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Study of SNR variation for capacity analysis of orthogonal access networks.

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Content :

ملخص :

تُعد الشبكات اللاسلكية أمرًا بالغ الأهمية في عالم اليوم المترابط، حيث توفر اتصالاً مرنًا وسلسًا من خلال الاستغناء عن الحاجة إلى الكابلات المادية. لقد تطورت شبكات الهاتف المحمول من الجيل الأول إلى الجيل الخامس، مما أدى إلى تعزيز سرعات نقل البيانات وكفاءتها واتصالها العالمي بشكل كبير. تهدف تقنية الجيل الخامس G 5إلى دعم العديد من الأجهزة، وتحسين بنية الشبكة، ودمج التقنيات اللاسلكية الجديدة، مما يتيح التقدم في مختلف القطاعات مثل النقل والمدن الذكية والرعاية الصحية. على الرغم من فوائدها، لا تزال هناك تحديات في مجال الأمن وإدارة الموارد، مما يتطلب البحث والابتكار المستمر. وعموماً، ترمز الشبكات اللاسلكية إلى التقدم الرقمي للمجتمع، حيث تعمل على تغيير طريقة عملنا وتواصلنا وتفاعلنا.

تُعد الشبكات اللاسلكية محورية في العصر الرقمي، حيث توفر اتصالاً سلساً بدون كابلات مادية. وغالباً ما يتم الخلط بين عرض النطاق الترددي، وهو مقياس حاسم لجودة الشبكة، والسرعة، ولكنه يشير تحديداً إلى السعة القصوى لنقل البيانات. يمكن أن يؤثر التداخل، من الأجسام المادية إلى الأجهزة الكهربائية، على الأداء اللاسلكي، بينما تؤثر قوة الإشارة، التي تُقاس بالديسيبل، على جودة الاتصال. تعمل تقنيات مثل التشكيل وتعدد الإرسال على تعزيز كفاءة الشبكة، كما أن نسبة الإشارة إلى الضوضاء (SNR) أمر بالغ الأهمية للحفاظ على معدلات بيانات عالية ومعدلات خطأ منخفضة. تضمن جودة الخدمة (QoS) أداءً موثوقاً للتطبيقات الحساسة، مما يجعل شبكات الهاتف المحمول ضرورية للابتكارات المستقبلية مثل الجيل الخامس وإنترنت الأشياء والواقع المعزز.

تُعد تقنيات الوصول المتعامد وغير المتعامد محورية في الاتصالات السلكية واللاسلكية، حيث تحكم نقل البيانات بكفاءة واستخدام الطيف. وتتيح أساليب الوصول المتعدد المتعامد، مثل FDMA و TDMA و CDMA و SC-FDMA و OFDMA، الإرسال المتزامن دون تداخل، مما يضمن اتصالاً موثوقًا في الشبكات اللاسلكية. يخصص FDMA نطاقات تردد مميزة لكل مستخدم، بينما يخصص TDMA فترات زمنية محددة، ويستخدم CDMA رموزًا فريدة لكل قناة. تعالج تقنيتا SC-FDMA و OFDMA تحديات كفاءة الطاقة والكفاءة الطيفية، مما يجعلها حيوية لأنظمة الاتصالات اللاسلكية الحديثة. بشكل عام، تعمل هذه التقنيات على تحسين استخدام عرض النطاق الترددي وزيادة السعة وتقليل التداخل، وهو أمر بالغ الأهمية للاتصال السلس في المشهد الرقمي الحالي.

تستكشف المحاكاة لدينا تقييم أنظمة الوصول المتعدد المتعامد (OMA) من خلال محاكاة MATLAB، مع التركيز على تأثير معدل التشويش الضوئي على تحسين السعة في الاتصالات اللاسلكية. يتم تفصيل معلمات نموذج OMA، والمعادلات الرياضية التي تربط بين معدل التشويش الضوئي ومعدل الإرسال، وطرق تقييم سعة النظام. وتكشف عمليات المحاكاة عن كيفية تأثير معدل التشويش اللاسلكي على السعة القابلة للتحقيق، مما يوضح دوره الحاسم في جودة الإرسال وكفاءة النظام. بالإضافة إلى ذلك، تُظهر المسافات المتفاوتة بين المستخدمين وتكوينات الشبكة تأثير معدل التشويش على السعة عبر سيناريوهات مختلفة، مما يؤكد أهمية إدارة معدل التشويش لتحسين أداء أنظمة الاتصالات. بشكل عام، تؤدي زيادة عدد المستخدمين إلى تعزيز سعة النظام، ولكن العلاقة بين معدل التشويش الترددي العريض والسعة تختلف، مما يستلزم تصميم النظام وتعديل البارامترات بعناية.

Abstract :

Wireless networks are crucial in today's interconnected world, offering flexible and seamless communication by eliminating the need for physical cables. Mobile networks have evolved from 1G to 5G, significantly enhancing data transfer speeds, efficiency, and global connectivity. 5G technology aims to support numerous devices, optimize network architecture, and integrate new wireless technologies, enabling advancements in various sectors like transport, smart cities, and healthcare. Despite the benefits, challenges in security and resource management persist, requiring ongoing research and innovation. Overall, wireless networks symbolize the digital progression of society, transforming how we work, communicate, and interact.

Wireless networks are pivotal in the digital age, providing seamless connectivity without physical cables. Bandwidth, a critical measure of network quality, is often confused with speed, but it specifically refers to the maximum data transfer capacity. Interference, from physical objects to electrical devices, can affect wireless performance, while signal strength, measured in decibels, impacts connection quality. Techniques like modulation and multiplexing enhance network efficiency, and the signal-to-noise ratio (SNR) is crucial for maintaining high data rates and low error rates. Quality of Service (QoS) ensures reliable performance for sensitive applications, making mobile networks essential for future innovations like 5G, IoT, and augmented reality.

Orthogonal and non-orthogonal access techniques are pivotal in telecommunications, governing efficient data transmission and spectrum utilization. Orthogonal multiple access methods, like FDMA, TDMA, CDMA, SC-FDMA, and OFDMA, enable simultaneous transmission without interference, ensuring reliable communication in wireless networks. FDMA assigns distinct frequency bands to each user, while TDMA allocates specific time slots, and CDMA uses unique codes for each channel. SC-FDMA and OFDMA address power efficiency and spectral efficiency challenges, making them vital for modern wireless communication systems. Overall, these techniques optimize bandwidth usage, increase capacity, and reduce interference, crucial for seamless connectivity in today's digital landscape.

Our simulation explores orthogonal multiple access (OMA) systems' evaluation through MATLAB simulations, focusing on SNR's impact on capacity optimization in wireless communication. OMA model parameters, mathematical equations linking SNR and transmission rate, and system capacity assessment methods are detailed. Simulations reveal how SNR affects achievable capacity, demonstrating its critical role in transmission quality and system efficiency. Additionally, varying user distances and network configurations like power transmission and number of users showcase SNR's influence on capacity across different scenarios, emphasizing the importance of SNR management for optimizing communication systems' performance. the relationship between SNR and capacity varies, necessitating careful system design and parameter adjustment.

Résumé :

Les réseaux sans fil sont essentiels dans le monde interconnecté d'aujourd'hui, car ils offrent une communication souple et transparente en éliminant le besoin de câbles physiques. Les réseaux mobiles ont évolué de la 1G à la 5G, améliorant considérablement les vitesses de transfert de données, l'efficacité et la connectivité mondiale. La technologie 5G vise à prendre en charge de nombreux appareils, à optimiser l'architecture du réseau et à intégrer de nouvelles technologies sans fil, permettant ainsi des avancées dans divers secteurs tels que les transports, les villes intelligentes et les soins de santé. Malgré les avantages, des défis persistent en matière de sécurité et de gestion des ressources, ce qui nécessite une recherche et une innovation continues. Dans l'ensemble, les réseaux sans fil symbolisent la progression numérique de la société, transformant notre façon de travailler, de communiquer et d'interagir.

Les réseaux sans fil sont essentiels à l'ère numérique, car ils offrent une connectivité transparente sans câbles physiques. La bande passante, mesure essentielle de la qualité d'un réseau, est souvent confondue avec la vitesse, alors qu'elle se réfère spécifiquement à la capacité maximale de transfert de données. Les interférences, provenant d'objets physiques ou d'appareils électriques, peuvent affecter les performances des réseaux sans fil, tandis que l'intensité du signal, mesurée en décibels, influe sur la qualité de la connexion. Des techniques telles que la modulation et le multiplexage améliorent l'efficacité du réseau, et le rapport signal/bruit (SNR) est crucial pour maintenir des débits de données élevés et des taux d'erreur faibles. La qualité de service (QoS) garantit des performances fiables pour les applications sensibles, ce qui rend les réseaux mobiles essentiels pour les innovations futures telles que la 5G, l'IoT et la réalité augmentée.

Abstract

Les techniques d'accès orthogonales et non orthogonales sont essentielles dans les télécommunications, car elles régissent la transmission efficace des données et l'utilisation du spectre. Les méthodes d'accès multiple orthogonal, telles que FDMA, TDMA, CDMA, SC-FDMA et OFDMA, permettent une transmission simultanée sans interférence, garantissant une communication fiable dans les réseaux sans fil. La FDMA attribue des bandes de fréquences distinctes à chaque utilisateur, tandis que la TDMA alloue des intervalles de temps spécifiques et que la CDMA utilise des codes uniques pour chaque canal. Les techniques SC-FDMA et OFDMA relèvent les défis de l'efficacité énergétique et de l'efficacité spectrale, ce qui les rend essentielles pour les systèmes modernes de communication sans fil. Globalement, ces techniques optimisent l'utilisation de la bande passante, augmentent la capacité et réduisent les interférences, ce qui est crucial pour une connectivité transparente dans le paysage numérique d'aujourd'hui.

Notre simulation explore l'évaluation des systèmes d'accès multiple orthogonal (OMA) par le biais de simulations MATLAB, en se concentrant sur l'impact du SNR sur l'optimisation de la capacité dans la communication sans fil. Les paramètres du modèle OMA, les équations mathématiques reliant le SNR et le taux de transmission, ainsi que les méthodes d'évaluation de la capacité du système sont détaillés. Les simulations révèlent comment le SNR affecte la capacité réalisable, démontrant son rôle critique dans la qualité de la transmission et l'efficacité du système. En outre, la variation des distances entre les utilisateurs et des configurations de réseau met en évidence l'influence du SNR sur la capacité dans différents scénarios, soulignant l'importance de la gestion du SNR pour l'optimisation des performances des systèmes de communication. Globalement, l'augmentation du nombre d'utilisateurs accroît la capacité du système, mais la relation entre le SNR et la capacité varie, ce qui nécessite une conception prudente du système et un ajustement des paramètres.

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Abstract :

- It is essential to analyze SNR (Signal-to-Noise Ratio) variation in order to assess the capacity of orthogonal access networks. Modulation and multiplexing techniques are employed in orthogonal access networks, such as Wi-Fi and cellular networks, to enable multiple users to share the same wireless communication channel. The signal-to-noise ratio (SNR) evaluates the quality of the signal in relation to the ambient noise, thus enabling us to assess the reliability of data transmission.

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In the name of Allah, the Merciful Benefactor! May Allah pray over Our Lord Mohamed, his family and his companions.

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Dedication :

To Mom and Dad : Ahmed and Arkia

In life, my life, you are the threads woven with love, strength and wisdom.
Every step I take, every success I celebrate and every challenge I face are a testament to the values you have instilled in me.
Your unfailing support and unconditional love have guided me through the darkest and the brightest of times.
Through you, I came into this world, you guided my first steps, you were my first history book, you are my school of life.
What can I say to you, who are the reason for my life? To say thank you would be too little for your rank, blood of my blood, flesh of my flesh...

I invoke Allah to give me strength and courage to live up to your expectations...

To My Dear Brother and Sisters: Adelbasset , Ikram and Salsabil

Along the path of life, you have been my steadfast companions, my confidants and my best friends. The bond between us is a tapestry of laughter, shared memories and unwavering support, woven with threads of love and understanding.
Thank you for being my partners on this journey, for lifting me up when I fall, and for always believing in me.
You are my heroes, my confidants and my greatest gifts. The bond we share is a testament to the power of family, and I am forever grateful to each and every one of you.

With all my love and gratitude

To My Dearest Friends : the groupe

In my life, you are the vibrant threads that add color, joy and richness to my days. Your friendship is a treasure, a source of endless laughter, unwavering support and boundless love.
Thank you for being the incredible people you are. Your friendship is a precious gift, and I am endlessly grateful for each and every one of you. You have enriched my life immeasurably, and I am honored to count you among my friends.

With all my gratitude

Dedication :

I dedicate this memoir to my dearest parents, my father Hadj NABIL and my mother NADIA, to my brother ALI, my sister LINA, my grandparents CHERIF and MEZIANE, my uncles and my tent, the whole CHERIF, MEZIANE, MAJIDI and BOURAYOU family .

Delighted to be the first to reach this level and to always evolve, to always honor the CHERIF name.

CMC

General introduction :

The importance of the Signal-to-Noise Ratio (SNR) in wireless communications is paramount, as it influences network performance and capacity. However, for orthogonal access networks, capacity analysis is often seen as simply a function of simplified SNR calculations. In reality, changes in SNR have a significant effect on network capacity, leading to changes in data transmission efficiency and effectiveness. Our in-depth communications research has taught us that capacity analysis is a versatile discipline, requiring in-depth analysis of a variety of parameters, including SNR fluctuations.

Orthogonal access, such as OFDMA, orthogonal frequency division multiple access (TDMA) and code division multiple access (CDMA), aims to reduce interference by allocating users different resources in terms of frequency, time or code. Understanding the correlation between SNR and network capacity is crucial, as fluctuations in SNR have a direct impact on the data rates that can be achieved. Maintaining high capacity in environments where signal quality varies is crucial to network reliability and user satisfaction.

The complex dynamics of SNR variation and its impact on the capacity of orthogonal access networks are the subjects of our study. Our aim is to clarify the impact of SNR variations on network performance, examining both theoretical foundations and practical consequences. This study is divided into two main sections. The first section focuses on theory and comprises three chapters:

CONCEPT AND CHARACTERISTICS OF WIRELESS NETWORKS.

CARACTERISTICS OF WIRLESS NETWORKS.

CONCEPT AND CHARACTERISTICS OF ORTHOGONAL ACCESS TECHNIQUES

The second part is practical, encompassing one chapter :

Results and Discussion.

In conclusion , the study of SNR evolution and its influence on the capacity of orthogonal access networks highlights a complex and subtle relationship that is of paramount importance for improving network performance. When assessing the capacity and efficiency of communication systems, our study highlights the importance of taking SNR variations into account.

Chapter I:
Concept of wireless networks :

I.1/ Introduction:

Wireless networks are now essential in our modern, interconnected world, revolutionizing the way we communicate, work and access information. They eliminate the need for physical cables and offer the flexibility to connect devices seamlessly over the airwaves.

The ability of wireless networks to deliver reliable, efficient communications is a key determinant of their effectiveness. Understanding and optimizing the performance of wireless networks is essential given the growing demand for seamless connectivity.

I.2/ mobile networks:

A mobile network is a telecommunications network that uses radio signals to provide services to cell phones. It is generally defined as a physical device that can be taken anywhere you want.

There are several steps that can be used by cell phones to use the services provided by a mobile network, but these steps will be described in more detail below:

Mobile subscriber units initiate calls and send them to a public switched telephone network (PSTN).

Terrestrial cables are used to transfer call signals from the PSTN to the mobile telephone switching center. These cables used to be made of copper. More often, they are made of fiber optics.

