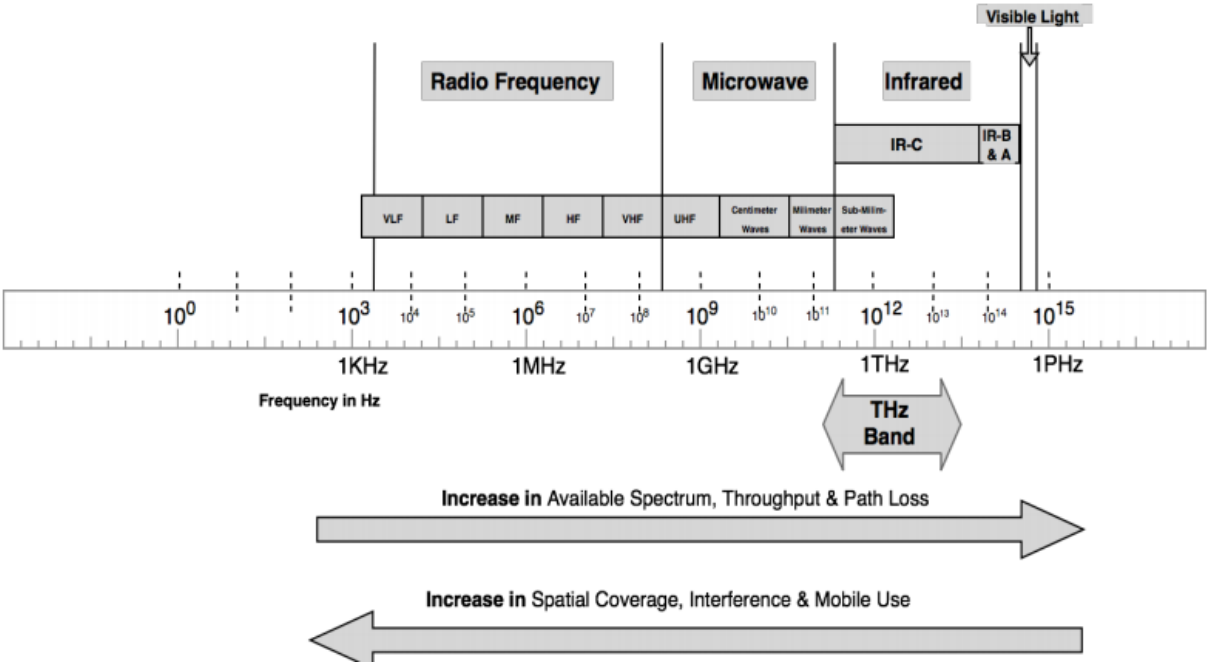

Figure I-5 Spectrum Allocation Chart with potential bands for future wireless communication

IV.2. Challenges Facing THz Bands

Moving to THz bands and applying it for b5G networks is indeed a key factor to support the wanted higher data rate. However, to put these bands to the use is very challenging and can create numerous issues, as we move to higher frequencies ranges, we experience many

limitations however we shall discuss three main issues: (a) High path Loss, (b) high sensitivity to Blockage, (c) Low transmit Power.

IV.2.1. High Path Loss

Path loss is the difference between the received and transmitted power measured in decibel (dB), it's one of the most important challenges caused due to the extremely high frequency of THz spectrum that is used to achieve the ultra-high data rate, which is extremely sensitive in this spectrum that can be effected by humidity and the distance between the transmitter Tx and the receiver Rx which will cause free-space loss absorption loss, reflection, refraction, scattering and penetration loss, in a distance of one meter, the total path loss in THZ bands can reach 100-200dB, which is very high comparing it to a distance of LTE bands in 1Km, path loss is a subject to occasional attenuation peaks that must be avoided to ensure high seamless throughput communication [15].

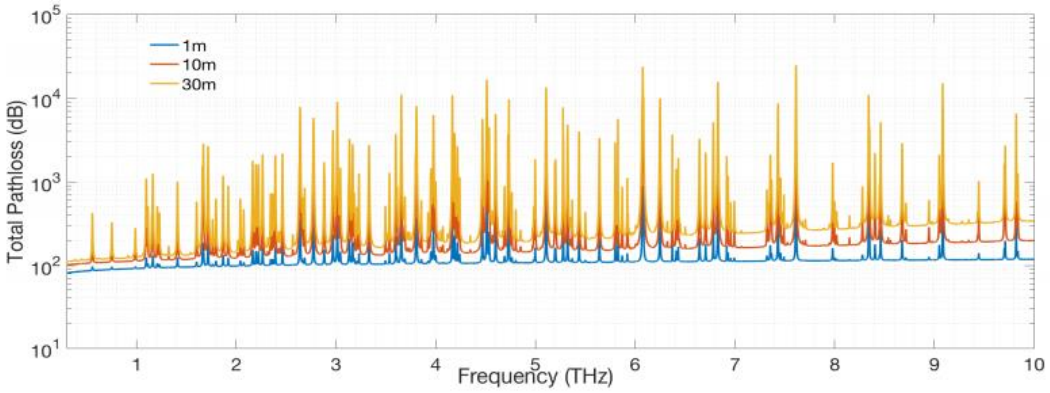

Figure I-6 Total Path loss from 0.1 to 10 THz frequency with 20% (5 g/m3) concentration of water

Figure above represents the total free space path loss for THz beams, based on modeling line of sight (LOS) transmission through obstacles-free air, the graph shows that there are some specific frequencies that are impractical for wireless communication due to their high absorption losses.

IV.2.2. Blockage Sensitivity

Using Millimeter waves in 5G has also caused the suffering from high sensitivity to blockage due to the very high frequencies of such bands, as we move to even higher frequencies: THz bands has even lower penetration power and cannot propagate well through different kinds of materials, which is a serious challenge for mobile communications, the coverage of THz base stations will be reduced due to blockage and

environment conditions, therefore LOS communication is needed even though NLOS communication will also be happening, some studies suggest to do research and find the best suitable materials that can be penetrated through by THz bands, other solutions suggest to measure frequency dependent absorption coefficient and refraction index for common materials in the indoor environment where THz communication is expected to be deployed [16].

IV.2.3 Low Transmit Power

For antennas operating in frequencies higher than 300GHz such as in our case, it is difficult to obtain high transit power as well as compensating the high path loss at the same time, currently THz Txs that exist have transmit power that equals to -5dBm at 650GHz and 0dBm at 800GHz which is very low comparing it to the transmit power at typical commercially deployed micro-cell which equals to -23dBm. Safety is also one of the main concerns in the case of increasing transmit power [15].

IV.3. Applications Scenarios for THz Bands

New applications and services will be imported as a consequence of the vast bandwidth in alliance to the use of THz bands, two main applications can be anticipated for the THz frequencies: macroscale and microscale applications, these applications can be seen through different kind of scenarios. Hence, we address emerging applications that will use THz frequencies for b5G ultra-fast networks:

IV.3.1. THz Wireless Local Access

THz communications will assure flawless connection between the ultra-high-speed wired networks and personal wireless devices with full transparency and rate convergence between the two links. This will accelerate the use of a bandwidth across static and mobile users mostly in indoor and local access scenarios with Tbps data rates along with a high connection reliability with a bit-error rate of 10^5 in a low mobility environment [21].

IV.3.2. Vehicular Communications

Vehicular communication has received more and more attention since the end of the last century, using THz bands in such type of communications will obtain ultra-high-speed of Tbps level of communication link.

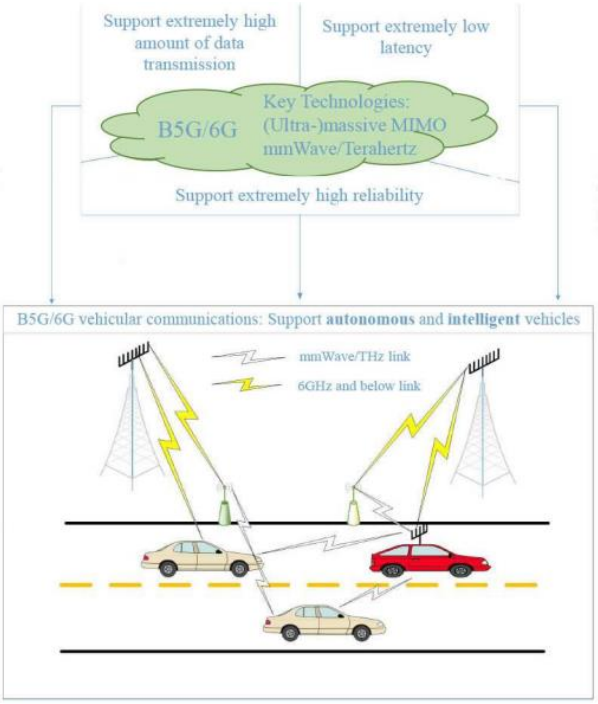

Figure I-7 Vehicular communications for b5G [17]

There are three main types of vehicular communications summarized in the table below [17,18]:

Table I-5 Vehicular communication types

Vehicle-to-Vehicle Communication (V2V)	Vehicle-to-Infrastructure Communication (V2I)	In-Car communication
Operating on THz bands to share ultra-high-speed data between two neighboring vehicles, this application has other purposes such as path planning and intent/trajectory sharing among others.	Infrastructure or roadside units (RSU) gather sensing data about the vehicles and the surrounding traffic, this kid of data can be used to obtain real-time maps of the environment in order to avoid congestion, as well as in general warning situations.	Instead of the traditional low-rate technologies used in the car such as Bluetooth and Zigbee, THz wireless personal area data (T-WLAN) is a better solution to provide ultra-high-rate and short-range in-car communication.

Vehicular communication working on THz frequencies is one of the most promised technologies to be produced in release 16 by 3GPP supporting seamless communication with

the required capacity at the lowest latency and for safer autonomous driving, this type of application will be called vehicle-to-everything (5G NR C-V2X) where x can be (V2V), (V2I) or networks (V2N) communications.

IV.3.3. THz Wireless Backhaul

Users nowadays suffer from a low connectivity especially in rural and remote regions, using optical fiber solutions has become time-consuming and an expensive method, for this reason, using THz links as a wireless backhaul extension of optical-fibers will guarantee a high-speed internet access everywhere, it will also assure a hundred of Gbps between cell towers (backhauls) for the users in both private, industrial and services sectors [21].

IV.3.4 THz Wireless Fronthaul for a C-RAN Based System

Fronthaul is implemented using different kind of technologies such as optical fibers communication, higher frequencies communications (mmwaves and THz bands). However, due to the massive growth of mobile data traffic with huge applications and services demanding for higher data speed, small cell networks based on cloud systems are deployed as a solution, these C-RAN networks will used THz bands in order to achieve the requirement of a cost-effective front-haul with a high capacity to accommodate the 1000*increase of cellular capacity [19]. Figure below demonstrates a small cell wireless front-haul solution based on cloud system, cloud radio access network or C-RAN was introduced to perform simpler and faster integration of products from multiple sources and provide a better coverage [20], the front-haul part of the network spans from remote radio unit (RRU) sites to the baseband unit (BBU) pool, The later one is connected with the mobile core network at the back-haul, as for RRUs, it is co-located with the antennas. THz links are used to connect RRU to the high-performance processors in the BBU pool, employing THz communication technologies in wireless front-hauls are cheaper and more flexible comparing it to the optical fibers [18].

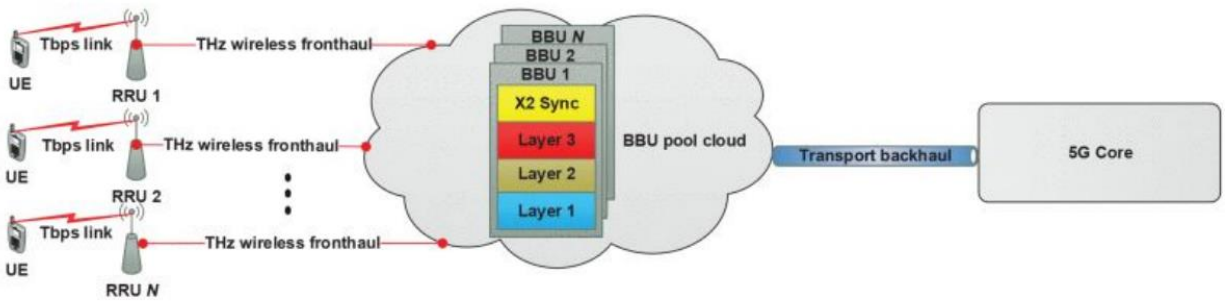

Figure I-8 THz band wireless fronthaul for C-RAN [18]

IV.4. Design of THz Wireless Network

The design of THz wireless network assists from the principle of co-design of new signals, codes and protocols including THz channel and propagation models as well as THz transceiver models. we approach the enabling technologies as we address the channel characteristics and the possibility of THz services for beyond 5G wireless networks.

IV.4.1. THz Channel

In order to implement the potential application scenarios discussed previously that are awaited from THz communications for beyond 5G networks plus dimensioning phased array configurations and transceiver architecture, it is highly important to study THz models first. For a full understanding of any type of wireless channels, it is necessary to adopt a specific model that perfectly describes the behaviors of the channel [10,22]. However, for THz communications case, its channel model is still largely unknown except those below around 300GHz [18] for stationary indoor environments, THz links suffers from severe atmospheric absorption due to water vapor molecules, moreover the free-space path loss (FSPL) is examined physically unavoidable [22]. Taking all this in consideration, THz band channel is considered highly frequency selective. That being the case, transmission distance is restricted by attenuation giving the application into consideration the appropriate carrier frequency is determined [18,22].

The figure below describes the possible LOS loses per kilometer with the respect to the distance between the transceiver's nodes, FSPL is at its highest levels at frequencies below 370GHz while above that, the molecular absorption loss is dominant [10].

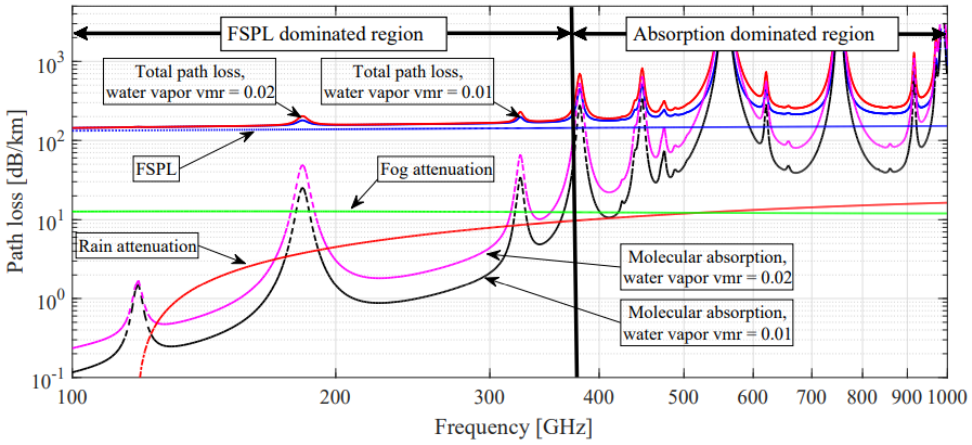

Figure I-9 Individual loss components of the lower THz band LOS channel [10]

As we mentioned previously, the recent works on channel modeling in the THz bands has been limited to indoor environments as we still suffer from shortage in the case of outdoor environments, the first statistical model for THz channel that operates in the range 275-325GHz is presented in the article [23], it relies on performing extensive ray-tracing simulations to obtain the channel statistical parameters. However, the problem of this model is that channel statistics information such as correlation function and power-delay function are extremely difficult to perceive. In the other hand [24] presented stochastic model for kiosk applications in the THz bands.

IV.4.2 THz Transceivers

Transceiver models designed with the conventional materials for lower frequencies such as microwaves and mmwaves are not suited for THz band frequencies, which rises some concerns about how to design a new transceiver that is suitable for THz spectrum [25], there are several challenges and expectations to be put in consideration for the new transceiver design for THz bands, such as the high losses in the THz spectrum as well as the high power, high sensitivity and low noise figure [10,18].

The fact that THz waves are located between the mmwaves and optical frequency bands qualifies both electronics-based and photonic-based technologies to be adopted, As for the electronics-based technologies, the most dominant frontend integrated technologies that witnessed a noticeable development in the recent decade are silicon complementary metal-oxide semiconductor (CMOS) and silicon Germanium (SiGe) [18,22], these technologies have been focusing on THz short-range communications deploying integrated on-ship antennas that is needed for THz backhaul requirements. One of the key factors for photonics-based technologies is the use of nanomaterials, [26] suggests using graphene for THz band compact transceivers, graphene is mostly known for its strength in atomic thickness, tenability and high kinetic inductance making it possible to reform THz waves, [10,22], finally as we pointed the most promised technologies to be applied for the THz band transceivers in b5G networks, these suggestions can only be confirmed through real experiments and analyzes to find the most suitable transceiver model for THz frequencies.

V. BEYOND 5G: NEW SERVICES CLASSES

V.1. Energy Efficiency Services

Future networks will be more complicated and need much more elements and equipment to fulfill their requirements and that leads us directly to the energy consumption problem. Therefore, future networks and devices will have to be energy efficient. according to this end, many studies has started focusing on this problem and suggest new services to solve it and make the future networks applicable.

V.1.1. Fog Computing

Fog computing is a new technology that allows the devices to store operations and perform computations such as tasks, caches, files, and data in general into a fog [27], this end will be installed as a node in studied locations [28]. Our main goal here is to conserve the energy of the device (that is called local services) by using the fog nodes (that is called task helper) as an assistance and the resource sharing between them is called the process of task offloading. When a device offloads a task, it conserves its energy between the local device and the task helper nodes. However, the task offloading is preferred when the energy consumption and latency can be reduced. Otherwise, the local computing is the best choice. The following table will present the recommended classification of applications.

Table I-6 Recommended offload locations based on application requirements

Application requirements	Offload location
Low computational and high latency requirements	Device/ fog
Hugh computational and high latency requirements	Fog only
High computational and low latency requirements	Fog/ cloud
Varying computational and low latency requirements	Flexible (device/ fog/ cloud)

Another key point, objectives of the task offloading options must be all cleaned. To that end, the author in [29] summarized all this subject as the following figure.

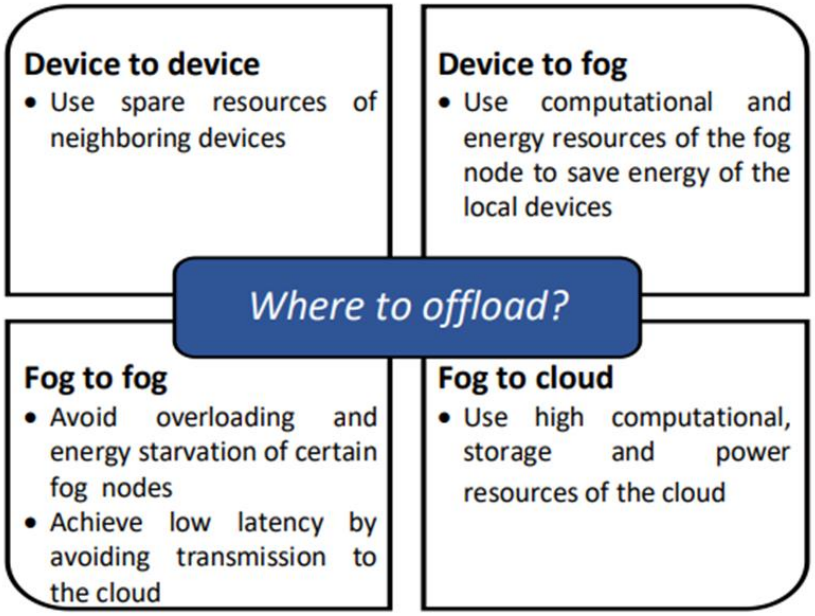

Figure I-10 Objectives of task offloading options [29]

a) **Device-to-device offloading**: when the devices are near to each other the transmission between them take the first place on the direct communication link, and this idea is based on the regular Device to Device communication [30].
b) **Device-to-fog offloading**: in this case, fog nodes are located to the end of the devices so the local devices will improve the latency and conserve the transmission energy which is the main objective of this service [31].
c) **Fog-to-fog offloading:** when the fog nodes have high workload or it needs to conserve energy, it can offload its tasks by another fog node [32].
d) **Fog-to-cloud offloading:** first of all, the cloud is for high computation, storage and power resources that are well known in the IoT networks, and since the devices needs to offload their tasks to the fog nodes, the fogs also need to offload their tasks to the clouds [33].

