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Optimization of multiple access protocols

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Dedication

To my dear parents,

I can't with these few lines to express my love and gratitude to you. However, I thank you very much for your continued support and great sacrifices in order to help me overcome all difficulties during my years of studies. I present this success with great respect and appreciation and hope to make you happy and proud of me more one day. ***«God bless you»****.*

To my dear sister Noura and My brothers Mohamed , Salah el din, Abed el Samed , Abed el Hak.

Thank you for staying with me and your sincere encouragement to me throughout my studies and during difficult times when I needed you most.

Thank you for staying by my side.

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To all my friends"Manel ,Houda ,Fatima ,Fatma", and to all my relatives,

For their help and moral support during the development of my graduation project.

To Sanaa,

Because you are a hardworking and persevering colleague, but you have also proven that you are a great friend

To ***TADJ EDDINE Mohamed Amine and Mohamed*** *for their helps.*

To my dear grandmother, May God bless her and place her in his widest heavens, to my dear grandfather, may God prolong his life, and to all those whose names I have forgotten.

"From the union of 'if' with 'but' was born a child named 'never' "

"There is no 'if' or 'but', you have to succeed"

Asma

Dedication

Praise be to Allah who has guided us in this humble work which I dedicate with the utmost expressions of love and gratitude:

I dedicate the results of this effort and the essence of this work to the one who gifted me the light of life, nurtured my steps, and dreamt of my future alongside me. To the one whose prayers were the secret of my success, my dear mother, may God prolong her life and keep her for me.

To the one who taught me how to hold the pen and how to write words without regret, I dedicate my success to my father, who worked hard and put in so much effort, only to leave before reaping the fruits of his labor and witnessing this success that would not have been possible without him.

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Abstract

Evaluating the performance of multiple access protocols (MAC) through the lens of Bit Error Rate (BER) is crucial for optimizing communication systems. BER measures the probability of errors occurring during data transmission. By analyzing BER under various MAC protocols, engineers can identify how these protocols handle collisions and channel access. This information is vital for choosing the most suitable protocol for a specific application. Protocols that are capable of reducing collisions will have a lower BER, which will lead to a more reliable data transmission. This evaluation process helps ensure efficient use of the shared channel and high-quality data delivery

The objective of this thesis is to evaluate the performance of multi-carrier systems, particularly focusing on systems based on the MC-CDMA (Multi-Carrier Code Division Multiple Access) technique. This technique combines OFDM (Orthogonal Frequency Division Multiplexing) and CDMA (Code Division Multiple Access), leveraging the advantages of both systems, making it highly suitable for the requirements of 4G and 5G.

We have attempted to use a new method to study and optimize the performance of the MC-CDMA system. We will apply genetic algorithms (GAs) for optimization. Then we have analyzing the importance of parameters using features selection methods .

Keywords: Multiple access protocols , BER ,MC_CDMA ,OFDM, CDMA,4G,5G Optimization , Genetic Algorithm , features selection

ملخص

تقييم أداء بروتوكولات الوصول المتعدد (MAC) من خلال معدل الخطأ الثنائي (BER) أمر بالغ الأهمية لتحسين أنظمة الاتصالات. يقيس BER احتمالية حدوث أخطاء أثناء نقل البيانات. من خلال تحليل BER تحت بروتوكولات MAC مختلفة ، يمكن للمهندسين تحديد كيفية إدارة هذه البروتوكولات للتصادم والوصول إلى القناة. هذه المعلومات ضرورية لاختيار البروتوكول الأكثر ملاءمة لتطبيق محدد. سيكون للبروتوكولات التي تتفوق في تقليل التصادم BER أقل ، مما يضمن نقل البيانات بشكل أكثر موثوقية. تساعد هذه العملية التقييمية في ضمان الاستخدام الفعال للقناة المشتركة وتسليم بيانات عالية الجودة.

تهدف هذه الأطروحة إلى تقييم أداء أنظمة الناقلات المتعددة ، مع التركيز بشكل خاص على الأنظمة التي تعتمد على تقنية MC-CDMA (Multi-Carrier Code Division Multiple Access).تجمع هذه التقنية بين OFDM (Orthogonal Frequency Division Multiplexing)و CDMA (Code Division Multiple Access) ، مستفيدة من مزايا النظامين ، مما يجعلها مناسبة تمامًا لمتطلبات 4 Gو G.5

لقد حاولنا استخدام طريقة جديدة لدراسة وتحسين أداء نظام MC-CDMA ؛ سنطبق الخوارزميات الوراثية (GAs) للتحسين ، بالإضافة إلى طرق اختيار الميزات لتحليل أهمية المعلمات.

الكلمات المفتاحية: بروتوكولات الوصول المتعدد ، نسبة الخطأ في البت(BER) ، MC_CDMA، OFDM، CDMA، الجيل الرابع(4G)، الجيل الخامس(5G) ، الخوارزمية الجينية، اختيار الميزات.

Résumé

Évaluer les performances des protocoles d'accès multiples (MAC) à travers le prisme du taux d'erreur binaire (BER) est crucial pour optimiser les systèmes de communication. Le BER mesure la probabilité d'erreurs lors de la transmission des données. En analysant le BER sous différents protocoles MAC, les ingénieurs peuvent identifier comment ces protocoles gèrent les collisions et l'accès au canal. Cette information est essentielle pour choisir le protocole le plus adapté à une application spécifique. Les protocoles qui excellent dans la réduction des collisions auront un BER plus faible, assurant une transmission de données plus fiable. Ce processus d'évaluation aide à garantir une utilisation efficace du canal partagé et une livraison de données de haute qualité.

L'objectif de cette thèse est d'évaluer les performances des systèmes multi-porteuse en se concentrant particulièrement sur les systèmes basés sur la technique MC-CDMA (Multi-Carrier Code Division Multiple Access). Cette technique combine OFDM (Orthogonal Frequency Division Multiplexing) et CDMA (Code Division Multiple Access), exploitant les avantages des deux systèmes, ce qui la rend très adaptée aux exigences de la 4G et de la 5G.

Nous avons utiliser une nouvelle méthode pour étudier et optimiser les performances du système MC-CDMA. Nous allons appliquer les algorithmes génétiques (GAs) pour l'optimisation. Ensuite nous avons utilisé les méthodes de sélection de caractéristiques pour analyser l'importance des paramètres.

Mots-clés : Protocoles d'accès multiple, BER, MC-CDMA, OFDM, CDMA, 4G, 5G, algorithme génétique, sélection des caractéristiques.

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List of Abbreviations

4G	Fourth generation.
ABC	Artificial Bee Colony .
AM	Amplitude Modulation
BER	Bit Error Rate.
CDMA	Code Division Multiple Access.
CS	Cuckoo Search
CSMA/CA	Carrier Sense Multiple Access /Collision Avoidance
CSMA/CD	Carrier Sense Multiple Access/ Collision Detection
CSMA/CR	CSMA with collision resolution
DE	Differential Evolution
DS	Direct Spreading
FA	Firefly algorithm
FDM	Frequency-division multiplexing
FDMA	Frequency Division Multiple Access.
FM	Frequency Modulation
FH	Frequency Hopping
GA	Genetic Algorithm
MC-CDMA	Multi-carrier Code-division Multiple Access

MIMO	Multiple-Input And Multiple-Output
MPC	Model Predictive Control
OSI	Open Systems Interconnection
OFMA	Orthogonal Frequency Division Multiple Access
PLC	Power Line Communication
PM	Phase Modulation
PSO	Particle Swarm Optimization
QAM	Quadrature Amplitude Modulation
SNR	Signal-To-Noise Ratio
TDM	Time-division multiplexing
TDMA	Time Division Multiple Access
TS	Tabu Search
WDM	Wavelength-Division Multiplexing
WLAN	Wireless Local Area Networks

General Introduction

In the world of computer networks, especially wireless ones, where numerous devices jostle for a single channel for communication, things can get messy. Imagine a room full of people all talking at once, creating a situation where chaos and confusion quickly take over. This is precisely where Multiple Access Protocols (MAC protocols) emerge as the ultimate traffic controller.

A MAC protocol is defined as a set of well-defined rules that govern how devices take turns transmitting data on the shared channel. The primary objective is to prevent collisions, which are unintended data glitches that arise when multiple devices communicate over each other. By ensuring orderly communication, MAC protocols facilitate the effective utilization of the channel.

Now, enhancing these protocols becomes a compelling challenge. There is no one-size-fits-all solution, as different protocols, such as Aloha, Carrier Sense Multiple Access (CSMA), and Frequency Division Multiple Access (FDMA)… each have their strengths and weaknesses. The optimal choice is contingent upon various factors, including the volume of data traffic, the degree of delay a network can tolerate, and the choice of wired or wireless connectivity.

The goal of optimization is to achieve the perfect balance between several key aspects. The highest priority is throughput, which refers to the amount of data successfully transmitted. However, speed is not the sole factor. The reduction of the time taken for data to reach its destination (delay) is equally crucial. Fairness also plays a crucial role in ensuring that all devices are afforded an equal opportunity to access the channel. Finally, stability is paramount - we do not want the network to become overloaded or collapse under the pressure!

MAC protocol optimization is a dynamic field that constantly evolves. As the demands on modern networks increase, researchers are constantly developing new and improved protocols to ensure smooth communication traffic flow and keep the network running efficiently.

This research seeks to evaluate the performance of multi-carrier systems, especially those based on the MC-CDMA multiple access technique. We are interested in optimizing the Bit Error Rate (BER) for optimal performance.

This manuscript is structured around four chapters:

- The first chapter presents an overview of the telecommunications system, the concept of modulation, and multiple access protocols.
- The second chapter covers the principles of spectrum spreading and an overview of MC-CDMA systems.
- The third part presents multiple access techniques and the essentials of genetic algorithms.
- And the fourth chapter describes the practical part. In this section, we present the corpus used, the results of applying decision trees, as well as the optimization results obtained.

CHAPTER 1:Multiple Access Protocol

1.1 Introduction

The efficient and fair sharing of communication channels between multiple devices is crucial for ensuring reliable data transmission in computer networking. This challenge is addressed by multiple access protocols, which govern how multiple users or devices access a shared communication medium, such as a wireless channel or a network segment. The management of shared resources, the prevention of data collisions, and the optimization of network performance require the utilization of MAC protocols. They are fundamental components of the Data Link Layer (Layer 2) in the Open Systems Interconnection (OSI) model and are essential for enabling communication between devices connected to the same network. Understanding MAC protocols is crucial for designing efficient and scalable networks, ensuring seamless communication, and accommodating diverse applications, ranging from local area networks to wireless networks and beyond.

This chapter provides an introduction to various MAC protocols, their mechanisms, and their applications in different network environments.

1.2 Telecommunication system

1.2.1. Definition: A telecommunications system is a collection of hardware, software, protocols, and infrastructure designed to enable the transmission, reception, and exchange of information over long distances. These systems facilitate communication between individuals, organizations, or devices through various means such as voice, data, video, and multimedia.[1]

1.2.2. The basic concept of telecommunication system

- ✓ **Information:** An information is the entity that is being transmitted. It can be expressed in the form of audio, video, temperature, picture, pressure, etc.

- ✓ **Message:** A message, in the context of communication, refers to a discrete unit of information that is transmitted from a sender to one or more recipients through a communication channel.

- ✓ **Signal:** In the context of telecommunications and electronics, a signal refers to a physical quantity or waveform that carries information from a sender to a receiver through a communication channel.

<u>Examples</u>:

- In a telephone conversation, the information might be a conversation between two individuals (spoken words), while the messages are the electrical signals carrying those words over the phone lines.
- In digital communication, information could be a text document (data), and the message would be the packets of data sent over a network.

<u>Relationship</u>:

- ✓ Transmission Process: Information is conceptualized and structured by a sender into a message. The message is then encoded into signals for transmission through a communication channel.
- ✓ Reception: Upon reception, the receiver decodes the signals back into the original message and interprets the information contained within it.

1.3. Multiplexing

Multiplexing or multiplexing is a method of sending multiple signals or information streams simultaneously as a single complex signal over a communications link (composite signal). When the signal search their destination, a process called demultiplexing or demultiplexing reconstructs the individual signals and outputs them to the individual lines. [2]

Multiplexing allows network devices to communicate with each other without requiring a dedicated connection between each pair of devices. However, multiplexing still requires shared media. For example, multiplexing can be used to transmit multiple signals over satellite uplinks, cables, or fiber optic bundles that run between metropolitan areas. [3]

1.3.1. Types of Multiplexing

There are several types of multiplexing, but the most common are:

- **Frequency-division multiplexing (FDM)**: This technique involves the division of the available bandwidth of a communication channel into multiple sub channels, each with a distinct frequency range. Each signal is modulated to a distinct carrier frequency within the designated bandwidth. The signals are then combined and sent over the channel. At the receiving end, the signals are separated by means of filters and demodulated in order to retrieve the original signals. [4]

Figure 1. 1 **:** Frequency-division multiplexing[4]

- **Time-division multiplexing (TDM)**: This technique divides the available time on a communication channel into multiple time slots. Each signal is assigned a specific time slot in which to transmit its data. The signals are transmitted sequentially over the channel. At the receiving end, the signals are separated based on their time slots and demodulated to recover the original signals.[5]

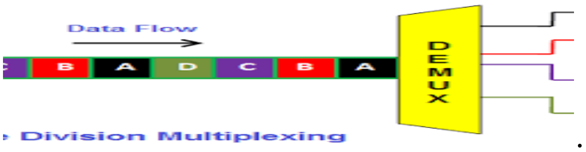

Figure 1. 2 **:** Time-division multiplexing.[5]

- **Wavelength-division multiplexing (WDM)**: This technique is similar to FDM, but it uses different wavelengths of light to carry different signals on a single fiber optic cable. Each signal is modulated onto a different wavelength of light. The signals are then combined and transmitted over the fiber. At the receiving end, the signals are separated using filters and demodulated to recover the original signals. WDM is commonly used in optical communication systems.[6]

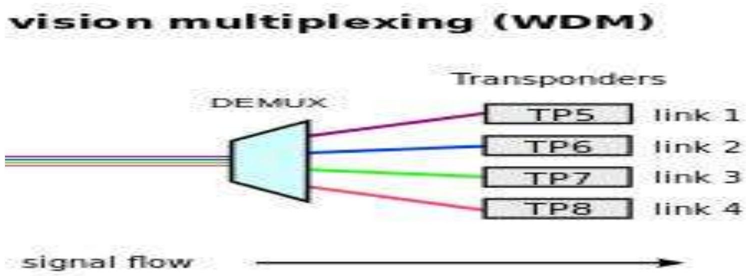

Figure 1. 3 : Wavelength-division multiplexing .[6]