The MTSO monitors subscriber calls, locates them and sends the signal to a cell site via a terrestrial cable.

Cell sites use radio signals to transmit call signals to mobile subscribers.

The call is received by the subscribers' mobile units, such as cell phones.

Any properly configured cell phone can connect to receivers anywhere in the world via this process. Today's mobile networks include local area networks (LANs), wide area networks (WANs) and 3G, 4G and 5G networks. [1]

I.2.1/ How mobile data works :

Devices can communicate via radio frequencies thanks to a wireless connection created by mobile data. A central cellular base station or macrocell, often located on a cell tower, broadcasts data uploaded or downloaded via a mobile network.A single macrocell can cover a large area, and multiple cells can overlap to efficiently transmit data and provide coverage over thousands of kilometers.Mobile service providers have delivered mobile data using a variety of technologies combined in a series of mobile networks called "generation".[1]

I.2.2/ the evolution of mobile networks :

Mobile networks are wireless networks that enable two or more terminals to communicate with each other without the use of a radio.

Wired cable. Mobility is the term used to describe how a user (subscriber) can remain connected to the network while moving within a more or less extended geographical perimeter thanks to this type of network. These networks use the radio interface as a transmission medium, and are based on a link using radio waves. [1]

I.2.2.1/ First-generation mobile networks (1G)

This was used in the 1970s. Voice calls were the sole objective of the first cellular mobile network systems (1G). It was based on an analog mobile communications system.

Two major technological advances in the 1970s benefited this generation: the microprocessor and digital data transmission between cell phones and base stations. The boxes used were particularly large. [1]

I.2.2.2/ Second-generation mobile networks (2G)

The second generation (also known as 2G) broke with 1G by switching from analog to digital. The standard enables the simultaneous transmission of data and speech. Thanks to FDMA and TDMA frequency division mechanisms, it enables users to share the same transmission channel.

The most common 2G standards are GSM, based on CDMA coding, and GSM, based on TDMA coding.

The GPRS (General Packet Radio Service: 2.5G) and EDGE (Enhanced Data for GSM Evolution: 2.75G) networks were created to correct the low data rates of GSM (around 9.6 kbps) by using this standard. GPRS offers an approximate data rate of 114 kbps, enabling data and voice to be transmitted simultaneously. EDGE enables the use of multimedia applications at data rates of up to 384 kbps. [1]

I.2.2.2.1/ GSM network (2G)

The second-generation (2G) cell phone system is known as GSM. First-generation (1G) cell phone systems were analog systems such as the Nordic Mobile Phone System (NMT) and the Advanced Mobile Phone System (AMPS). GSM is a digital standard that uses GMSK digital modulation and time-division multiplexing (TDMA) as its multiple access technology. [1]

I.2.2.2.2/ GPRS network (2.5G)

The GPRS standard is an evolution of the GSM standard. GPRS is generally referred to as 2.5G, because it is a second-generation telephony standard that enables the transition to third-generation 3G.

The architecture of the GSM standard can be extended with GPRS, enabling packet data transfer at high theoretical data rates. Packet transfer mode allows data transmissions to use the network only when necessary. The GPRS standard allows users to be billed by volume exchanged, rather than by connection time, enabling them to stay connected at no extra cost. [1]

I.2.2.2.3/ EDGE network (2.75G)

The EDGE standard, also known as the GPRS standard, is an evolution of the GSM standard that modifies the modulation type to allow the use of 8-PSK modulation, which implies modifications to base stations and mobile terminals. It is regarded as the transition to third-generation mobile telephony (3G), also known as 2.75G.

Data throughput with reduced coverage can be tripled thanks to EDGE. In EDGE theory, fixed stations (pedestrians and slow-moving vehicles) can achieve data rates of up to 384 kbit/s, and mobile stations (fast-moving vehicles) up to 144 kbit/s. [1]

I.2.2.3/ Third-generation 3G mobile networks

Two families of commercially successful technologies are part of the third generation of mobile networks (3G): UMTS (Universal Mobile Telecommunications System), which was created from GSM and is widely used around the world, and CDMA2000, which was created from IS-95 and is mainly used in Asia and North America. Both families have radio interfaces that share similar technical features, such as a Code Division Multiple Access (CDMA) system. [1]

3G is characterized by the telecommunications industry's determination to define a global standard. Providing global roaming for users and reducing the unit costs of mobile terminals and network equipment through economies of scale were the challenges. Within the 3GPP consortium, these companies, particularly those from the GSM world, came together. The UMTS standard was created at the end of the 1990s thanks to this approach. Release 99 is the name of the first edition of the standard. The access network, which interfaced with the GPRS core network, was the main innovation of the UMTS system. The aim of UMTS was to increase the system's capacity to provide voice services, but mainly to improve support for data services. [1]

I.2.2.3.1/ HSDPA technology (3.5G)

Third-generation technology (UMTS) costs a lot to achieve GPRS-like speeds, and is rapidly being replaced by the next generation (3.5G), known as HSDPA. Downlink speeds of this new technology exceed 10 Mbps. HSDPA can be installed and deployed without significantly modifying the UMTS architecture. As a result, operators can carry out this modification at no great cost. [1]

I.2.2.3.2/ HSUPA technology (3.75G)

3.75G is an HSDPA variant under development. HSUPA can be regarded as the successor to HSDPA, thanks to its 5.8 Mbps uplink and 14 Mbps downlink, just like HSDPA. The advantage of this technology lies in the ability to send electronic documents such as images and videos to other mobile devices, thus contributing to the development of mobile broadband Internet. [1]

I.2.2.4/ Fourth-generation 4G mobile networks

The definition of 4G has changed in a new wave of mobile data marketing efforts to differentiate brands. The International Telecommunications Union (ITU), which oversees the development of most cellular data standards, recently issued a statement pointing out that the term 4G is undefined. In response, mobile operators using advanced 3G architectures have begun to offer 4G services. [1]

I.2.2.4.1/ 4G technologies LTE (Long Term Evolution) 3.9G network

LTE . This refers to a project led by the 3GPP standardization body, which aims to develop methods for upgrading the UMTS standard for 3G cellular networks to the fourth generation, in order to meet future technological evolutions. LTE aims to improve spectral efficiency, enabling very high-speed data transfer of around 50 Mbps, with greater range, more calls per cell than UMTS, and lower latency. To enhance services, the fourth generation includes multi-technology platforms capable of supporting innovative new applications. As with previous versions, 4G uses an access network called E-UTRAN and a core-vehicle network that only broadcasts data packets. It is designed for this purpose with all-IP.

4G technology, also known as LTE (Long Term Evolution), is based on an IP packet-switched transport network. Unlike 3G, which transports voice in circuit mode, it has no routing mode for voice other than VoIP.

LTE uses radio bands from 1.4 MHz to 20 MHz, enabling a theoretical downlink bit rate of 300 Mbit/s for a 20 MHz band. True 4G, on the other hand, offers downlink speeds of up to 1 Gbit/s.

OFDMA (Orthogonal Frequency Division Multiple Access) is a modulation technique that maximizes frequency utilization while minimizing interference. Multiple antenna techniques (already used for Wi-Fi or WiMax) enable the multiplication of parallel communication channels, increasing total throughput and range. [1]

I.3/ 5G :

Although the current 4G network based on the LTE (Long Term Evolution) standard has brought many solutions, such as increased throughput and bandwidth compared with older generations of mobile networks. 4G, which uses IP technology, enables comfortable internet browsing with smartphones, tablets or laptops. However, this network, whose frequency spectrum is fairly overloaded, will no longer be able to meet the diverse demands of the boom in connected objects with their different categories of use. The new 5G standard for mobile telecoms systems opens up new prospects for addressing these problems and those of the future.

One of the latest wireless technologies is fifth-generation (5G) mobile wireless telephony. 5G, also known as mobile networks or fifth-generation wireless systems, is a set of technologies that represent the next major step in mobile telecoms standards after the evolution of the current 4G LTE standards. The International Telecommunications Union (ITU) and the 3GPP (3rd Generation Partner hip Project) consortium have approved the 5G network. 5G has no specific definition. However, 5G is the fifth generation of cellular networks in its simplest definition. It is the next stage of mobile technology, which will be used by future phones and tablets for data. [1]

I.3.1/ 5G objectives :

Leading wireless manufacturers and operators are currently working on standards and objectives for the fifth generation of mobile networks (5G). The standardization phase has begun within various consortia of operators and manufacturers (3GPP, NGMN...). To ensure high-speed internet access from a smartphone or tablet, the upstream and downstream throughput allocated to each user is the first objective to be achieved. The targeted cell-edge throughput per user is over 100 Mbit/s in a context of little or no mobility, and the maximum throughput per user should exceed 10 Gbit/s. Improving network architecture in highly mobile contexts (e.g. vehicle-to-vehicle communications). In particular, improved network architecture should help reduce communication latency. The aim is to reduce transmission delay to 10 ms. A high level of reliability will also be required for other Internet of Things applications (telemedicine, security, etc.). To achieve these goals, current

2G/3G/4G networks will have to undergo major changes in network architecture and integrate new wireless technologies. To find an economically viable solution, the costs and energy consumption of the new network components and associated mobile terminals will be crucial.

5G aims to deliver very high data throughput for a large number of users, support multiple communications simultaneously to deploy a large number of sensors, and improve network spectral efficiency for a large number of sensors. [1]

The evolution of mobile networks

	1G	2G	3G	4G	5G
APPROXIMATE DEPLOYMENT DATE	1980s	1990s	2000s	2010s	2020s
THEORETICAL DOWNLOAD SPEED	2 Kbps	384 Kbps	56 Mbps	1 Gbps	10 Gbps
LATENCY	N/A	629 ms	212 ms	60-98 ms	< 1 ms

SOURCE: SETTING THE SCENE FOR 5G/KEMAL HUSENOVIC, ©2019 ITU, 2018 PAGE 6

Figure I.1: the evolution of mobile networks [1]

I.4/ performance of 5th generation mobile networks :

Wireless connectivity for a wide range of new applications shown in the Figure will be provided by 5G. Every aspect of our future society will be touched by 5G, creating a multidimensional, user-centric information ecosystem. It will break the boundaries of time and space to enable an immersive, interactive user experience. 5G will also reduce the distance between humans and things by implementing seamless integration to enable simple, intelligent interconnection between people and all things. 5G enables us to realize the vision that "information is at our fingertips and everything will be in touch".

Various organizations have proposed a large number of use cases. The two main market drivers for future mobile communications development are the mobile Internet and the Internet of Things (IoT), which will trigger a wide range of use cases. [1]

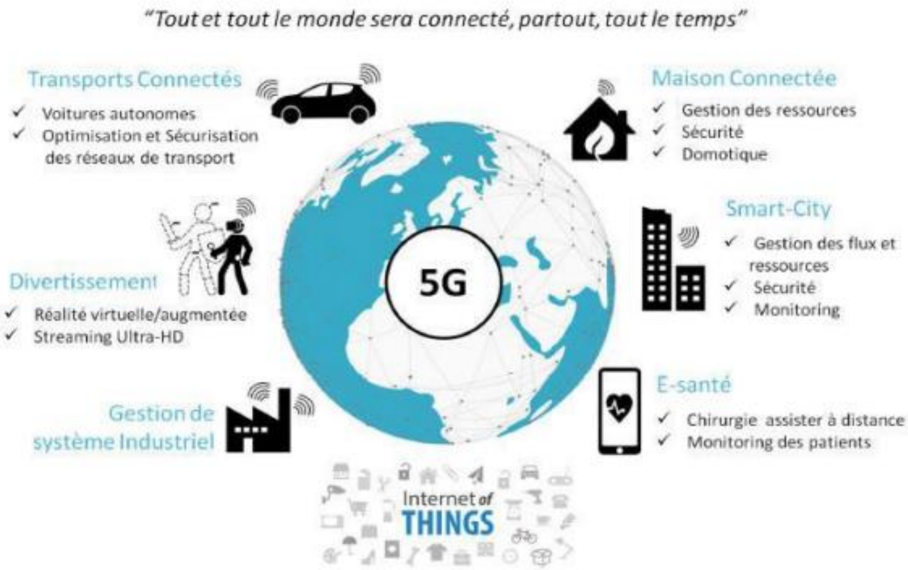


Figure I.2: Using 5g [1]

I.4.1/ Connected transport :

As autonomous vehicles become more widespread, it is crucial for them to remain connected at all times, as connectivity is essential to the modern world. Mobile networks are crucial to enabling seamless communication between autonomous vehicles and the ecosystem in which they operate, due to their unrivalled breadth and reliability. Mobile networks and autonomous vehicles work together, creating numerous opportunities.

Autonomous vehicles and mobile networks have accelerated the growth of advanced communication standards. In this context, 5G, the latest mobile network technology, has changed the game. 5G enables autonomous vehicles to communicate and share vital information with other vehicles, pedestrians and infrastructure in real time thanks to ultra-high-speed data transfer, low latency and massive device connectivity.

Mobile networks play an important role in improving the safety of autonomous vehicles. Vehicles and their environment can share important data such as road conditions, traffic updates and potential hazards in real time through constant communication. This reduces the risk of accidents, as it enables autonomous vehicles to adapt and make informed decisions. [2]

I.4.1.1/ Optimization and efficiency :

An essential element of contemporary urban planning is optimizing the efficiency of transportation systems. The combination of mobile networks and autonomous vehicles offers numerous possibilities for optimization. [2]

I.4.1.2/ Traffic management and congestion reduction :

The potential to revolutionize traffic management and reduce congestion is one of the most important advantages of autonomous vehicles connected to mobile networks. Intelligent algorithms can analyze patterns and optimize traffic flow by suggesting alternative routes, adjusting signal timing and coordinating vehicle speeds using real-time data from various vehicles and infrastructures. This could make traffic flow more smoothly, reduce journey times and cut carbon emissions. [2]

Figure I.3: automobile [2]

I.4.1.3/ smart city :

This is a smart city based primarily on the use of mobile networks and New Information and Communication Technologies (NICT).

The smart city makes effective use of real-time user and infrastructure data to optimize resources and achieve the highest possible quality of life. All areas of daily life, including food, work, leisure and travel, can be endowed with an extra level of intelligence, enabling city dwellers to acquire qualitative and useful information about their actions, those of other users and the city in general. In short, an interconnected world for people and the environment.

Like the "smart city", other terms are often used: sustainable city, digital city or resilient city. [2]

I.4.1.4/ importance of the smart city :

By 2050, 66% of the world's population will live in cities, adding a further 2.5 billion people to the urban population over the next three decades. Managing the environmental, social and economic sustainability of resources is necessary with this expected population growth.

Smart cities enable citizens and local authorities to collaborate on initiatives and use smart technologies to manage assets and resources in a rapidly expanding urban environment. [2]

Figure I.4: The smart city [2]

I.4.1.5/ Connected homes :

Smart home appliances focus primarily on improving home efficiency and security, as well as enhancing home connectivity. Gadgets such as smart plugs monitor electricity use, and smart thermostats offer better temperature regulation. Hydroponics systems can use IoT sensors to manage the garden, while IoT smoke detectors can detect tobacco smoke. Home security systems such as door locks, security cameras and water leak detectors can detect and prevent threats and send alerts to homeowners.

Connected home devices can be used to :

Automatically shut down unused appliances.

Manage and maintain rental properties.

Finding things that have been misplaced, like keys or wallets.