Moreover, the fog computing will help the b5G to reach another helpful benefit and that leads it to achieve the THz:

- The top of its benefits is the latency, the fog nodes will improve its latency as the data are analyzed and accessed near to the devices [33].
- It enhances the network capacity and improves also the usage of the frequency spectrum.
- The fog computation will help b5G to enable the massive IoT that refer to the large-scale connectivity of a large number of devices, sensors and machines (up to around 1 million

devices per square kilometer). thus, a huge number of devices will share data with each other with a large number of applications. However, the security of this fog nodes must be improved.

V.1.2. Massive Wireless Energy Transfer (mWET):

The massive Wireless Energy Transfer is a technique to enable the massive IoT networks in b5G, and as it's known that the IoT is energy powered. Moreover, the Energy Harvesting (EH) is a needed technique that will solve the externally recharge batteries or avoid replacement [34]. The EH has the same principal to large-scale renewable energy generation such as wind turbines, the EH is the conversion from ambient energy present in the environment into electrical energy for the use in powering autonomous electronic devices or circuits.

The EH allows the wireless charging and simplifies the servicing and the maintenance of the IoT devices, so we can say that the EH is a clean attractive solution for the battery recharging and waste processing problem [35]. The EH is classified into two categories:

- Ambient EH: the energy resources are available in the environment and can be sensed by EH receivers.
- Dedicated EH: the on-purpose energy transmissions from dedicated energy sources to EH devices.

According to what have been discussed before. we can say that the RF-based EH is the main element in the WET architecture that is shown in figure below [36]. Which is a strong candidate for powering many low-power IoT use cases [37]. WET will help to:

- simplifying servicing and maintenance.
- increasing IoT devices' durability.
- supporting network-wide reduction of emissions footprint.
- allowing miniaturized hardware implementations and supporting multi-user operation.

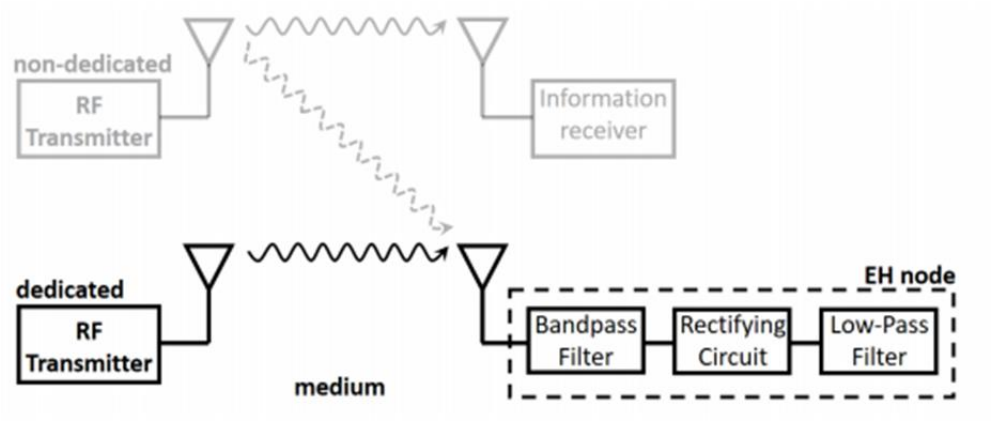

Figure I-11 WET system. RF-EH module structure [36].

WET's basic structure based on both of RF & EH and it consist [36]:

- the receive antenna that designed to work with single frequency or multiple frequency bands.
- a combination matching network/band pass filter that ensure to maximize the power that is transferred from the antenna.
- A rectifying circuit that ensures to deliver the power smoothly to the load.
- The low-pass filter to remove the harmonic frequencies in the output.

V.2. Mobile Edge Computing (MEC)

Mobile Edge Computing is an open platform that is close to the data source, it combines network, storage, capacity, computing and mobility at the edge of a network and get decided in which mobile operators can open their Radio Access Network (RAN) to serve third-parties [41].

The goal is to deploy rapidly and flexibly applications, services and solution to be provided to the end costumers and user. Moreover, MEC will play an important role in the IoT such as smart cities, intelligent transportation [41], industrial automation, autonomous driving...etc. and it has 3 main shortcomings:

- The most important one which present a big issue nowadays: large energy consumption like what we have discussed before.
- real-time demand for all things connected.
- data security and privacy.

The proposed MEC architecture is shown in figure 12. The MEC servers are equipped with two different powers:

- Each active antenna unit (AAU) with low-power.
- Each Distributed Unit (DU) with high-power.

The two servers will treat the requests of UEs which will be forwarded to a centralized unit (CU) in the cloud [42].

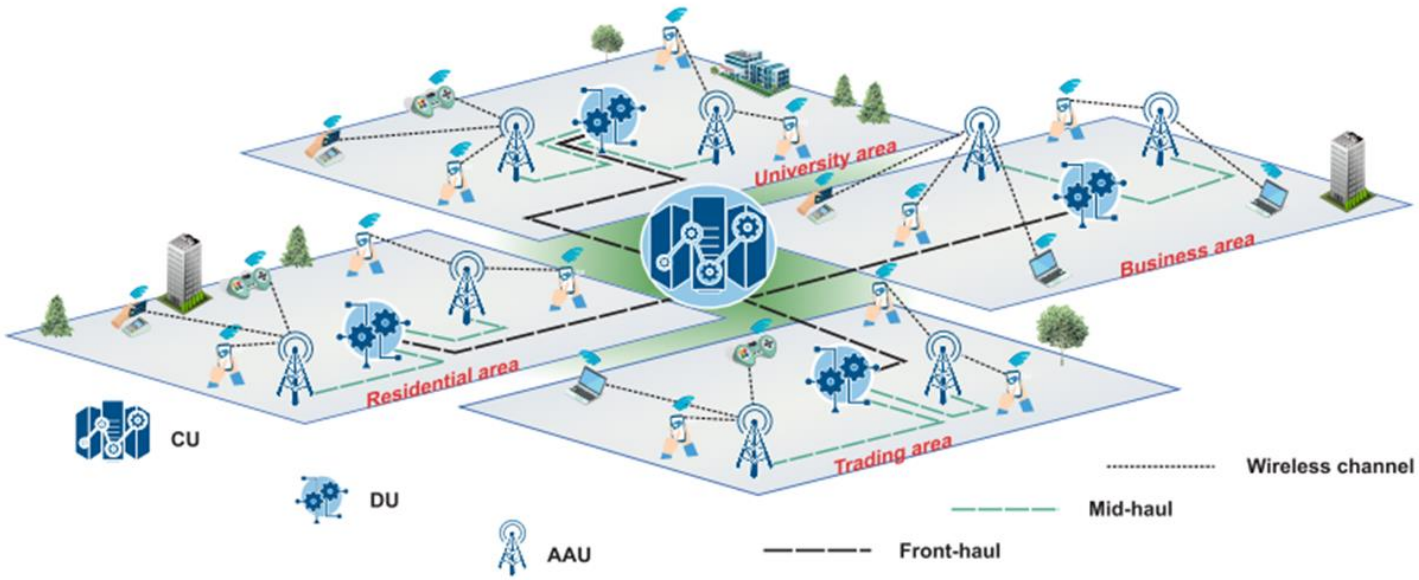

Figure I-12 Proposed MEC architecture, which also provides computational resources at the AAU level [42]

V.3. TaNTIN: Terrestrial and Non-Terrestrial Integrated Networks

To achieve certain goals in the b5G, the researchers suggested to collaborate with individuals, so they can work together and share information, object, resources and make decision together. This collaboration will introduce a new service that has been highly demanded in the recent period specially in the corona virus disease pandemic (covid-19) [38]. The new technique is called TaNTIN, which will be applied in the business communication and online education fields [39].

The elements of collaboration technologies play apart in the device realization (like shown in the following figure) such as: mobile phones and laptops, video conferences, online gaming, instant chatting, education.

Moreover, we need some key technologies to enable this collaborating like: Augmented reality and virtual reality, Network slicing, Network virtualization, Smart IoTs, Softwarization,

Cloudification, Blockchains [40]. These different types of networks represent the TaNTIN services.

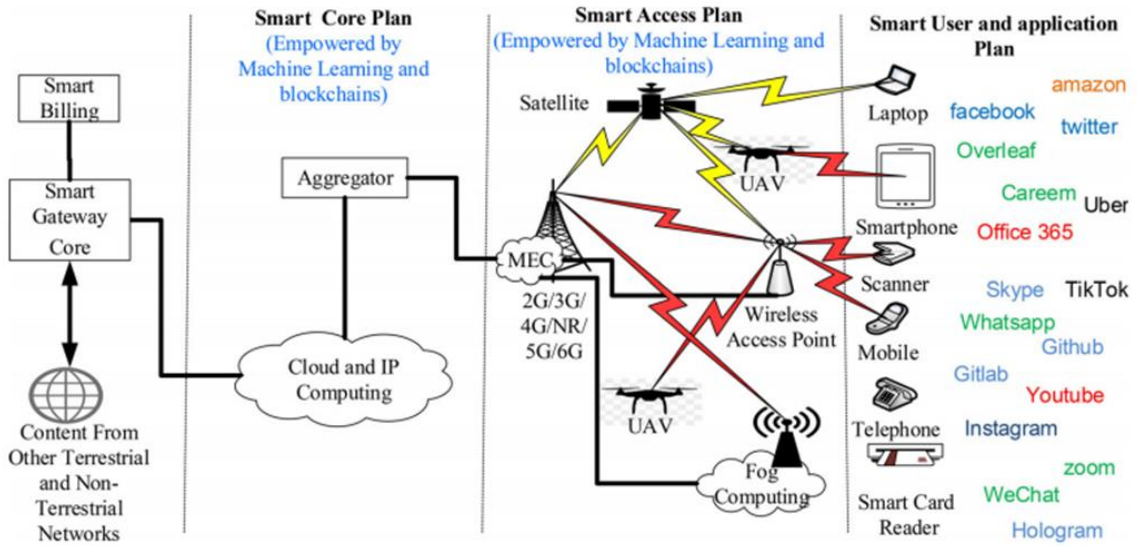

Figure I-13 TaNTIN architecture for b5G/6G with collaborative network technologies perspective [40]

IV.4. The Core Services

The 5G was based on 3 main core services:

- eMBB: enhanced Mobile Broadband is a service that increase data rates with peak rates of Gbps.
- URLLC: Ultra-Reliable and Low-Latency Communications.
- mMTC: massive Machine-Type-Communication, it is service to connect a large number of cost and energy constrained devices that require low data rate.

As for beyond 5G networks, these core services and will be combined to achieve its demands: URLLC + mMTC, eMBB+URLLC, eMBB+mMTC.

V.4.1. Massive URLLC (URLLC + mMTC)

The regular URLLC (Ultra-Reliable and Low-Latency Communications) that is used in 5G refers to a communication with ultra-reliability, low latency and high viability for mission-critical scenarios [45]. However, b5G needs to increase the size of the regular URLLC service to a massive URLLC which is a combination between URLLC with the classical mMTC, it

must achieve low-latency, high reliability, high data rate, massive connectivity and full mobility at the same time.

The uplink that is considered for beyond 5G network, where multiple eMBB and URLLC devices aim at transmitting independent packets to the same BS [43] (figure 14).

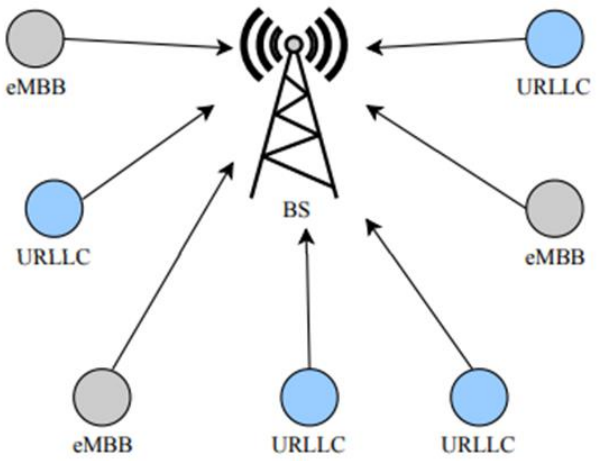

Figure I-14 Uplink transmissions to a common base station (BS) [43]

V.4.2. eMBB+URLLC

This service came to support some promising applications in beyond 5G such as holographic meeting, due to its high transmission rates, low-latency and high reliability communication. It must be satisfied in high mobility conditions like air, sea travel [46].

V.4.2. eMBB+mMTC

This service will support low-latency, connectivity among workers, sensors and actuators to improve the operations and functions in large scale IIoT (Industry Internet of Thing) [46].

VI. BEYOND 5G NEW APPLICATIONS

VI.1. Holographic Communication

Holographic Telepresence (HT) will be the most attractive application in beyond 5G for both profession and social communication, it can project realistic, full motion, rea-time three dimensional (3D) images of distant object and people. What's more, it is used for 3D video conferencing and news broadcasting or applications [44].

HT is highly data-intensive application which help to minimize business travel costs and people will appear in many locations simultaneously. Whereas, latency of 0.1ms and data rates of multi Gbps is highly recommended in b5G to implement the HT into the reality [44].

VI.2. Satellite Communication

In order to achieve widespread connectivity, beyond 5G networks will integrate with cellular networks and satellite communications. this will be very helpful in cases where the coverage of Mobile network could be limited like the suburban and isolated geographic locations that have high user density. Furthermore, the satellite communication can provide large area coverage at low cost, like shown in the following figure the satellite will be integrated in 2 orbits Highly-Elliptical-Orbit (HEO) & Low-Earth-Orbit (LEO) using same frequency band to ensure the global seamless coverage of the end users [47].

According to what have been mentioned above, the satellite communication has some challenges, the main one is to use the spectrum without any interference or congestion. Therefore, the non-orthogonal multiple access NOMA is the suitable solution for spectrum sharing technologies without any problems.

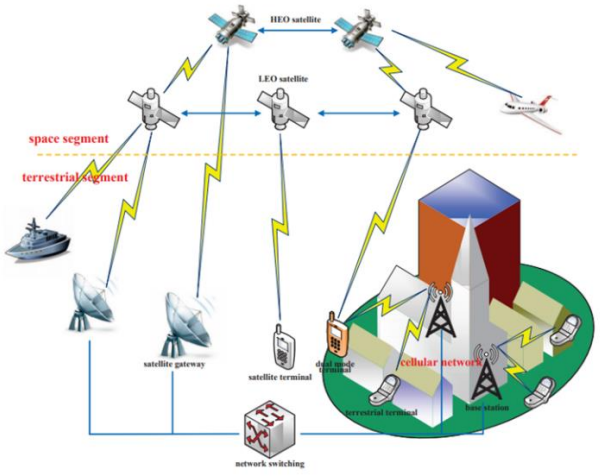

Figure I-15 Network model for the satellite communication [47]

VI.3. Intelligent Healthcare

Due to the prominent features and the promises of beyond 5G communication, many researchers are attracting to its technologies and the Intelligent Healthcare is one of them. The requirements of beyond 5G for this application are represented in the following table.

Table I-7 intelligent Healthcare requirements

High data rate	≥1Tbps
High operating frequency	≥1Thz
Low end-to-end delay	≤1ms
High reliability	10^{-9}
High mobility	≥1000 km/h
wavelength	≤300 μm

The Intelligent Healthcare is expected to help the future healthcare system to get rid of many problems that can put the human's health at risk. the ambulance for example is just a transport with oxygen facility and road propriety, which can be served by a normal car too, also we have seen a lot of cases when the patient dies in ambulance while it is in the road or before reaching the spot. Besides, the accident detection systems are highly recommended also we must control the epidemic and pandemic outbreaks like the COVID 19, without forgetting the Holographic communication it needs to be exploited by the healthcare system. However, all of what we have suggest requires to be applied in real-time communication [48].

The Intelligent Healthcare will enable some services that make it special and elegant like: The Blood Sample Reader (BSR), Intelligent Wearable Devices (IWD), Health Insurance at Hospital (HIH) and Hospital to Home service (H2H) [48].

VI.4. Kiosk Downloading

Kiosk is stations that placed in the crowded places: airport gates, train stations, shopping malls and traffic jams (figure 16) in order to serve the users, moving and downloading files with ultra-high data rates with Tbps in short time. Likewise, Kiosk can serve one user in short duration (point-to-point P2P) or several users (point-to-multipoint) simultaneously, it allows also the cars to download any multimedia content (3D 4K map video).

Furthermore, the Kiosk stations reduce the burden of networks and the number of users connected to the network operator. However, it is limited to short distances (few centimeters up to few meters) and its communication is asymmetric because the data rate in the downlink is higher than the uplink therefore it named Kiosk downloading [49].

Figure I-16 Data kiosk scenarios [49]

VII. CONCLUSION

In this chapter, we introduced the multi-Tbps intelligent b5G wireless networks for the future upcoming years. We began by laying out the phases released and yet to be released for 5G wireless networks. We then presented a beyond 5G vision and discussed the main capabilities and requirements for the b5G networks. We also mentioned the key factor to achieve the ultra-high data rate expected from b5G networks; the THz communications, as we specified the promising spectrum bands that are considered as well as the constraints obtained from applying it for b5G networks. Lastly, we identified the several highly involved applications and services including the energy efficiency services, the Massive URLLC communications, the role of holographic and satellite communications for the future b5G networks...etc. we basically conclude that there is an exciting future that lies ahead for the wireless networks. However, the road to overcome the challenges facing is full of obstacles. Therefore, new techniques and technologies needs to intrude the place.

CHAPTER II: SIGNAL PROCESSING TECHNIQUES RELATED TO b5G

I. INTRODUCTION

One of the main stream communication systems that grabbed the interest of researchers for many decades are the Multiple antennas technologies. due to the fact that multiple antennas technologies have become a key component for the already finished first release of the 5th generation wireless network were using massive MIMO technologies along with hybrid beamforming helped to achieve a high data rates per user and per cell. Nevertheless, it is not the end of MIMO development, it is time to move further and present new technologies and develop in the already existing massive MIMO to meet the future networks namely beyond 5G networks requirements and pass the Tbps data rate. b5G networks are expected to realize an intelligent and software reconfigurable paradigm where all parts of the device hardware will adopt to the changes of the wireless environment. With that been said, another prominent member that must be discussed in our thesis, that is the Multiple access techniques that are proposed for the b5G networks.