- **Space-division multiplexing (SDM)**: This technique divides a physical medium into multiple channels and transmits different signals on each channel simultaneously. An example of SDM is the use of multiple lanes on a highway to carry different streams of traffic. SDM is also used in some wireless communication systems, such as MIMO (multiple-input and multiple-output).[6]

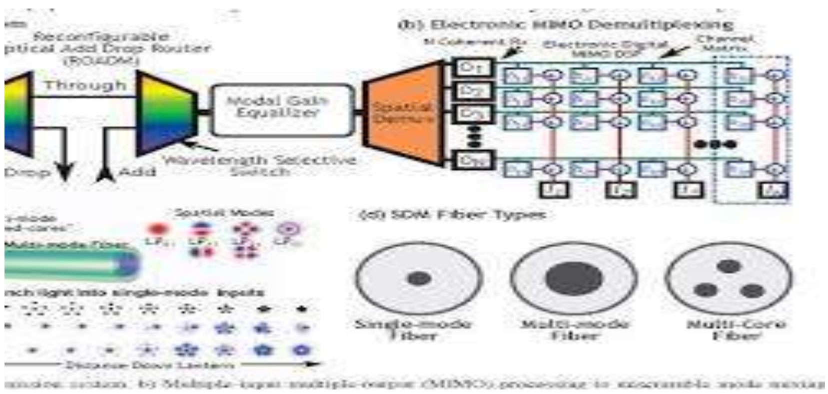

Figure 1. 4 : Space-division multiplexing .[6]

1.4. *Modulation*

1.4.1. ***Definition*** **:** Modulation is a process of conversion of data into waves by adding information to a carrier signal. A signal can be an electronic or optical carrier, but it should have a steady waveform. A signal with a steady waveform indicates that it possesses a constant amplitude and frequency. Moreover, one can add information on such a carrier through modulation by altering its frequency, phase, amplitude, polarization in the case of optical signals. [7]

1.4.2. Types of modulations

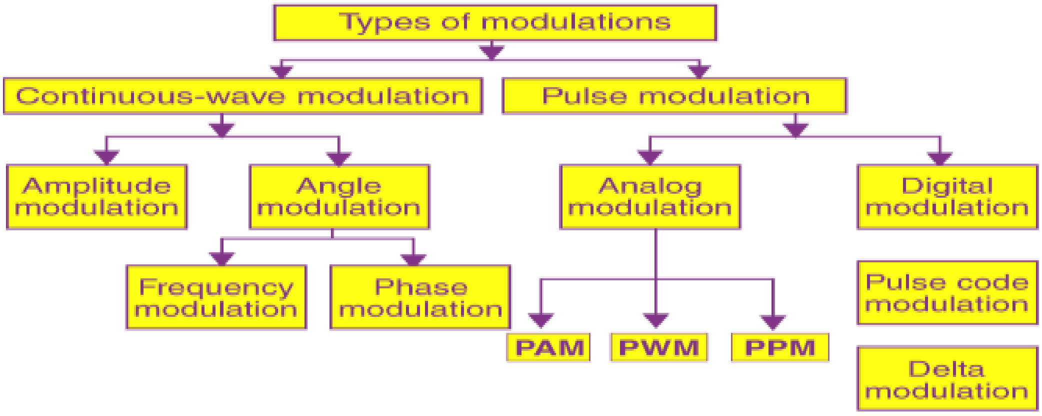

Figure 1. 5 : Types of modulation.[8]

1.4.2.1. Amplitude Modulation (AM): The process of changing the amplitude of the signal wave by impressing or superimposing it on a high-frequency carrier wave, keeping its frequency constant, is called amplitude modulation.**[8]**

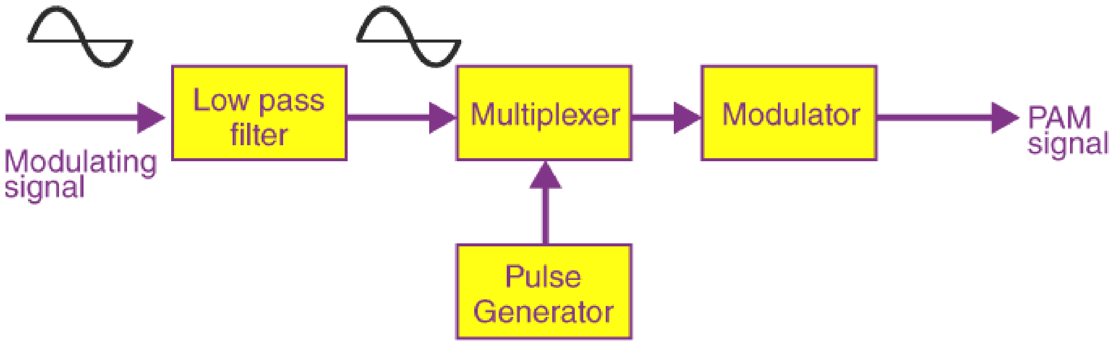

Figure 1. 6 : Amplitude Modulation[8]

1.4.2.2. Frequency Modulation (FM) : Frequency modulation is a technique in which the frequency of the message signal is varied by modulating with a carrier wave. It is better than amplitude modulation because it eliminates noise from various sources.[8]

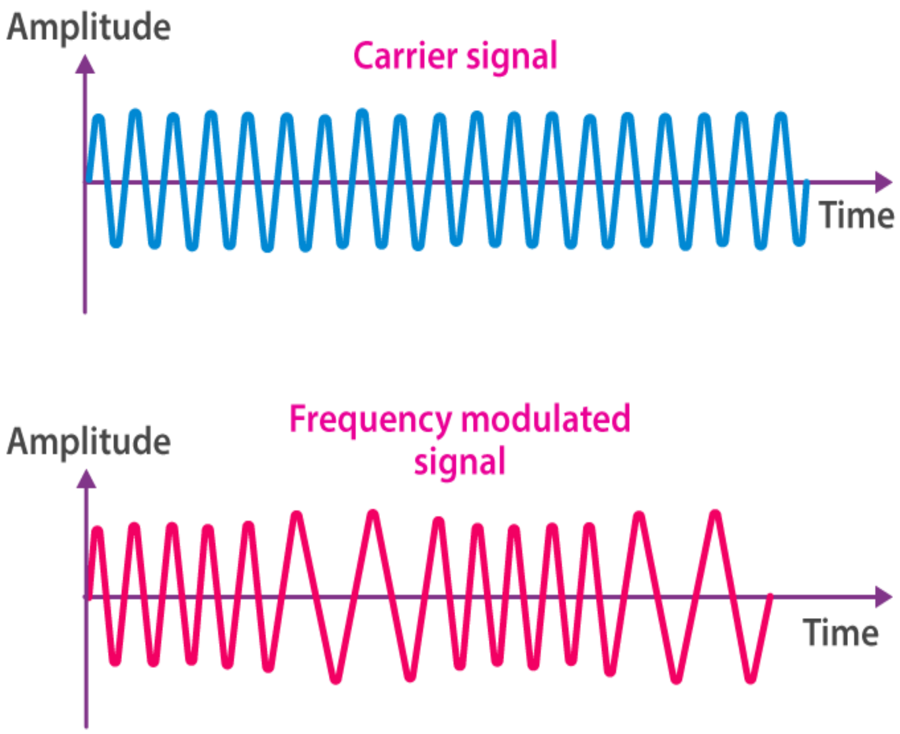

Figure 1. 7: Frequency Modulation. [8]

1.4.2.3. Phase Modulation (PM) : The phase of the carrier wave changes the phase of the signal wave. The phase shift after modulation is dependent on the frequency of the carrier wave as well. Phase modulated waves are immune to noise to a greater extent. [8]

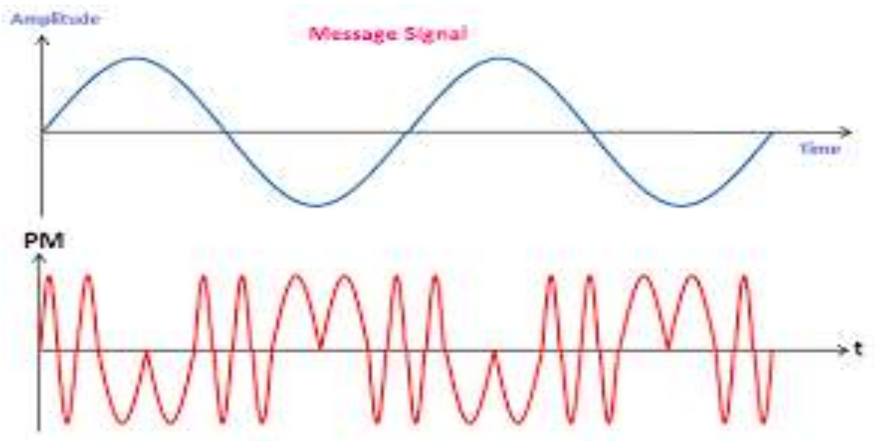

Figure 1. 8: Phase Modulation. [8]

1.4.3. Importance of modulation

Modulation is of paramount importance in telecommunications and signal processing for several reasons, it plays a critical role in communication systems by enabling the efficient transmission and reception of information. It acts as a bridge between the information source (e.g., microphone, computer) and the communication channel (e.g., cable, airwaves).

Here's a breakdown of its importance:

- **Overcoming Source Signal Limitations:**
  - Information sources like microphones or computers generate signals with low frequencies and weak power levels, making them unsuitable for direct transmission over long distances.
  - Modulation addresses this by encoding the information signal onto a high-frequency carrier wave with properties more appropriate for the channel. This is explained in detail in "Communication Systems Engineering.
- **Efficient Channel Utilization:**
  - Communication channels have a limited bandwidth (capacity to carry information). Modulation allows for efficient use of this bandwidth by utilizing different characteristics of the carrier wave.
  - For instance, Amplitude Modulation (AM) varies the amplitude, while Frequency Modulation (FM) varies the frequency of the carrier wave to represent the information signal. This concept is covered in "Fundamentals of Communication Systems
- **Multiplexing and Sharing Channel:**
  - Modulation enables a technique called multiplexing, which allows multiple signals to share the same channel simultaneously. Different carrier waves can be modulated with separate information sources and then separated at the

receiver using demodulation techniques. This is explained in “Communication Systems. [9]

1.5. Multiple Access Protocol

Multiple Access Protocol is an access mechanism and a set of rules for successful transmission of information using a common medium.

When a sender and receiver have a dedicated link to transmit data packets, the data link control is sufficient to manage the channel. However, when multiple stations share a channel and simultaneously transmit data, it can lead to collisions and crosstalk. Therefore, a multiple access protocol is necessary to minimize collisions and prevent crosstalk between the channels. [10]

1.5.1. Classification of Multiple Access Protocols

Multiple Access Protocols can be classified into many different processes , are listed below:

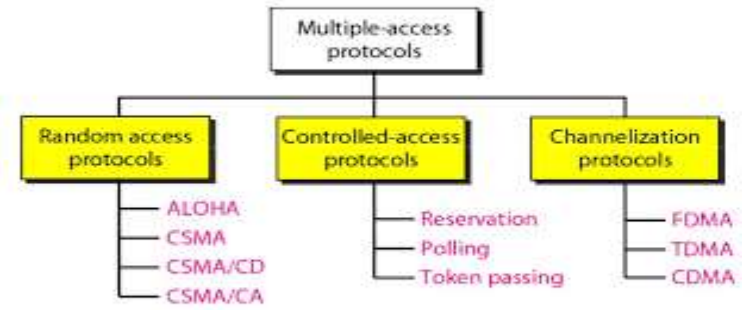

Figure 1.9: Classification of multiple access protocols. [11]

1.5.1.1. Random Access Protocols

This protocol, all stations have the same priority when sending data over the channel. In a direct access protocol, one or more stations cannot depend on another station, nor can one station control another station. Depending on the status of the channel (idle or busy), each station sends a data frame. However, if multiple stations send data over a channel, collisions or data collisions may occur. Data frame packets may be lost or altered due to collisions. So it won’t be received on the receiving end.

The Random access protocols are divided in for types:

1) **ALOHA protocol:** The ALOHA protocol was designed by Abramson to provide radio communication between several terminals scattered at various places over the

islands of Hawaii. The terminals were sending their data packets to a central station over a common channel (the upstream channel). The central station was then retransmitting the packets to another channel (the downstream channel) that could be listened to by all the terminals.