Automate daily tasks such as cleaning, making coffee, etc. [2]

I.4.1.6/ How mobile networks can enhance augmented reality :

None of the new immersive video applications that have emerged thanks to advances in mobile connectivity have the capacity to transform augmented reality and virtual reality (AR and VR). Despite the fact that these technologies have been around for some time, fifth-generation (5G) mobile connectivity is about to finally unleash their full power to revolutionize everything from education and training to telemedicine, industrial design and entertainment. [2]

I.4.1.6.1/ Healthcare :

With 5G, the healthcare sector has many options for using augmented reality and virtual reality. Instructors can use VR in a training scenario to demonstrate a new procedure or technique to medical students, doctors and nurses remotely, wherever they are, saving travel costs. Instructors can use augmented reality to indicate steps and points of interest in live procedures. They can also use VR to bring remote patients into an operating or examination room, enabling them to observe and ask questions.

From the patient's point of view, AR and VR on 5G enable healthcare professionals to carry out examinations remotely, highlight areas of concern for patients and even accompany patients through procedures before their appointment. [2]

I.4.1.6.2/ Training and education :

AR and VR over 5G offer the possibility of high-quality teaching and training for remote participants, anywhere in the world. Today, teaching scenarios that require in-person instruction, such as laboratory experiments, could be carried out using VR and AR, making education more accessible and less expensive.

By eliminating the need to bring field workers to in-person training courses or send trainers to deliver in-person training in the field, the cost of training field staff in new products and techniques can be reduced. Industries operating in remote locations, such as mines, drill sites and other areas without access to high-speed wired network services, are particularly interested in using AR and VR over 5G for training. [2]

I.4.1.7/ Conclusion :

Wireless networks are more than just a means of communication. They symbolize our society's ongoing progression towards a merged digital age. Their ability to offer flexible, ubiquitous connectivity has profoundly transformed the way we work, communicate and interact with our environment. However, these benefits also bring challenges, not least in terms of security and resource management. To maximize the potential of wireless networks while minimizing their dangers, a balanced, proactive approach is essential. By continuing to research, innovate and adapt our methods, we can reap the benefits of wireless networks while ensuring that they remain a positive force for society.

Chapter II :
Caracteristics of wirless networks

II.1/ introduction :

Today, in the contemporary digital age, wireless networks play a crucial role in our daily connectivity. From home Wi-Fi to cellular networks to new technologies such as 5G, these networks offer limitless connectivity, providing devices with the ability to communicate and share data without the need for expensive cables. This in-depth analysis examines the essential elements that characterize these wireless networks, looking at their scope, speed, security and reliability. By grasping these essential elements, we can gain a better understanding of the influence and consequences of these ubiquitous technologies on our daily lives and the world around us.

II.2/ Bandwidth:

Since bandwidth and speed are two measures of network quality, they are often confused. However, they differ slightly. Network bandwidth is the maximum amount of data that can be transferred over an Internet connection in a given time, while network speed refers to the rate at which data is transferred from source to destination. Bandwidth is calculated in megabits per second (or Mbps) in this case. [3]

II.2.1/ Bandwidth measurement method :

Bandwidth is usually expressed in bits per second (bps), but modern network links have much greater capacity, which is why bandwidth is more often expressed in Mbps or Gbps.

Bandwidth connections can be asymmetrical, meaning that upload and download capacities are not equal, or symmetrical, meaning that data capacity is the same in both directions (upload and download). Upload capacity is generally lower in asymmetrical connections, which is common in consumer broadband Internet connections. [3]

II.2.2/ Why is bandwidth crucial? ;

Bandwidth has no limits. The capacity available in a given deployment location, such as a home or business, is limited. Sometimes this is due to the physical limitations of the network device, such as cabling, the wireless frequencies used, or the router or modem. In other situations, a network administrator or Internet/WAN operator intentionally limits bandwidth.

To illustrate this, here's the average bandwidth used by various services: [3]

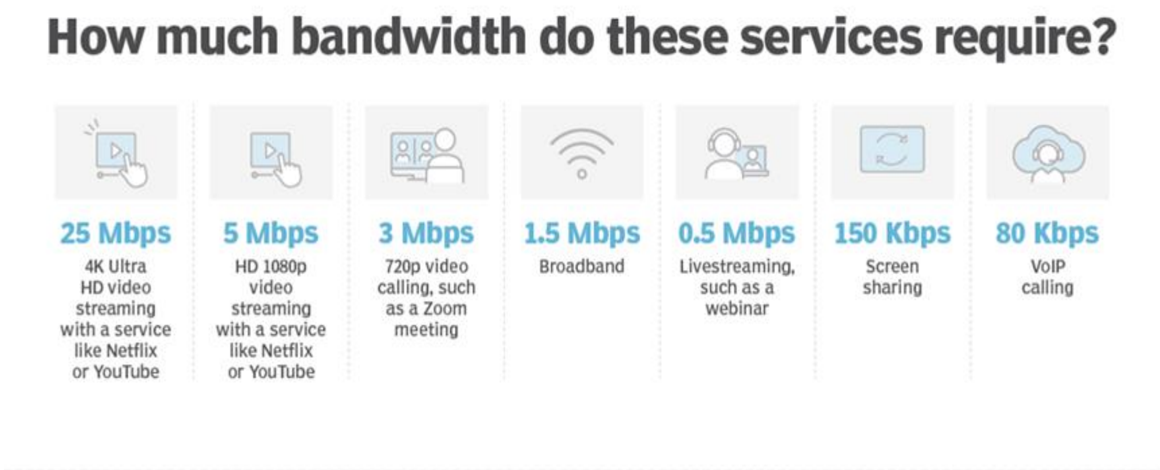


Figure II.1: bandwidth capacity required for each service [3]

II.3/ The different types of interference:

When planning a wireless network, wireless interference is a crucial element to consider. Unfortunately, interference is unavoidable, but the trick is to minimize interference levels, which requires a clear, unobstructed transmission path. [4]

II.3.1/ Interference can be caused by the following:

II.3.2/ Physical objects:

The most common sources of interference include trees, construction, buildings and other physical structures. The number of walls the RF signal can pass through while maintaining adequate coverage depends on the density of materials used in the construction of a building. Concrete and steel walls are particularly difficult to penetrate. These structures sometimes reduce or completely prevent wireless signals. [4]

II.3.3/ Electrical interference:

Appliances such as computers, refrigerators, fans, lighting or other motorized devices can cause electrical interference. The proximity of the electrical device to the wireless access point determines the impact of electrical interference on the signal. Advances in wireless technologies and electrical devices have reduced the effects of these devices on wireless transmissions. [4]

II.3.4/ Environmental factors:

Weather can significantly affect the integrity of wireless signals. For example, lightning can cause electrical interference, and fog can weaken signals as it passes through them.

Many applications can be used in the home or office wirelessly. Every office has many wireless obstacles, even when external interference, such as weather conditions, is not a problem. [4]

II.4/ Signal strength :

The strength of the connection between your phone and a neighboring tower is known as the cellular signal strength. The decibel per milliwatt is the unit of measurement used for the connection. In general, you'll prefer a stronger signal, as it means faster connection speeds and better quality of service. On most phone models, the phone's status bar displays this connection rating. Therefore, fewer signal bars indicate a weak signal.

Signal strength between transmitter and receiver, also known as signal-to-noise ratio, S/N ratio or SNR ratio. Essentially, this is a measure that compares the desired signal level with the level of background noise and interference. The stronger the signal to carry the information, the greater the background noise. [5]

II.4.1/ example :

Imagine you're in a small room talking to someone 6 meters away to illustrate the relationship between signal, noise, transmit power and distance. You can hold a conversation at normal volume if no one else is around. However, you can have dozens of people in the same room, for example at a lively party, each having their own conversation. Suddenly, you won't be able to hear the person you're talking to! Of course, you could start talking louder, but that would increase the "noise" for everyone around you. These people would then start talking louder, increasing the noise and intrusion. Everyone in the room can only communicate a few meters apart in an instant. You've already witnessed the intruding noise first-hand at a noisy party, or if you've had to bend over to hear a conversation. [5]

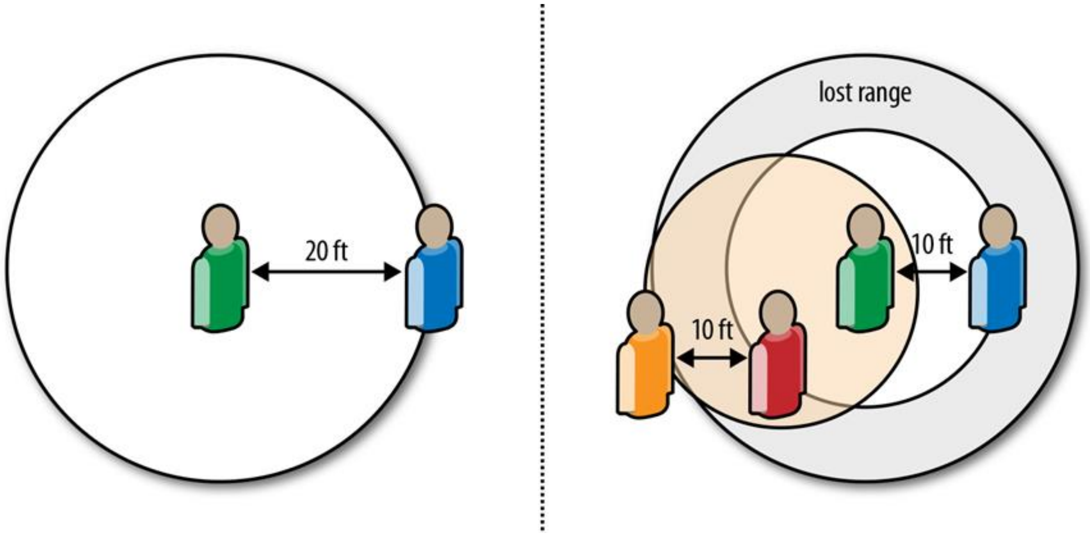


Figure II.2: proximity and distance[5]

*Ft.----- distance

*1Ft ----30.48 cm

II.4.2/ Problems related to proximity and distance :

In a situation where a receiver picks up a strong signal, making it impossible to detect a weaker signal, the weaker signal is "crowded out".[5]

II.4.3/ Cell breathing :

Situation in which the coverage area, or signal distance, increases and decreases as a function of cumulative noise and interference levels.

The problem with proximity and distance is that one or more loudspeakers next to you can block weaker signals from further away. Likewise, the more conversations there are around you, the greater the interference and the more limited the range from which you can perceive a useful signal - breathing. Not surprisingly, all forms of radio communication are subject to these same limitations, whatever the underlying protocol or technology. [5]

II.4.4/ Ideal mobile network signal strength :

The phone model determines the optimum phone signal strength. You should generally aim for a connection above -85dBm. Some phone models indicate a signal strength of 0 to 100dBm. If the signal is below -100dBm, your phone may lose the connection or have poor quality of service.

The signal strength ranges and associated strength quality are shown below.

Near 0 dBm, the signal is exceptional (close to the base station).

The signal is excellent between -50 and -64 dBm.

The signal is good between -65 and -84 dBm.

-85 to -100 dBm: below-average/bad signal. If the signal is below 100 dBm, there is almost no signal. [5]

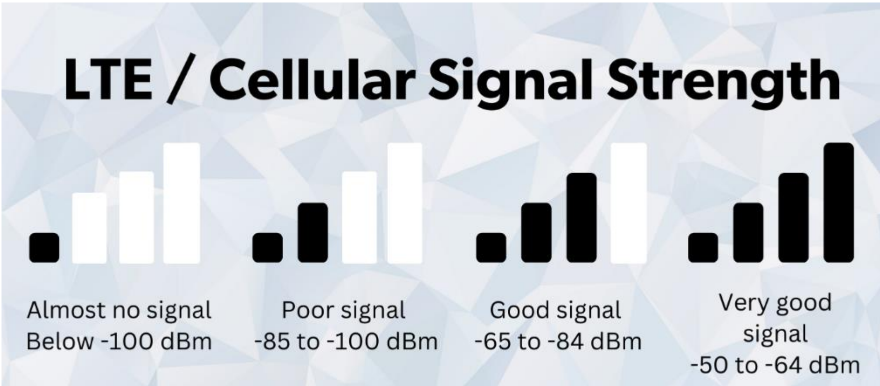


Figure II.3: cell signal strength [5]

II.4.5/ SNR :

The SNR of a wireless channel is a measure of the excess of signal strength over noise level. The higher the SNR, the better the signal quality and the lower the bit error rate (BER), i.e. the percentage of bits corrupted or lost during transmission. A low BER means that the signal is weak or distorted by noise, while a high BER can lead to delays, retransmissions or data loss. [6]

II.4.5.1/ What are the sources of noise? :

Noise is an unwanted signal that interferes with the desired signal in a wireless channel. It can come from various sources, such as thermal noise, which corresponds to random fluctuations in the electric current in the transmitter, receiver and antenna circuits, caused by the thermal agitation of electrons. Atmospheric noise is natural electromagnetic radiation from the sun, stars, lightning and other phenomena in the atmosphere. Man-made noise is artificial electromagnetic radiation from other devices such as radios, televisions, computers, microwaves and power lines that use the same or adjacent frequency bands as the wireless network. Finally, multipath noise is the reflection, refraction, diffraction and scattering of the signal by objects in the environment, creating multiple copies of the signal that arrive at the receiver at different times and angles. [6]

II.4.5.2/ How can the signal-to-noise ratio (SNR) be determined? :

SNR is usually expressed in decibels (dB), a logarithmic scale that compares the ratio between two power levels. The signal power (S) and noise power (N) of the wireless channel are needed to calculate the SNR in dB. The formula is :

SNR (dB) = 10 * log10 (S/N)

For example, if the signal power is 100 mW and the noise power is 1 mW, the SNR is as follows:

SNR (dB) = 10 * log10 (100/1) = 20 Db. [6]

II.4.5.3/ How can the signal-to-noise ratio be improved?:

There are several strategies to consider for improving signal-to-noise ratio (SNR) and reducing bit error rate (BER) in wireless networks. While increasing transmit power can boost signal strength and overcome noise and attenuation, it can also increase interference and power consumption. Reducing the distance between transmitter and receiver can reduce path loss and multipath effects, but it can also limit coverage and mobility. Choosing a better location can avoid or minimize obstacles that block or degrade the signal, but this may not be practical for some applications. While it can reduce interference from other devices using the same or adjacent frequencies, changing frequency can have an impact on bandwidth, propagation and compatibility. Directional antennas can concentrate the signal in a specific direction and reduce noise from other directions, but they can also reduce diversity and flexibility. The use of coding and modulation techniques enables the number of bits per symbol, error correction schemes and data rate to be adjusted to suit channel conditions, but increases complexity and latency. [6]

II.4.5.4/ Why is the signal-to-noise ratio important? :

The performance and reliability of wireless networks depend on the signal-to-noise ratio (SNR). A high signal-to-noise ratio results in a higher data rate and a lower bit error rate (BER), which in turn increases throughput. On the other hand, a low signal-to-noise ratio increases the bit error rate and the number of retransmissions, which in turn increases latency. What's more, SNR is crucial to providing quality of service to a variety of applications and users with varying requirements in terms of reliability, delay, bandwidth and jitter. Thus, a high SNR guarantees a better quality of service for the network. [6]

II.5/ Techniques used to improve the performance of wireless networks.