For these reasons, we will talk in this chapter through the main multiple antenna technologies that will play a big role in beyond 5G networks, cell-free massive MIMO, beam space massive MIMO and intelligent reflecting surfaces (IRS). as we address the key characteristics of each technology and their technical progresses, as well as the new roles that these technologies can play for the new introduced communication types such as unmanned aerial vehicle (UAV)-support communication in sub-THz bands. Next, we discuss the possible candidates for the potential multiplexing access techniques including the ones based on OFDM, as well as NOMA technology. after that, we comment on the new modulation technique regarding the mobility, namely OTFS.

II. CELL-FREE MASSIVE-MIMO

One of the main issues for 5G cellular technologies is the inter-cell interferences and the handover issues that occurs due to the limitations of cell-edge performance. Beyond 5G networks is expected to overcome these challenges by entering the cell-free paradigm excluding the cell boundaries that alleviates the inter-cell interference and handover issues. However, it will also cause for new challenges to appear.

The main reason behind deploying cellular networks in the first place is to compensate the power consumption when transmitting data as well as having better special reuse of the frequency resources by using a set of geographically distributed fixed access points (APs) that has been the main way for cellular networks to handle the higher traffic volumes [50].

Regardless, the AP densification causes to more inter-cell interference and more frequent handovers increasing the traffic congestion at cell-edges.

One of the discussed solutions in the past is to connect each user with a multitude of APs [51] this solution was given many names such as network MIMO and distributed MIMO and coordinated multi-point (CoMP), however the actual implementation of this solution is very complicated.

Cell-free Massive MIMO was introduced to fully resolve these issues, by allowing each user to select the best served set of APs rather than the network deciding, each AP will also be coordinated with a different set of other APs, the basics of cell-free massive MIMO will be discussed next.

II.1. Basics of Cell-Free Massive MIMO

A cell-free massive MIMO networks consist of a large numbers APs that serves a much smaller number of UEs on the same time-frequency resource. in other words, it is the case when the antennas are distributed over a large geographical area so that each user is essentially surrounded by BS antennas, rather than the conventional case of each BS being surrounded by users, this network operates in TDD mode and exploits both uplinks and downlinks channel reciprocity [52].

Channel State information (CSI) is assisted for each AP, between itself and all the UEs from Uplink pilots, this CSI will be enough for the implementation of transmission and reception [53]. only this way data will be sent between APs by connecting all of the them via fronthaul to a cloud-edge processor, the later one will be responsible for the encoding and decoding of data, in this case we deploy Cloud radio access networks (C-RAN).

C-RANs networks are one of the undertaken scenarios for the deployment of cell-free massive MIMO, the figure below represent the basic view of network architecture of a free-cell massive MIMO system.

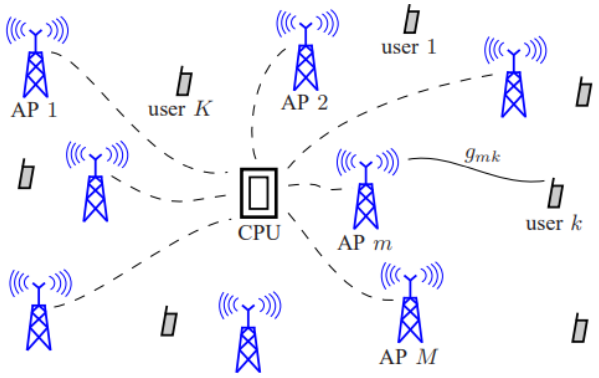

Figure II-1 Cell-Free Massive MIMO system [52].

Previous papers have analyzed the performance of cell-free Massive MIMO in different kind of scenarios, starting with a single antenna APs, single-antennas UEs, Rayleigh fading channels and infinite capacity error-free fronthaul connections [53]. later on, more realistic implementations were considered [52], these studies has shown that cell-free massive MIMO technology is suitable for a variety of deployment scenarios, it is also have been proven that cell-free massive MIMO can achieve proximally fivefold improvement with 95% per user spectral efficiency [52] comparing it with the conventional massive MIMO used in 5G cellular networks, a ten times improvement in the energy efficiency will be also achieved by the cell-free massive MIMO technique comparing it to the traditional cellular massive MIMO [54,555]. In short, these improvements in both spectral and energy efficiencies are the main reason for the cell-free massive MIMO to be an important candidate for the multiple antenna technologies for beyond 5G networks.

II.2. System Characteristics

The study provided by the paper [52] considered L APs, each one is provided with N antennas and K single-antenna UEs, each user is served by a subset of M_K of the APs, the selection is according to a user centric way, an example on how the APs will be divided in subsets with the serving UEs is provided in the figure below.

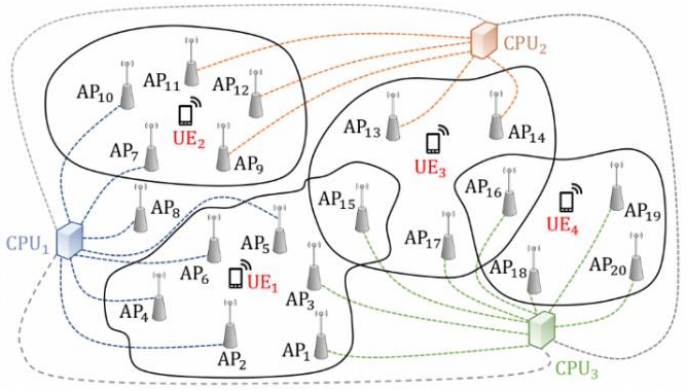

Figure II-2 Example of how different subsets Mk of APs serve three UEs (k = 1, 2, 3) in a cell-free massive MIMO system [56].

[52] provides a full mathematical analyses and simulations of the cell-free massive MIMO performance in both uplink and downlink data transmissions. The results showed that using cell-free massive MIMO for the uplink case resulted to a great improvement in the performance for the weakest UEs in the network thanks to the power control design used that maximizes the worst-user performance [52]. However, other power control designs needed to be developed to focus on the optimization of the performance of other UEs. As for the downlink data transmission we conclude that using the same power allocation schemes as the uplink case is not an optimal option because each AP needs to select how to distribute their power among different UEs, therefore more enhancements are needed to pay more attention at other criteria than optimizing the worst UEs performance.

II.3. Challenges Of Using Cell-Free Massive MIMO

II.3.1. Scalable Large Deployment

The main challenge is to actually implement cell-free massive MIMO in a large network (an entire city) where the scalability is considered infinite, that's the case where we can evaluate if the cell-free massive MIMO can operate successfully or not. [56]

II.3.2. Power Control

Unlike conventional cellular networks where the uplink and downlink are symmetric, for the cell-free massive MIMO case issues appeared when analyzing the downlink power allocation, where each AP needs to serve power to the assigned UEs without considering about the channel conditions of other APs.

II.3.3. Fronthaul/Backhaul Provisioning

Fronthaul/backhaul will suffer from a heavy burden in a cell-free network comparing it to the traditional cellular systems, with a large number of APs distributed across the intended coverage area, optical fibers are insufficient option as a wired provision. while wireless provision is a realizable solution despite having its own challenges such as the availability of spectrum and the difficulties of delivering ultra-high data rate wirelessly [57]. using THz bands for fronthaul/backhaul links has already been discussed, a suggestion of a co-existing of a cellular massive MIMO networks and cell-free massive MIMO networks is provided to solve the issue, more suitable solutions will be studied in the future as the cell-free massive MIMO becomes a reality for beyond 5G (b5G) networks.

III. BEAMSPACE MASSIVE MIMO

The use of a massive number of antennas in a MIMO transceiver requires a very high frequency and a very large available bandwidth which is very complicated to implement, in order to maintain the performance and the flexibility of transceiver implementation, a special structure of the channels and transceiver hardware; beamspace massive MIMO needs to be applied. A beamspace massive MIMO is the concept that uses hybrid beamforming and its future successors.

As mentioned before, the number of antennas will continue to increase therefore beamspace terminology, notation and techniques will be critical for beyond 5G systems, MIMO processing will use subspace approach based on virtual or effective channels, Optical-like thinking will also begin to be important which sets perfectly in beamspace technique, in this section we will focus on the recent research regarding the beamspace massive MIMO technology as well as the challenges facing the implementation of such technique.

III.1. System Characteristics

In order to simplify the model etude, a single-user MIMO system is considered, where the input-output expression is:

Equation 1 $$y = Hs + n$$

where y ∈ C Nr is the received signal, H ∈ C Nr×Nt is the channel matrix, s ∈ C Nt is the transmitted signal, and n ∈ C Nr is additive noise, the transmit signal s is decomposed to a linear precoder:

Equation 2 $$s = Wx$$

A beamspace approach decomposes the precoder furthers as a product of 2 different precoders:

Equation 3 $$W = W1 \times W2$$

These two precoders can be constrained and selected using different criteria (for further explanation, see the paper [58]), the receiver might also use linear processing. In this setup, the receiver applies a linear combining filter Z ∈ C Nr×Nv,r and processes the received signal yv = Z Hy. Typically, the precoder W1 and receiver Z are selected first. Then, the second transmit precoder W2 is selected18 conditioned on the selected W1 and Z. Thus, W2 is selected using a virtual or effective, Nr × Nv MIMO model:

Equation 4 $$yv = Hv\,W2X + nv$$

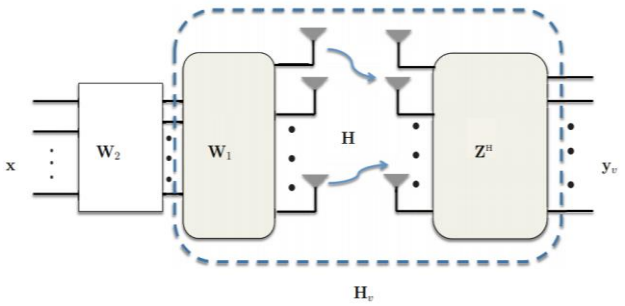

Figure II-3 Illustration of the beamspace system model for (4)

This virtual channel is used that can display a collection of advantageous proprieties such as containing a limited number of non-zeros entries with the assumption that the virtual channel is sparce, this sparsity will allow the UE to be configured with multiple reference signals and CSI feedback reports, however the virtual approach allows operators and manufactures to employ sophisticated precoding schemes that are easily upgradable to newer precoding schemes because the user does not need to have any knowledge of the number of reference signals, CSI feedback signals, this type future-thinking have gained interest for the 3GPP using hybrid beamforming an precoding at mmwaves and sub-THz communications [58].

III.2. Basics Of Beamspace Massive MIMO

In order to convert the traditional channel in the spatial domain to the beamspace channel, a well-designed discrete lens array (DLA) must be employed [59]. The beamspace channel is sparce, therefore the dimension of the massive MIMO can be reduced by selecting a small number of powerful beams, a precoding scheme in beamspace is proposed where spatial channel sparsity was exploited, the results showed that beamspace techniques have a great impact in accomplishing a satisfactory precoding with a low complexity, in the other hand, other studies uses an optimal hybrid cross-entropy (HCE) based hybrid precoding scheme and lens array architecture that achieved a great performance and a high energy efficiency .

The figure below illustrates the basic of beamspace massive MIMO and hybrid beamforming.

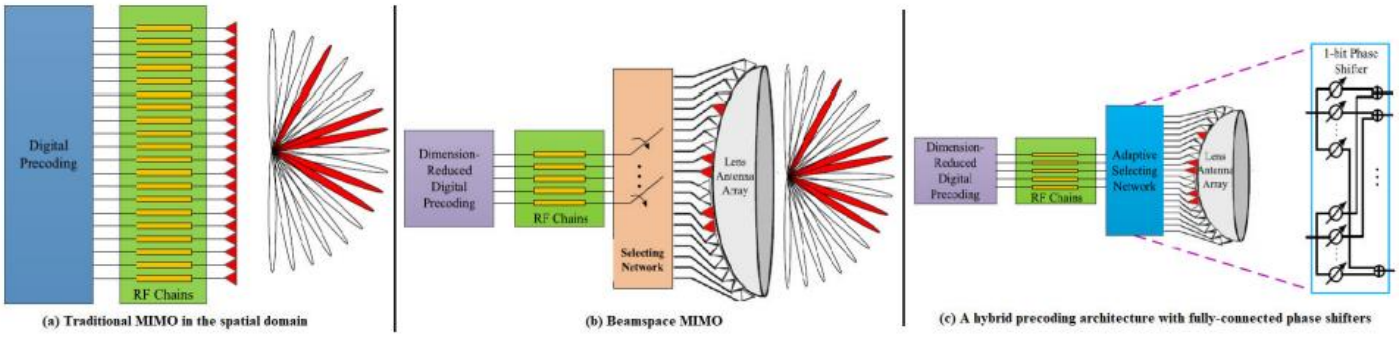

Figure II-4 Traditional MIMO in the spatial domain, beamspace MIMO, and hybrid precoding architecture [59]

III.3. Beamspace Massive MIMO Using Lens Arrays

The definition of lens array is a device that its main purpose is to support a variable phase shifting for electromagnetic (EM) rays at different point s on the lens aperture in order to achieve angle dependent energy focusing property [60]. Most recent research are working on discrete antennas elements in RF technology where antenna arrays operates more like optical system, using lens-based technologies have come to the forefront of wireless communications beginning with mmwaves communications and it is expected to be applied for the THz communications as well [61], the basic is harnessing the focusing capabilities of lens arrays to focus on the EM power that arrives from different directions on different lens ports, as a result of that the special MIMO channel will be transformed into sparse beamspace representation, by doing so, only a small number of dominant beams are selected that carry most of the EM energy.

III.3.1. Open Challenges

The area of the channel estimation is most effect by deploying beamspace massive MIMO with lens-based technologies**,** lens arrays offer substantial hardware and power savings compared to phase shifters. Nevertheless, the total implementation cost and power consumption of a mmWave transceiver are quite high and reducing them will result for the problem of channel estimation to be far more complicated, particularly for wideband systems where different antennas at each sampling time collect non-identical data symbols.

The other problem is at the level of hardware imperfections, lens arrays are well known for being lossy devices, they display a various error due to the imperfect absorption and isolation characteristics; such devices also cause spillover losses at the uplink multiuser MIMO mmwaves systems with lens array at the BS [62].

IV. INTELLIGENT REFLECTING SURFACE

It is highly needed to put in mind that the attempts that have been going on trying to maximize the energy efficiency MIMO systems do not come for free, the performance improvements of wireless technology might also saturate due to financial reasons. [62] it was also shown that optimizing the power allocation and the network topology requires large number of antennas which is not the best way to improve the energy efficiency [53], therefore, other ways are needed to achieve a design of spectral and energy efficiency communication systems with a low hardware cost and realizing economically sustainable wireless communication system, the recent searches are focusing on the intelligent reflecting surfaces (IRS) [63] also known as software-controlled meta-surfaces that uses passive MIMO, in this section we discuss this technique and what makes it a candidate for future B5G Networks systems.

IV.1. Basics Of IRS

Despite the great effect of MIMO systems in achieving a high-speed wireless communication system, the performance of the wireless networks is still bound by its channel, particularly the (EM) waves radiated by a transmitter experience reflection, refraction, diffraction and pathlosses in the channel before reaching a receiver, that was the purpose for developing communication techniques (beamforming, diversity, channel coding..), the newly introduced IRS is based on manipulating the propagation of EM waves in a communication channel with the intention of improving the systems performance [64] .

Basically, an IRS is a meta-surface consisted of a large set of tiny elements that diffusely reflects the incoming signals in a controllable way [64], it is built on the reconfigurable reflect array with some modifications that allow real-time reconfigurability and control.

Unlike cell-free massive MIMO system that we discussed previously; an IRS is expected to only require a small operational power appearing suitable for implementation in energy-limited systems [65], it also operatable in a full-duplex manner without self-interference cancelation. IRS can also be thin and conformable material; hence it can be flexibly deployed to provide additional capacity in needed areas, it is not meant to replace the traditional MIMO systems but rather complement it by being a passive device that reflect signals to improve the SNR.

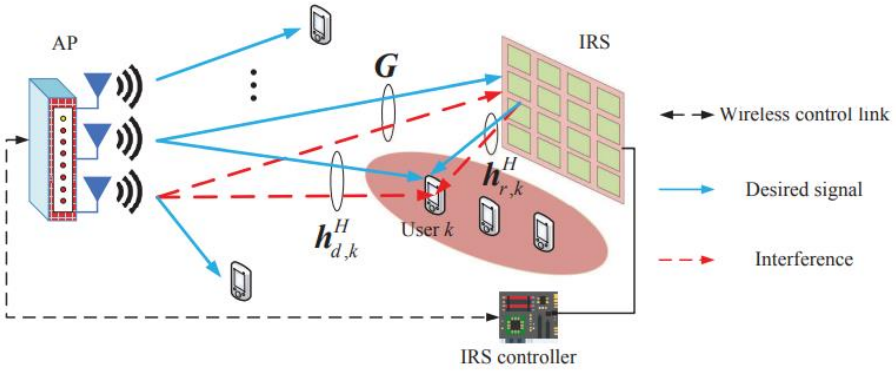

Figure II-5 an example of an IRS-aided multiuser communication system [53].

IV.2. System Characteristics

As we mentioned before, an IRS is an array of meta-atoms that is able to control the direction of the reflected signal, this can be achieved by allowing every point on the surface to induce a certain phase shift to the incoming signal, the figure below illustrates how different phase-shift signals are being reflected as a beam in different directions, the IRS behaves as a reconfigurable lens that are able to focus signals at points in the near-field of beamform signals toward points in the far-field.

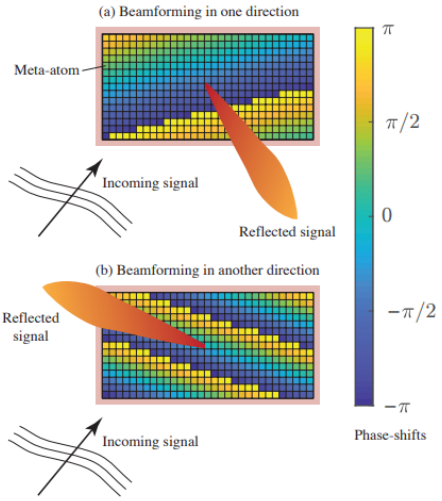

Figure II-6 An IRS Illustration[53].

In order to understand the system characteristics, we will discuss two scenarios of IRS-based communication where types of beamforming are facilitated when using IRS in traditional MIMO systems, (see figure below), the IRS deployed will assists the communication between a multiple antenna transmitter and a user, the first scenario is when a Ling-of-sight (LOS) signal is generated between the transmitter and the user, beamforming is also performed at the transmitter to enhance the received signal at the user, in this case IRS will receive the information signal, the later one will be reflected by the IRS, the main direction of the reflected signal will be controlled with the help of the IRS controller. To be more specific, proper phase shifts are introduced on all the meta-atoms to generate a reasonable combination of their individually scattered signals, as a result of doing so, a signal beam at the user will be created, the beam gets narrower as the surface gets larger, this strategy is known as energy focusing [75].

The second scenario, is when the LOS signal cannot be achieved due to heavy shadowing or blockage, in this case beamforming is performed with the help of IRS at the transmitter level, then, the IRS will play the role of a non-amplifying full duplex relay by focusing the information signal to the UE as explained in the figure below (b) with the consideration of a multiple antenna transmitter that serves user A in the presence of user B, we assume that the message of user A cannot be decodable by user B, in this situation destructive reflection will be performed at the IRS by adjusting the phases of the scattered signals to null out the signal at user B, this strategy is called energy nulling [75].

These two scenarios shows that IRS can operate in different applications with various communication systems, it can also act as an interference manager, coverage extensor and capacity improver.