Collisions could occur at the upstream channel if more than one terminals were attempting to transmit their packets. If this happened, the central computer was informing all the terminals that a collision had occurred.[12]

The two protocols of Aloha are:

- **Pure Aloha :** is the original version of ALOHA, operates on a single shared channel where stations can send frames whenever they have data to transmit. However, due to this shared nature, collisions between frames from different stations can occur.[10]
- **Slotted Aloha:** is a straightforward adaptation of Pure-ALOHA. It mandates that messages be transmitted during the time slot between two synchronization pulses and only at the start of a time slot. This adjustment effectively cuts the collision rate in half. Consequently, the throughput doubles and the average transmission delay is halved compared to Pure-ALOHA. Additionally, the impact of the Capture effect is altered.[10]

2) **Carrier Sense Multiple Access (CSMA) protocols:**

The CSMA protocol is an evolution of ALOHA and takes advantage of certain terminal features to improve performance. It turns out that the necessary terminal functionality exists in real systems depends on the transmission medium, i.e. H. Whether communication occurs via cables (twisted pair, coaxial cable, fiber optics) or via radio waves in the atmosphere (wireless communications).[13]

CSMA is based on the principle “sense before transmit” or “listen before talk” CSMA can reduce the possibility of collision, but it can not eliminate it. [14]

The CSMA access modes:

- **1-persistent:** The I-persistent method is simple and straightforward. Use this method: When a station is free, it immediately sends its frame (with probability I). This method has the highest probability of collision because two or more sites can be found The line is idle and the frame is sent immediately.[14]

- **Non-persistent:** In the non-persistent method, a station that has a frame to send senses the line. If the line is idle, it sends immediately. If the line is not idle, it waits a random amount of time and then senses the line again.[14]

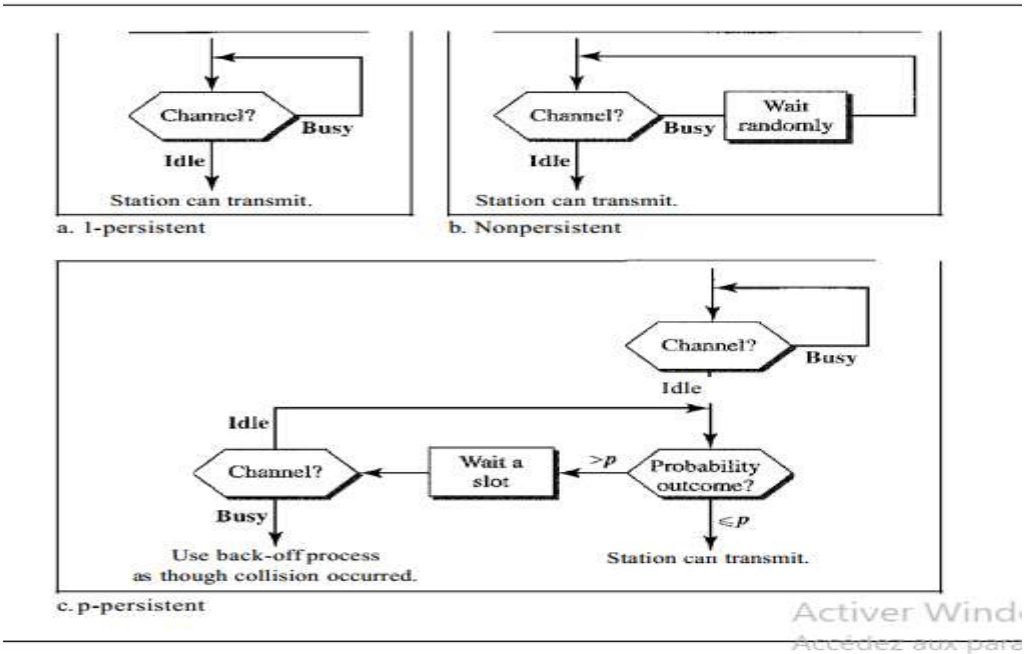

Figure 1.10: the flow diagrams for these methods.[14]

3) **Carrier Sense Multiple Access/ Collision Detection (CSMA/CD):** CSMA/CD is the basis of the classic Ethernet LAN. Making it essential to examine in detail. It’s crucial to understand that collision detection is an analogy process. The station’s hardware needs to monitor the channel while transmitting. If the received signal differs from the transmitted signal, it indicates a collision. This implies that the received signal should not be significantly weaker than the transmitted signal (a challenge for wireless, where received signals may be 1,000,000 times weaker than transmitted signals). Additionally, the modulation must be selected to enable collision detection.[12]

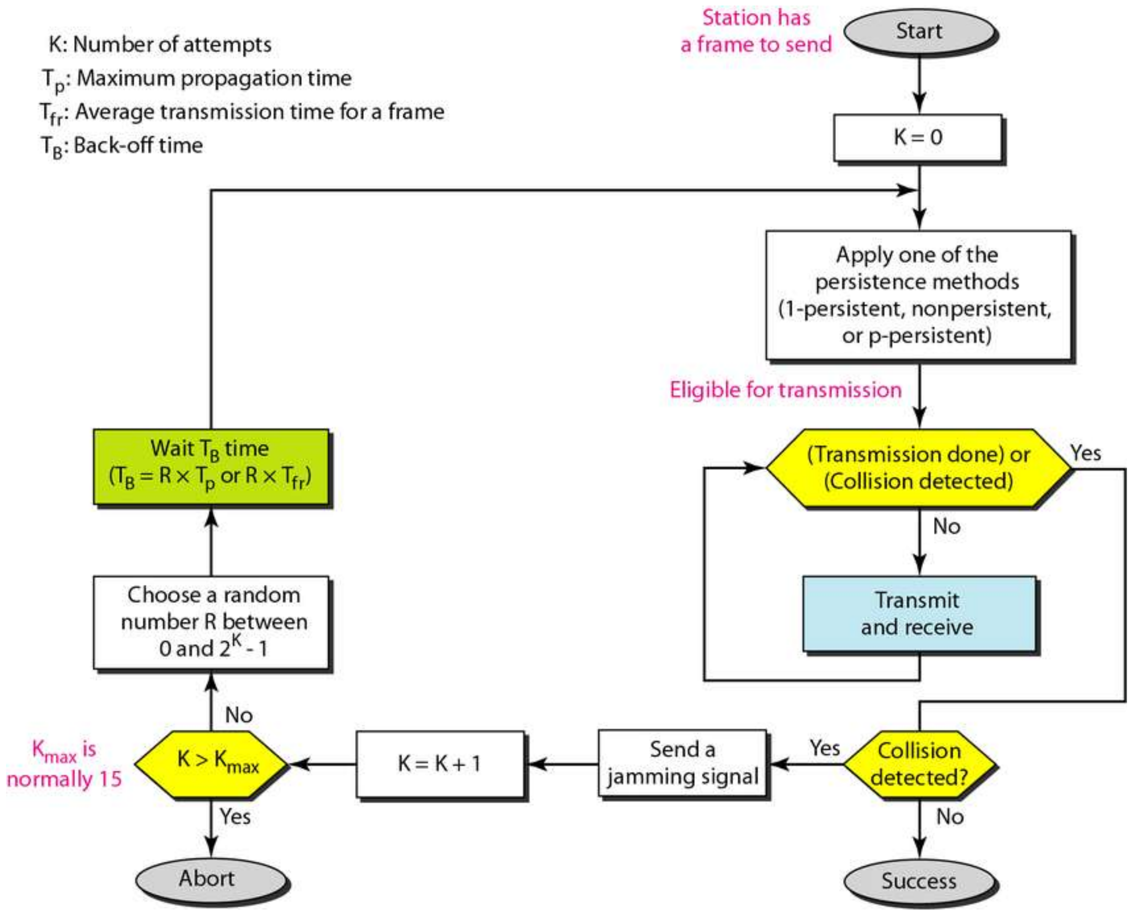

Figure 1.11: Flow diagram for the CSMA/CD. [14]

- In CSMA/CD, stations listen for network traffic and wait for the medium to be clear before transmitting. If a collision is detected during transmission, a jam signal is broadcasted to resolve the collision. CSMA/CD aims to improve network efficiency by avoiding collisions through collision detection and resolution. CSMA/CD has been compared to CSMA with collision resolution (CSMA/CR), which offers lower delay and improved throughput-delay characteristics. CSMA/CR allows transmitting stations to detect collisions and resolve them by broadcasting a jam signal during a collision detection period. By finding the optimal length of the collision detection period based on the number of contending stations, CSMA/CR achieves lower delay and improved performance compared to traditional CSMA/CD protocols. Overall, CSMA/CD and CSMA/CR are both multiple access protocols that aim to efficiently manage network traffic and minimize collisions in Ethernet networks. [15]

4) **Carrier Sense Multiple Access /Collision Avoidance (CSMA/CA) :** The carrier sense multiple access with collision avoidance (CSMA/CA) mechanism of the MAC protocol of this standard.

The principles of the CSMA/CA protocol have been applied to the specification Wireless Local Area Networks (WLAN), it used for carrier transmission in networks using the 802.11 standard. [13]

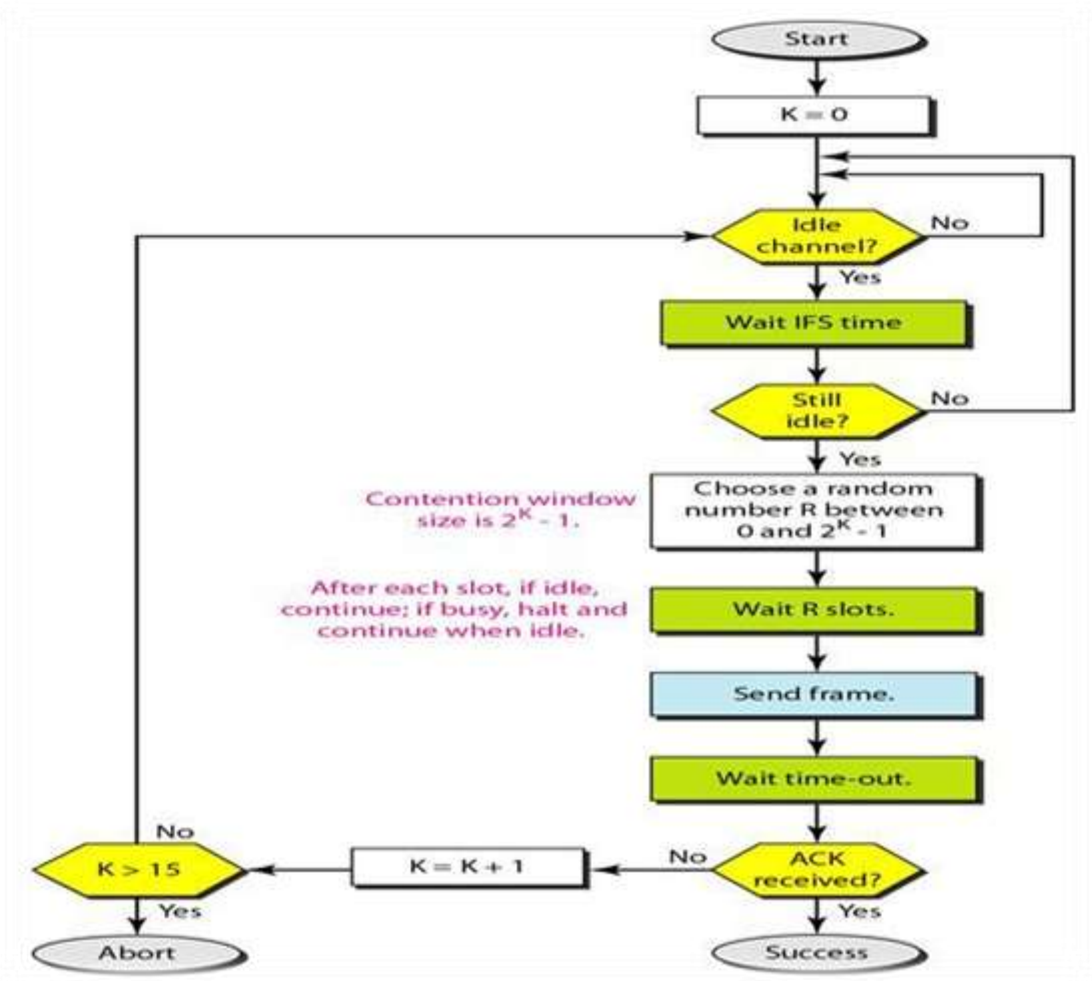

Figure 1.12: Flow diagram for CSMA/CA. [13]

1.5.1.2. Controlled Access Protocols

The **station** sends **the data after receiving approval from all other** stations. **Controlled access** stations **exchange information** to **determine which station** is **authorized** to **transmit**. To **prevent message** collisions on **the shared medium**, **only one node** is **allowed** to **send** at a **time**.

There **are three controlled access** technologies:

1. **Reservation**: Reservation is method of controlled access, stations must reserve a slot before transmitting data. Time is segmented into intervals, with each interval containing a reservation frame preceding the data frames transmitted within that interval. If there are N stations in the system, there are precisely N reservation mini-slots within the reservation frame. Each mini-slot is assigned to a specific station. When a station needs to transmit a data frame, it reserves its allocated mini-slot. [14] Figure shows a situation with five stations and a five-mini slot reservation frame. In the first interval, only stations 1, 3, and 4 have made reservations. In the second interval, only station 1 has made a reservation.

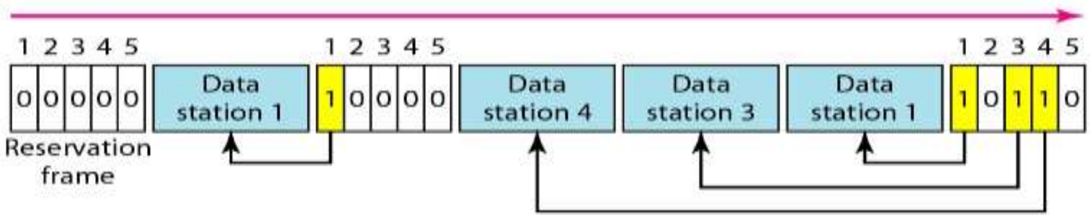

Figure 1.13: *Reservation Access Method. [11]*

2. P**olling:** Polling is suitable for topologies in which one device is designated as the master the remaining devices are slave stations. All data exchange must occur through the primary device, even if the final destination is the secondary device. The primary device controls the connection; the secondary device follows its instructions. It the master device decides which device can use the channels specific time. Therefore, the master device is always the initiator of the session. [14] This method uses poll and select functions to prevent collisions.