II.5.1/ Modulation :

Modulation is the action of modifying a signal to transmit useful information. Three components can be assigned to the modulation of a signal: its amplitude, frequency and phase. Phase describes the position of the waveform in the cycle with respect to time, amplitude is the power or intensity of the signal, and frequency is the frequency at which the signal is repeated. [7]

II.5.1.1/ Analog modulation

The simplest and oldest form of modulation is analog modulation, in which the carrier wave is directly modulated by an analog signal, such as voice or video. Amplitude modulation (AM), frequency modulation (FM) and phase modulation (PM) are the most common analog modulation schemes. The advantage of analog modulation is that it is simple to use and compatible with existing systems, but it also has several disadvantages.

Noise and interference affect the signal quality of analog modulation. To transmit a given amount of information, analog modulation also requires a large bandwidth, which limits the number of channels and users that can share the same frequency band. Analog modulation is mainly used in low data-rate broadcasting and television applications. [7]

II.5.1.2/ Digital modulation :

The carrier wave is modulated by a discrete sequence of bits, representing digital data, in digital modulation, the modern, dominant form of modulation. Amplitude shift keying (ASK), frequency shift keying (FSK), phase shift keying (PSK) and quadrature amplitude shift keying are the most common digital modulation schemes. Because it can use error detection and correction techniques, and transmit more bits per symbol, digital modulation has the advantage of being more robust and efficient than analog modulation. By using several levels or dimensions of modulation, digital modulation also makes it possible to increase the number of users per channel and data rates. However, digital modulation does have its drawbacks.

Digital modulation requires more complex and expensive hardware and software, as well as greater power to maintain a given signal-to-noise ratio. In addition, quantization and timing errors caused by digital modulation have an impact on signal accuracy and synchronization. Most applications requiring reliable, high-speed data transmission, such as the Internet, voice and video, use digital modulation. [7]

II.5.1.3/ Types of modulation :

II.5.1.3.1/ Amplitude modulation:

This is a type of modulation in which the data added to the signals is represented by the amplitude of the carrier signal, while the phase and frequency of the signal remain unchanged. [7]

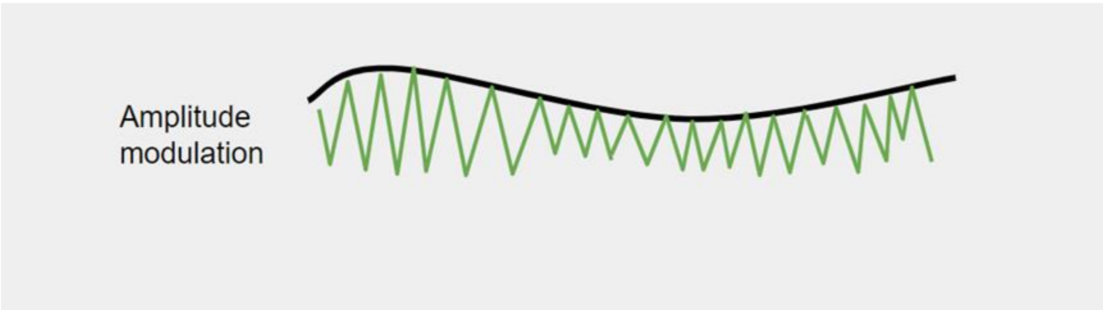


Figure II.4: Amplitude modulation [7]

II.5.1.3.2/ Frequency modulation:

This is a type of modulation where the only frequency of the carrier signal changes to represent the data frequency, while the phase and amplitude of the signal remain unchanged. [7]

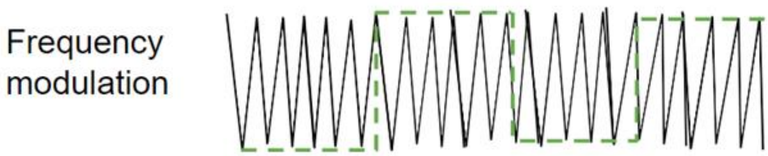


Figure II.5: Frequency modulation [7]

II.5.1.3.3/ Phase modulation:

This is a type of modulation where the phase of the carrier signal changes to represent the data added to the signal. Separate stages are used to represent the different information values. [7]

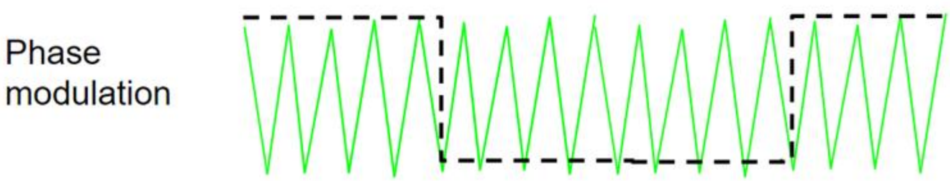


Figure II.6: Phase modulation [7]

II.5.1.3.4/ Quadrature amplitude modulation:

A modulation technique called quadrature amplitude modulation (QAM) can be used to combine two amplitude-modulated waves in a single channel to increase the channel bandwidth.

Quadrature amplitude modulation is a modulation method that can be used in both analog and digital modulation concepts.

There are two types of modulation: analog and digital, depending on the shape of the input signal.

In QAM, we can modulate two individual signals and transmit them at the receiver, and the channel bandwidth increases using both input signals.

QAM can send two message signals on the same channel.

"Quadrature carrier multiplexing" is another name for this QAM technique. [7]

II.5.1.3.5/ Amplitude shift keying (ASK):

The amplitude of the carrier signal is modified in amplitude shift keying to create signal elements. Although the amplitude changes, the frequency and phase remain the same. [7]

II.5.1.3.6/ Binary amplitude shift keying (BASK):

Binary amplitude shift keying (BASK) or on-off modulation are terms used to describe ASK modulation with only two levels. One signal level an peak amplitude of 0 while the other is equal to the amplitude of the carrier frequency. [7]

II.5.1.3.7/ Phase shift keying (PSK):

This is a digital modulation method that modifies the phase of a constant-frequency reference signal to transmit data. By varying the sine and cosine inputs at a given time, this modulation is achieved. In phase-shift keying, the phase of the output signal is modified as a function of the input. The phase carrier signal will be transmitted if m(t) is =1. Similarly, a phase-shifted carrier signal is transmitted if m(t) = 0 for the baseband signal. Examples of applications include wireless local area networks, biometrics, contactless operations and satellite communications. [7]

II.5.1.3.8/ Binary pahse shift keying (BPSK) :

This is also known as PSK or Phase Reversal Keying or 2-phase PSK. In this method, the sine wave carrier takes two phase reversals, such as 0° and 180°. The BPSK modulation method is essentially a double-band carrier suppression modulation method. [7]

II.5.2/ Multiplexing and multiple access (MAC) :

II.5.2.1/ Multiplexing :

Multiplexing is a means of combining several signals into a single transmissible signal on a shared medium.

The multiplexer is a device used for this purpose. The multiplexer combines several input signals into a single output signal.

The output signal is then transmitted to the shared medium. [8]

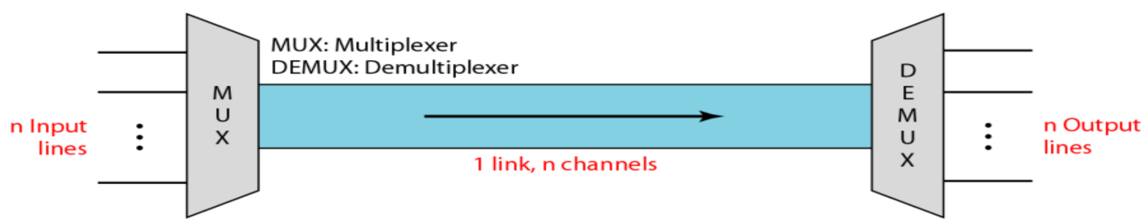


Figure II.7: multiplexer combining several input signals. [8]

II.5.2.2/ Multiplexing is used in a variety of applications, including:

II.5.2.2.1/ Communications:

Multiplexing is a technique for combining multiple voice or data signals into a single signal, which can be transmitted over a shared telephone line or fiber-optic cable. [8]

II.5.2.2.2/ Broadcasting:

Multiplexing involves combining several radio or TV signals into a single signal that can be transmitted over a shared broadcast channel.

Multiplexing layers: [8]

Multiplexing can be performed at several layers of the network protocol stack. The physical layer and the data link layer are the layers most frequently used to perform multiplexing. [8]

II.5.2.2.3/ Physical layer multiplexing:

This type of multiplexing merges several signals into a single signal.

This is the lowest layer in the protocol stack and is responsible for transmitting and receiving raw data bits on a physical medium. [8]

2.5.2.2.4/ Data link layer multiplexing:

This type of multiplexing combines several signals into a single signal.

Data scaling, error detection and correction are all responsibilities of this layer. [8]

II.5.2.2.5/ Example of multiplexing:

A common example of multiplexing is the way telephone companies combine multiple voice signals into a single signal that can be transmitted over a shared copper telephone line.

They use a device known as a frequency-division multiplexer (FDM) to do this.

FDM takes several voice signals and assigns them to different frequency bands.

Then the FDM output is transmitted to the copper telephone line. [8]

II.5.2.3/ Types of multiplexing techniques:

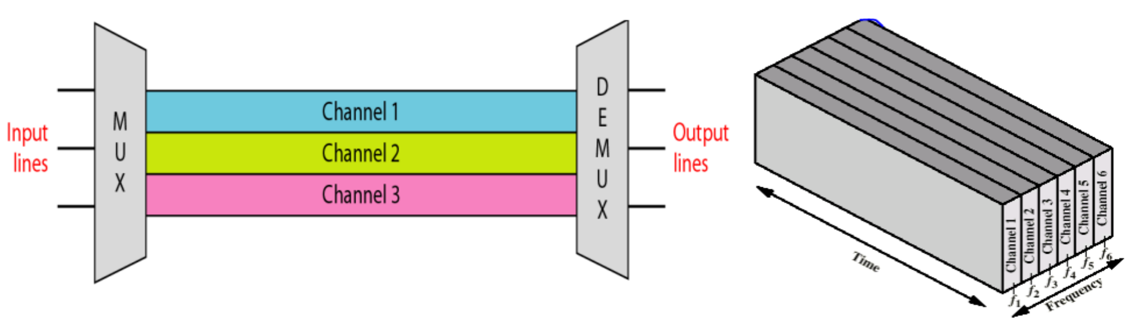


Figure II.8: Frequency-division multiplexing (FDM). [8]

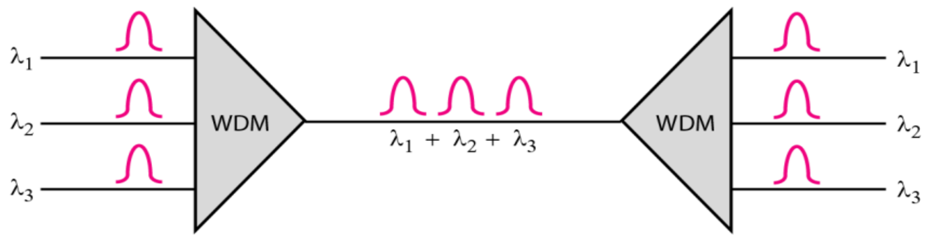


Figure II.9: Wavelength division multiplexing (WDM). [8]

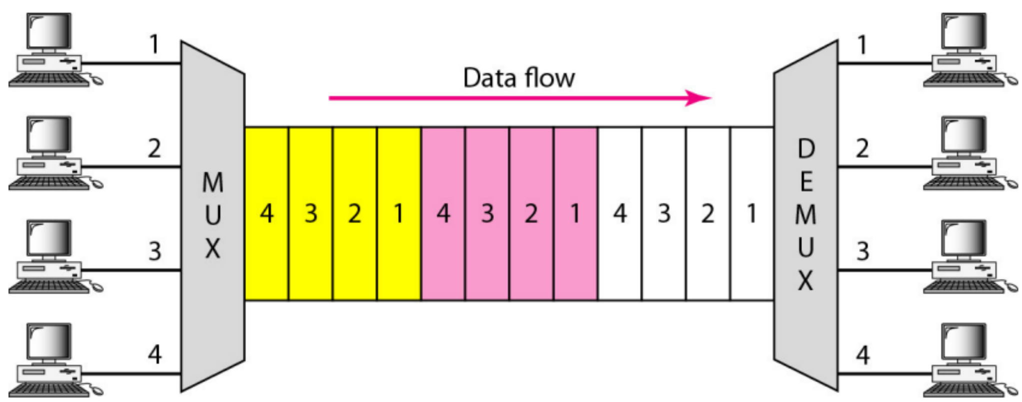


Figure II.10: Time-division multiplexing (TDM). [8]

II.5.2.4/ Multiple Access :

A multiple access method allows several devices to share a common medium. [8]

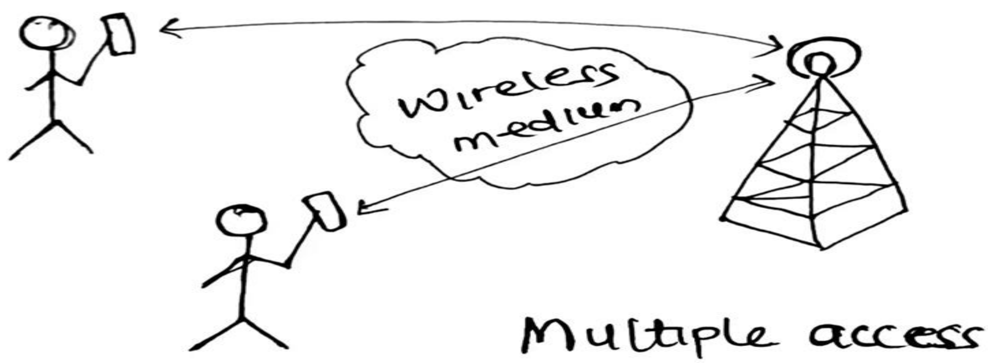


Figure II.11: multiple access (MAC) [8]

II.5.2.4.1/ Example of Multiple Access:

The way cell phones share a common radio frequency band.

To do this, a method known as Code Division Multiple Access (CDMA) is employed.

Each cell phone is equipped with a unique code thanks to CDMA, which allows its signal to be broadcast over a wide range of frequencies.

This enables several cell phones to share the same frequency band without interfering with each other. [8]

II.5.2.4.2/ Types of multiple access:

Time division multiple access (TDMA).

Frequency Division Multiple Access (FDMA).

Code Division Multiple Access (CDMA). [8]

II.5.3/ Quality of service (QoS) :

Any technology that manages data traffic to reduce packet loss, latency and jitter on a network is known as quality of service (QoS). QoS prioritizes specific types of data on the network, and controls and manages network resources.

When applications such as voice, video and delay-sensitive data traverse a network, networks must provide predictable and measurable services. Users use QoS to meet the traffic requirements of sensitive applications such as real-time voice and video, and to prevent quality degradation caused by packet loss, delay and jitter. [9]

II.5.4/ Conclusion :

The future of mobile networks presents many fascinating opportunities. 5G technology promises even higher data speeds, lower latency and greater capacity, opening up new opportunities in areas such as augmented reality, the Internet of Things (IoT) and autonomous systems. As technology advances, mobile networks are likely to play an important role in shaping the digital landscape, connecting more and more devices and improving the way we live and work. Mobile networks are essentially a constant story of innovation, modification and the ability to transform seamless connectivity.

User satisfaction, business productivity and the successful integration of emerging technologies are directly affected by the efficiency of mobile networks. It fosters innovation in areas such as augmented reality, virtual reality and the Internet of Things, and enables smoother communication. What's more, companies that prioritize and invest in optimizing mobile network performance deliver superior connectivity experiences, giving them a competitive edge.

The techniques employed to improve mobile network performance play a key role in meeting the growing demand for faster, more reliable and more efficient connectivity. As dependence on mobile communications continues to grow, a range of strategies and technologies have been developed to optimize network performance and ensure a seamless, tailored user experience.