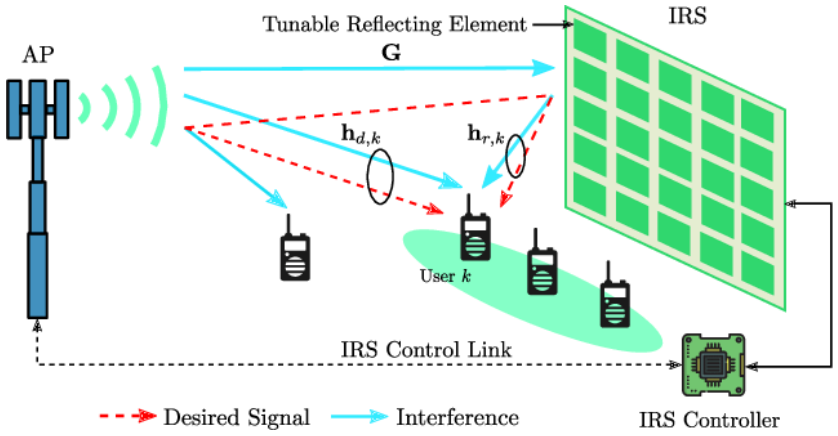

Figure II-7 An IRS-enhanced multiple antennas wireless communication system [66].

IV.3. Open Research Challenges

IRS technology is still in its first steps for the wireless communication systems and therefore it still faces some research challenges that needs to be addressed spatially for IRS-Based MIMO communication systems:

IV.3.1. Channel Estimation

The performance of the IRS relies on its beamfocusing capability which depends on the availability of CSI at the IRS controller. To be specific, channel information needs to be acquired in order to select the transmitter-to-user links, which can be accomplished by using conventional channel estimation strategies. However, for the transmitter-to-IRS and IRS-to-user links, it is more complicated to do so due to three main reasons, the first reason is that an accurate channel estimation cannot be initiated due to the passive elements consisted in the IRS, secondly a long delay maybe occurred because of the limited IRS controller, and lastly performing a channel estimation in a high-dimensional channel that is needed to achieve a reasonable system performance would put a heavy signal burdens and energy consumption at wireless transceivers [71]

IV.3.2. Controlling IRS

Controlling IRS in practical systems is very challenging, the controller that should be installed must be smart ones in order to exploit the performance of IRS systems, and communicate with the transmitter to facilitate the estimation of CSI and real-time

beamforming, however practical control protocols for smart IRS controller are not exploited yet and therefore not available, its also not decided yet for the IRS controller to be separated or if it should be via dedicated time slots.

IV.3.3. Hardware Impairments

The research sone so far for the IRS-assisted communication models are based on a perfect hardware, which is not the case for real-life deployment, using fabricated low-cost components for IRSs and IRS controllers will lead to hardware impairments, for example. a study provided in [67] shows the effect of finite resolution phase shifters on the IRS-based communication systems.

V. FUTURE MIMO APPLICATIONS

After discussing the expectations of MIMO techniques for future beyond 5G networks, we now provide a briefly overview of some future applications and other communication technologies that are expected to compliment MIMO systems in order to fulfill the upcoming Quality of Service (QoS) requirements for B5G wireless systems.

V.1. Unnamed Arial Vehicle-based MIMO Communications

Despite the high forecast of MIMO in an attempt to enhance the SNR of a communication link such as the cell-free massive MIMO that we mentioned earlier, there are some cases where such techniques are not sufficient to provide decent coverage and capacity due to some harsh environment conditions where the path loss is very high due to blockage events.

Other than that, terrestrial wireless networks may malfunction due to natural disasters, power outages or maintenance problems, to address these issues, Aerial communication systems based on UAVs are viewed as a capable new norm, the figure below represents two main use cases, the first scenario (at the right) where a blockage occurs between a MIMO transmitter and a ground user, a UAV can be employed as an aerial relay to create a decent communication link between the desired transceivers, the relaying protocols used are either the traditional ones or the new IRS approach described previously can be used as well, the second scenario (on the left of the figure) when a communication infrastructure is out of service or unavailable, UAV will be served as an aerial base station to establish a temporary communication hotspot for multiple ground UEs.

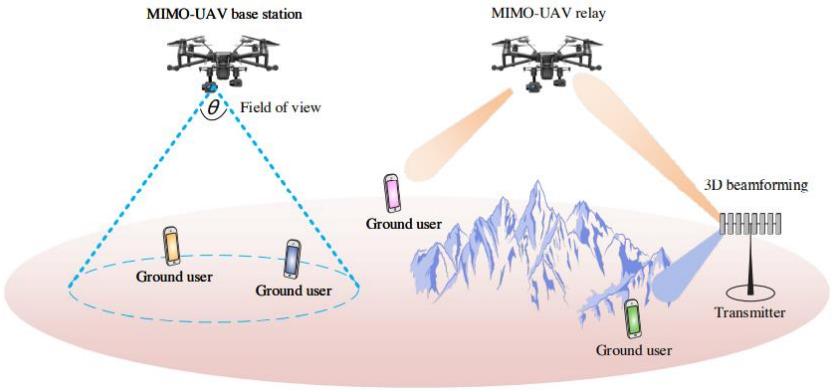

Figure II-8 Different aspects of a MIMO-UAV assisted wireless communication system

UAVs will introduce additional spatial degree of freedom in resource allocations and improves in the performance of the wireless systems due to its high mobility where it can relocate and adopt its trajectory to a region with decent UEs to offer high seamless communication services.

V.1.1. Open Challenges

Integrating such technology will lay on new challenges that needs to be addressed, the first issue is the concerning dimensions of the UAV systems; the size, weight and energy consumption of UAVs are very high and almost impossible to employ in traditional communication systems, small UAVs (less than 25Kg) for safety reasons. [68] this will limit the battery life of the UAVs it will also create some difficulties in the implementation of massive MIMO UAVs (MIMO-UAV).

The second challenge is related to the performance of MIMO-UAV which is based on the trajectory and resource allocation designs that are based on LOS scenarios only, hence, the trajectory of UAVs, location of UEs and beamforming vectors designs will be very complicated to obtain [69].

V.1.2. 3D Beamforming

Basic deployments for a seamless communication are the use of directional high gain antennas with a predefined antenna patterns that focus the signal energy onto the ground-based coverage area. However, such deployment is not a viable option of UAVs since the later one serves a 3D distribution of UEs, because of this, 3D beamforming is more suitable [70] a 2D array is deployed at the bottom of UAV that controls the magnitudes and phases of each antenna element, but due to the limited size of UAV, narrow beams cannot be

obtained, with that been said, a new algorithms of 3D beamforming and trajectory designs at UAVs needs to be well studied.

V.1.3. Hybrid Beamforming

Even with hybrid analog-digital beamforming been a considered in 5G networks, implementing it in a THz communication for b5G networks can be very challenging, building analog or hybrid transceivers for sub-THz bands will result of a small size of each antennas element that a dedicated RF chain cannot be placed behind it. and by doing so the RF design will be more cumbersome, therefore it is highly needed to determine how is the channel and the hardware constraints will affect sub-THz band and reconsider whether if hybrid Beamforming is suitable for sub-THz bands used in B5G networks [72]. In the other hand beamspace approach discussed earlier is a proper methodology for signal processing in sub-THz bands.

VI. CANDIDATE MULTIPLEXING TECHNIQUES BASED ON OFDM IN BEYOND 5G

Future beyond 5G supports a large variety of services and applications with enormous volume of data therefore perfect multiplexing technique is highly needed, that should fulfill the major key performance indicators (KPIs) [73].

- High spectral efficiency: is to transmit the maximum amount data using the minimum bandwidth that is possible.
- Peak-to average-Power-Ratio (PAPR): which indicates the ratio between the maximum peak and the average transmitted power of sing.
- Processing Delay: this can be controlled by reducing the symbol temporal duration or period or increasing the sub-carrier spacing [73].
- Robustness to frequency-selective channel.
- Robustness to time-selective channel.
- Massive Asynchronous transmission: in order to efficient channel utilization so the nodes can communicate with each other in a given time.
- Complexity: the overall system complexity will influence the energy efficiency and the cost of the system [73].

- High flexibility, reliability and MIMO friendless: an extremely high reliability is necessary, also the new Multiplexing access should support the MIMO especially Ultra massive MIMO.
- Filtering/windowing: the used Multiplexing technique should allow filtering and windowing operations to be performed in both the transmission and reception stages [73].

The multiplexing techniques can be classified as a Single-Carrier (SC) and Multi-Carrier (MC) waveforms, the first one exploit only one single frequency for transmitting date, and for the second one the MC divide the frequency channel into many subcarriers. However, when we compare between the SC and MC, the single carrier waveforms are less capable of dealing with multipath fading channels [74].

VI.1. Orthogonal Frequency Division Multiplexing (OFDM):

As one of the multi-carrier digital transmission methods used in high-speed data transmission systems, its concept is based on the transmission of high-rate data through a large number of low-rate carriers on the same channel. Use conventional digital modulation to modulate the subcarrier. With low symbol rate and orthogonal schemes (QPSK, 16QAM...), the frequency gap between them is also generated using fast Fourier transmission (FFT). The figure below shows the schematic diagram of the OFDM transceiver [74].

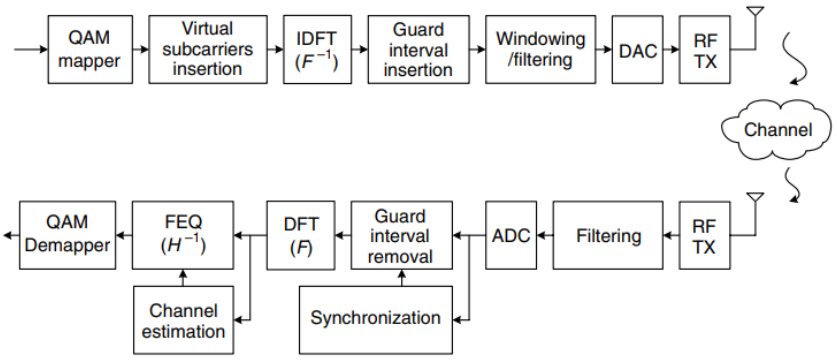

Figure II-9 Typical OFDM transceiver architecture [74]

OFDM has become the most popular multi-carrier signaling scheme due to its unique advantages. One of its main advantages is the ability to work with frequency selective channels for broadband communications. Therefore, OFDM has been adopted by LTE and NR radio networks and is also a candidate technology for the beyond 5G.

One of the biggest problems in the OFDM is the Inter-Symbol Interference (ISI), where the last part of the current symbol adds with the first part of the same delayed symbol. For the purpose of avoiding ISI, related with multipath fading, it is necessary to add a cyclic extension of the symbol itself in each OFDM symbol, it called Cyclic Prefix (CP) that is a copy of the tail of symbol placed at its beginning, what leads to develop a new multiplexing technique called CP-OFDM. But is spite of that, using CP with OFDM symbol increase the transmission overhead that lowers the effective throughput of the CP-OFDM, more than that CP has another aspect which is related to the power wasted that reduces the power efficiency of OFDM transceiver [75].

CP-OFDM is a waveform technique that used in the 5G wireless network system and also it is candidate in beyond 5G, besides a several alternative techniques being proposed with greater spectral and power efficiency and that is what we will talk about next.

VI.2. Filtered Orthogonal Frequency Division Multiplexing (F-OFDM)

F-OFDM based OFDM is another processing waveform candidate for beyond 5G that gives the authorization to share some of OFDM's proprieties like [76]:

- PAPR reduction technique based on Discrete Fourier Transform (DFT) recording.
- Low complexity that reduces the energy consumption.
- The receiver that has the CP block and does not require any interference cancelation algorithm.
- MIMO friendliness since the Ultra massive MIMO is highly recommended in beyond 5G.

F-OFDM is based on separation and filtering, which means that an independent OFDM system can coexist on the bandwidth [76]. The figure below shows the structure of the F-OFDM uplink transceiver with the recommended filter parameters and protection bandwidth optimization scheme, where the filter parameter optimization helps to minimize multi-user side lobe interference of the Adjacent users while maintaining the ISI and inter-carrier interference (ICI) from the user itself under an acceptable level.

The main reason of applying a filter in each sub-band is to obtain lower Out of Band radiation (OOB) emission and also to suppress the inter-sub-band interference [76], this made the expanse of losing of the time domain orthogonality between OFDM symbols in each sub-

band. Compared with OFDM, F-OFDM's relatively high complexity due to the filtering operation.

As in [76], the ideal prototype filter has a rectangular frequency response that causes no OOB radiation, no distortion in the pass-band and limits considerably the ISI introduced between consecutive OFDM symbols. From the F-OFDM's receiver side, it is very similar to the CO-OFDM receiver, nevertheless each sub-band receiver signal is first filtered with the perspective matched filter used upon transmission this is followed by the CP removal and then the frequency domain equalization (FDE) and finally the detection of the data symbol and bitstream.

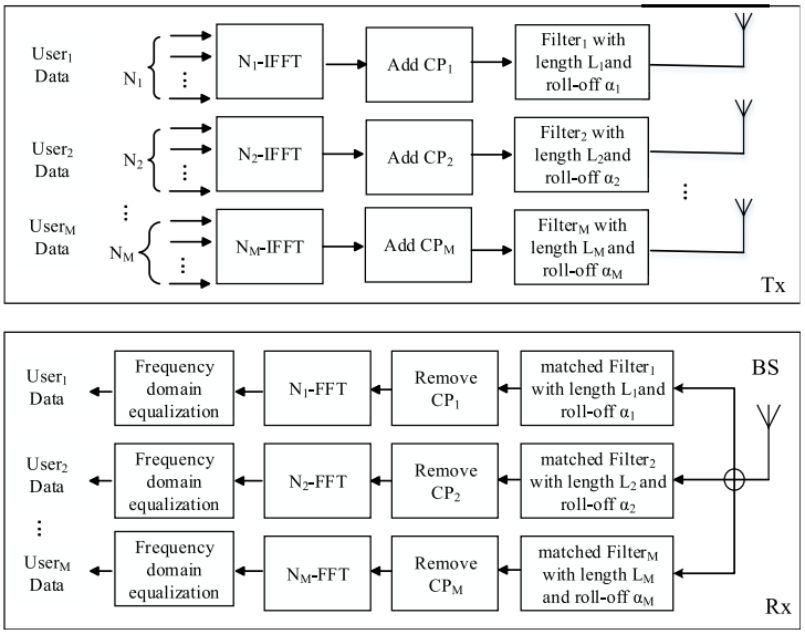

Figure II-10 Transceiver structure of uplink F-OFDM system [76]

VI.3. Generalized Frequency Division Multiplexing (GFDM)

Compared with OFDM, GFDM provides additional degrees of freedom, because GFDM can flexibly transmit multiple carriers relative to the time-frequency structure design. The difference between the two is the total number of GFDM modulation constellation symbols in a frame with N sub-symbols and different time-slots and sub-carriers [77].

Figure (3) presented block diagram of the GFDM transmitted, where every stream is unsampled by M K, and then shifted to its carrier frequency, in the filtering part the sub-carriers are circularly convoluted with prototype filter such as root raised cosine window (RRC) [77]. Thereby, GFDM is characterized by the following [87]:

- Minimize the possibility of adjusting the sub-carrier spacing and that leads to minimize the OOB.
- The adjacent filters are convoluted over defined number of symbols, this can lead to non-orthogonal sub-carrier and arise both ISI and ICI.
- Instead of adding a CP to every symbol, the GFDM transmitter has a single CP for an entire block that includes multiple sub-symbols.
- Under those circumstances, GFDM can achieve higher spectral efficiency than OFDM technique, but in another hand its transmitter is more complicated, supplementary it needs for long filter lengths requires higher block processing which can lead to higher latency [73].

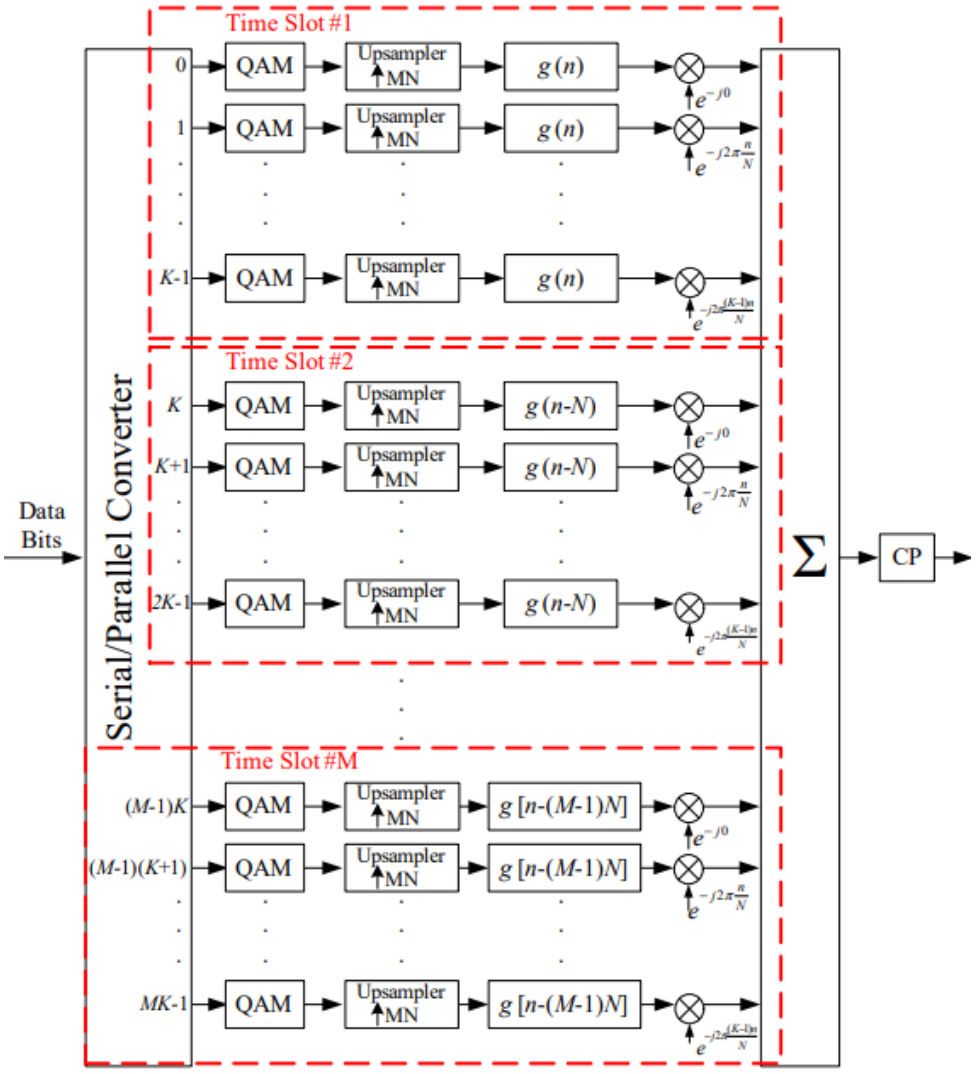

Figure II-11 block diagram of the GFDM transmitter [77]

VI.4. Time Interleaved Block Windowed Burst Orthogonal Frequency Division Multiplexing (TIBWB-OFDM)

TIBWB-OFDM is a new technique that employ the transmitted signal with power spectral density (PSD) as compact as F-OFDM schemes in order to allow a better spectral efficiency and better power efficiency

- For the purpose to achieve great spectral efficiency, TIBWB-OFDM increases the spectral confinement and lowering the OOB emission.
- So as to increase in power efficiency it concatenates a number of OFDM symbols to which a single prefix of zeros is added, thus elimination the need of a CP [79].