3. **Token Passing:** Token Passing is one of the Controlled Access method in which there is a control mechanism that decides which station gets the access to transmit the data. The System on Chip for token passing mechanism as seen from the flowchart in **(Figure 1.14)**makes use of a token of 2 bits, an enable to activate the device and four stations that contest with one another to transmit the data.[11]

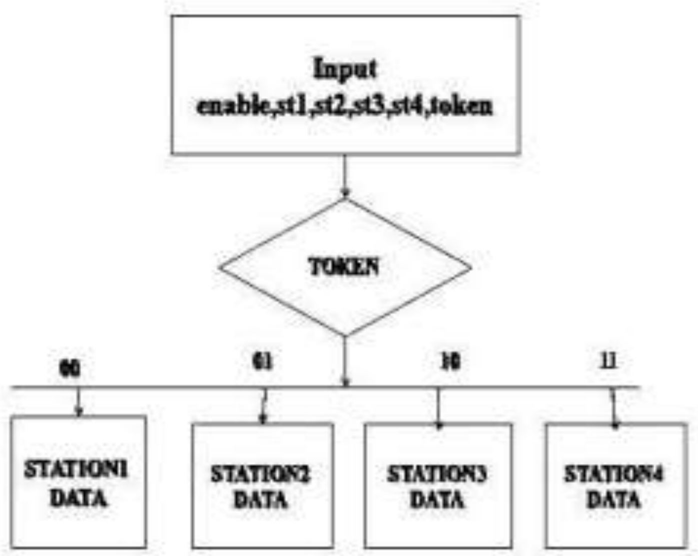

Figure 1.14: Flow Chart for Token Passing Implementation. [11]

1.5.1.3. Channelization Protocols:

Channelization protocols allow multiple stations to access the same channel simultaneously by dividing the link's available bandwidth by time, frequency, and code. The three types of channelization are:

✓ **FDMA (**Frequency Division Multiple Access) : In this system, the frequency bandwidth is divided into disjoint subband (channels), each subband is individually allocated to a single user and separated by guard bands to avoid resource overlap. Resources are defined here as subband. Since each sub-band is always occupied by a dedicated user, continuous communication is possible over a longer period of time. FDMA is more suitable for narrowband systems because the subband channels can be very narrow.[16]

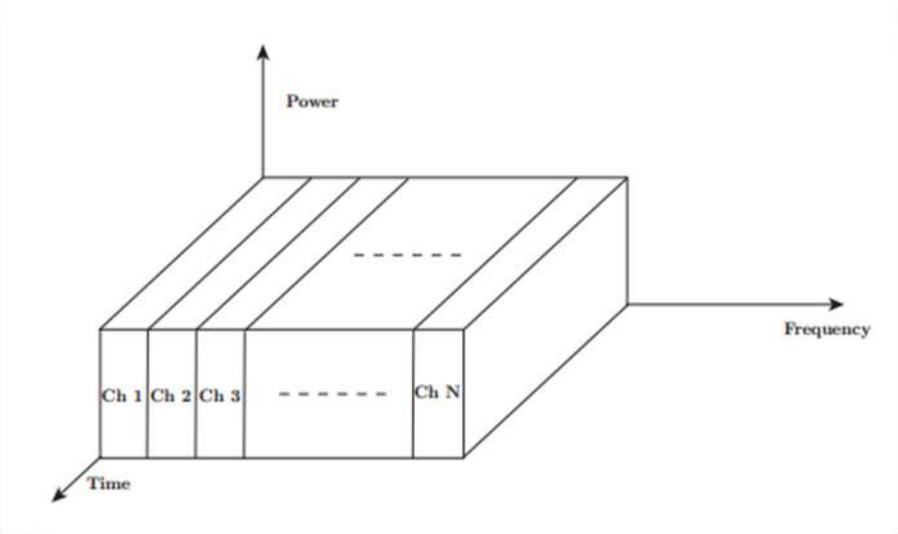

Figure 1.15: The concept of FDMA. [16]

FDMA is a well-established technology that's relatively simple to implement compared to other methods like TDMA or CDMA (Code Division Multiple Access).But As the number of users increases, so does the demand for channels. With a fixed amount of spectrum available, FDMA can become inefficient if too many users try to access the system simultaneously.

- ✓ **TDMA (**Time Division Multiple Access): In this system, each user occupies the entire bandwidth during specific time slots allocated to them, in a setup known as a TDMA frame transmission. This frame gathers a fixed number of slots, and each user's time occupancy within a frame's time slot is cyclically repeated. While this approach may introduce delays between successive transmissions and potentially varying channel environments, it offers the advantage of low battery consumption.

Similarly to FDMA, short yet sufficient guard time intervals are required to avoid interference between adjacent time slot signals.[16]

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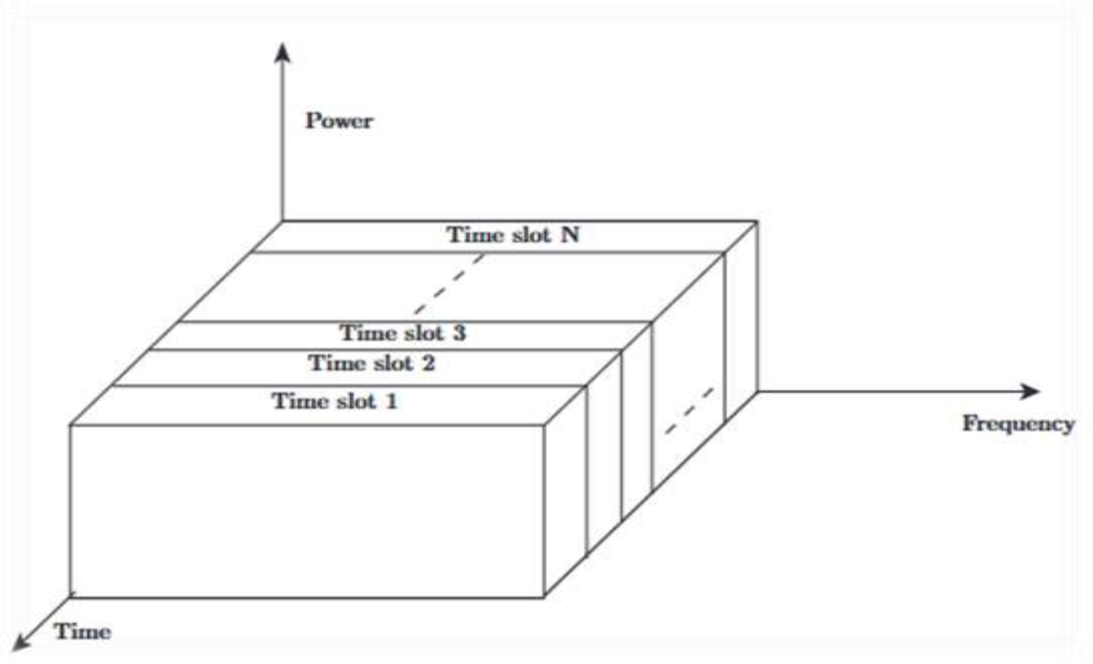

Figure 1.16: The concept of TDMA [16].

- ✓ **CDMA (**Code Division Multiple Access)**:** It can be considered a hybrid of FDMA and TDMA, as all active users can simultaneously occupy the entire carrier frequency bandwidth. Differentiation between user signals is achieved through the use of unique spreading codes, either through Direct Spreading (DS) or Frequency Hopping (FH). Each user's transmitted information can be independently retrieved by the receiver, which utilizes a match filter for each code. Despite the lack of synchronization between transmitters for resource utilization, CDMA effectively mitigates interference through code separation. However, it is important to note that CDMA has relatively low throughput performance. [16]

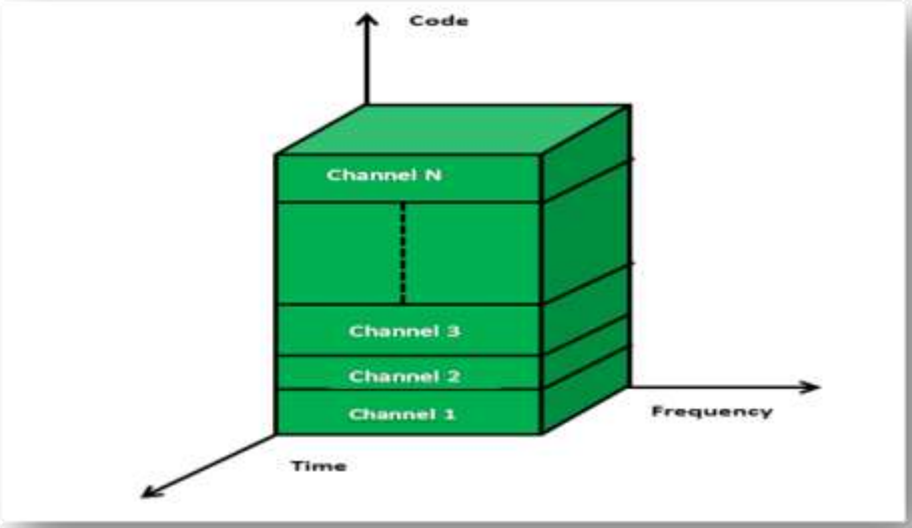

Figure 1.17: The concept of CDMA. [16]

- ❖ Code Division Multiple Access (CDMA): is a channel access method used in various communication systems, particularly cellular networks. Unlike FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access) which divide the channel based on frequency or time slots, CDMA allows multiple users to share the same frequency band simultaneously. It achieves this through a clever technique called spread-spectrum communication. [17]

- ❖ CDMA is a powerful technology that has revolutionized cellular communication by enabling increased capacity and smoother handoffs. While its complexity and potential for interference pose challenges, CDMA remains a key player in modern wireless communication systems, especially for applications requiring high capacity and robust connections.[17]

2. Orthogonal Frequency Division Multiple Access (OFDMA):

(OFDMA) is a multi-user version of the popular orthogonal frequency-division multiplexing (OFDM) digital modulation scheme. In OFDMA, the total spectral resource is divided into multiple orthogonal subcarriers, which are assigned to different users for simultaneous transmission. This technique allows for low-data-rate transmission from several users at the same time. OFDMA is known for its robustness to narrowband interference, impulse noise, and other signal impairments typical in networks like CATV. Adaptive user-to-subcarrier assignment can be achieved based on channel feedback information, improving system spectral efficiency. Different numbers of subcarriers can be assigned to different users to support differentiated quality of service. OFDMA combines frequency-domain and time-domain multiple access, making it suitable for broadband wireless networks due to its scalability and ability to utilize multiple antennas. Overall, OFDMA offers advantages in terms of bandwidth and power efficiency, making it a promising technology for high data rate wireless and wire line communications.[18]

1.5.2. Evaluation

All these protocols (CSMA/CA, TDMA, FDMA, and SDMA) tackle the challenge of sharing a single communication channel efficiently among multiple devices. Here’s a breakdown of their key differences:

A. Approach to Sharing the Channel:

- **CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance):** Relies on carrier sensing and random back off to avoid collisions altogether. Devices listen before transmitting and wait for a random amount of time to minimize the chance of multiple devices transmitting simultaneously. (Think of taking turns in a conversation with a short, random wait to avoid talking over each other).

- **TDMA (Time Division Multiple Access):** Divides the channel into fixed time slots and assigns these slots to devices. Only one device transmits per slot, eliminating collisions. (Think of designated speaking times in a meeting).

- **FDMA (Frequency Division Multiple Access):** Divides the available frequency band into multiple non-overlapping channels. Each channel carries data for a specific user or conversation, preventing interference. (Think of multiple radio stations broadcasting on different frequencies).

- **OFDMA (Orthogonal Frequency Division Multiple Access):** An advanced version of FDMA used in Wi-Fi 6 and beyond. It divides the channel into smaller subcarriers and allocates them dynamically to users based on their needs. This allows for more efficient use of the frequency band. (Think of dividing a highway into lanes, but lanes can be dynamically assigned to different types of vehicles based on traffic).

- **SDMA (Space Division Multiple Access):** Employs smart antennas to create focused signal beams directed towards specific users. This spatial separation reduces interference and increases capacity. (Think of a teacher using a microphone to direct their voice towards the students, minimizing background noise).[19]

B. Focus:

- **CSMA/CA, TDMA, FDMA, and OFDMA:** Primarily focus on managing access to the shared resource (channel) by dividing it in time, frequency, or subcarriers.

- **SDMA:** Focuses on directing the signal itself towards specific users, improving spatial efficiency .[19]

Feature	CSMA/CA	TDMA	FDMA	OFDMA	SDMA
Approach	Collision Avoidance	Time Slots	Frequency Channels	Subcarriers (Dynamics allocation)	Focused Signal Beams
Resource Division	**No**	Time	Frequency	subcarriers	space
Focus	Channel Access	Channel Access	Channel Access	Channel Access	Signal direction
Suitability	Wired/ Wireless Networks	Voice Communication	Cellular Networks	Wi-Fi 6 and beyond	Cellular Networks (often combined with others)

Table2: Difference between CSMA, TDMA, FDMA, OFDMA and SDMA. [19]

1.6. Conclusion

In conclusion, the basic concepts of telecommunication form the foundation of modern communication systems, enabling the transmission of information over short and long distances efficiently and reliably. These concepts encompass various elements such as information sources, communication channels, transmitters, receivers, and multiplexing techniques. By understanding these fundamental principles, telecommunications engineers and professionals can design, implement, and manage robust communication networks that meet the growing demands of users and applications.

Telecommunication systems continue to evolve rapidly, driven by advancements in technology, increasing demand for connectivity, and emerging applications. As new technologies such as 5G, Internet of Things (IoT), and artificial intelligence (AI) reshape the telecommunications landscape, a solid understanding of the core concepts remains essential for addressing challenges, optimizing performance, and harnessing the potential of emerging opportunities.

In summary, multiple access protocols are a fundamental aspect of modern communication systems, enabling efficient sharing of communication channels among multiple users. Through the use of various techniques such as TDMA, FDMA, CDMA, and others, these protocols facilitate the simultaneous transmission of data, ensuring optimal utilization of available bandwidth. Each protocol has its strengths and weaknesses, and the choice of protocol depends on the specific requirements and characteristics of the communication system.

CHAPTER 2:MC_CDMA

2.1. Introduction

The multi-carrier code division multiple access (MC-CDMA) is a potential candidate for the air interfaces of future mobile radio systems. This scheme *derives advantages* from the robustness of OFDM multi-carrier transmission to multi-path propagation on *the* one hand and the *adaptability* of CDMA code division multiple access technique *on the other hand*. *The MC_CDMA system is by far* the *most studied technique* combining multiple carrier modulations and spread spectrum.

This chapter aims to explain the basic concepts of MC-CDMA. We selected the MC-CDMA system due to its numerous advantages:

- It enhanced frequency diversity, which significantly improved the system's robustness and reliability in combating frequency-selective Fading. By distributing the data over multiple subcarriers.
- It offers a simpler implementation for high-speed services compared to DS-CDMA.
- It is highly resistant to fading.

The main advantage of the MC-CDMA scheme over other schemes (DS-CDMA, MC-DSCDMA or MT-CDMA) is that the MC-CDMA Receiver can always use all received signal energy scattered in the frequency domain to detect the desired signal. Nonetheless, by means of a frequency-selective fading channel, the subcarriers may exhibit distinct amplitude levels and phase shifts, despite exhibiting a high correlation among them, resulting in the distortion of orthogonality among users.

2.2. The principles of spread spectrum in MC-CDMA

MC-CDMA combines two powerful techniques for enabling multiple users to share a single channel in wireless communication: [20]

1. **Spread Spectrum:** This technique widens the bandwidth of the original data signal by modulating it with a high-rate pseudo-random noise (PN) code. This creates several advantages:
    - Reduced Interference: The spread signal occupies a larger bandwidth making it harder for narrowband interference to Significantly affect the data.