Chapter III :
orthogonal access techniques.

III.1/ access techniques :

III.1.2/ introduction :

Access techniques are fundamental strategies in telecommunications and networking that govern how users and devices connect and communicate over a network. These techniques are essential for determining the reliability and efficiency of data transmission between devices.

III.1.3/ Introduction to orthogonal and non-orthogonal access techniques:

Access techniques are essential in the context of wireless communications, as they govern the way in which several users or devices share the limited resources of a communication channel. Orthogonal and non-orthogonal access techniques are the two main categories. These methods are essential for optimizing spectrum efficiency, mitigating interference and facilitating reliable communication in wireless networks. [10]

III.1.4/ why use orthogonal multiple accesses:

Communication systems use orthogonal multiple access techniques to enable multiple users to transmit data simultaneously on the same channel without interference. Orthogonal multiple access methods offer a number of advantages:

Efficient use of bandwidth: orthogonal techniques ensure that each user's signal occupies a distinct set of frequencies or time slots that do not overlap with others. This allows the available bandwidth to be used without interference between users.

Increased capacity: Orthogonal techniques improve the overall capacity of the communication system by allowing several users to transmit simultaneously. This is particularly crucial in situations where there is a high demand for communication services.

Reduced interference: By ensuring that their signals are orthogonal, or do not interfere with each other, orthogonal techniques reduce interference between users. This maintains communication quality and reduces the risk of data corruption or loss.

Flexibility: a variety of modulation schemes and coding techniques can be used to employ orthogonal multiple access techniques, enabling adaptation to different environments and communication requirements.

Ease of synchronization: orthogonal techniques often use simple synchronization mechanisms, making it easy to coordinate transmissions between multiple users.

Overall, orthogonal multi-user access techniques are essential to enable efficient and reliable communication in multi-user scenarios, such as cellular networks. [10]

III.1.5/ Orthogonal multi-user access (OMA) techniques:

III.1.5.1/ FDMA :

We assign each signal a different type of frequency band (range) in this type of multiple access. Consequently, the frequency band type must not be the same for two signals. Even if we send these signals in a single channel, there will be no interference between them.

Our radio channels are an excellent example of this type of access. It goes without saying that each station has been allocated a specific frequency band in which to operate.

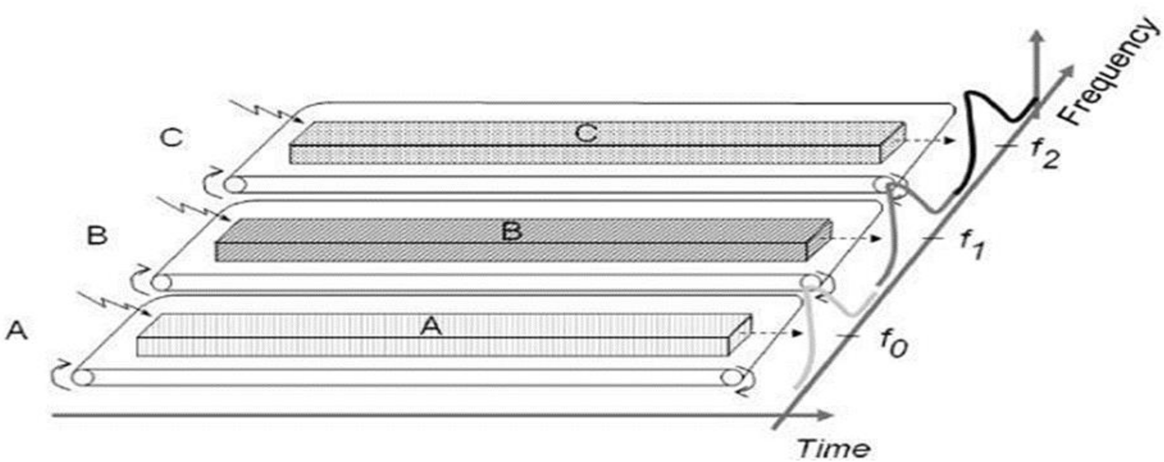


Figure III.1: FDMA [10]

Let's take three stations, namely A, B and C. We want to access them using the FDMA method. So we've assigned them various frequency bands.

The figure shows that satellite station A has been kept in the frequency range 0 to 20 HZ. Similarly, stations B and C were assigned to 30-60 Hz and 70-90 Hz respectively. They do not conflict with each other.

The main disadvantage of this type of system is that it is very noisy. For dynamic and irregular channels, this type of multiple access is not recommended. It will make their data inflexible and inefficient, in effect.

B= N / Nu

N: Total available bandwidth (in Hertz)

Nu: Number of users

B : Bandwidth allocated to each user (in Hertz). [10]

III.1.5.2/ TDMA :

As its name suggests, TDMA is based on access time. Here, we assign a specific time to each channel. Within this period, the channel can access the entire bandwidth of the spectrum.

Each station has a specific length or slot. Unused slots remain inactive.

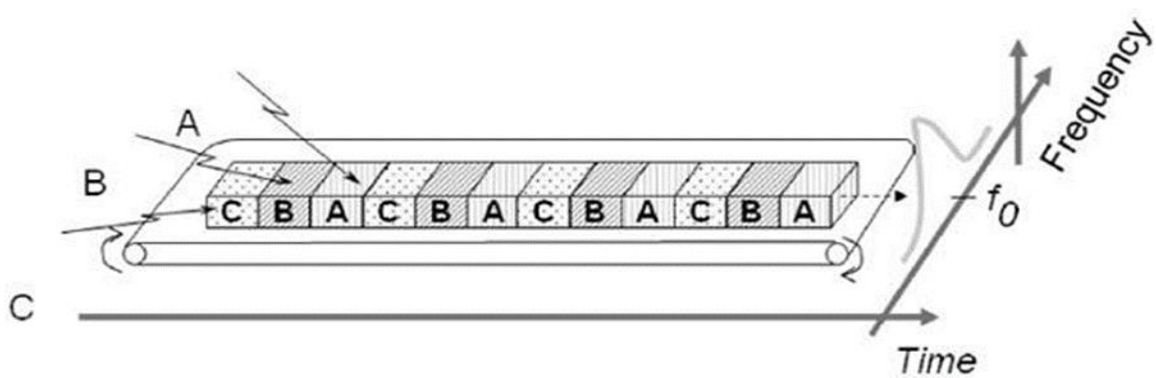


Figure III.2: TDMA [10]

Suppose we want to use the TDMA technique to send five packets of data on a specific channel. Therefore, we need to give them certain time intervals or time frames in which they can access the full bandwidth.

Packets 1, 3 and 4 are active and transmitting data, as shown in the figure above. However, packets 2 and 5 are inactive as they are not involved. Each time we assign bandwidth to this particular channel, this format repeats itself.

Although we have assigned specific time slots to a channel, load capacity can also change them. In other words, one channel may receive a larger timeslot than the channel that receives lighter loads. The main advantage of TDMA over FDMA is that it is more efficient. TDMA's low power consumption is another advantage.

tu = T/ Nu

T: Total image duration (in seconds)

Nu: Number of users

tu: Time allocated to each user (in seconds). [10]

III.1.5.3/ CDMA :

Each channel, in the CDMA technique, has been given a distinct code to differentiate it from the others. An excellent example of this type of multiple access is our cellular system. No two people have the same cell phone number, even though they are customers of the same mobile service company X or Y and use the same bandwidth.

We decode the inner product of the coded signal and the shredding sequence in the CDMA process. Therefore, the mathematical writing is as follows:

Coded signal = original data : \N- Time\N- Chipping\N-Sequence\N$$.

The main advantage of this type of multiple access is that it allows all users to use the full bandwidth simultaneously. There is no interference, as each user has its own code.

Unlike FDMA and TDMA, this technique allows a certain number of stations to have a certain number of channels. The advantage of this method is that each station can use the entire spectrum at any time. [10]

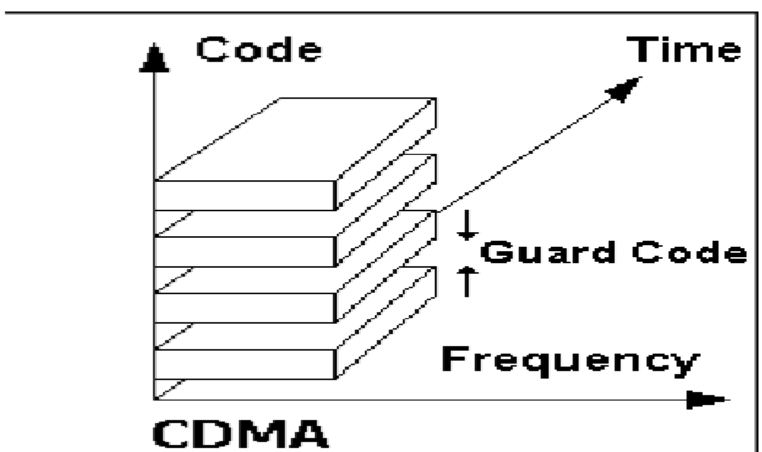


Figure III.3: CDMA [10]

III.1.5.4/ SC-FDMA (single-carrier frequency-division multiple access):

The SC-FDMA digital modulation and access scheme is used in wireless communication systems, particularly in the uplink transmission of cellular networks such as LTE (Long-Term Evolution) and 5G.

In terms of peak-to-average power ratio (PAPR), SC-FDMA is specially designed to overcome the traditional limitations of OFDMA (Orthogonal Frequency Division Multiple Access). In OFDMA, the available frequency spectrum is divided into sub-carriers for multiple users, which are then allocated to different users. However, OFDMA an a high PAPR, which means that signal power fluctuates considerably, potentially leading to distortion and reduced efficiency of power amplifiers.

By combining the advantages of single-carrier modulation and multicarrier access, SC-FDMA solves this problem. It uses a single-carrier waveform, similar to traditional single-carrier modulation schemes such as QPSK (Quadrature Phase Shift Keying) or QAM (Quadrature Amplitude Modulation), but applies frequency-domain equalization and offers multicarrier access similar to OFDMA. [10]

III.1.5.5/ OFDMA (orthogonal frequency division multiple access):

(OFDMA) enables access points to serve several customers simultaneously. OFDMA rules allow data to be transmitted between several terminals or clients on one transmission medium. Any device connected to a transmission channel, such as a computer or telephone, can serve as a terminal, and the medium can be a wireless network.

A signal modulation method called orthogonal frequency division multiplexing uses several subcarriers in the same communication channel. These subcarriers transmit in parallel, are closely spaced and carry data at low data rates. The technique is resistant to selective fading and interference thanks to the use of multiple subcarriers, while offering fairly high spectral efficiency.

OFDM is based on frequency-division multiplexing and was used in the past for cellular networks, broadcast media and older Wi-Fi standards such as IEEE 802.11ac (Wi-Fi 5). OFDM is a variant of OFDMA. More precisely, it is a multi-user OFDM variant, meaning that several users can access data at the same time. It's an improvement on FDM and OFDM. [10]

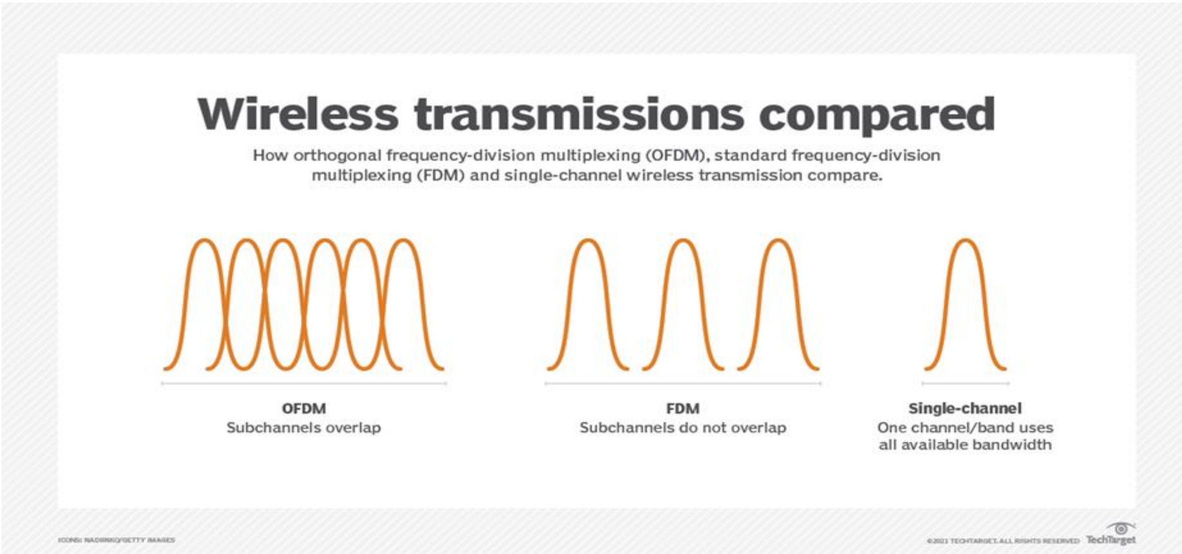


Figure III.4: The differences between OFDM, FDM and a single wideband channel frequency wireless data transmission scheme. OFDMA is a variant of the OFDM scheme. [10]

III.1.5.5.1/ How OFDMA works:

Analog modulation is used in conventional multiplexing technologies. However, OFDMA uses carrier signal waves, also known as subcarriers, to move small chunks of information in a more logical way. These can be null subcarriers, reference signal subcarriers or data subcarriers. Data can only be transmitted via data subcarriers. So that wireless operators can occupy and efficiently use the frequency bands for which they are licensed, the channel is divided into smaller frequencies, called resource units (RUs).

OFDMA enables users to communicate with multiple clients and transmit data simultaneously by allocating subsets of time-frequency resource units to multiple users (e.g. access points). RUs are allocated according to the bandwidth required by the user and other factors, such as QoS requirements, packet size and device constraints. Thanks to the use of several closely-spaced subcarriers and the flexible allocation of RUs, OFDMA takes account of all user usage patterns or data loads.

Two telephones sending data over the same telephone line is an example of how OFDMA works. Each phone can be given a time interval so that it can take turns sending its signal over the line at its allocated interval. However, these time intervals are imperceptibly small, giving the impression that both phones are transferring data at the same time and without interruption. [10]

III.2Conclusion :

In contemporary telecommunications, orthogonal access techniques play an essential role in enabling efficient, scalable and interference-free communication. Their ability to handle multiple simultaneous transmissions without cross-interference is essential to meet the high data rates and reliability required by today's wireless networks.

Chapter IV : Results and Discussion

IV.1/PART 01

IV.2/ Introduction

In this chapter, we focus on assessing the capabilities of orthogonal multiple access (OMA) systems as a function of the value of the signal-to-noise ratio (SNR) using a MATLAB simulation tool. This study takes on singular importance in the field of wireless communications, where it is crucial to optimize resource allocation and maximize data transmission speed. To this end, we detail the simulation set-up, the key parameters to be taken into account, how Rayleigh effects are modeled and the method for assessing system capacity. The aim of this chapter is to provide a comprehensive understanding of the OMA capacity evaluation process, enabling better control of wireless communication systems.

IV.3/ OMA (orthogonal multiple access) system model:

A transmission system that can support several users (K) at the same time.

K users are connected to the transmission system.

IV.3.1/ Transmission channel:

Each transmission channel is characterized by a unique bandwidth (W) and signal-to-noise ratio (SNR)

The signal transmitted by each user is modulated on the Rayleigh channel.