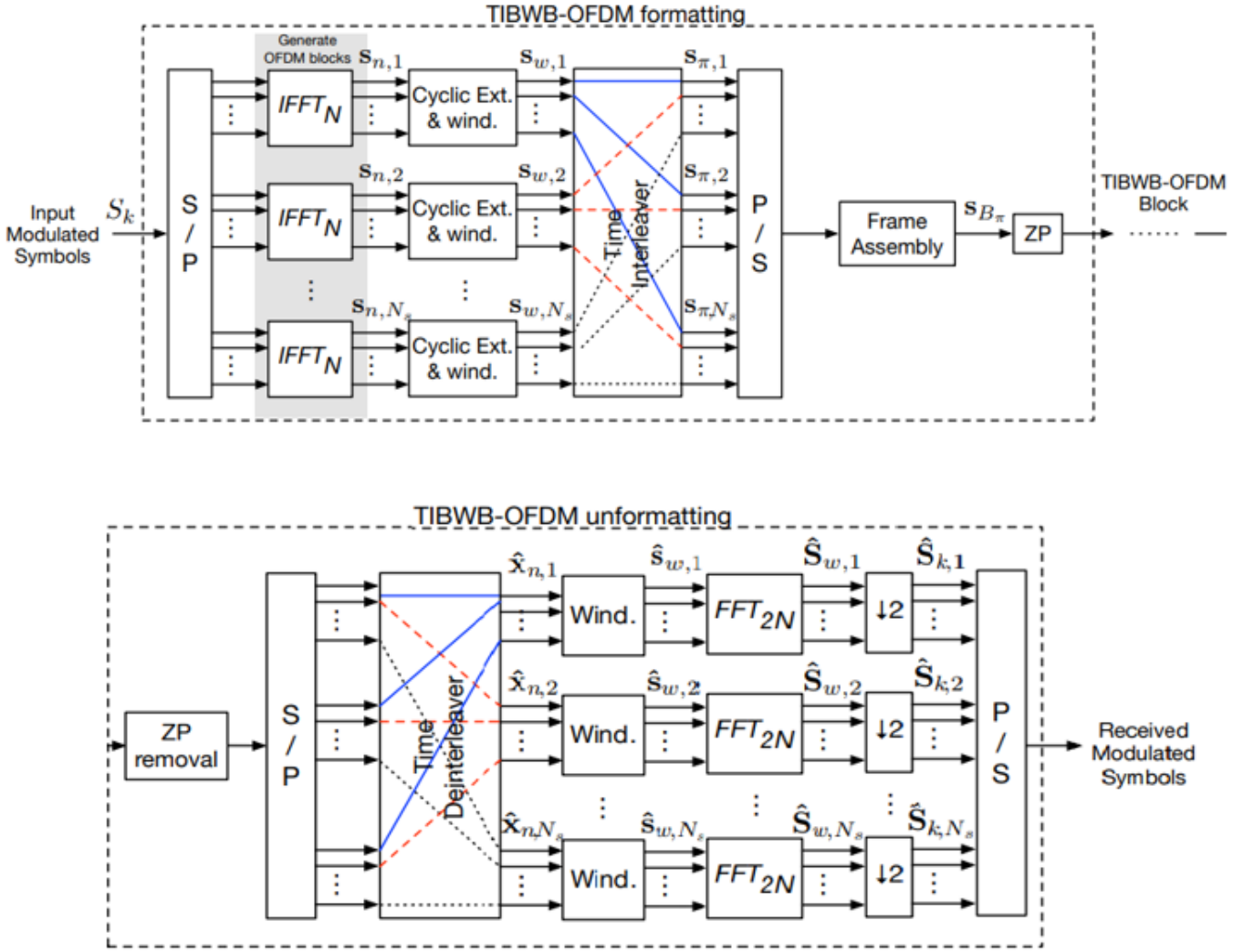

Figure II-12 Basic building structure of TIBWB-OFDM block formatting and unformatting upon transmission and reception [80]

The figure above describes the basic building striction of TIBWB-OFDM block formation and unformatting upon transmission and reception respectively, where the cyclic extension and windowing operation preformed before the time interleaved operation, that caused the compression and reliction of the spectral data creating in the frequency domain a diversity effect, ergo it allows partial data recover from eventual unaffected spectrum replicas by increasing the robustness method against deep fading of channel [80] .

VI.5. Comparison Through KPI's Factors:

The KPI's factors is highly needed for the sake of knowing which the better performer technique between the discussed multiplexing techniques:

1. Processing delay and filtering & windowing [73]:

- GFDM: the processing delay is high because it preforms the filtering operation by sub-carrier that requires a long filter length.
- TIBWD-OFDM: preform the filtering per sub-band so it uses shorter filter length.
- F-OFDM schemes: use shorter filter lengths and includes large CP lengths that leads to a lower duration remain.

As a consequence, the most fitting techniques are OFDM and F-OFDM.

2. Robustness to frequency-selective channels:

Primary, all MC techniques are robust to the frequency selective of the wireless channel, but from the point of view of this KPI, TIBWB-OFDM is more suitable than the others because it allows a deeper level of robustness against deep fading by granting a higher degree and diversity in frequency demand and the inclusion of time interleave & deinterleave operations. [80].

3. Robustness to time-selective channels: Taking mobility into account

- F-OFDM is same as OFDM concerning this KPI.
- GFDM & TIBWB-OFDM are most suitable because it allows a more accurate estimation of carrier frequency offset (CFO).

4. High flexibility and efficient MIMO implementation:

Most of discussed techniques are flexible with the possibility of employing multiple parameters, GFDM is an exception case because its sub-carrier is preformed infrequency

domain causing ICI that must be dealt in the receiver, and ergo GFDM is the only technique that is no recommended concerning this KPI [73].

VII. COOPERATIVE NON-ORTHOGONAL MULTIPLE ACCESS (NOMA) FOR BEYOND 5G NETWORKS

Beside OFDMs techniques another known technique has been recognized as a promising multiple access candidate for b5G networks which is the Non-Orthogonal Multiple Access (NOMA). Particularly, it helps to fulfill the requirements of the Beyond 5G: increases the data traffic, much lower latency, massive connectivity and higher spectral efficiency, by allowing a multiple use to use the same time and frequency resources.

NOMA schemes are primary divided into two categories: Code Domain NOMA (CD-COMA) & Power Domain NOMA (PD-NOMA). CD-NOMA uses spars spreading sequences to spread the data over subcarriers [81] that help to achieve certain spreading gain shaping gain at the cost of the increased bandwidth, also allow for w higher number of unique codes to avoid inter-user interferences [81]. In PD-NOMA, users share time, frequency or code segments, and use different performance levels for each available resource. According to the classic NOMA principle, power levels are allocated before transmission, users with poor channel conditions are allocated a higher power level, and users with better channel conditions are allocated a lower power level [82].

The figure below represents the proposed NOMA system mode, the user data is sent to the quadrature amplitude modulation (QAM), where the information bits are displayed. These bits are allocated using a predefined code words, and power is allocated according to the principle of NOMA, the information is sent to the receiver through the attenuated channel, the multi-user detection (MUD) on the receiver side eliminates channel interference, the signal is distributed as the predesigned code that known at the receiver. Lastly the maximal ratio combining (MRC) is used after demodulating the user bits [83].

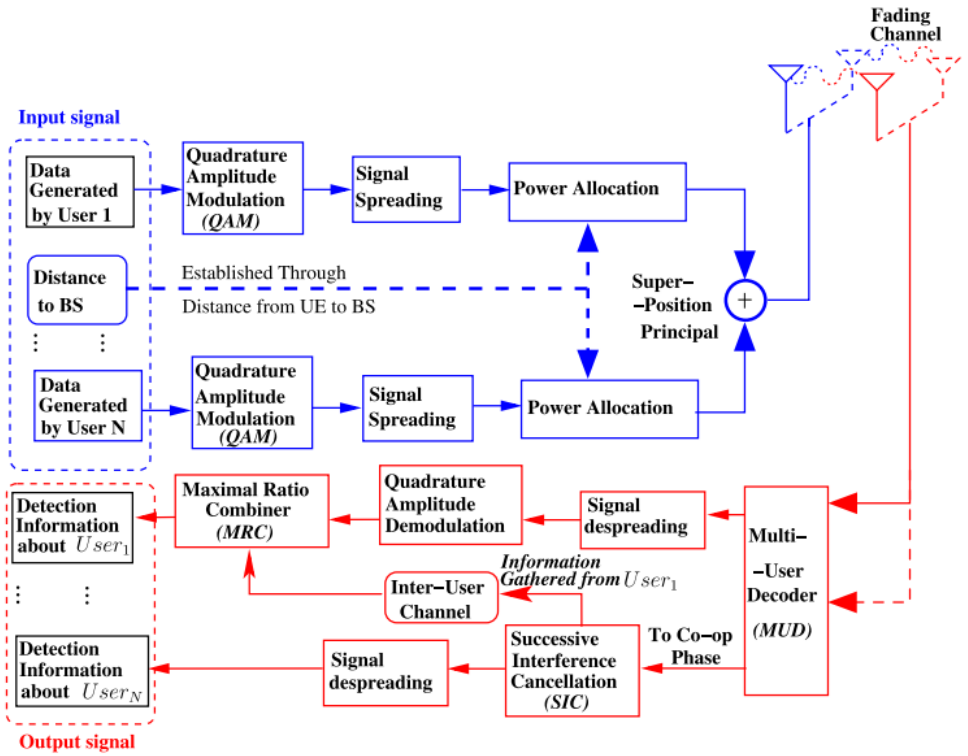

Figure II-13 Proposed NOMA System Model [83]

VIII. ORTHOGONAL TIME FREQUENCY SPACE MODULATION FOR NEW MOBILITY TECHNIQUE

Recently, proposed orthogonal time frequency space (OTFS) modulation has been taken into consideration as a promising candidate for accommodation numerous rising communication and sensing applications in high mobility environments, OFDM modulation may degrade due to the significant Doppler spread induced by high-mobility can severely undermine the orthogonality between subcarriers.

OTFS modulation considers the Delay-Doppler (DD) domain signal representation to time-frequency (TF) domain, wherein the channel responses are extraordinarily sparring and robust. The channel propriety of the DD domain leads to the symbol's position in the DD domain which enables the information symbols to interact directly with response of the DD domain channel, resulting in a much simpler input-output relationship compared to OFDM modulation in channels with high mobility. Subsequently, OTFS modulation offers the potential to achieve

full channel diversity in a high mobility environment [84]. The following figure shows the OTFS system model in the DD domain [85],

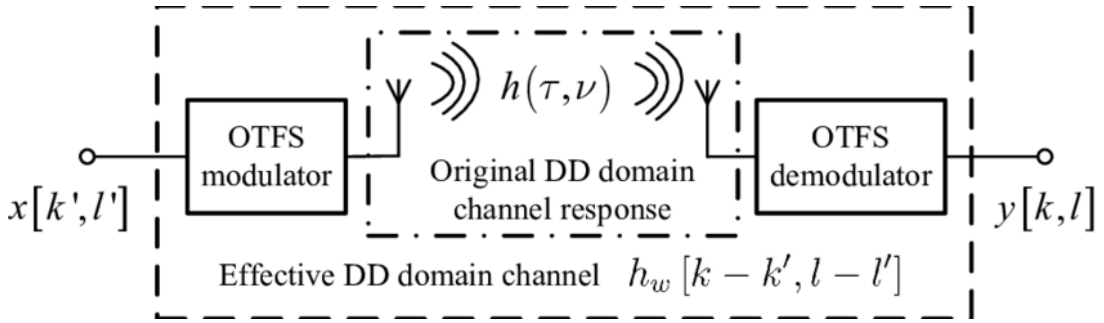

Figure II-14 OTFS-system-model-in-the-DD-domain [85]

Although OTFS modulation has many advantages over traditional OFDM, but in order to achieve the potential full channel diversity, it requires a very complex detection algorithm. Like it discussed previously OFDM needs the help of the CP to get rid of the ISI challenge, in contrast, enables a reduced CP frame structure for OTFS modulation, in which interferences due to channel impairments have to be compensated for by advanced algorithms [86].

Note that many existing OTFS discovery efforts take advantage of the lack of DD domain channels to reduce the complexity of discovery. However, if the OTFS frame duration is not long enough, the effective DD range channel generated may be due to insufficient Doppler frequency resolution, such as H. Fractional Doppler shift, dense [86]. In this case, the traditional recognition method may face very high recognition complexity because there is no longer a lack of channels. This fact reminds people of OTFS discovery based on different domains. The figure below shows the OTFS system that use a periodic superimposed pilot (SP) with zero-mean data symbols. This enabled them to mitigate the mutual interference between data and pilot symbols using the first-order statistics of the received signal [87].

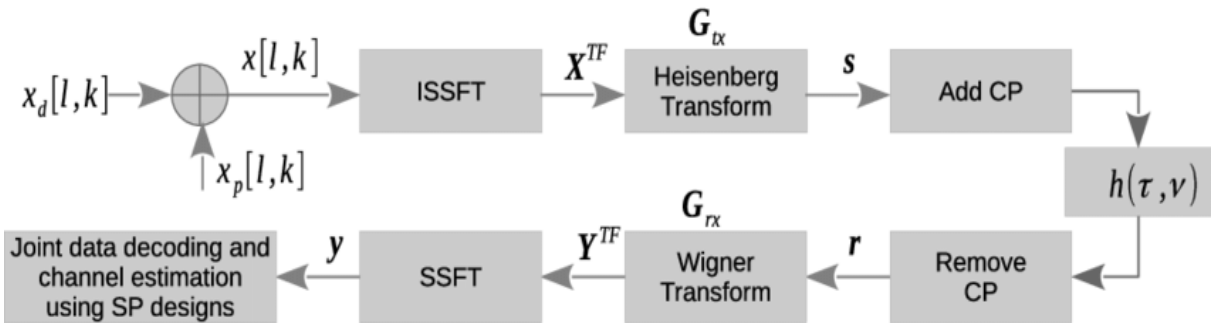

Figure II-15 OTFS system model with superimposed pilot (SP) sequence [87].

OTFS can effectively convert the time-frequency domain of a rapidly changing time channel into a quasi-stationary Doppler delay model. In the case of high mobility, this quasi-

stationary channel model simplifies the channel estimation and symbol recognition of the wireless receiver [87]. OTFS provides diversity amplification for channels with fixed multipath and dual selectivity. Other related work has focused on OTFS modulation in multiple input/output (MIMO) and millimeter wave (mmWave) communication systems [88].

Recent work has proposed a new form of OTFS-NOMA, in which high-mobility users using OTFS in the Doppler delay domain are combined with a group of low-mobility OFDM users to share non-orthogonal channels. For the simple alignment suggested by the OTFS-NOMA system, these ideal bi-orthogonal OTFS pulses are also required. In addition, the performance analysis of the OTFS-NOMA solution only considers the perfect SIC process, and requires the mobile connection to have network delay and Doppler shift, which is still an unrealistic assumption in the actual implementation of the OTFS-NOMA system [88].

VIII.1. OTFS Based NOMA (OBNOMA) Signal Model for Mobile Users [89]

Imagine a multi-user coded uplink system, where (U + V) users communicate with the base station (BS) at the same time, as shown in Figure below, where U = {1, 2,...,U} represents a group of entities User..., V = {U + 1, U + 2, ⋯, U + V} represents a group of mobile users. For simplicity, we use u = {1, 2... U} ∈U and v = {1, 2,...,V}∈V to describe the u-th fixed user and v a mobile phone respectively Designated user.

In order to avoid unnecessary confusion, the author uses a simple model in which the user

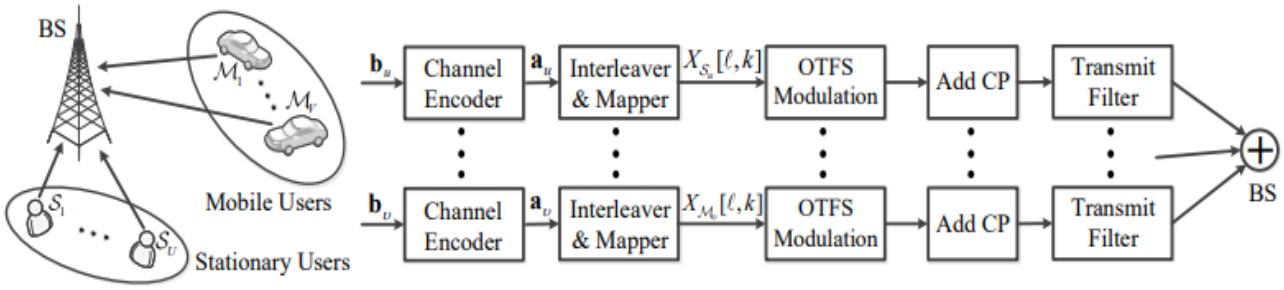

Figure II-16 Figure 8 System model for coded uplink OBNOMA scheme [89]

terminal and the receiving BS are equipped with the same transmitting and receiving antennas. Every user uses OTFS for uplink transmission, thus benefiting from it. Of course, this model is also applicable to the case of multiple transmit and receive antennas with expected diversity gain. In practice, the Doppler frequency and fading rate of stationary and mobile users will change differently. This difference in channels allows us to develop a dedicated NOMA based on OTFS (OBNOMA) to group users with different mobility profiles.

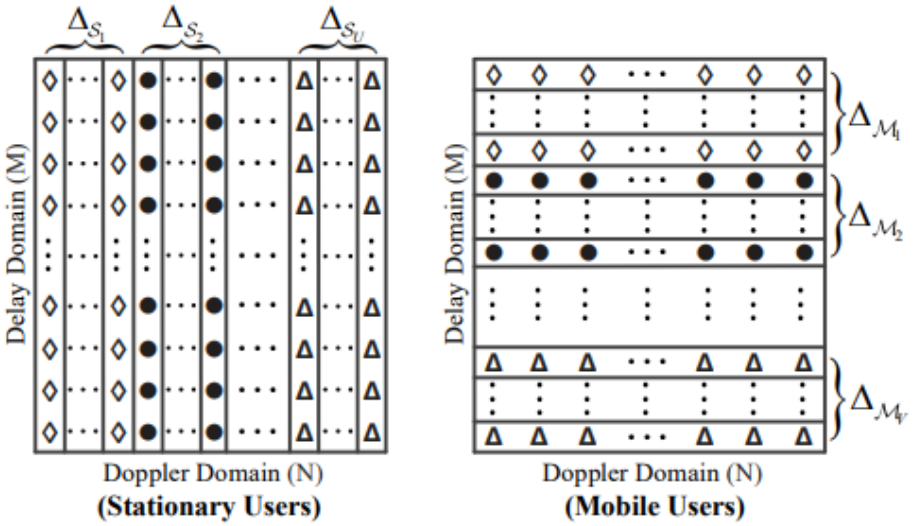

Figure II-17 Resource allocation in OBNOMA [89]

Taking into account the characteristics of stationary users and mobile users in terms of Doppler shifts and channel delay spreads, the author proposes a new resource allocation in the OBNOMA scheme, as shown in the figure above. These stationary users do not interfere with each other. On the other hand, non-overlapping and adjacent containers are allocated to mobile users along the delay axis to reduce their interference.