○ Multiple Access: Different users can be assigned unique PN codes. Receivers can then use these codes to differentiate between desired signals and those from other users.[20]

2. **Multi-Carrier Modulation:** This technique splits the data stream into multiple subcarriers, each modulated onto a separate carrier frequency. This offers benefits like:

○ **Reduced Channel Fading:** If a particular frequency band experiences fading (weakening of the signal), other subcarriers on unaffected frequencies can still transmit data.

○ **Flexibility:** The number of subcarriers can be adjusted depending on the channel conditions and data rate requirements. [20]

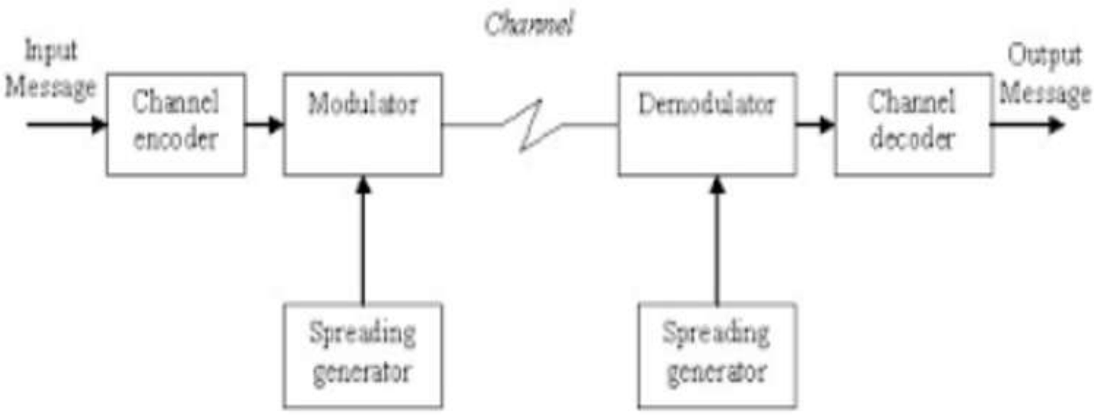

Figure2.1: Block diagram of the spread spectrum communication system. [20]

2.3. MC-CDMA System

MC_CDMA system is based on the combination of code division multiple access (CDMA) and orthogonal frequency division multiplexing (OFDM), which is potentially robust to channel frequency selectivity.[21]

The MC-CDMA system model consists of two parts, the transmitter and the receiver.

• **At the Transmitter:**

1. **Data Source:** The information to be transmitted is in digital form (bits).
2. **Channel Coding (Optional):** Error correction codes can be added to the data stream for improved reliability during transmission.

3. **Spreading:** The user's data is modulated with a high-rate pseudo-random noise (PN) code. This code sequence is unique to each user and spreads the data signal over a wider bandwidth. This spreading offers two key benefits:
    - **Reduced Interference:** The wider bandwidth makes the signal less susceptible to narrowband interference.
    - **Multiple Access:** Different users can be assigned unique PN codes. The receiver uses these codes to distinguish the desired signal from those of other users sharing the same channel.
4. **Symbol Mapping:** The spread signal is then mapped onto multiple subcarriers using a modulation technique like Quadrature Amplitude Modulation (QAM). Each subcarrier carries a portion of the user's data.
5. **Transmission:** The modulated subcarriers are summed and transmitted over the wireless channel. [22]

• **<u>At the Receiver:</u>**

1. **Signal Reception:** The receiver receives a composite signal containing data from multiple users.
2. **Subcarrier Demodulation:** The received signal is separated into its constituent subcarriers. Each subcarrier is demodulated to recover the symbols transmitted on that subcarrier.
3. **Dispreading:** The demodulated symbols from each subcarrier are then dispreading using the same PN code assigned to the desired user. This process removes the PN code and recovers the original data.
4. **Channel Decoding (Optional):** If channel coding was used at the transmitter, the receiver employs decoding techniques to remove any errors introduced during transmission.
5. **Data Extraction:** The recovered data stream is extracted and presented to the user.[23]

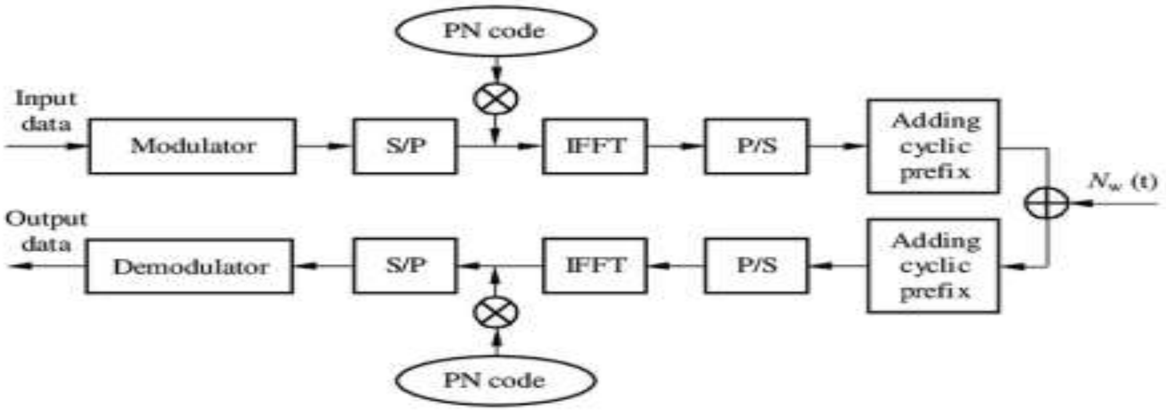

Figure 2.2: system model of MC-CDMA . [23]

2.4. The MC_CDMA system model

The MC-CDMA system described here is based on a single base station and a certain number of mobile terminals. Both uplink transmissions (from the mobile to the base station) and downlink transmissions (from the base station to the mobile) are considered. Uplink and downlink refer to the two directions data travels in a communication system, like radio, satellite, or computer networks. It's basically like upstream and downstream for data flow.

- **Uplink:** This is the data transmission from a user device to a network. Imagine you're talking on a walkie-talkie - the uplink is when you press the button and speak, sending your voice up to the receiver. In cell phones, uplink is when you send a text message or make a video call - your phone transmits data to the cell tower.

- **Downlink:** This is the data transmission going from the network to a user device. On a walkie-talkie, the downlink is when you hear the other person speaking - their voice is being transmitted down to your device. With cell phones, downlink is when you receive a text message, download a file, or listen to music streaming - the data travels from the cell tower to your phone.

Figure 2.3: Uplink and Downlink.

The MC_CDMA system model outlines the structure, operation, and key components of the Multi-Carrier Code Division Multiple Access system. It defines how data is transmitted, how multiple users access the channel simultaneously, and how interference is managed within the system. This model includes details such as the modulation scheme used, the spreading codes employed, synchronization mechanisms, and signal processing techniques utilized for demodulation and decoding. Additionally, it may encompass considerations such as channel estimation, power control strategies, and error correction methods employed to optimize system performance.

2.5. The Transmitter

MC-CDMA is a modulation method that uses multi carrier transmission of DS-CDMA type signals. An MC-CDMA transmitter spreads the original data stream in the frequency domain over different sub carriers using a given spreading code. In this system the sub carriers convey the same information atones time. The MC-CDMA offers better frequency diversity to combat frequency selective fading.

The transmitter MC-CDMA system for i number of user. The MC-CDMA transmitter spreads the original data stream using a given spreading code in the frequency domain. The code generator creates different unique codes for each different user and then combines together. Then the frequency generator combines different carrier frequency to the data signal and then combines the entire signal together by a combiner. After combining all the signals the CDMA antenna transmits the signals over the wireless media.

Briefly a transmitter which multiplies a transmitting signal by a sinusoidal signal, which has an amplitude of r and is orthogonal as a result that the frequency periods are different among users, in a frequency domain to be spread and split into orthogonal sub-carriers, an multiplexes the sub-carriers. [24]

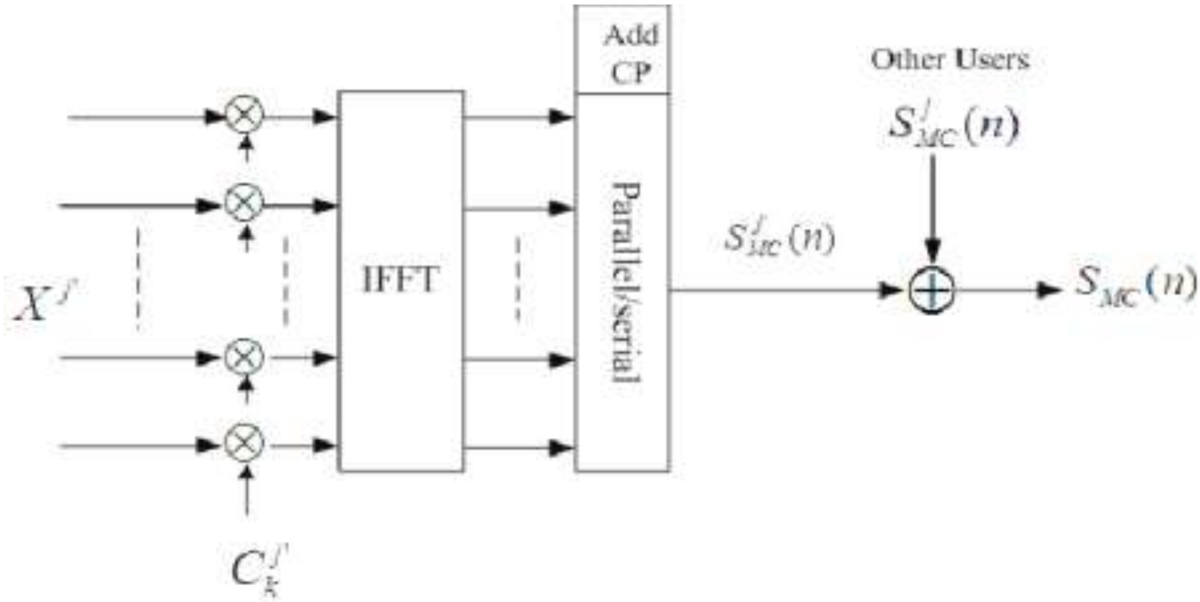

Figure2.4: Transmitter MC-CDMA .[24]

2.6. The Receiver

MC-CDMA receiver is designed by the capacity of i number of user. MC CDMA receiver also receives the transmitted signal as a summation of i number of users. At first demodulates the received signal by the same career frequency of each signal and then the signals multiply with the specific codes given by the receiver code generator. Then we get the signal of itch user which is same for transmitter and receiver. After that low pass filter remove the high frequencies portion of the signal. Finally, the P/S converter presents the actual digital data signal. In receiver side we get the all combing signal with some unexpected signal which are MUI, ICI and Noise signal .[24]

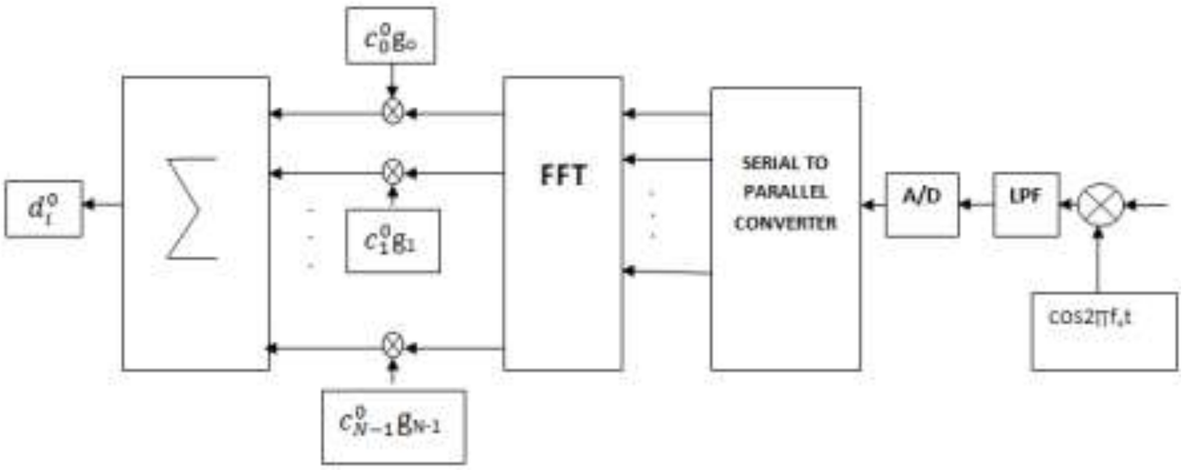

Figure2.5: Receiver MC-CDMA. [24]

2.7. Performance Evaluation

In order to study the performance of any data channel, we must discuss the bit error rate (BER) the BER is an important parameter for evaluating the performance of data channels. When transmitting data from one location to another, whether through a radio/wireless link or a wired telecommunications link, the primary criterion is the quantity of errors that will manifest in the data at the receiving end. As a bit error rate, the BER applies to everything from fiber optic links to ADSL, Wi-Fi, cellular communications, IoT links, and many others. Even though data links may use very different types of technology, the basic principles for evaluating the bit error rate are exactly the same.

2.7.1. Bit Error Rate and Signal-To-Noise Ratio

- ***BER***

A bit error rate (BER) is defined as the rate at which errors occur in a transmission system. This can be directly translated into the number of errors that occurred in a string of a stated number of bits. [25]

The definition of bit error rate can be translated into a simple formula:

$$BER = \frac{\text{number of errors}}{Total\ number\ of\ bits}$$

BER indicates how often data must be retransmitted due to errors. A BER that is too high may indicate that a slower data rate will actually improve the overall transfer time for a given amount of data transferred, as the BER may be reduced and the number of packets that need to be present is reduced.

Example: As an example, assume this transmitted bit sequence:

1 1 0 0 0 1 0 1 1

and the following received bit sequence:

<u>0</u> 1 0 <u>1</u> 0 1 0 <u>0</u> 1,

The number of bit errors (the underlined bits) is, in this case, 3. **The BER** is 3incorrect bits divided by 9 transferred bits, resulting in a BER of 0.333 or 33.3%.