The receiver is responsible for recovering the signals transmitted by the users.

IV.4/ Mathematical model:

The basic equation of the OMA system is given by:

$R = W \times \log2(1 + SNR)$

Where:

R is the transmission rate (in bits/second)

W is the bandwidth (in Hz)

SNR is the signal-to-noise ratio (in decibels(

The above equation describes the relationship between transmission rate and SNR in each channel.

Or the SNR value of the nth user is :

$$SNR_{OMA} = \frac{p_n}{N}$$

The Signal-to-Noise Ratio (SNR) is an essential parameter that measures the proportion between the useful signal power p_n and the noise power N in a transmission system. This value is used to assess the contribution of noise and its impact on signal degradation.

These equations show how resources are allocated and how system capacity and efficiency are calculated in different orthogonal multiple access schemes.

IV.5/ Model simulation :

Noise is a key factor in communications, as it can lead to transmission errors and disturbances in signal transmission. To ensure reliable communication, it is essential to understand and control the effects of noise on data transmission. This is why SNR (Signal-to-Noise Ratio) has been introduced as a critical variable for assessing communication quality.

SNR is an indicator that measures the relationship between the power of the useful signal and the power of the background noise. The higher the SNR, the stronger the signal in relation to the noise, meaning better transmission quality.

SNR is also linked to a system's transmission capacity, as too low an SNR can limit transmission speed and lead to transmission errors. A high SNR guarantees faster, more reliable transmission. On the other hand, an SNR that is too low can lead to problems of signal distortion, which can affect transmission quality.

Consequently, SNR is a crucial factor in communications, as it directly determines the quality of a given communication. This factor must be taken into account when designing and controlling transmission systems to ensure reliable and efficient communication”.

Our study consists of simulating a system model using the OMA technique to study system performance as a function of parameters such as transmission power, SNR, number of users, and system capacity.

IV.6/ Capacity as a function of SNR: Study of the impact of transmission power (pt) :

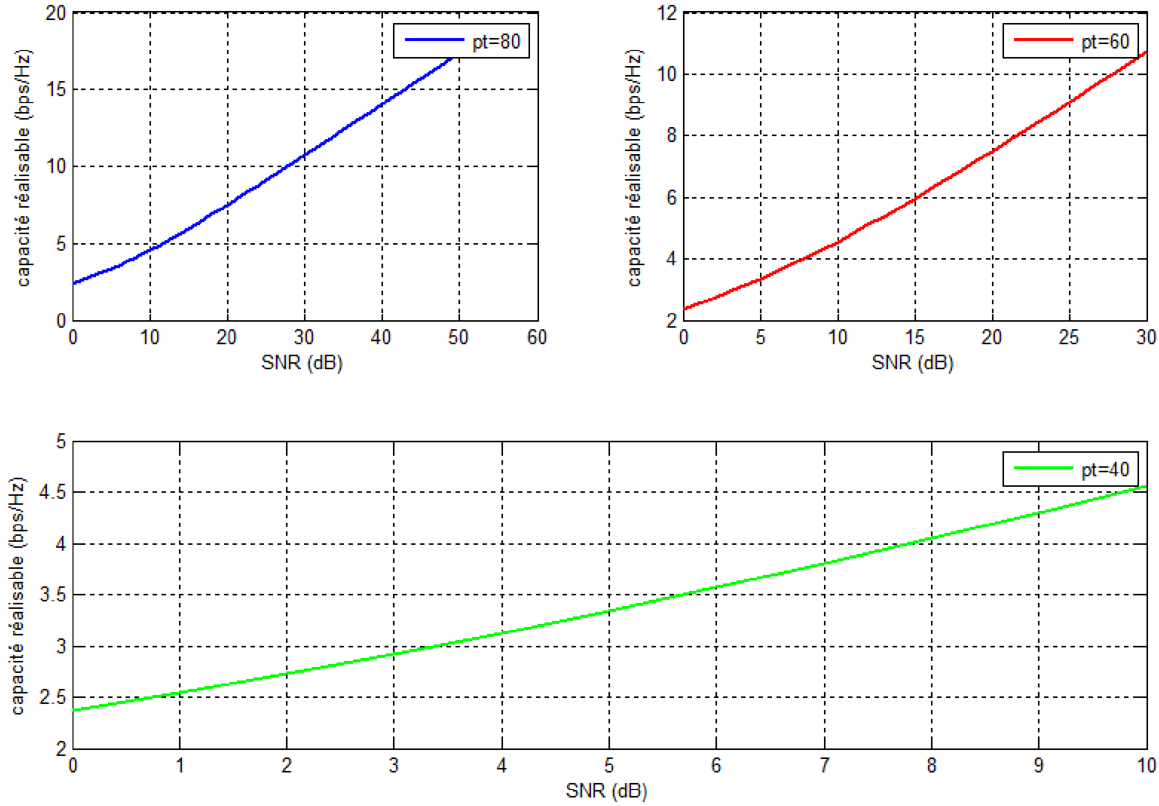


Figure IV.1: The relationship between signal-to-noise ratio and achievable capacity for Various Transmission Power (Pt)

Using only one user in this simulation, we conclude that, the relationship between signal-to-noise ratio (SNR) in decibels (dB) and achievable capacity (in bits per second per Hertz, bps/Hz) is illustrated by the graphs presented for three different power transmission levels (Pt). Each graph illustrates the variation in achievable capacity as the SNR increases for a specific Pt value.

Higher Pt values result in higher capacities: the graphs show that increasing transmission power (Pt) results in higher achievable capacities for the same SNR value.

In all the graphs, there is a faster increase in capacity as SNR increases, suggesting a non-linear relationship between SNR and capacity.

Each chart offers a variety of ranges for SNR and capacity, corresponding to the specific Pt value in question. The higher the Pt values, the wider the SNR and capacity ranges.

The bottom line These graphs convincingly demonstrate how SNR influences the achievable capacity of a communication system at various transmission power levels, keeping in mind that this simulation was conducted for only one user. As transmission power increases, the system can achieve higher capacities, but the relationship between SNR and capacity remains uneven from case to case. The design and optimization of communication systems requires this information in order to maximize data throughput under varying SNR conditions.

IV.7/Part 02:

IV.7.1/ Evaluation of system capacity/SNR as a function of propagation distance:

	Distance between users and base station		
users	**Figure 01 (1)**	**Figure 02 (2)**	**Figure 03 (3)**
U1	5	50	100
U2	3	30	50
U3	2	20	30
U4	1	10	20
U5	0.35	3.5	10

Table IV.1: Distance between users and base station

Table 01 shows The distances between different users (U1 to U5) and a base station are compared in the table in three different scenarios, as shown in Figures 01, 02 and 03.

IV.7.2/ Network categories:

Figure 01:

General conclusion :

A small cell or femtocell (indoors, in the office)

Figure 02:

Microcell or picocell (urban environment)

Figure 03:

Macrocell (on the outskirts or in rural areas)

Figure 01:

Nearest user: U5 (0.35 units)

Farthest user: U1 (5 units)

Range of values: from 0.35 to 5 units.

This structure offers the shortest distances, suggesting a compact network or indoor environment.

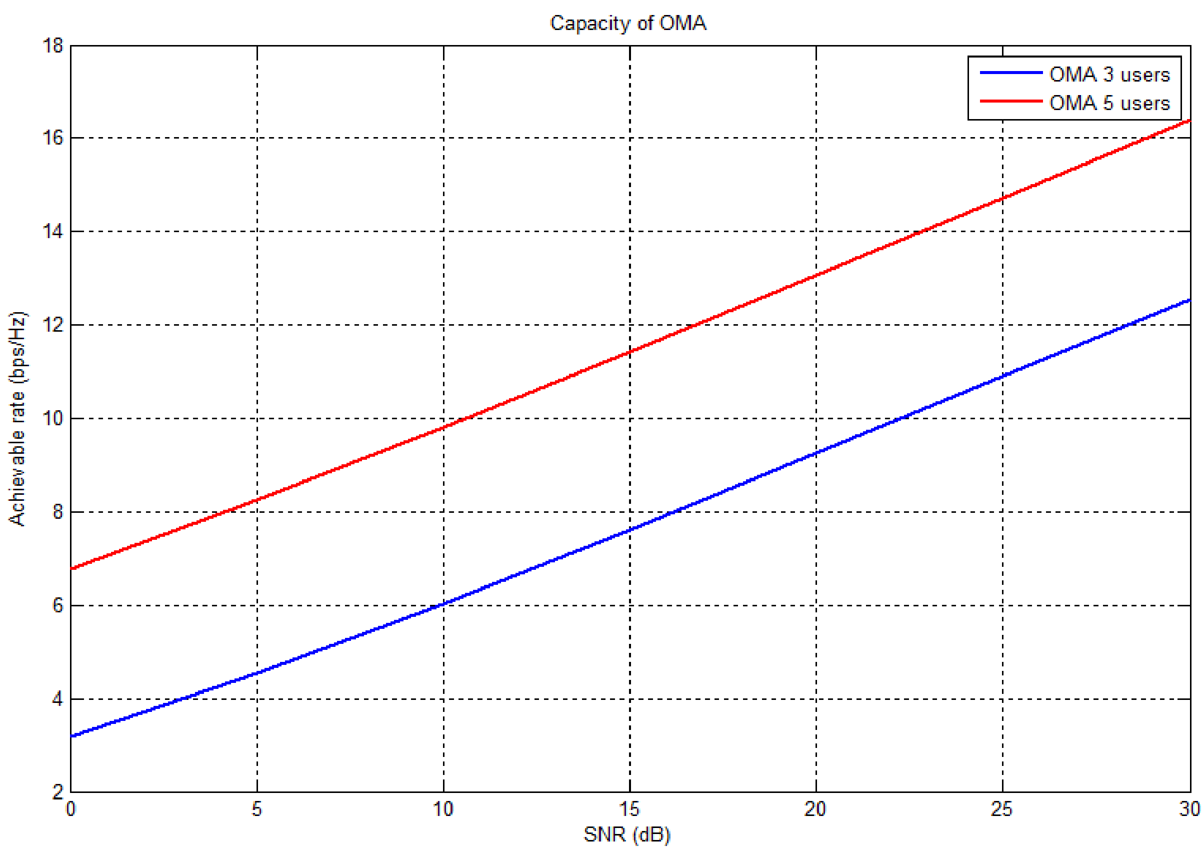


Figure IV.2 (1): Distance between users and base station D= 5 ,3 ,2, 1 ,0.35

The frequency of the Y axis is ~2-18 bits/Hz - The lines are fairly close, with a constant spacing.

As the signal-to-noise ratio increases, both lines increase steadily, and the gap narrows slightly.

The gap is about 4 bits/Hz at an SNR of 30 dB (16 vs. 12.(

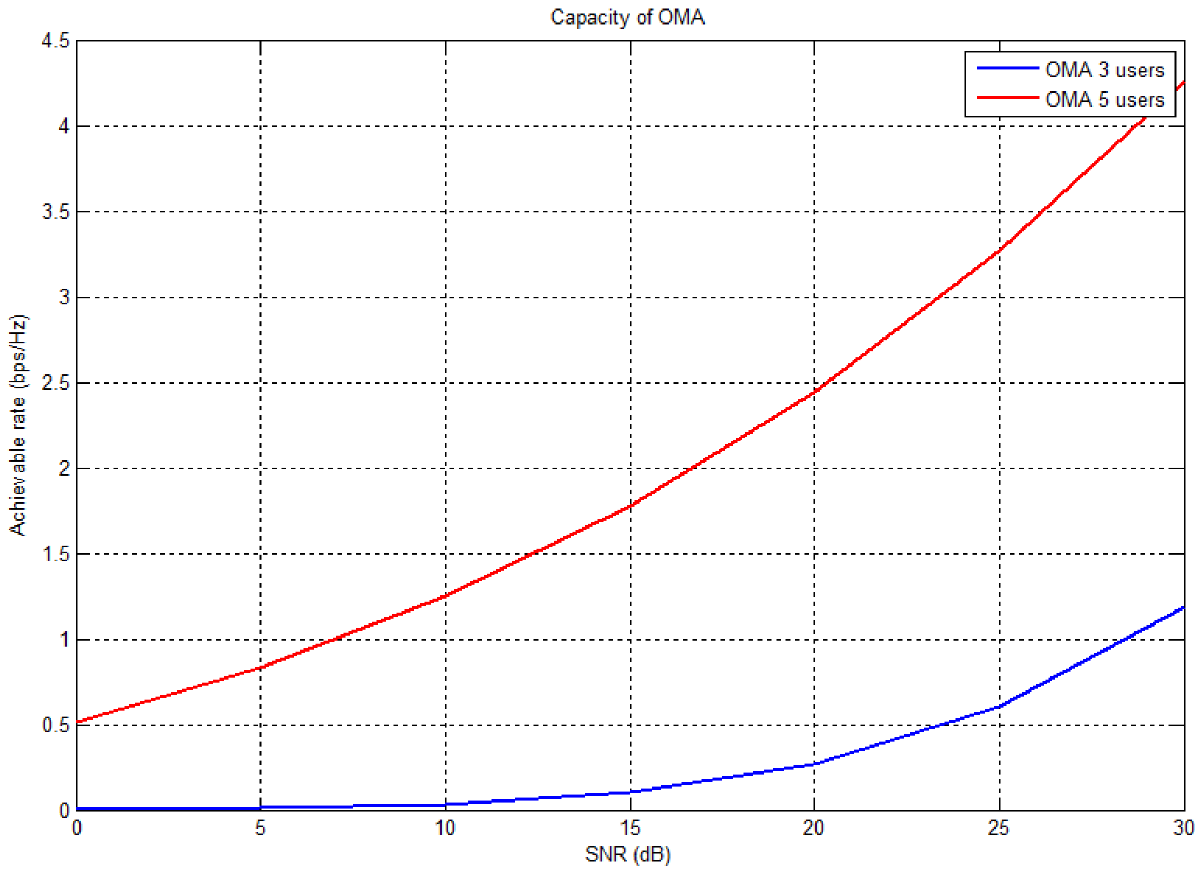
Figure 02 :

Nearest user: U5 (3.5 units)

Farthest user: U1 (50 units)

Range of values: from 3.5 to 50 units.

Distances are about 10 times greater than those shown in figure 01, suggesting a larger area or external environment.



<u>Figure IV.3 (2):</u> Distance between users and base station D=50 ,30 ,20 ,10 , 3.5

Y-axis speed is ~0-4.5 bits/Hz.

The lines start out very close together at low SNR, but diverge significantly as SNR increases.

The number of users on the "OMA 5" line increases significantly faster than on the "OMA 3" line.

The difference is around 3 bits/Hz (4 vs. 1) at an SNR of 30 dB, which is considerably higher than in image 1.