IX. CONCLUSION

In this chapter, we outlined three promising research avenues concerning the multiple antenna technologies for beyond 5G networks. Through model system, performance analysis, signal processing circuit and realization of vision, we introduced massive Free-cell massive MIMO, beam space MIMO and IRS benchmarks and historical viewpoints created by the latest technological advances. Broadly speaking, the network will become more complex and heterogeneous in the future. The traditional bulk MIMO technology is combined with a unitless distributed implementation that supports IRS and simplified signal processing. Signals can be made possible by beam space methods. These technologies can be used for traditional frequency bands and new sub-THz frequency bands, and the network can include unmanned aerial vehicles to provide better coverage. We believe that even after decades of research and development, multi-antenna technology will still be a very important and exciting direction. The study. Applicable to systems other than 5G. Next, we studied possible 5G waveforms and key KPIs in the future, and discussed the challenges they bring to meet the different needs of future wireless communications. The advantages and disadvantages of each waveform have also been explained in detail. Provide a detailed description of the transceiver architecture of

each MC circuit. In the end, we can say that no ideal waveform can meet all requirements, and there are trade-offs. Therefore, in order to select the most suitable waveform format for a given scenario, future wireless systems must flexibly respond to different b5G and higher service requirements and propagation conditions. Another solution is to select and adjust the signal format to meet most of the service requirements of a particular type of application. Lastly, for the mobility case, a new promising modulation techniques was presented; OTFS that can satisfy interesting use cases (high-speed trains, autonomous vehicles, drones, THz communications), and is promising for b5G and other applications Modulation scheme.

CHAPTER III: b5G FULL-STACK LAYERS

I. INTRODUCTION

For the previous chapters, we gave a full study on the future beyond 5G networks, from different angles starting from the promised THz communications as we talked about the necessary to develop new THz channel models and Transceivers, moving on the technologies and the network solutions that will help to achieve the Tbps high data rate. From the study done we have noticed that the harsh propagation characteristics of the terahertz band, the limited coverage of a terahertz access point, the directionality, and the huge availability of bandwidth, introduce a new challenges and potential for the physical layer, the link layer including the Medium Access Control (MAC), network, and transport layers. With that been said, we need to discuss the protocols related to the full stack end to end for b5G network, more specifically, At the PHY and link layers, two parallel set of modules for nanoscale and macroscale scenarios have been developed, in this chapter we will have an overview about the proposed physical and MAC protocols for the THz communications for the future beyond 5G Networks.

II. B5G USAGE SCENARIOS

In our study, we focus on two main scenarios for the THz communications as we analyze the main phenomenal occurring during the transmission; path loss effects on the THz bands. With categorizing the THz communications, we can observe and suggest a proper and more suitable full stack layers solutions for each scenario as we later on put this study for simulation purposes. The two categorized THz communication are as follows [90]:

II.1. Nanoscale scenario

This scenario is for data transmissions with distances below one meter, where THz frequencies is considered as a single transmission with 10THz wildness. More suitable layers will be suggested for this scenario such as the femtosecond-long pulses technology for physical layer that will be studied later.

FigureII-1 Terahertz Band applications at the nanoscale

II.2. Macroscale scenario

This scenario is for data transmissions for long distances above 1 meter, where THz bands are divided into multiple transmission windows with tens of Gbps wideness. Using multi-carrier modulations is highly suggested (chapter II), highly directional antennas or beamforming antennas is also needed to overcome the challenges facing this type of scenarios.

FigureII-2 Terahertz Band applications at the macroscale

III. PHYSICAL LAYER FOR THZ COMMUNICATIONS

Fifth-generation (5G) networks will not be able to meet the latency, bandwidth and traffic density requirements of 2030 and beyond, and will require next-generation wireless networks with disruptive technologies. Improve performance by providing advanced features such as

doping of graphene-based devices and the number of the available hole and electrons in it. Based on the results obtained, it is necessary to study new ultra-wideband modulations suitable for communication in the THz range, such as the formation of femtosecond pulses and pulse changes due to material doping. According to the above-mentioned channel behavior related to distance.

III.2. Coding

the transceiver requires the development of novel channel codes in order to communicate in the THz band, the classic channel codes was designed to maximize the data rate of a specific transmission power or to minimize a target data rate equivalently. However, along with transmission power, decoding power is another critical source of power consumption. In fact, at a distance of less than ten meters, the decoding power required by most modern decoders is usually equal to or higher than the transmission power. Despite the increased transmission power, unencrypted transmissions are usually used in 60 GHz systems to reduce decoding performance. Therefore, for terahertz communication, due to the extremely high bandwidth and very high data rate, the decoding performance and decoding time must be carefully considered when designing and selecting a channel code. from this side, the challenges are:

- For characterizing the error sources at THz Band frequencies, the nature of the channel errors that can be calculated based on the Molecular absorption noise and multipath fading, must be analyzed by a random analysis of noise multipath propagation.
- It is important to study the trade-off between transmission power and decoding time, and to design channel codes, in order to develop new types of channel coding schemes with extremely low complexity, so it maximizes the overall transmission and decoding performance.

III.3. Dynamic massive MIMO

In the 2nd chapter, we have talked about the Massive MIMO and how: i) it can benefit the THz communications specially when using the cell-Free Massive MIMO even if it has some challenges. ii) a very large antenna arrays can be designed to overcome too high channel loss and performance limitations of Tera Hertz transceiver. Which opens up many new ranges of possible alternatives for the large-scale development of massive MIMO, by correctly connecting the elements of the antenna array, different array patterns can be created and that is what the following table shows:

IV. LINK LAYER FOR THZ COMMUNICATIONS

Along with the development of THz devices and physical layer solutions, investigation for new network layer mechanisms is highly needed in order to achieve the extremely-high-speed wireless data for b5G networks. Therefore, there is a requirement to improve the conventional Medium Access Control (MAC) protocols for the THz Communications, where a very large bandwidth is provided for the devices. For this end, a high bit-rates and a very short transmission time are achieved. Several challenges are facing the link layer for THz bands such as temporal energy fluctuations and, thus, availability introduced by required energy harvesting systems.

To solve these challenges, a new MAC protocols are introduced for the very-high-speed wireless communication networks in the THz band. The following titles explains these MAC protocols for the THz communication.

IV.1. MAC Protocols for THz Communications

Alongside with the advancement of THz devices and physical layer mechanisms, there's a requirement to research new networking solutions for very-high-speed wireless data networks. ancient Medium Access management (MAC) protocols got to be revised in lightweight of the properties of THz-band communication. In particular, the THz band provides devices with a really massive bandwidth and thus, these don't need to sharply contend for the channel. In addition, such very large bandwidth leads to very high bit-rates and consequently, very short transmission times, and so the collision probability will be compensated. However, because of the low transmission power of THz transceivers and due to the high path-loss at THz-band frequencies, extremely high directive antennas are required to determine wireless links for transmissions above one meter. Whereas, directional communication will also decrease multi-user interference, it needs tight synchronization between transmitter and receiver to beat the deafness drawback. Moreover, the comparatively long propagation delay once transmission at Tbps over multi-meter-long links leads to low channel utilization. Where, these two problems are overcome in nanoscale applications (transmissions case of distance below one meter), there are alternative challenges that have an effect on the link layer of THz nano devices, including their temporal energy fluctuations and, thus, availability, introduced by needed energy harvesting systems. To overpower these limitations, a synchronization and MAC protocol for very-high-speed wireless communication networks has been developed within the THz band. The protocol depends on a receiver-initiated handshake as how to guarantee synchronization

between transmitter and receiver. In addition, it incorporates a window flow control mechanism, which is combined with the one-way handshake, maximizes the channel utilization. they have two completely different application scenarios: a macroscale scenario, during which nodes utilize high-speed turning directional antennas to sporadically sweep the space, and a nanoscale scenario, in which nodes create use of an electricity nano-generator to reap energy. for each scenario, they consider a unique physical layer, namely, a standard carrier-based modulation for the macro-scenario and a femtosecond-long pulse-based modulation with user interleaving for the nano-scenario. They have analytically investigated the performance of the planned MAC protocol in terms of delay, throughput and successful packet transmission probability [90].

IV.2. THz-Band Communication System Model [90]

A full Model for THz communication was analyzed considering Signal-to-noise Ratio, Bit Error Rate and Frame Error Rate, Collision probabilities and Energy Model for both nanoscale and macroscale scenarios.

This analyze shows that THz bands communication networks certainly needs an initial handshake in order to guarantee link layer synchronization between the transmitter and the receiver, these handshakes are required for the propose of preventing unnecessary data transmissions where the receiver is not available; due to different occasions; a LOS link cannot be generated for the macroscale scenario, or due to the low energy of the receiver that can no longer support another transmission progress for the nanoscale scenarios.

The main idea behind the proposed MAC protocol is to reduce the overhead caused by such handshaking events, by giving the control of announcing the availability to receive data of nodes to themselves. Along with the one-way handshake, the proposed protocols also utilize sliding flow control window at the link layer to maximize the channel utilization. Specifically, the delay caused by waiting for the receiver availability as well as the long propagation delay in the case of multi-Gbps and Tbps transmissions. To solve these issues, a specific amount of time needs to be determined by the receiver to maintain its current direction and also to control the amount of data packets willing to be accepted according to its currently available energy.

IV.3. Protocol Overview

The basic concept of the protocol is summarized as follows: the node can be in the sending or receiving mode:

The node is in the transmitting (TM) mode where the data is being sent, Firstly, it checks whether the target received a "Clear-To-Send" (CTS) frame recently. We consider that the expiration time of CTS is equal to the value of the parameter in our system. Otherwise, the node will listen to the channel until a new CTS frame is received. In the macro scenario, we assume that the nodes in the TM point their directional antennas at the receiver. And we assume that the TM nodes in the link layer, know the location of the receiver, the later one provides this information during the discovery process, which will be reserved for future work. In the nano-scenario, omnidirectional antennas are used.

As for the Receive mode (RM), nodes that have enough resources (such as power or even memory) to handle new incoming transmissions, transmit their state on the CTS frame. In the macro scenario, the RM node uses dynamically rotating narrow-beam to expand the CTS frames throughout the environment. These electrically controlled rotating high-speed directional antennas can be implemented, for example, by using large graphene-based nano arrays. the node cannot know in advance who is ready to broadcast, so the node has to scan the entire room. the turning speed of beam is the parameter that should be optimized in our analysis. In the nano scenario, this information is transmitted in all directions (omnidirectional). The CTS frame also contains information about the current size of the receiver's sliding window. After receiving the CTS frame, the node checks whether the data is available for the destinated data receiver, and whether the TM mode have enough resources to transmit. If so, the DATA frame is sent considering the size of the receiver's sliding window. If the transmission is successful, the node in the RM will send an ACK frame (positive acknowledgment). Otherwise, after the timeout period, the node in the TM will set a random rollback time based on the number of attempts to send and the number of times the entire process is repeated after completion. After successfully receiving the data packet, that is, after successfully sending the CTS, DATA and ACK frames, the node in the RM can decide to continue to rotate, collect other data packets or switch to TM mode. There are a few things to keep in mind about fairness. If the reaction protocol is activated, the nodes in the TM wait for a random period of time after receiving the CTS frame and before sending the DATA frame. In the macro scneario, the carrier sense is realized at this time, as for the nanoscale scenario, a pulsed-based physical layer is used where the sense carrier detection is not supported, but the possibility of collision is very low, for the macro scenario, it is only necessary to note that the nodes in the RM cannot simply stop on the nodes in the TM indefinitely, but must continue to "rotate". Therefore, we need to ensure that in a short time, when the node in the RM is facing the node in the TM, the DATA

frame can be successfully sent. It is possible because the node transmits at multiple Gbps or even Tbps, so it usually only takes a few nanoseconds, which is much less than the existing wireless communication system.

IV.4. Other Proposed MAC Protocols

The exceptional possibilities of terahertz bandwidth and high-direction transmission require further research on media access and retransmission mechanisms. In particular, the high speed of the physical layer can allow four MAC protocols to continue to achieve high performance and spectral efficiency. For terahertz channels, when it comes to media access, the main decision is between scheduled and contention-based protocols. Each of these protocols represent functions and constraints that can be used in various scenarios and use cases.

a- Scheduled MAC:

base stations in a cellular network assign time and frequency resources to connected users, thereby avoiding collisions and consequently increasing spectrum efficiency. In addition, the central control at the base stations enables the connection to be adapted and monitored quickly. Base stations can assign specific tracking or reference signals to associated users and coordinate with the infrastructure to understand the evolution of channel dynamics for a particular user. However, given the harsh propagation environment in the terahertz band and the adaptation of the control plane to directivity, it can be difficult to establish and maintain a connection to the fixed infrastructure.

b- Contention based MAC:

Most research on the design of the terahertz MAC layer has suggested approaches based on contention based medium access. Compared to a scheduled MAC, a contention-based MAC does not require any connectivity from the control plane to the infrastructure. In addition, the highly directional transmissions and their short duration (thanks to the extremely high data rate available) limit the effects of collisions between different simultaneous data exchanges. However, the two endpoints of the communication still have to agree on the optimal beam pair, so a beam search step is required.

The base station could disrupt the constant flow of acknowledgments between the receiver and the transmitter, which affects the drafting of retransmission policies. Coding the high data rate and forward error correction could make the transceiver design too complex. Therefore,

an efficient retransmission process remains an open issue. To this end, network coding techniques needs to have low complexity implementations to simplify the retransmission.

IV.5. Additional challenges at the link layer

One of the main issues for the link layer is the risk of deafness that faces the devices in a wireless access network that operate at THz frequencies, where this issue is not questionable for the traditional cellular networks because of the use of broadcast omnidirectional antenna such as the case of LTE networks. However, since 5G networks and beyond use highly directional antennas like it is discussed previously, this caused the deafness issue to rise. Mobile users need to gather awareness to the surrounding environments in order to have knowledge and sense the channel to know if its occupied or no. Moreover, introducing awareness of the fixed infrastructure is highly urgently recommended for the improvement of the link budget and the extension of the communication range.

V. NETWORK LAYER FOR THZ COMMUNICATION [21]

The limited communication distances as well as the utilization of highly directional antenna systems in the THz communications for b5G networks, has raised some challenges on the level of network layer. Especially, for neighbor discovery and routing. Moreover, in small cell systems, handovers become more frequent for mobile users. Therefore, new mechanisms are needed to manage the network layer.

The main issues for the network layer are:

- To discover the possibilities of multi-hop communication with each passive and active relays. There are several advantages of mistreatment intermediate relays between a transmitter and a receiver at THz Band frequencies. the transmission power, and so the energy consumption, may be reduced as in any wireless communication system, by having many intermediate hops between the transmitter and the receiver. Otherwise, the reducing of the transmission distance results into the provision of a lot of wider bands and thus, the transmission can be done at much higher bit-rates thanks to the distinctive distance-dependent behavior of the available bandwidth. These will contribute, once again, to major energy savings. In addition, besides standard relaying nodes, dielectric reflective mirrors, like the IRS discussed previously can be utilized to boost the signal propagation. Optimal readying topologies that take into consideration

the situation and orientation of such mirrors, their reflection coefficient, and their cost, have to be compelled to be developed.

- New routing metrics needs to be determined in order to develop new routing algorithms customized to the physical and link layers of THz frequencies networks. Since the available bandwidth relies on the molecular composition of the channel, this needs to be considered for the routing decision process. As an example, the routes priority should be given to the lower-humidity areas, the information captured by the cellphone's humidity sensors could be incorporated in the routing decision process as part of the channel conditions, other classical metrics should be considered as well with taking in consideration the transmission distance, physical and link layer resources, and energy savings. Once the route has been selected, the data is transmitted to the next hop by the link layer.
- The other issue is handover algorithms used for the current networks that needs to be reconsidered, as we discussed in the previous chapter, a new intelligent novel handover that support the network architecture needs to be designed for the THz communications. the transmission at a very high data rates will cause crucial speed of handovers. With that been said, more suitable small cell network architectures should be designed to reduce the number of handovers and by that reducing the handover drops, such networks have been discussed previously like the basic of free-cell systems.
- Another open challenge is related to the addressing is introduced, even though this issue can be solved by using IPv6 addresses due to their long 128-bit. However, assigning different addresses to every nano-node for the nanoscale application is very complicated for the reason that a very long addresses are required for every nano machines. Therefore, more feasible alternative can be explored taking into account the nano-node and coordinate the same nano-router to have different addresses.

VI. TRANSPORT LAYER FOR THZ COMMUNICATIONS [21]

While flow control at the link layer is needed to stop data losses in a single link. It is also important to revise the functioning of unquestionable transport layer solutions to control the aggregated traffic flow due to the multi-Gbps and Tbps links. It is also necessary to prevent, limit, control and recover network congestion issues by developing protocols such as TCP protocols. Moreover, the overhead of exciting transport layer must be minimized in order to overcome additional performance constraints.

The open challenges regarding the transport layer for THz communications:

II.2. SINR (Signal-to-interference-plus-noise ratio)

SINR is commonly used in wireless communication as a way to measure the quality of wireless connections. Typically, the energy of a signal fades with distance, which is referred to as a path loss in wireless networks. Conversely, in wired networks the existence of a wired path between the sender or transmitter and the receiver determines the correct reception of data. In a wireless network one has to take other factors into account (e.g., the background noise, interfering strength of other simultaneous transmission). The concept of SINR attempts to create a representation of this aspect. The definition of SINR is usually defined for a particular receiver (or user). In particular, for a receiver located at some point x in space (usually, on the plane), then its corresponding SINR given by:

Equation 2. SINR

$$\frac{P}{I+N}$$

where P is the power of the incoming signal of interest, I is the interference power of the other (interfering) signals in the network, and N is some noise term, which may be a constant or random. Like other ratios in electronic engineering and related fields, the SINR is often expressed in decibels or dB.

III. POINT-TO-POINT SIMULATION

III.1. The Scenario

As we already know, Terahertz frequencies has brought the communications and networking challenges to the extreme comparing it to the lower mmWave band. To address these limitations, we suggest a point-to-point scenario using MATLAB software, where a reference user is always placed in the area center, since on average does not affect the simulation. we consider just one user (then it can be iterated to whatever number of users).

The bandwidth of mmWave chosen is 400MHz with frequencies ranging from 25GHz to 50GHz, as for the THz link the bandwidth is 50GHz with frequencies ranging from 0.3THz to 1THz.

III.1.1. Link Budget and Directionality impact on the link layer

In order to analyze the link budget and directionality effects on the link layer especially on the MAC performance, we calculate SNR values for different distances (5m, 30m and 100m) for both mmwaves and Terahertz bands.