The BER may be improved by choosing :

- A strong signal strength (unless this causes cross-talk and more bit errors).
- A slow and robust modulation scheme or line coding scheme, and by applying channel coding schemes such as redundant forward error correction codes.

- **Signal-To-Noise Ratio (SNR)**

Signal-to-noise ratio (often abbreviated SNR or S/N) is a measure used in science and engineering to quantify how much a signal has been corrupted by noise. It is defined as the ratio of signal power to the noise power corrupting the signal. A ratio higher than 1:1 indicates more signal than noise.[26]

It defines the level difference between signal and noise for a given signal level. The lower the noise generated by the receiver, the better the signal-to-noise ratio.

Signal-to-noise ratio is defined as the ratio of the power of the signal (meaningful input) to the power of the background noise (meaningless or unwanted input):

$$SNR = \frac{\text{Signal Power}}{\text{noise Power}}$$

- ***The relationship between BER and SNR :*** The relationship between bit error rate and signal-to-noise ratio is critical for evaluating the performance of communication systems. Higher SNR usually results in lower BER, indicating better transmission quality. BER is affected by the noise level in the communication channel, the lower the noise level, the fewer errors there are. SNR is defined as the ratio of signal power to noise power and represents the quality of the received signal relative to background noise.

2.8. Applications of MC-CDMA

The MC-CDMA technique holds promise for [27]:

- Future generations of mobile radio communication systems.
- Power line communication (PLC) channel.
- Cognitive radio.
- Indoor wireless environments

2.9. Conclusion

MC-CDMA provides a powerful technique for enabling reliable and efficient multi-user communication in wireless environments. We have presented in this chapter the MC-CDMA multiple access technique. The latter combines the multiple access code division, using CDMA spread spectrum, and the multiple carrier modulations OFDM. Furthermore, the MC-CDMA technique offers an excellent performance-to-complexity ratio. That's why this MC-CDMA technique is now one of the potential candidates for the downlink of mobile telecommunications networks. The objective of this part is to present the main basic concepts of this technique (spread spectrum, Transmitter, receiver...). The chapter also presents the concept of BER, which is a fundamental element in the evaluation of the performance of multiple access techniques in general.

CHAPTER 3 : Optimization Technique

3.1. Introduction

Optimization techniques are essential tools across various domains, from engineering and finance to artificial intelligence. These methods entail systematic procedures to enhance or diminish specific functions, frequently subject to constraints. Their goal is to find optimal solutions to problems, whether they be maximizing profits, minimizing costs, or enhancing performance. Key techniques include linear programming, nonlinear optimization, genetic algorithms, and simulated annealing, each offering unique approaches to addressing different types of optimization problems.

3.2. What is optimization?

Optimization refers to the process of making something as effective, efficient, or functional as possible. The process involves the systematic enhancement of a system, process, or design to attain the optimal outcome within specified constraints or limitations.

Optimization is the process of optimizing or minimizing a function with respect to a set of constraints. It usually represents a range of options available in a specific situation. This function facilitates the comparison of various alternatives to determine the most optimal option. Common applications include minimum cost, maximum profit, minimum error, optimal design, and optimizing management and mutation principle.

3.3. Optimization technique

There are many types of mathematical and computational optimization techniques. An essential step in the optimization technique is to categorize the optimization model since the algorithms used for solving optimization problems are customized as per the nature of the problem**. (Figure 3. 1)**

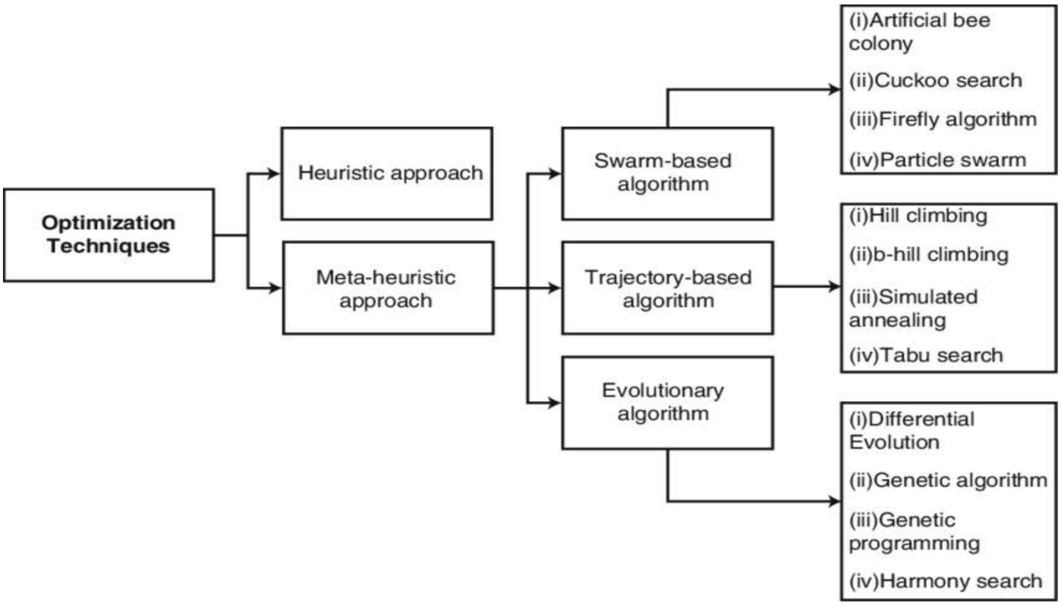

Figure 3. 1 : Type of optimization technique [28].

3.3.1. Heuristic approach

Heuristics are methods typically used to solve large problems that are not based on formal models and do not necessarily lead to optimal solutions. Heuristics work by successive evaluations and temporary hypotheses. If optimality is not required, it is a very interesting alternative for dealing with large optimization problems.

3.3.2. Meta-Heuristic approach

The term meta_heuristic is derived from the combination of two Greek words:

- Heuristic, from the verb heuriskein, meaning "to discover."
- Meta, suffix, meaning "beyond", "higher level".

Meta_heuristic are methods inspired by nature. They are modern heuristic methods dedicated to solving problems, especially optimization problems, aiming to reach a global optimum that is often hidden among numerous local optima.[29]

Meta_heuristic are divided into three subcategories:

✓ **Swarm based algorithm:** Swarm-based algorithms are a class of optimization techniques inspired by the collective behavior of social organisms such as flocks of birds, fish, or ants. These algorithms are characterized by their decentralized nature, in which simple agents called "particles" or "individuals" interact with each other and their environment to jointly solve complex problems.

Examples of popular swarm-based algorithms:

- Artificial Bee Colony (ABC).
- Cuckoo Search.
- Firefly algorithm.
- Particle Swarm Optimization (PSO).

➢ **Artificial Bee Colony (ABC):** ABC algorithm is one of the recent swarm-based algorithms proposed by Karaboga in 2005 is a swarm intelligence algorithm. ABC simulates the intelligent foraging behavior of a honeybee swarm.[4] The ABC algorithm Based on a correlation model describing bee foraging behavior characterized by colony fragmentation. Specifically, a bee colony consists of three types of bees (search agents), namely worker bees, display bees, and scout bees. The first type defines the bee's current food source . its position in the search space. The second type evaluates the food sources found and probabilistically selects some of them to enhance the search. The last type performs a random search.[30]

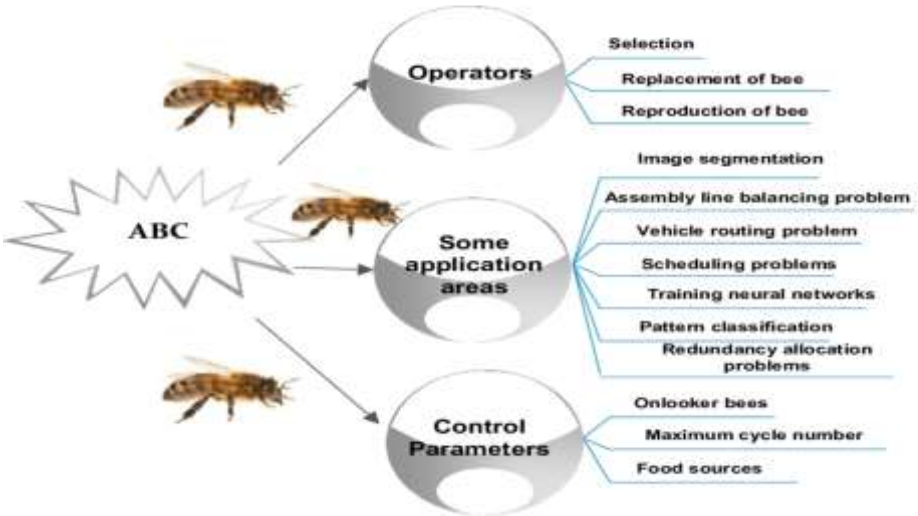

Figure 3.2 : Artificial bee colony (ABC) Algorithm .[30]

➢ **Cuckoo Search:** Cuckoo Search (CS) is a meta_heuristic optimization algorithm and type of swarm based algorithm .CS was developed by Yang and Deb in 2009. The concept was inspired by the parasitic breeding habits of cuckoo birds, who deposit their eggs in the nests of other bird species. While host birds frequently detect the intrusion and either destroy the foreign eggs or abandon their nests, certain cuckoo species possess the ability to deceive host birds by mimicking the color and texture of their eggs. Upon hatching, the young cuckoo birds instinctively eliminate the remaining eggs in the host birds' nest, allowing them to secure a larger share of the available resources.[31]

The CS optimisation algorithm is basically based on the following three rules:

- Each cuckoo selects a nest randomly and lays one egg in it.
- The best nests with high quality of eggs will be carried over to the next generation.
- For a fixed number of nests, a host cuckoo can discover a foreign egg with a probability *paϵ* [0,1]. In this case, the host cuckoo can either throw the egg away or abandon the nest and build a new one somewhere **(Figure 3.3)**

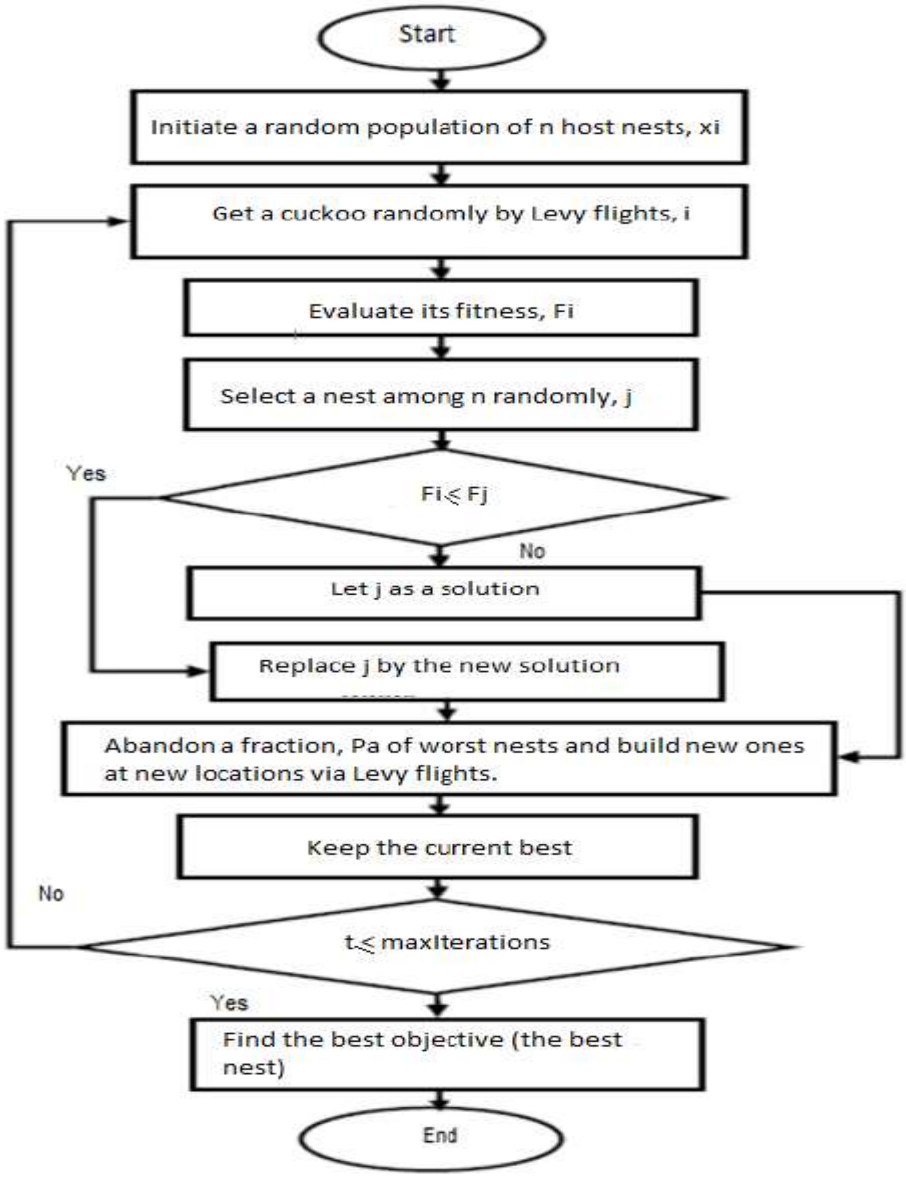

Figure 3.3 : Flow chart for Cuckoo Search Algorithm[31].