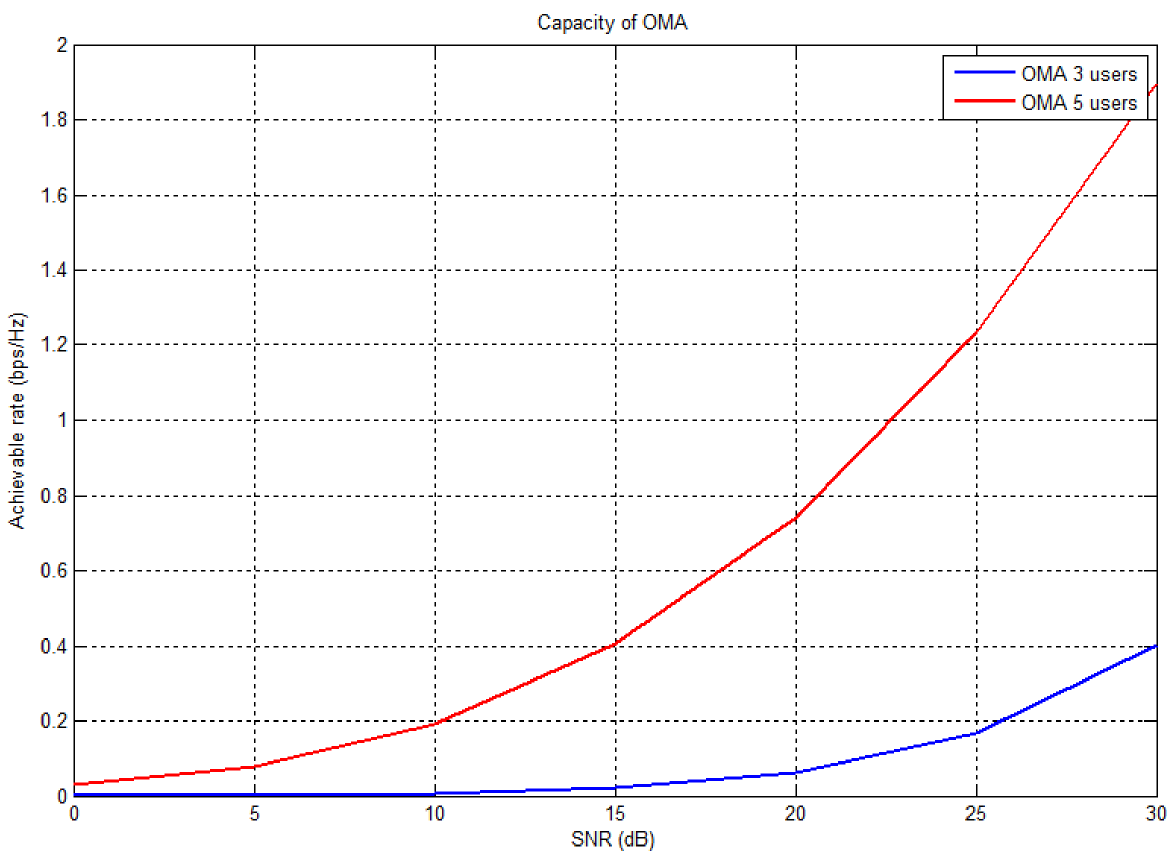
<u>Figure 03:</u>

Nearest user: U5 (10 units)

Farthest user: U1 (100 units)

Variation in values: from 10 to 100 units.

Distances are approximately 20 times greater than in figure 01 and twice as great as in figure 02, suggesting a very large area or a rural environment.



<u>FigureIV.4 (3) :</u> Distance between users and base station D=100 ,50, 30, 20 ,10

The speed of the ordinates varies from ~0-2 bits/Hz.

The two lines are very close, with low SNR and gradually increasing SNR.

There is a clear divergence between them after an SNR of 15 dB.

When using an SNR of 30 dB, the difference is about 1.4 bits/Hz (1.8 vs. 0.4), which is the largest proportional difference.

IV.7.3/ Comparative analysis:

IV.7.3.1/ Increase in scale :

Scaling increases steadily from Figure 01 to Figure 03, typically by factors of 10 and 20.

This indicates varying network configurations or environments (e.g. room → building → university.)

IV.7.3.2/ User organization :

In all illustrations, U5 is closest and U1 furthest away, with U2-U4 in between. This consistent order means that users are arranged in a spatially stable manner in relation to the base station.

IV.7.3.3/ Distances:

In each illustration, U1 is roughly three times further away than U5. This consistent ratio suggests that the base station is arranged in a linear or radial fashion.

IV.7.3.4/ Technological consequences:

Short distances (Fig. 01) are suitable for high frequencies (e.g. 5G mmWave) over a wide frequency range.

For optimum penetration, longer distances (see figure 03) require lower frequencies (e.g. below 6 GHz).

IV.8/ Conséquences for OMA results:

Due to lower path loss, it is likely that the closest users (U4, U5) will have a higher SNR.

In an OMA system with 5 users, the addition of these closer users could lead to a significant increase in capacity, especially for U5.

The limited capacity of the 3-user system could lead to the exclusion of the closest users (U4, U5.(

The various scales shown in the table may correspond to the various capacity configurations shown in Figures 1, 2 and 3.

Network designers need this data to optimize the location of base stations, select appropriate technologies and guarantee quality of service over different distances. These data illustrate the complexity of today's networks, which have to adjust to different geographical scales.

In all three graphs, a general trend can be observed where capacity increases as the signal-to-noise ratio increases, whether for 3 or 5 users. This is understandable, as a higher SNR implies sharper signals, enabling more information to be transmitted more reliably.

IV.9/ Impact of the number of users:

In terms of capacity, the 5-user system is more efficient than the 3-user system, consistently across all graphs. This suggests that OMA is ideally suited to a larger number of users, probably due to better resource utilization or a gain in diversity due to a larger number of users.

IV.10/ Impact of signal-to-noise ratio:

In all graphs, a greater variation in signal-to-noise ratio results in more significant differences. This suggests that the improvement in signal quality leads to an increase in the difference in capacity between 3-user and 5-user OMA systems.

IV.11/ Influence of the number of users:

The “5-user OMA” system continues to demonstrate superior performance to the “3-user OMA” system, suggesting that increasing the number of users in the OMA system improves its capacity. This effect is reinforced when SNRs are higher.

IV.12/ Part 03

IV.12.1/ Exploring capacity limits with varying signal-to-noise ratio and increasing number of users (k=20, 40, 60, 80) :

In this section we present graphs that seem to illustrate the sum rate for different systems with a variable number of users K as a function of the signal-to-noise ratio (SNR).

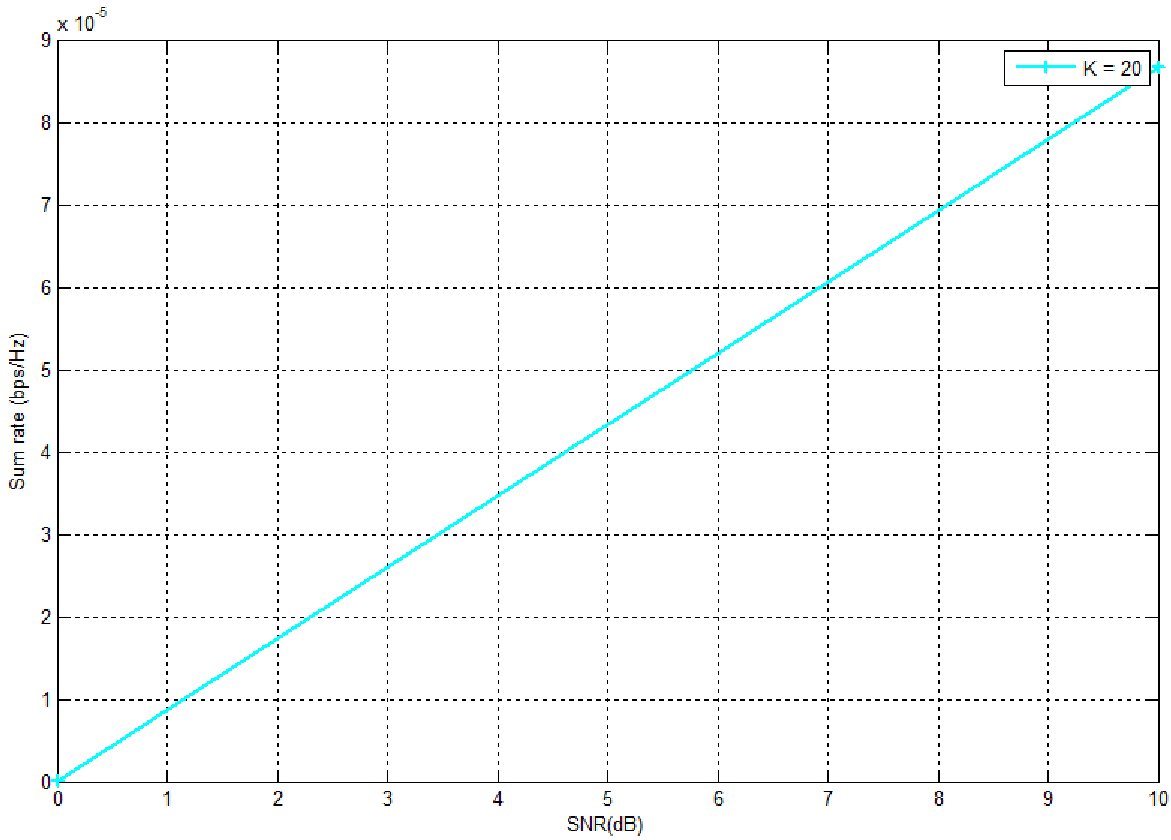


Figure IV.5: Impact of number of users k=20 on Sum Rate as a Function of SNR

The trend is for the summation rate to increase linearly with increasing SNR.

For K = 20, the summation rate is extremely low and has a linear relationship with SNR in the range listed. With increasing signal-to-noise ratio, the summation rate increases steadily.

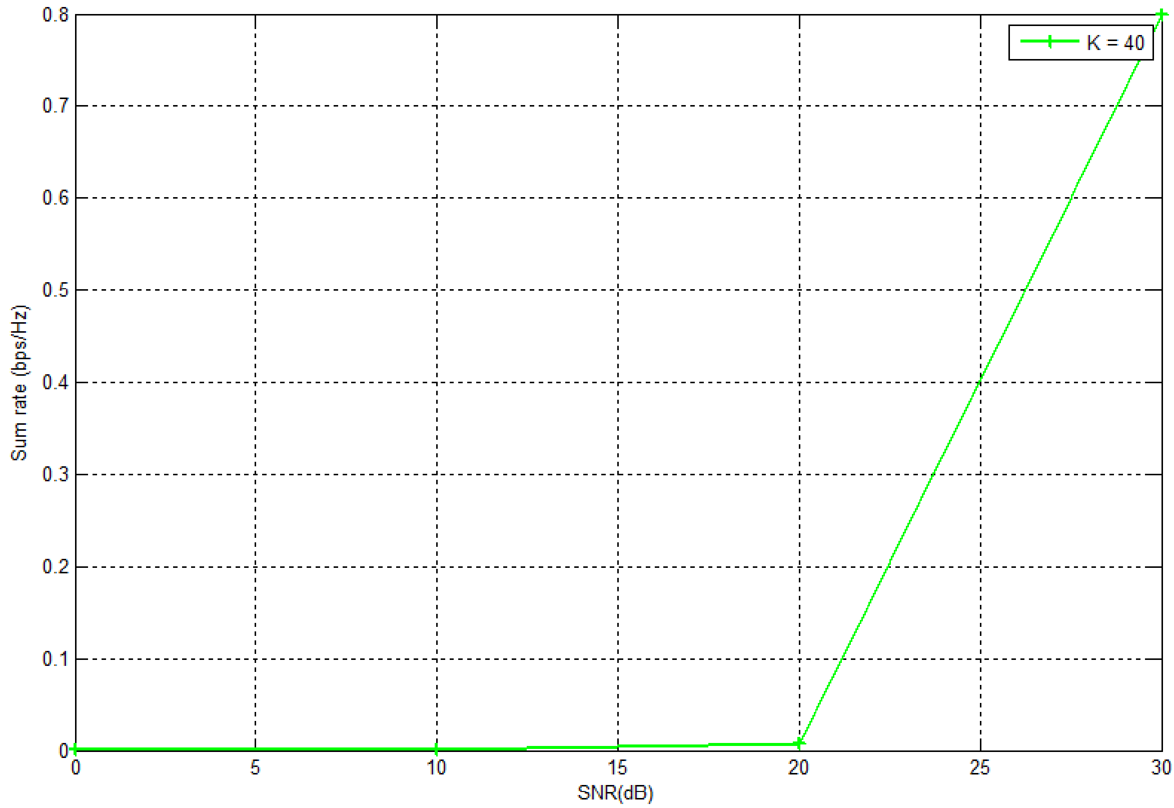


Figure IV.6: Impact of number of users k=40 on Sum Rate as a Function of SNR

The summation rate is practically zero until it reaches an SNR of around 20 dB, then it increases considerably.

The summation rate is initially zero for lower SNR values and increases rapidly when the SNR exceeds 20 dB This suggests a threshold situation where the system requires a higher SNR in order to achieve a significant summation rate.

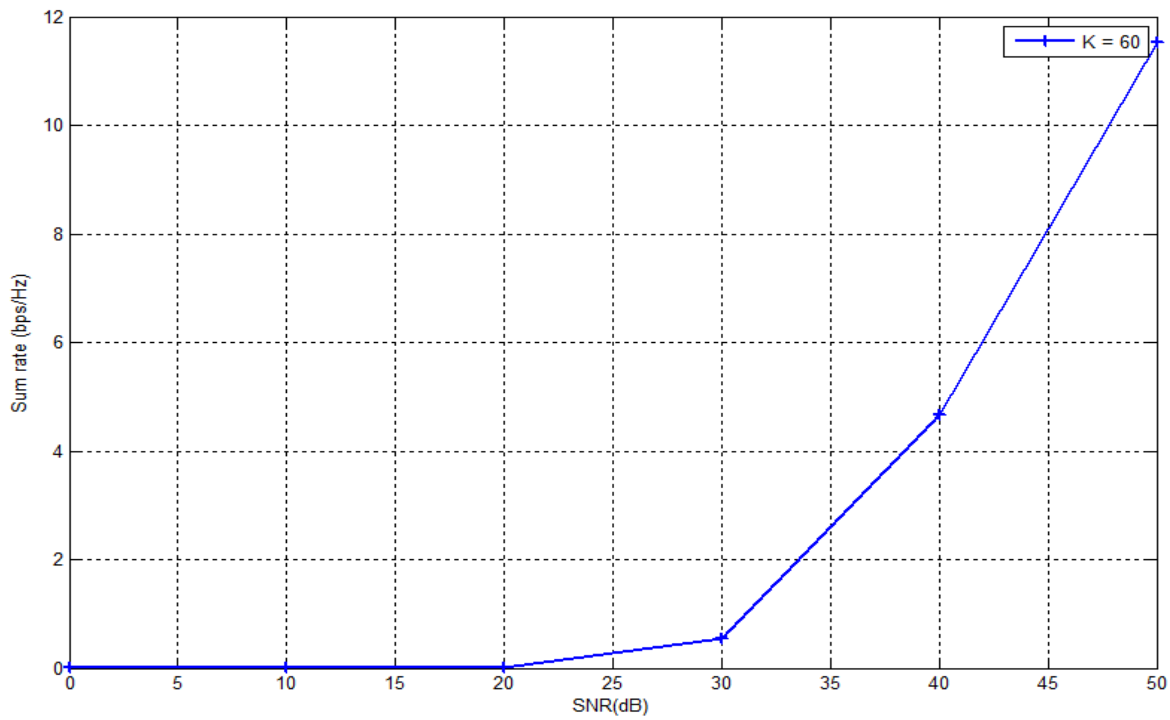
The summation rate for a value of K = 40 is much higher (up to 0.8 bps/Hz) than for a value of K = 20 (up to 9×10-^5 bps/Hz). This suggests that increasing K from 20 to 40 leads to a considerable improvement in system capacity.

IV.12.2/ Analysis of the impact of noise on transmission: study of system behavior as a function of signal-to-noise ratio :

The study shows that the summation rate increases linearly with the improvement in SNR, with no apparent threshold for a number of users of 20. However, for a number of users of 40, there is a clear threshold of 20 dB SNR, below which the summation rate is almost zero, and above which it increases rapidly.