The SNR is obtained without the beamforming gain for the reason of analyzing the impact of the very high frequency used in mmWave and THz communications on the propagation loss, the figure below represents the simulation results with a Transmitter power of Ptx = 0.5 W, and a noise figure F = 10 dB:

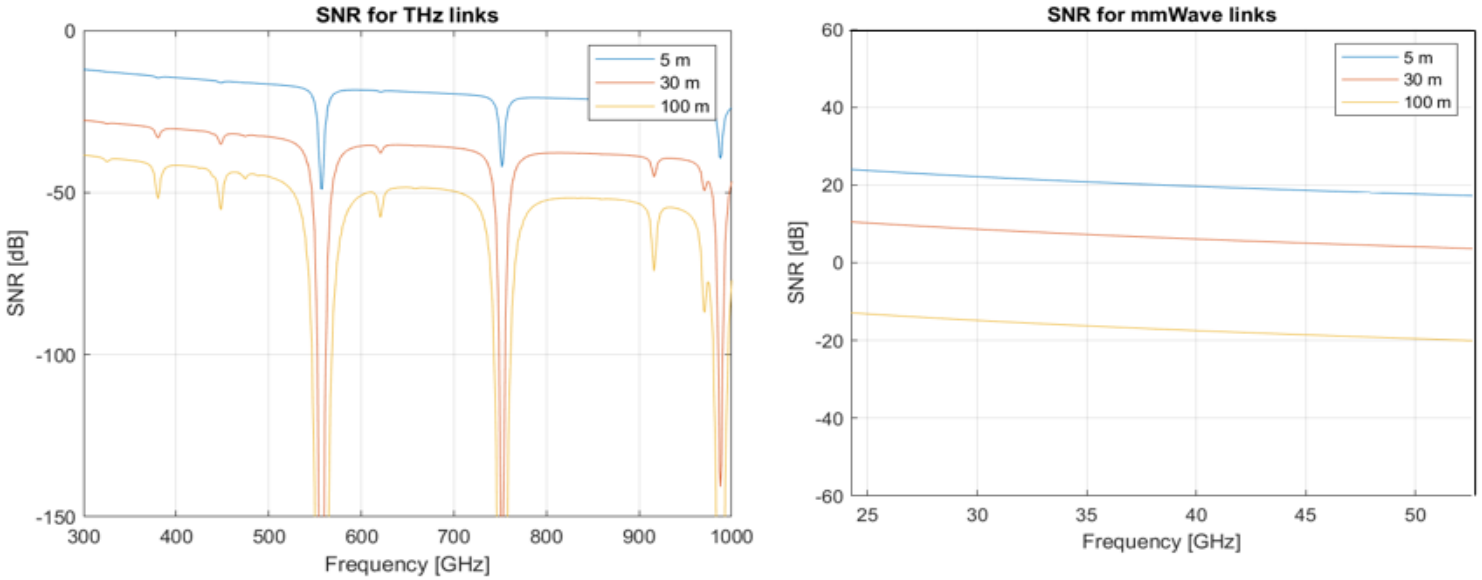

Figure IV-1 Link Budget for mmw and THz links

III.1.1.2. Simulation Output and Discussion

For a clear analyze, we compute the SNR values of different distances with a carrier frequency of 30GHz for mmWave links and 1THz for THz links, the table below sums up the obtained results:

Table IV-1 SNR Simulation results

Distance	SNR for mmw links with f=30GHz	SNR for THz Links with f=1THz
5m	22.6 dB	-24.2 dB
10m	8.5 dB	-48.2 dB
100m	-14.86 dB	-76.9 dB

We observe that the SNR gap in a carrier of 30GHz and 1THz at distance of 5 meters is equal to 46dB, this gap can be minimized by increasing the number of antenna elements which is possible for the THz frequencies due to the narrow beam that can be obtained thanks to the smaller wavelengths comparing it to the mmWave links, by doing so, the link budget will be enhanced. However, the deafness problem will increase at the same time, which leads to limitations in the awareness of mobile devices.

The figure below represents the SNR at different other distances in the THz links:

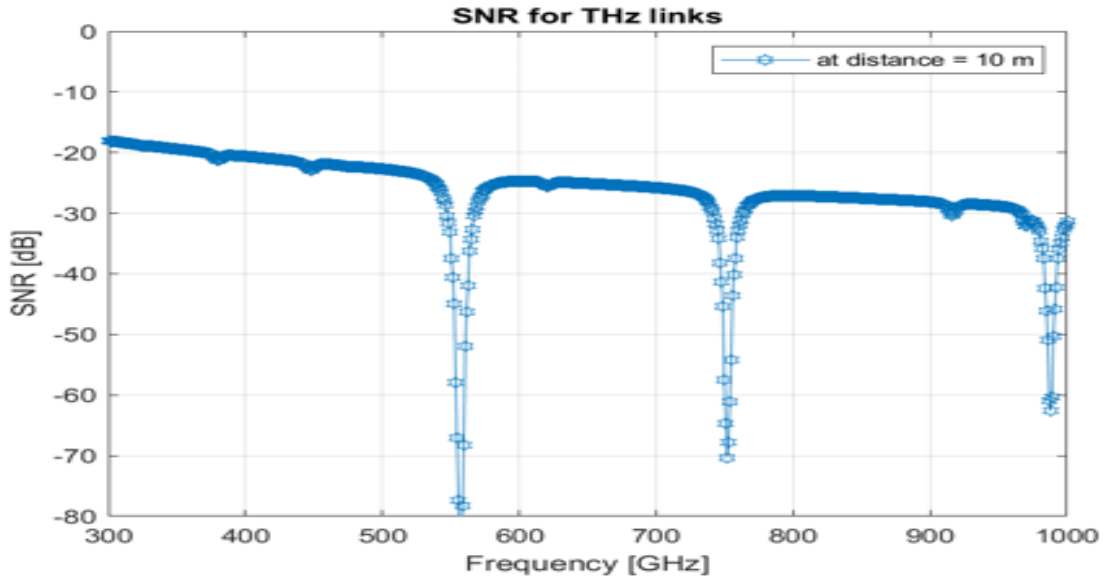

Figure IV-2 SNR values for 10 meters

- **Discussion:**

We notice that for a distance of 10 meters, the SNR reached a very low value of -80dB, these rates are expected from such high frequencies of THz links. However, it is quite difficult to be applied in real wireless networks.

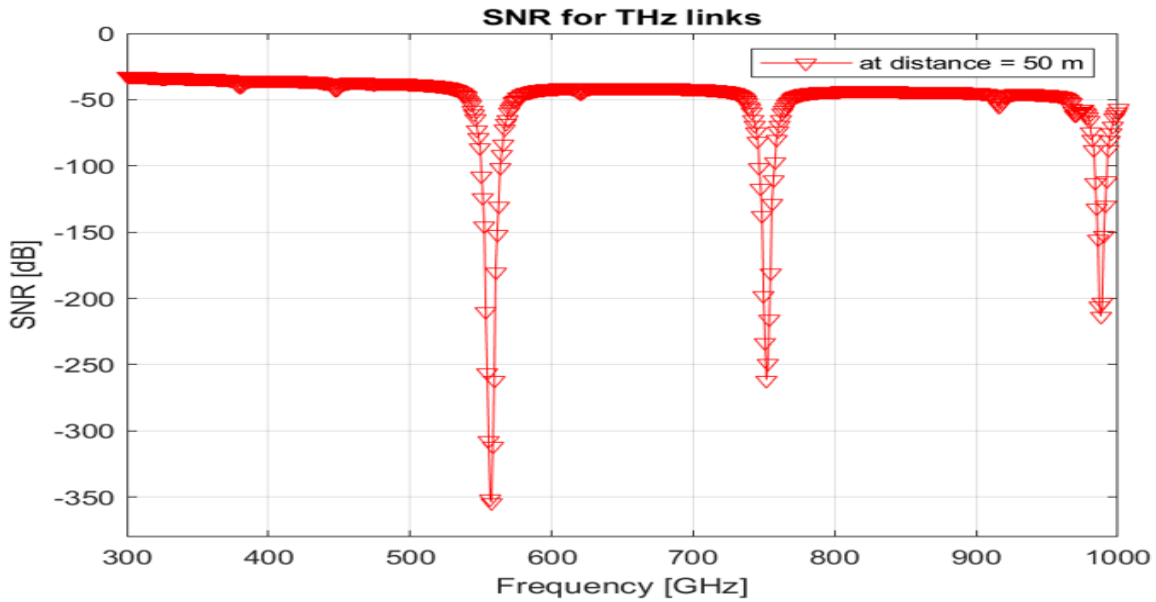

Figure IV-3 SNR values for 50 meters

- **Discussion:**

As we go further in distance the SNR keeps dropping to insufficient values reaching up to -350dB.

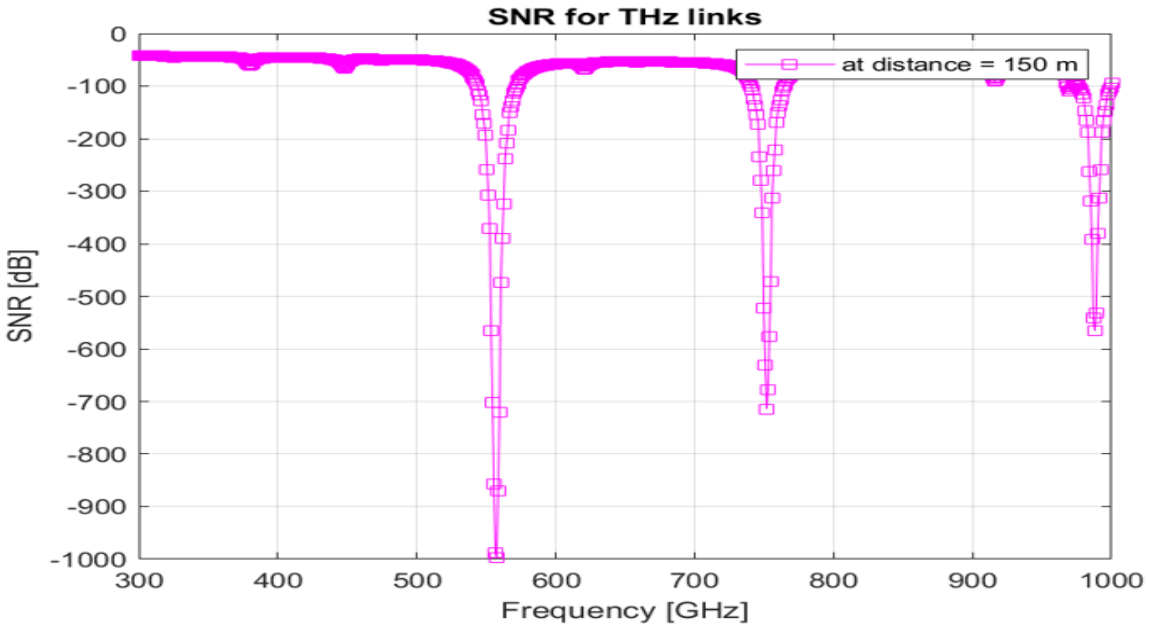

Figure IV-4 SNR values for 150 meters

- **Discussion:**

The third simulation proves that THz links are still suffering from high path losses for long distances causing the SNR to drop out and therefore more propagation loss models need to be developed.

III.1.2. Link Establishment Delay

As mentioned before, the narrow beams are achieved by using a highly directional antennas, the latter one will affect higher layers such as the mac layer, in order to know the impact of the directionality on the MAC layer, we present the parameters used for the next simulation in the table below:

Table IV-2 Important parameters related to the simulation

	MmWave links (3GPP NR)	THz links
• Number of directional synchronization signals (Nss) sent every T_{ss}	• 8 ,16, 32 or 62	
• Number of antenna arrays implemented	• 16 at the base station • 4 at the user equipment	• 1024 at the base station • 256 at the endpoints
• Gain obtained	• 18dB	• 54dB

The directional synchronizations sent will permit the mobile users to access the channel quality in order to search and determine the best beam pairs and with that the latency for the initial link establishment is calculated.

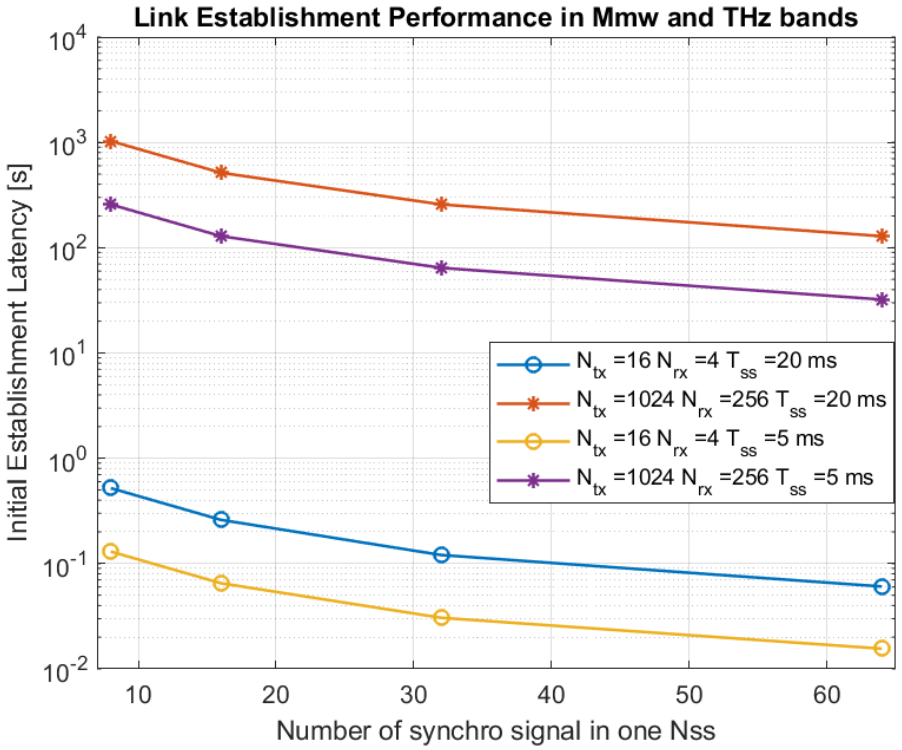

Figure IV-5 Initial latency according to synchro sent signals

III.1.2.2. Discussion

For mmWave links, the initial establishment delay is low due to the suitable link establishment model used for the 5G NR networks and therefore the search for the best beam pair for UE will be much quicker. However, when we used the same Latency Model for THz links, the establishment delay rises and hence, the research for best beam pairs with this setup is not possible and exhaustive. With that been said, more suitable link establishment models should be developed.

It is also important to reconsider the number of directional antennas used in THz links for a more realistic implementation.

IV. END-TO-END SIMULATION

III.1. Network simulator-3

Ns-3 is a discrete event network simulator, designed to replace the popular Network Simulator 2 (ns-2), mainly dedicated to improving the basic architecture, software integration,

model and learning components of the actual network devices and protocols. It simulates unicast and multicast protocols and is widely used in ad hoc research on cellular networks.

Figure IV-6 ns-3 logo

ns-3 aims to provide an open and extensible network modeling platform for network research and teaching. Therefore, ns-3 provides a model for the functions and functions of the packet data network, and provides users with a simulation engine for simulation experiments. One of the reasons for using ns-3 is to conduct research that is more difficult or impossible compared to actual systems, to study the behavior of the system in a highly controlled and reproducible environment, and to study how the network works. The model specified in NS-3 focuses on modeling how Internet protocols and networks work. However, NS-3 is not limited to Internet systems. Multiple users are using ns-3 to simulate non-web-based systems.

- ns-3 is actively maintained by a responsive user mailing list, while ns-2 is slightly supported and has not seen any major changes in the main code tree in the past ten years.
- ns-3 provides functions that are not available in ns-2, such as: B. Implementation code runtime (it allows users to run the actual implementation code in the simulator).
- ns-3 provides an additional level of basic abstraction, which is lower compared to ns-2, which allows you to better align it with the way the actual system is combined. Fixed bugs found in ns-2 in ns-3 (for example, correct support for multiple interface types on the node). Due to its long history, ns-2 has a more diverse set of additional modules than ns-3. -3 in several popular research areas, more detailed models (including complex LTE and WiFi models) and implementation code support a very wide range of high-fidelity models.
- ns-3 uses the DCE framework (direct code execution). Sometimes the ns-2 model can be ported to ns-3, especially when implemented in C++.

III.2. Development Environment

Under Linux, the ns-3 system uses various components of the GNU "tool chain" for development. A software toolkit is a collection of programming tools available in a specific environment. Gcc, GNU binutils and gdb are used. However, GNU is not for making system tools or auto tools. Instead, Waf is used for these functions. MacOS uses the Xcode.ns-3 toolbox. It is strongly recommended that Mac users install Xcode and the command line toolkit from the Apple App Store. For more information, see ns-3 Installation Wiki. Usually the user of ns-3 works in Linux or Unix-like environment. For Windows users, some environments mimic the Linux environment to varying degrees. The ns-3 project has historically (but not yet) supported Cygwin development for these users. Visit ns-3 wiki for more information about Cygwin and ns-3. MinGW is presently not officially supported. Another alternative to Cygwin is to install a virtual machine environment such as VMware server and install a Linux virtual machine.

III.3. Installation Process

ns-3 is built as a system of software libraries that work together. User programs can be written that links with (or imports from) these libraries. User programs are written in either the C++ or Python programming languages. ns-3 is distributed as source code, meaning that the target system needs to have a software development environment to build the libraries first, then build the user program. ns-3 could in principle be distributed as pre-built libraries for selected systems, and in the future, it may be distributed that way, but at present, many users actually do their work by editing ns-3 itself, so having the source code around to rebuild the libraries is useful.

DOWNLOADING NS-3

```
Cd

 Mkdir ns3

 Cd ns3

Wget http://www.nsnam.org/release/ns-allinone-3.28.tar.bz2

Tar xjf ns-allinone-3.28.tar.bz2

Cd ns-allinone-3.28/
```

BUILDING NS-3

```
./build.py --enable-examples --enable-tests.
Configuration with waf
./waf -d debug --enable-examples --enable-tests configure ./waf
```

TESTING THE INSTALLATION

```
./test.py
```

IV.4. TERASIM: Terahertz-band communication networks Simulator

In parallel to the development of b5G networks that will use the THz communications, simulation tools are highly requested to test the validations and the capabilities of this type of communications and networks. Under the light of this, the first simulation platform for THz bands is presented, TeraSim is an ns-3 extension developed for the purpose to testbeds the THz bands in different scenarios, using a common channel module that implements the frequency selective channel models.

IV.4.1. System review

TeraSim is built Taking into account the physics of the THz frequencies and the envisioned application scenarios, the propagation of signals in the ultra-large bandwidth provided by the THz-band is exposed to the spreading molecular absorption loss, we take this phenomenon as a main parameter to divide the THz-band communications into two main scenarios, the nanoscale scenario (with transmission distance below one meter) and the macroscale scenario (with transmissions over long distances). With that been said, the structure of TeraSim is as follows:

- One common channel module is implemented for both nanoscale and macroscale scenarios, (refer to [] for more details on the channel model).
- Two different PHY layer solutions are presented, pulse-based communication for the nanoscale and continuous-wave solution for the macroscale (we discussed these solutions in the third chapter).
- ALOHA and CSMA MAC protocols have been implemented at the link layer.
- Other modules are included such as the directional antenna module and the energy harvesting module for both of the scenarios.