- **Firefly algorithm:**

The firefly algorithm is a meta_heuristic optimization algorithm inspired by the flashing behavior of fireflies in nature. FA is originally proposed by Xin-She Yang at Cambridge University in 2007. [32]

The three idealized rules followed by FA are: [33]

- Fireflies are attracted to other people regardless of their gender because they are naturally gender fluid.
- The attractiveness of FA depends on the brightness of FA, and both decrease with increasing distance. Therefore, less attractive FAs will move toward more attractive FAs. If there is no firefly brighter than a particular firefly, the movement of the fireflies is random.
- The brightness depends on the objective function.
- The basic operation of Firefly algorithm is described :

Basic Steps of Firefly Algorithm
1. Initialize the population by randomly generated the Fireflies.
2. Initialize the FA algorithm parameters.
3. Calculate the fitness of all the Fireflies in the population by using defined objective function.
4. Find the attractiveness and relative distance between each pair of fireflies.
5. Update Fireflies positions.
6. Generate of new Fireflies and update the light intensities.
7. Rank the fireflies based in their fitness.
8. Select the better Fireflies for the next population as compared to previous Fireflies from old population.
9. Check the termination criteria. If it is true, then go to Step.10. Else, go to Step.3.
10. Return the best Firefly from the final population.
11. Exit

- Steps of Firefly algorithm show**(Figure 3. 4):**

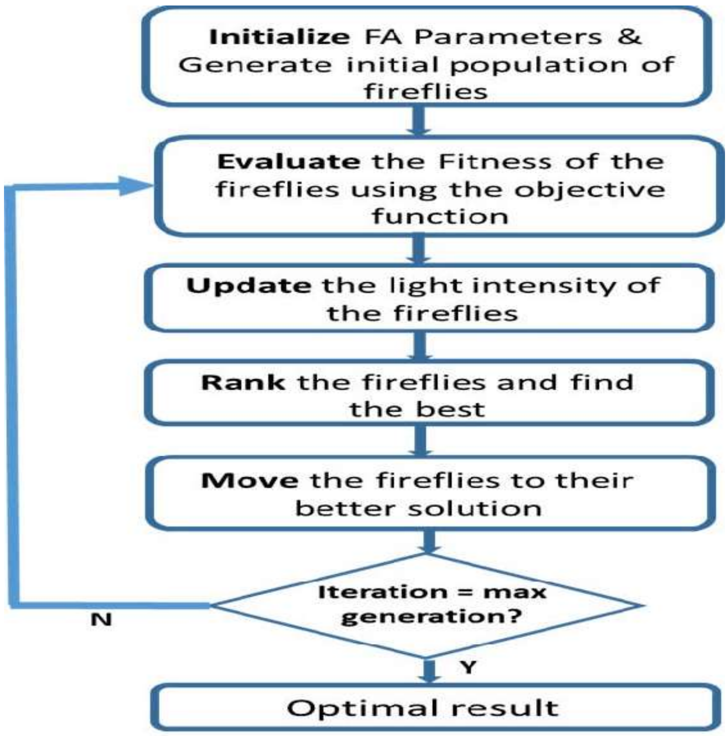

Figure3. 4: Steps of Firefly Algorithm.[32]

- **Particle Swarm optimization (PSO):**

  Particle swarm optimization (PSO) is the most popular swarm-based optimization algorithm for continuous problems, originally proposed by Eberhart and Kennedy in 1995. Its development begins with simulations of swarm search agents. The final model is shown Similar to models in the field of particle physics, basic ideas and related symbols from the field of particle physics are adopted.

  In the figure below, gb represents the attraction of global best and ob is its own best which are measured by the past movement of the particle and coefficients generated randomly **(Figure 3. 5)**.[34]

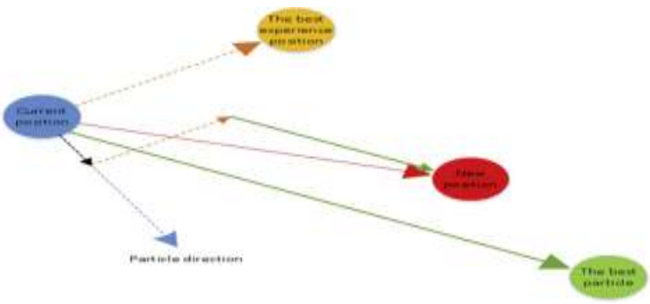

Figure 3.5 : The motion of particles in PSO.[29]

In the Particle Swarm Optimization (PSO) model, there exist two distinct approaches: the global optimum (g_{best}) and the local optimum (p_{best}), each characterized by the size of their neighbourhoods.

- The global optimum: refers to a scenario where the position of each particle is influenced by the best particle in the entire swarm. Consequently, all particles within the swarm receive the same social information.

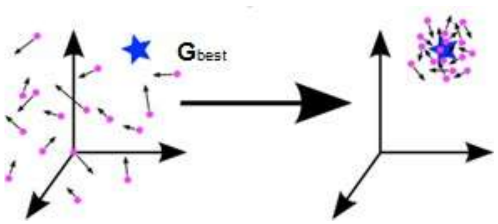

Figure3.6: The global optimum model of the PSO.[29]

- The local optimum entails a smaller neighbourhood size, where each particle's position is influenced by the best particle within its local vicinity. Consequently, particles in the swarm receive social information from a limited subset of their neighbours, leading to localized exploration and exploitation of the solution space.

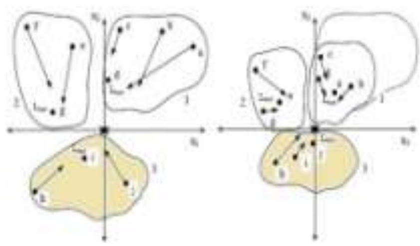

Figure 3.7: The local optimum model of the PSO.[29]

✓ **Trajectory based algorithm**

Trajectory optimization is a class of metaheuristics optimization algorithms that use a single agent or solution to move through the search space in a step-by-step manner. It is the processes of designing a trajectory that minimizes (or maximizes) some measure of performance while satisfying a set of constraints. Generally speaking, trajectory optimization is a technique for computing an open-loop solution to an optimal control problem. It is often used for systems where computing the full closed-loop solution is not required, impractical or impossible. If a trajectory optimization problem can be solved at a rate given by the inverse of the Lipschitz constant, then it can be used iteratively to generate a closed-loop solution in the sense of Caratheodory. If only the first step of the trajectory is executed for an infinite-horizon problem, then this is known as Model Predictive Control (MPC).

The types of trajectory-based algorithms are:

Hill climbing, B_hill climbing, Simulated annealing, Tabu search.

- **Hill climbing:**

Hill climbing is a meta_ heuristic search used for mathematical optimization approach within the realm of local search algorithms, operates iteratively to enhance a target function's value, either by maximizing or minimizing it. This iterative process involves making gradual adjustments to a solution until reaching a point where no further enhancements can be achieved.

The current path is extended with a successor node which is closer to the solution than the end of the current path. In simple hill climbing, the first closer node is chosen whereas in steepest ascent hill climbing all successors are compared and the closest to the solution is chosen. Both forms fail if there is no closer node. [35]

- **Simulated annealing:**

The name and inspiration come from annealing process in metallurgy, a technique involving heating and controlled cooling of a material to increase the size of its crystals and reduce their defects. The heat causes the atoms to become unstuck from their initial positions (a local minimum of the internal energy) and wander randomly through states of higher energy;

the slow cooling gives them more chances of finding configurations with lower internal energy than the initial one. In the simulated annealing method, each point of the search space is compared to a state of some physical system, and the function to be minimized is interpreted as the internal energy of the system in that state. Therefore the goal is to bring the system, from an arbitrary initial state, to a state with the minimum possible energy.[35]

➢ **Tabu search:**

Tabu search (TS) is a metaheuristics search method that employs local search methods for mathematical optimization . It was created by Fred W. Glover in 1986 and formalized in 1989. TS enhances the performance of local search by relaxing its basic rule, allowing for worsening moves if no improving move is available, and introducing prohibitions to discourage the search from coming back to previously-visited solutions.

The main feature of Tabu Search is the use of explicit memory, with two goals:

- To prevent the search from revisiting previously visited solutions.
- To explore the unvisited areas of the solution space.

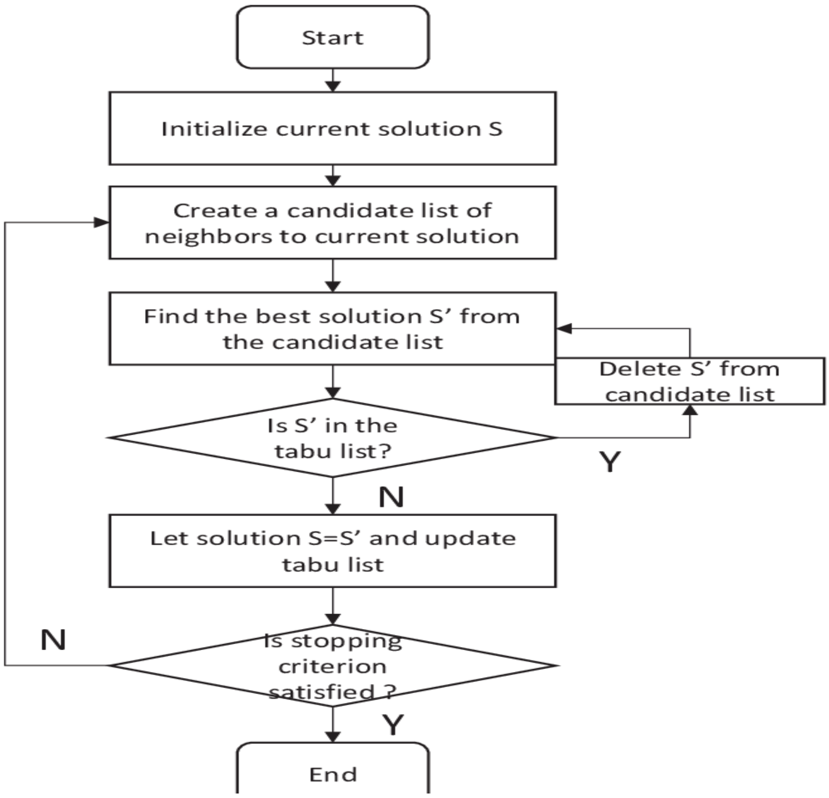

Figure 3.8: Flowchart of Tabu search algorithm [35]

✓ **Evolutionary algorithm**

Evolutionary algorithms are heuristic methods used to solve problems that cannot be easily solved in polynomial time, such as the classic NP-hard problem. They are inspired by natural selection and incorporate mechanisms such as reproduction, mutation, recombination and selection to develop candidate solutions over successive generations. These algorithms use a fitness function to evaluate the quality of the solution and select the most suitable individuals to reproduce in each iteration. This process continues until the best solution is found, making evolutionary algorithms a powerful tool for optimization in various fields.

The types of Evolutionary algorithms are: Differential Evolution, Genetic Algorithm, Harmony Search.

➢ **Differential Evolution**

Differential Evolution (DE) is a heuristic method for the global optimization of nonlinear and non differentiable continuous space functions. Candidate solutions are iteratively improved and the optimization problem does not have to be differentiable. DE maintains a set of possible solutions and creates new solutions by combining existing solutions based on simple formulas. The algorithm is known for its simplicity, requiring only a few parameters such as population size, scaling factor and crossover rate, making it practical and easy to use.

➢ **Genetic Algorithm**

Genetic Algorithm (GA) is an optimization algorithm based on natural selection and genetics mechanisms. In a genetic algorithm, candidate solutions to a given problem are analogous to individuals in a population. Each individual is encoded as a string of characters called a chromosome. New candidate solutions are generated from the parent chromosome by a crossover operator. The mutation operator is then applied to the population.

The quality of each individual is assessed and evaluated through the so-called fitness function. Similar to the mechanism of natural selection in biological systems, more adapted individuals have a greater chance of passing information on to the next generation. If a chromosome carries once the required fitness is reached, it is accepted as the optimal solution and the optimization process ends.[35]

- **Harmony search**

Unlike some meta_heuristic inspired by natural phenomena, we are interested in a meta_heuristic inspired by the process of seeking the best musical harmony in a gold-Chester. Each musician plays a note with different musical instruments at once to find the perfect harmony. This meta_heuristic is called Harmony Search (HS), proposed and developed by Geem et al [36]. The Harmony Search imitating the improvisation process of musicians. In the process, each musician plays a note in order to find a better harmony described by the ensemble.[36] (**Figure 3. 9**)

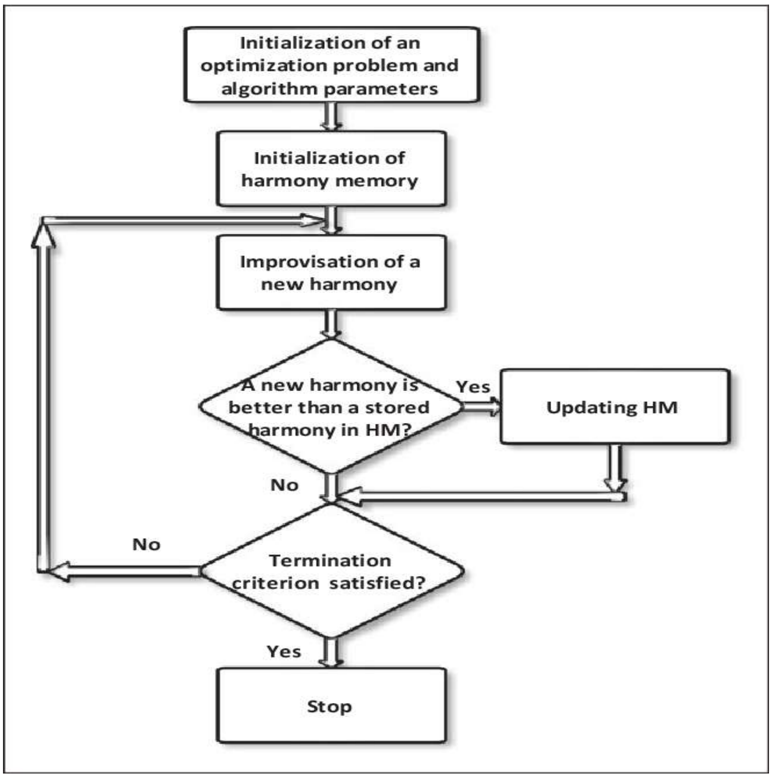

Figure 3.9 : Basic_Harmony_Search_ Algorithm.[36]

3.4. Optimization with genetic algorithm

3.4.1. Genetic Algorithm

Genetic algorithms (GA) are stochastic research and optimization techniques derived from genetics and mechanisms of natural selection and evolution: selections, crosses, mutations, etc. The genetic algorithm is an iterative global search algorithm whose goal is to optimize a user-defined function.