System performance with 40 users is higher at higher SNR values, but a higher SNR is required to benefit from this improvement.

The graphs above illustrate how the summation rate varies as a function of the signal-to-noise ratio for different numbers of users. When the number of users is lower, the summation rate increases steadily as a function of the signal-to-noise ratio, showing a steady but limited improvement in performance. For a higher number of users k=40, the system has a threshold effect, where performance remains poor until a certain SNR is reached, beyond which the summation rate improves considerably. As a result, increasing the number of users improves overall capacity, but requires a higher SNR to free up this capacity.



<u>Figure IV.7:</u> Impact of number of users k=60 on Sum Rate as a Function of SNR

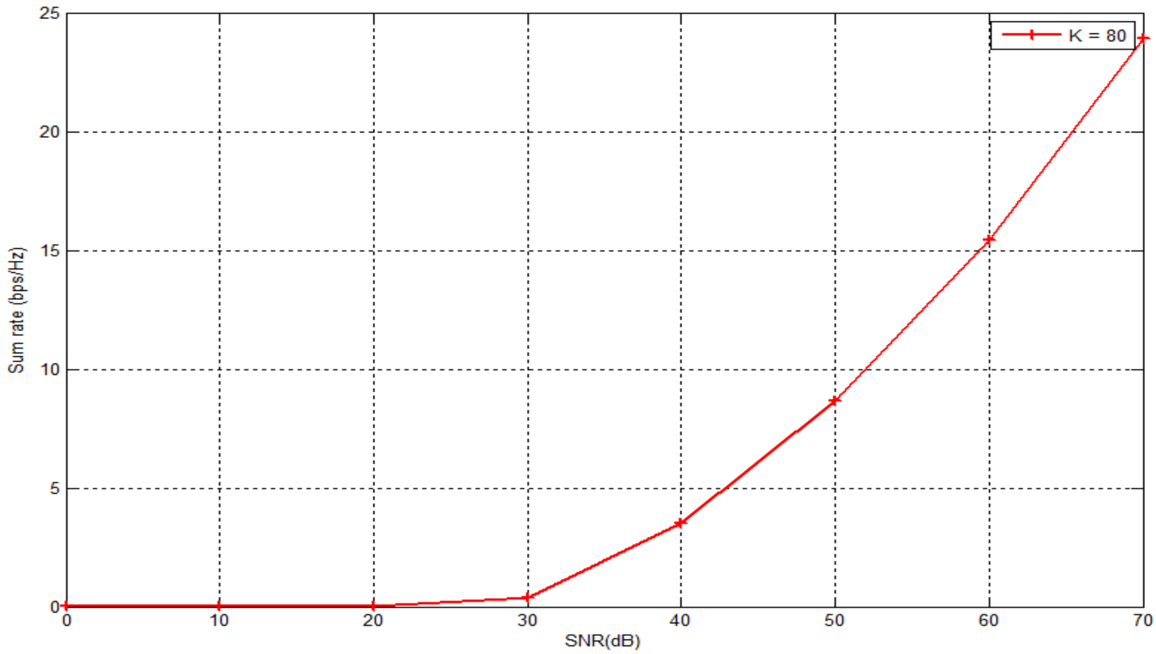


Figure IV.8: Impact of number of users k=80 on Sum Rate as a Function of SNR

Figure 3 shows a curve with K = 60. The SNR increases approximately constantly as the summation rate increases from 0 to 50 dB. The summation rate increases rapidly with increasing SNR when K is set to 60, indicating a steep slope of the curve.

Figure 4 shows a curve with a value of K = 80. In the first graph, there is a linear increase in the addition rate as the SNR increases, but at a slower rate than when K = 60. The slope of the curve is gentler, suggesting that the increase in summation rate is slower as the SNR increases when K is set to 80.

Comparing the two graphs, we can see that the number of users K has an impact on the speed at which the summation rate increases as a function of SNR. The summation rate increases more rapidly with increasing SNR when K is lower (K = 60), which is reflected in a narrower curve. On the other hand, when K is higher (K = 80), the summation rate increases more slowly with increasing SNR, resulting in a less straight curve.

It would be beneficial to use these graphs to study the performance of communication systems, or to adjust system parameters according to the desired trade-off between summation rate and SNR for various values of K.

IV.12.3/ Conclusion:

In wireless networks with multiple users, SNR is beneficial for prioritizing various users and plays a crucial role in network management and enhancement. By modifying the weights, the system can give priority to certain users, which has an impact on the overall sum rate.

In short, the number of users or access points has a considerable influence on the sum rate in different communication systems

Chapter 05 : NOMA VS OMA

V.1/Introduction :

The radio access technology known as non-orthogonal multiple access (NOMA) is designed to increase the capacity of wireless communication networks. Unlike conventional multiple access methods, such as orthogonal multiple access (OMA), which separate users in time, frequency or code domains, non-orthogonal multiple access allows multiple users to share the same time and frequency resources. To achieve this, signals from different users are superimposed at different power levels, and advanced signal processing techniques are used at the receiver to separate the signals.[11]

V.2/NOMA's main features :

Overlay coding is used by NOMA to transmit several signals at the same time. Signals from different users are combined at different power levels.

At the receiver, the SIC is used to decipher superimposed signals. First, the signal with the highest power is decoded, then subtracted from the received signal, and the process is repeated for the other signals.

By allowing multiple users to share the same resources, NOMA considerably improves spectral efficiency.

NOMA has the ability to dynamically adjust power according to users' channel conditions, improving system fairness and flexibility. [11]

V.3/Differences Between OMA and NOMA:

V.3.1/Orthogonal Multiple Access (OMA):

In OMA, users receive orthogonal resources such as time, frequency or codes to avoid interference. Examples include Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA) and Code Division Multiple Access (CDMA). [11]

NOMA vs OMA :

OMA users are provided with orthogonal resources such as time, frequency or codes to avoid interference. Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA) and Code Division Multiple Access (CDMA) are examples.

Orthogonal separation limits resource utilization, which can lead to under-utilization.

Implementation is generally easier due to direct resource allocation and less complex receiver design. [11]

V.3.2/Non-Orthogonal Multiple Access (NOMA):

NOMA offers multiple users the possibility of sharing the same resources at different and frequent times, by separating users according to their power level.

Interference management requires advanced management methods such as SIC to understand superimposed signals.

Increased spectral efficiency due to simultaneous resource sharing between multiple users.

Due to the increased complexity, it is essential to implement power allocation and SIC strategies at the receiver level. [11]

V.4/Conclusion :

NOMA holds great promise for future wireless communication systems, offering significant improvements in spectral efficiency and ease of use over conventional OMA methods. When implementing NOMA, careful consideration must be given to power allocation and interference management, in order to take full advantage of its benefits. [11]

NOMA vs OMA :

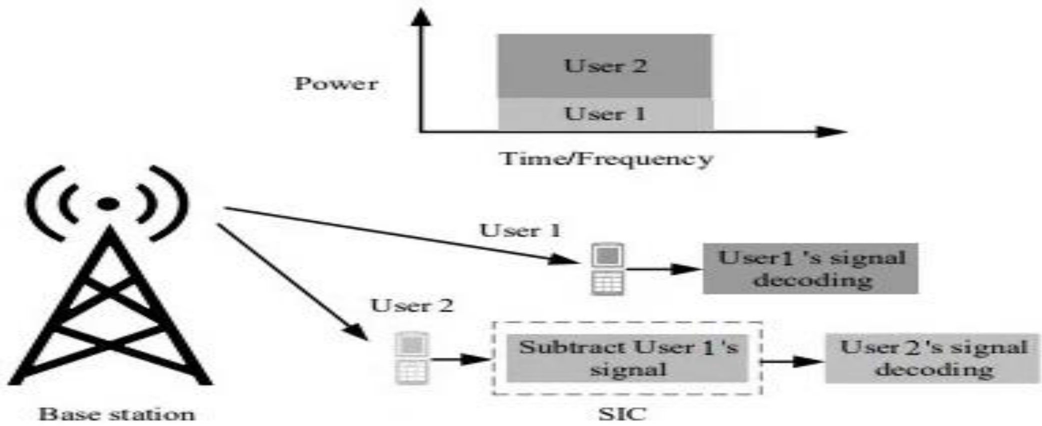
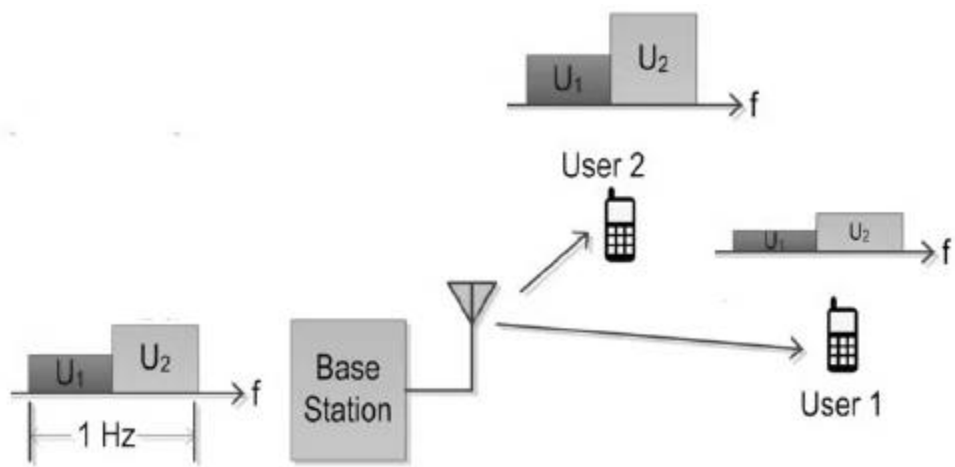


Figure V.1: NOMA [11]



Figue V.2: OMA [11]

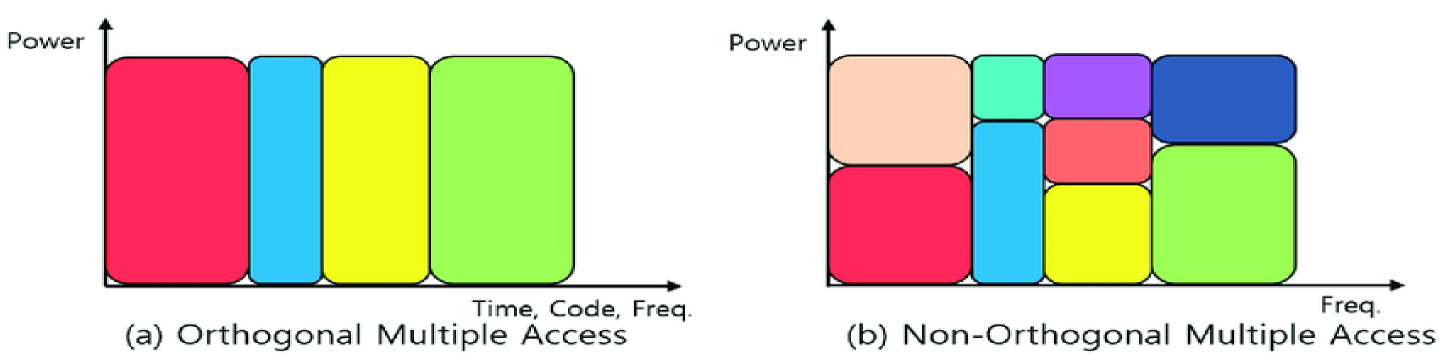


Figure V.3 : The difference between orthogonal multiple access OMA and non orthogonal-multiple

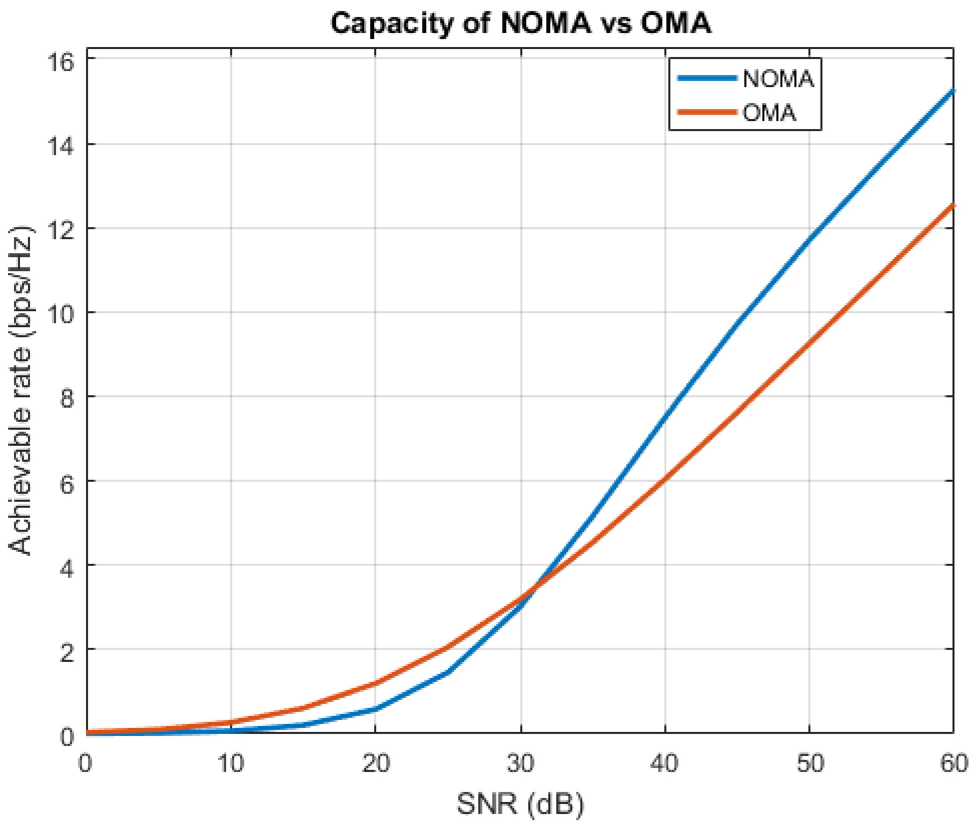


Figure V.4: Capacity NOMA VS OMA

General conclusion :

In conclusion, the continuous evolution of mobile networks has brought about a significant transformation in modern communication, providing users with seamless connectivity and easy accessibility. These advancements are made possible through the integration of cutting-edge technologies such as multiple access, multiplexing, and signal-to-noise ratio optimization, which work together to efficiently manage data transmission amidst the growing number of devices and users in the network. Various techniques, (FDMA), (TDMA), (CDMA), (OFDMA), (FDM), (TDM), (CDM), play crucial roles in optimizing network resources and maximizing spectrum utilization.

Ensuring a high signal-to-noise ratio is essential for maintaining reliable communication, particularly in challenging environments where interference and noise may disrupt signal transmission. It is imperative for network designers and engineers to have a deep understanding of these principles and leverage them effectively in the design and optimization of mobile networks to meet the increasing demand for high-speed data transmission and uninterrupted connectivity. By embracing these technologies and strategies, mobile networks can enhance user experiences, ultimately catering to the needs of an interconnected world that relies heavily on seamless communication and information exchange.

In summary, the ongoing evolution of mobile networks signifies a paradigm shift in the telecommunications landscape, ushering in an era of enhanced connectivity, accessibility, and user-centric experiences. By embracing and integrating advanced technologies and principles, mobile networks can continue to adapt and thrive in an environment where seamless communication and reliable connectivity are essential for driving innovation, productivity, and social interconnectedness.

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