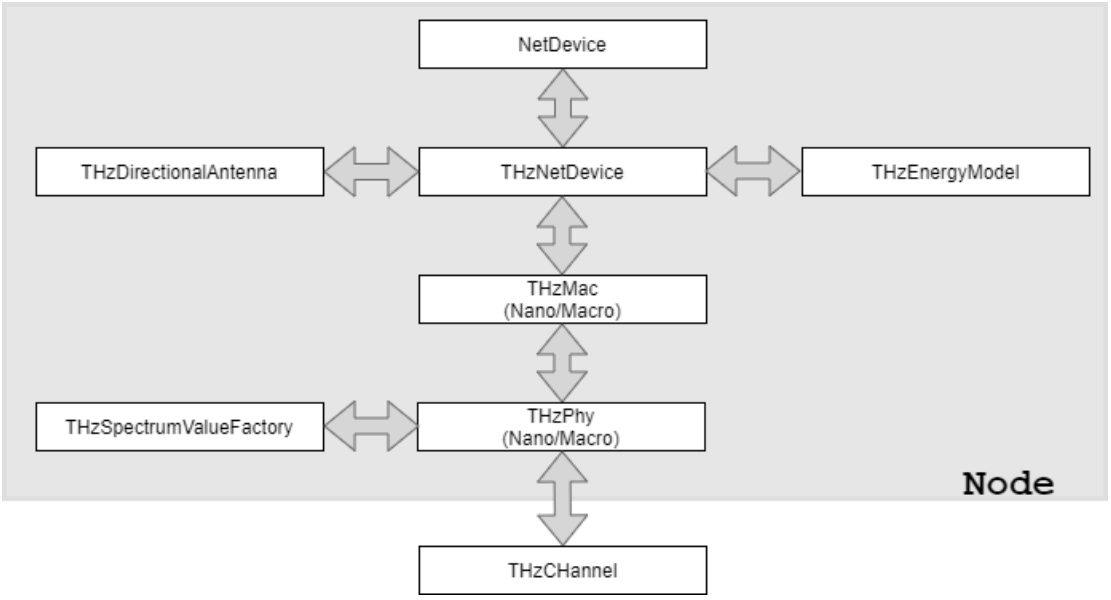

Figure IV-7 Different Objects used in TeraSim

- **Ns-3 Node Object:** each Node is provided with one of more of THzNetDevice objects.
- **THzNetDevice:** points to the THzMac and the THzPhy objects.
- **THzMac & THzPhy:** used to create new MAC and PHY layers solutions, THzPhy uses THzSpectrumValueFactory object to generate pulse for the nanoscale scenario, and carrier waveform for the macroscale scenario.
- **THzChannel:** a transmission link is formed through the THzChannel where a Node communicates with another Node.
- **THzSpectrumPropagationLoss:** used by the THzChannel to calculate spreading loss as well as absorption loss for different frequency bands.
- **THzEnergyModel:** provided for each Node to reproduce energy harvesting systems that is accurate to real-life behavior.
- **THzDirectionalAntenna:** controlled by THzNetDevice to be configurated as an omnidirectional antenna for the nanoscale scenario as an example.

IV.4.2 Packet route in a TeraSim system

After describing how each module is designed, an illustration for the packet flow is presented next, from the protocol stack prospective where all layers are provided, an na-3 TCP and IP protocols are used.

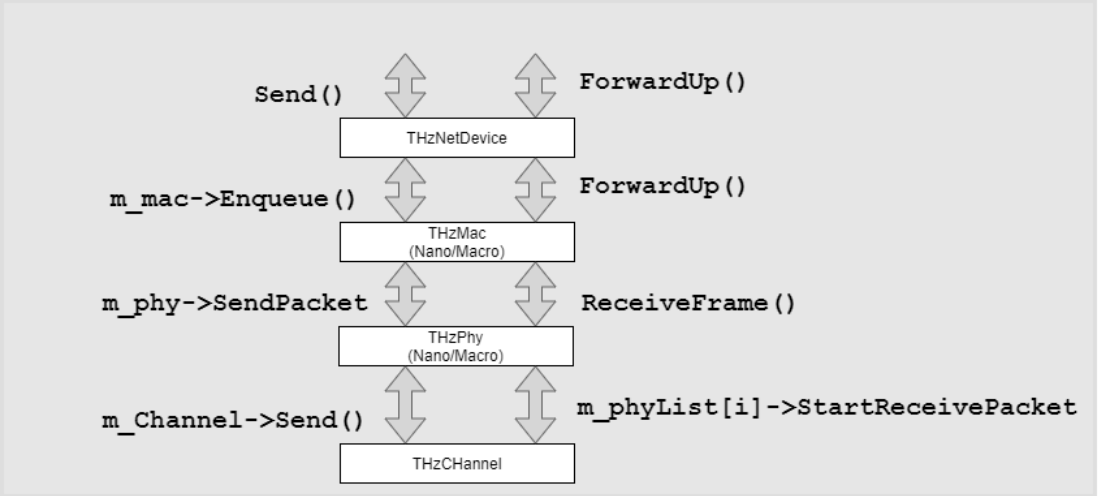

Figure IV-8 packet route in a TeraSim full stack

- The packet length and arrival time are both adjustable by the user at the configuration time.
- UDP protocol is used to deliver the packets to the transport layer and then the packet is sent to the network layer
- The packet then is passed to the THzNetDevice, the later one creates a data structure using Enqueue () method of the corresponding MAC protocol.
- The data structure of the packet information includes the packet, enqueue time and the destination, with this obtained information, the throughput of a packet is calculated based on the successful arriving of an acknowledgment (ACK).
- If the THzPhy have enough energy or whether the channel is available or no, the data is passed.
- The MAC layer then, behaves on two different ways depending on the resources mentioned above (energy and channel availabilities):

- **One-way handshake protocol**: MAC layer directly hands over the data packet to the PHY layer.
- **2-way handshake protocol:** The availability of the receiver is checked first by the MAC layer, using RTC/CTS, the availability of the receiver for the nanoscale is defined by the energy capacity to handle another packet receiving or no, as for the macroscale scenario, it is based on whether the receiver directional beam is facing the transmitter.

- After delivering the packet to the PHY layer, the later one adds its own data structure and then the packet is sent by the THzChannel.

V. END-TO-END SIMULATION

During the packet transmission at THz frequencies, we calculate the main KPIs parameters that affect such transmission, using the TeraSim platform that we built in the ns-3 simulator. These parameters are Throughput, SNIR that shows the performance of THz communications. And for this simulation, we have implemented the 2-way handshake MAC protocol.

V.1. Simulation Scenarios

The simulation is applied for macroscale scenario provided in TeraSim module as we modified in it to create a full scenario where the wireless nodes are equipped with directional arrays and with 64 Antenna Element (AE) and 16 AE, the following Table explains the main parameters for each scenario, and then figure after represents an illustration of what the scenario looks like:

Table IV-3 Simulation parameters for each scenario

First Scenario	Second Scenario
• Server nodes 2 • Client nodes 20 • Communication distances [10m,20m,40m] • Packet length 15000byte • Bandwidth 74,68GHz	• Server nodes 2 • Client nodes [20.60] • Communication distance 40 meters • Packet length 15000byte • Bandwidth 74,68GHz

Note: This Simulation parameters were carefully chosen for the reason of the extremely long time required to simulate for longer distances as well as taking in consideration the computer requirement to run such simulations (the computer freezes when trying to run simulations of 100 meters).

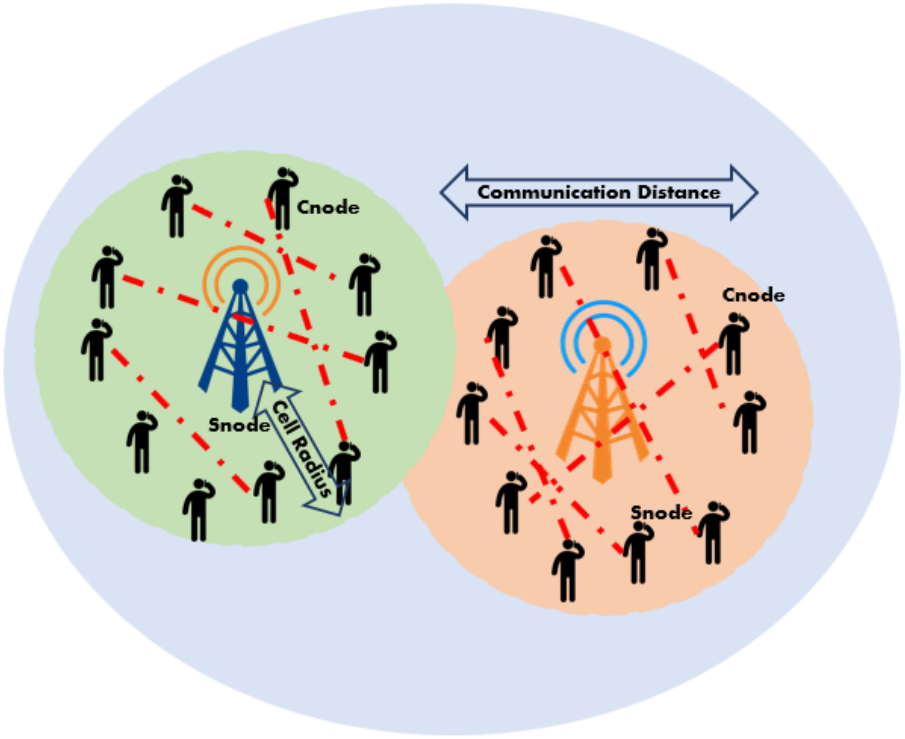

Figure IV-9 Illustration of the proposed scenarios

V.2. Scenario 1

we plot the throughput and SINR for successful packet transmission using the Mac handshake protocol, the throughput results are exported from Macro MAC Helpers, as for the SINR value, it is calculated and exported from the macro physical layer helper, the figures below are the simulation results for different distances.

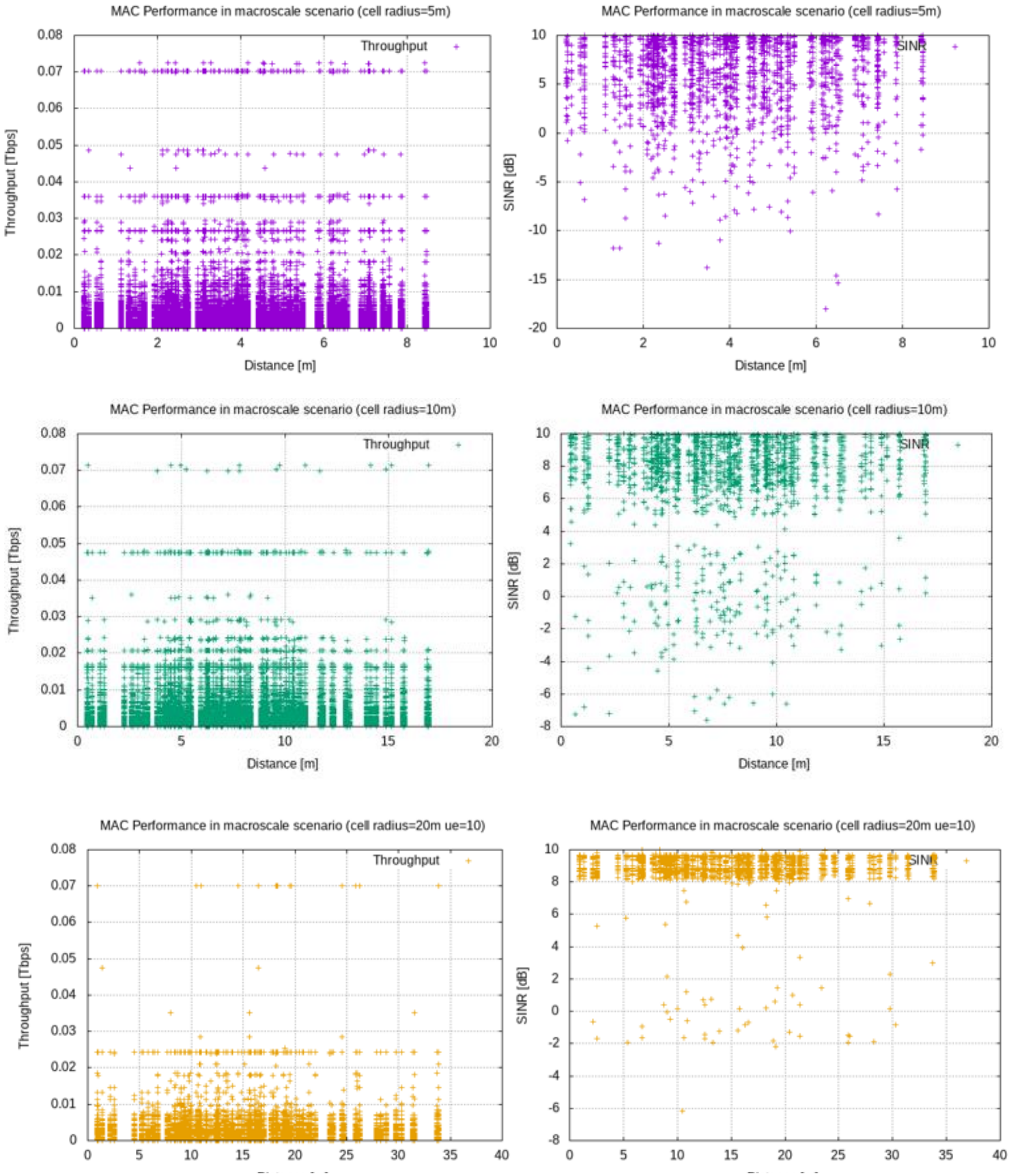

Figure IV-10 Throughput and SINR values for scenario 1

V.3. Simulation Output and discussion

We plotted the Throughput with respect to the number of communications occurred in different distances, the reason behind such simulation is to observe the behaviors of THz links for users' case by case, and to study the behavior of each node in the THz communications, by doing so. The experience is well-studied for real packet exchanges and therefore, the channel quality of THz physical layer is well analyzed.

First thing to observe is that the maximum throughput for this distance reached 0.08Tbps with only few communications reaching this level. The average throughput is 0.02Tbps, we also notice that the throughput decreases with the increasing of distance and number of communications where there are no values for higher distances such as 40 meters, meaning that there was a lot of discarded packets as we get further in distance due to the Transmitter not directly facing the Receiver.

As for the SINR Comparing it to the throughput of each distance, it decreases in the quality of transmission in some areas and therefore causing for a drop out of throughput levels.

IV.4. Scenario 2

We guarded the same previous distance, 20m and increased in the user equipment to 20 UE in each cell in order to see how much UE a cell can handle and how further will the transmission reach in crowded areas.

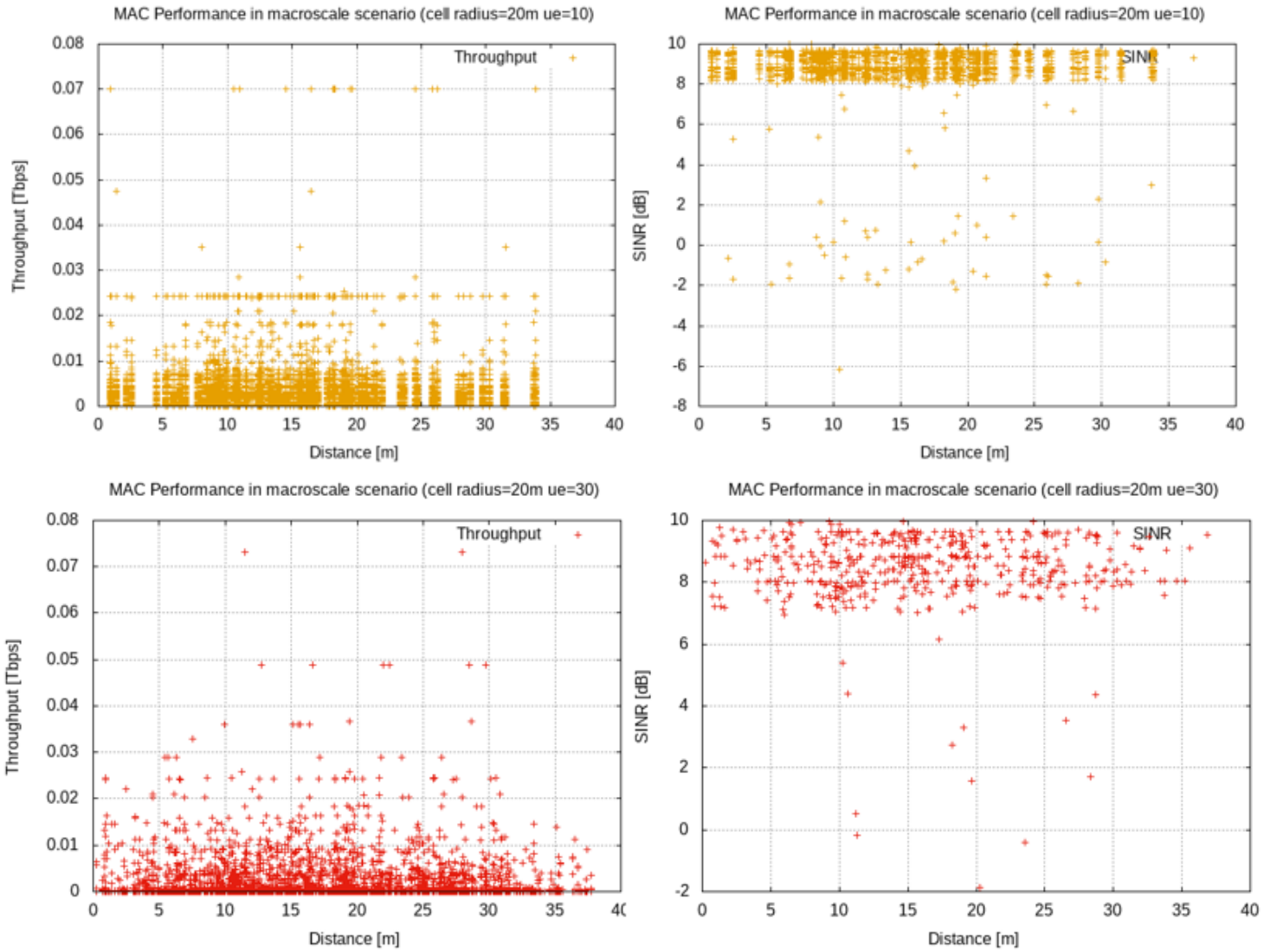

Figure IV- 10 Throughput and SINR values for scenario 2

III.5. Simulation Output and Discussion

We observe that the throughput has decreased comparing it with the scenario of 10 UEs. hence, the discarded packets have increased and we can say that this is due to the increasing number of client nodes, and that what the SINR graph shows. Another note to observe, is that server nodes battery life needed to be considered for real implementations of such scenario.

VI. CONCLUSION

THz frequencies is visioned as a key factor for b5G networks. However, in order to apply such high frequencies, a deep study is needed in order to capture the THz communications comportment for different scenarios.

Through this simulation, we are looking for an effective investigation concerning the phenomena's occurring during communications at THz frequencies, we managed to observe the SNR and Initial delay for a point-to-point scenario as we addressed the need for narrower beams and the deafness problem introduced for these high frequencies, then we moved to a full end-to-end scenario where we concluded that THz links performance is not optimal and needs to be developed, we have also noticed that the Throughput is not very stable during communication.

Finally, we can say that the terahertz physical layer design still presents many open research questions such as Which are the most effective strategies to deploy and enhance a high density, b5G network of Tbps of data rates?

GENERAL CONCLUSION

In this work, we went through the future wireless communication systems that are beyond 5G networks (b5G). Particularly, the technologies that are expected to be applied in it such as the multiple antenna techniques and the multiplexing technologies.

We have talked about the THz spectrum allocation as well as it standardization as we stated the challenges facing the deployment of THz bands in b5G networks hinting for the need to develop new Transceivers and Channels that can adopt to the THz frequencies. then, in order to have a full analyze of such bands and its behaviors in the network, we concluded that the THz issues needs to be overviewed from higher layers than the physical layer (link and transport layers) for the real integration of THz technologies in complex mobile networks.

With that been said and for our simulation, after comparing THz and mmWave bands in a Point-to-Point- scenario, we concluded that b5G requires a more developed propagation loss model. Next, we focused on simulating a full End-to-End scenario using TeraSim tool to plot important parameters such as throughput and SINR, the results showed the random behavior of THz frequencies according to the number of communications is random and unstable.

This presented work, can be used in future works to develop different solutions and algorithms in b5G high layer, where an open research question can be presented:

- How can the THz Channel design be improved in order to enhance and satisfy the requirements of b5G networks?

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