Genetic algorithms have been introduced by John Holland , his colleagues, and his students at the University of Michigan.[37] With the basic principles explained, the genetic algorithms work as follows (**Figure 3.10**):

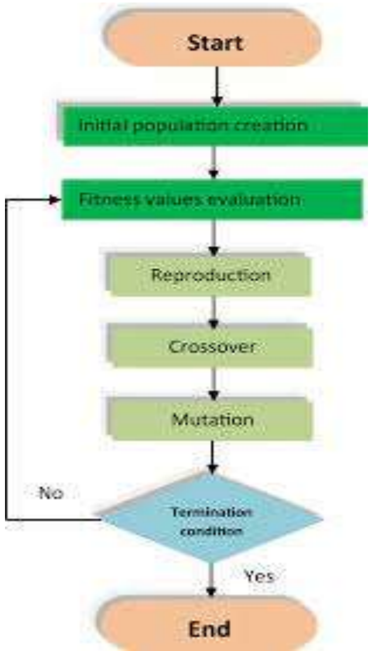

Figure 3.10 *: Flow Diagram of Genetic Algorithm.[37]*

3.4.2. Terminology

- **Genes and Chromosomes**

The gene is the basic component of the GA. A string of genes is called a chromosome. Chromosomes can be encoded as binary strings, as strings of real numbers, etc.

- **Populations and Generations**

A population is a set of chromosomes. GA begins with a set of randomly created individuals (chromosomes). This set is called the initial population. The iterations of GA are called generations. Each iteration involves selecting individuals with closely related characteristics and recombining them until a new generation is created to replace the old one [38].

❖ **Fitness**

The objective function that defines the optimization purpose is called the fitness function. It indicates"goodness" or"badness" for each individual.

❖ **Allele**

It is the value a gene takes for a particular chromosome.

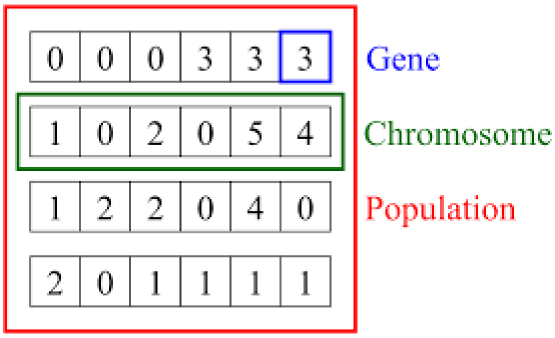

Figure 3.11 *: Gene, Chromosome, and population [38].*

❖ **Genotype**

Genotype is the population in the computation space. In the computation space, the solutions are represented in a way which can be easily understood and manipulated using a computing system.

❖ **Phenotype**

Is an external visualization of the individual, it indicates its ability to survive in its environment and therefore to reproduce.

3.4.3. Encoding Methods

- **Binary Encoding:**

The most common encoding type is a binary string, as shown in (**Figure 3.12**).

Each chromosome is encoded as a binary string. Each bit in the string can represent some of these solutions Characteristics Thus any string is a solution, but not necessarily the best solution. Another possibility is that the entire string represents a number.[39]

Binary coding results in many potential chromosomes with a smaller number of alleles.

Chromosome A	101100101100111001 01
Chromosome B	111111100000000111 11

Figure 3.12 *: Binary encoding.[39]*

- **Hexadecimal Encoding**

This encoding uses a string composed of hexadecimal numbers (0–9, A–F).

- **Real Number Encoding :**

is usually used for ordering issues. In this type of encoding, each chromo-some represents a sequence of reals ; for example, in the traveling salesman problem, the string of numbers represents the sequence of cities visited by the salesman [39].(**Figure 3.13)** shows example .

Chromosome A	1 5 3 2 6 4 7 9 8
Chromosome B	8 5 6 7 2 3 1 4 9

Figure 3.13 *: Real number encoding. [39]*

3.4.4. A Basic Genetic Algorithm

In general, a genetic algorithm must be able to achieve six basic tasks [40] :

1. Encoding the solution elements in the form of genes.
2. Create a string of genes to form a chromosome.
3. Initialize a starting population by generating a set of specific chromosomes, usually randomly.
4. Evaluate and assign fitness values to individuals in the population.
5. Perform reproduction by the fitness weighted selection of individuals of the population.
6. Perform recombination and mutation to produce individuals of the following generation.

A GA, then, is an iterative optimization method that simulates the adaptation and evolution of a single kind of organism. Using a chromosomal mapping system, the GA starts with a large number of possible design configurations. The range of potential configurations is defined by the limitations of the problem and the method of encoding all configuration information into the chromosome [38, 41]

3.5. The operations of a GA

The operators of genetic algorithms are tools that make it possible to modify the population of individuals from one generation to another in order to promote the search for solutions optimal. The most commonly used operators are:

3.5.1. The selection operator

Selection consists in choosing the most suitable individuals in order to have a solution population closest to converge towards the global optimum. This operator is the application of the adaptation principle of Darwin's theory .

Various selection methods exist. The most used are listed below:

- **Roulette Wheel Selection :**

The selection of individuals by the roulette system is inspired by lottery wheels. To each individual of the population is associated a sector of a wheel. The angle of the sector being proportional to the quality of the individual it represents. You turn the wheel and you get an individual. Individual draws are thus weighted by their quality. And almost logically, the best individuals are more likely to be crossed and participate in the improvement of our population.

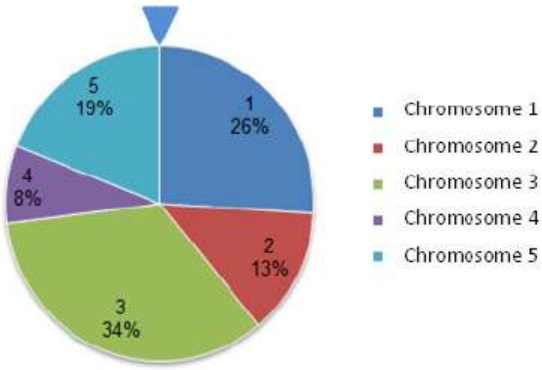

Figure 3.14 *: Roulette Wheel Selection. [41]*

- **Tournament Selection :**

In K-Way tournament selection, we randomly select K individuals from the population and select the best among them to become parents. Repeat the same process to select the next parent. Tournament selection is also popular in the literature as it can be used even with negative fitness values.

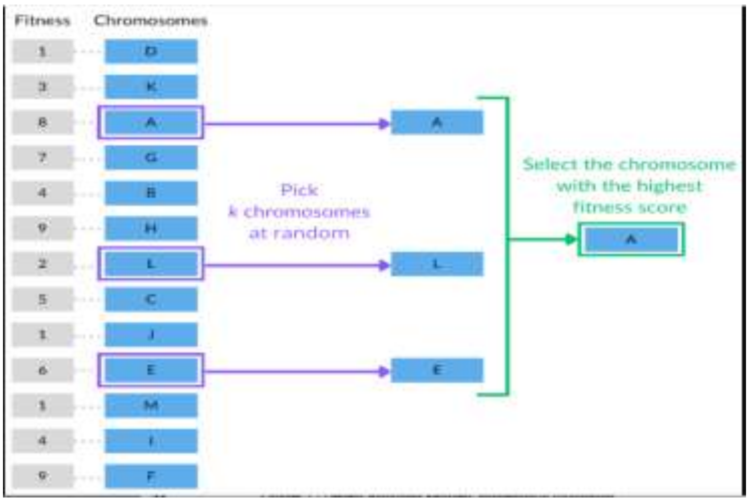

***Figure 3.15** : Tournament Selection [41].*

- **Rank Selection :**

The selection by rank first makes a sorting on the population in relation to fitness. Then, to each chromosome is associated a rank according to its position. As a result, for a population of N chromosomes, the worst will have rank 1, and so on up to the best chromosome that will have rank N. Selection by rank and selection by roulette are almost identical, except that, with selection by rank, populations are related to rank rather than to the value of evolution. Thus, the final probabilities will be calculated with the formula**: Rank / (of the ranks)** .[42]

- **Random Selection :**

In this strategy, we randomly select parents from the existing population. There is no selection pressure for fitter individuals, so this strategy is usually avoided.

3.5.2. The crossover operator :

The crossing operator is the essential search operator of a GA. It takes place after selection. It allows the exchange of genetic information between individuals after selection, randomly in one (or more) caesura position (locus). In this case, two of the selected individuals (parents) exchange one or more parts of their genotypes, according to a probability Pc (often greater than 60%). To form two different individuals from those original. [42] There are different ways to cross: the crossing «at one point», «at two points", "multipoint", "and uniform".

- **One-point Crossover :** A crossing point is randomly chosen for each pair (**Figure 3.16**). Note that the crossing is done directly at the binary level, and not at the level of genes. A chromosome can therefore be cut in the middle of a gene.

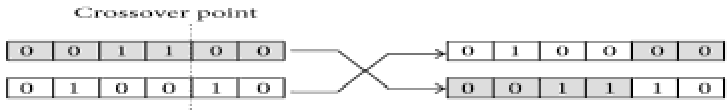

***Figure 3.16** : One-point Crossover [42].*

- **Two-point Crossover :** Two crossing points are randomly selected (**Figure 3. 17)**. Subsequently, we used this operator because it is generally considered more efficient than the previous one. However, we did not find any significant difference in the convergence of the algorithm.

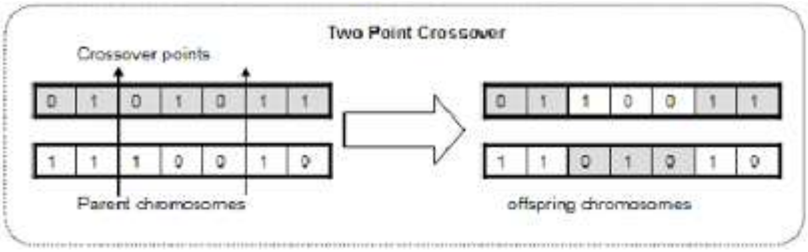

*Figure **3.17** : Two-point Crossover [42]*

- **Uniform crossover :** In uniform crossover, we do not split the chromosome into segments but treat each gene individually. Essentially, we flip a coin for each chromosome to determine whether it will be included in the offspring. We can also target coins at parents to get more genetic material from their parents in their children.

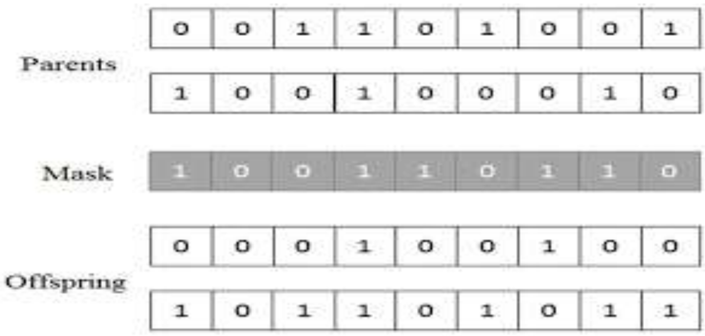

***Figure 3.18** : Uniform crossover .[42]*

3.5.3. The mutation operator

Mutation **can** be **defined** as a **small random change** in a **chromosome** to **obtain** a **new solution**. It is used to **maintain and introduce diversity into genetic populations and** is usually **applied** at a **low probability** (pm). If **the probability** is **very high**, **the genetic algorithm** reduces to a **random search**. Mutation is the part of the genetic algorithm related to the "exploration" of the search space. It is observed that mutations are critical for GA convergence, but crossovers are not.

- **Bit Flip Mutation**

In this bit flip mutation, we select one or more random bits and flip them. This is used for binary encoded GAs.

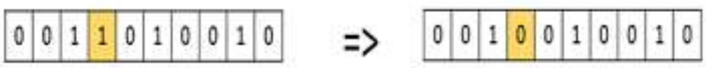

***Figure 3.19**: Bit Flip Mutation. [42]*

- **Random Resetting**

is an extension of the bit flip for the integer representation? In this, a random value from the set of permissible values is assigned to a randomly chosen gene.

- **Swap Mutation**

In swap mutation, we select two positions on the chromosome at random, and interchange the values. This is Common in permutation based encodings.

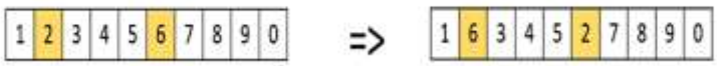

Figure 3.20 *: Swap Mutation.[42]*

- **Scramble Mutation**

Scramble mutation is also popular with permutation representations. In this, from the entire chromosome, a subset of genes is chosen and their values are scrambled or shuffled randomly.

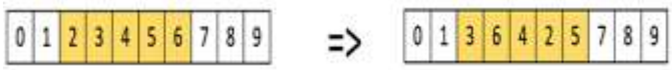

Figure 3.21: *Scramble Mutation.[42]*

- **Inversion Mutation**

In inversion mutation, we select a subset of genes like in scramble mutation, but instead of shuffling the subset, we merely invert the entire string in the subset.

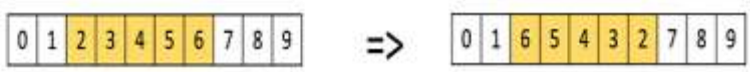

Figure 3.22*: Inversion Mutation.[42]*

3.6. Goals of genetic Algorithm

GAs have two main objectives:

- Explain theories on adaptations of natural systems.
- Solve problems whose GAs are particularly adapted. GAs present both robustness and adaptation. That is, they have the ability to evolve (fitness) for the purpose of satisfying research. But they are also able to be attracted to solutions.

3.7. The Genetic Algorithm Applications

The GA applications are multiple:

- Optimization of difficult numerical functions (discontinuous, etc.)
- Image processing (alignment of satellite photos, recognition of suspects, etc.)
- Optimization of schedules, design optimization, control of industrial systems, learning of neural networks, etc.
- Genetic Algorithms can be used to control a system evolving over time (production chain, nuclear power plant, etc.) As the population can adapt to changing conditions. They can also be used to determine the minimum energy configuration of a molecule.
- Genetic Algorithms are also used to optimize networks (cables, optical fibres, but also water, gas, etc.),

Antennas. They can be used to find the parameters of a small-signal model from experimental measurements.

3.8. Conclusion

We have presented in this chapter some of the most well-known optimization methods for problem solving. These methods are generally classified into two categories: heuristic and meta_heuristic. Optimization techniques which are powerful tools for finding good solutions to complex problems. While they may not guarantee the absolute optimum, their efficiency, flexibility, and ability to handle large-scale problems make them invaluable in various fields like engineering, scheduling, machine learning, and resource allocation.

CHAPTER 4 : Implementation and Experimentation

4.1. Introduction

This chapter is to present the techniques, languages, and tools used to implement our prototype. Our experimental work is divided into two parts:

- The first part is the application of genetic algorithms to optimize the BER calculation function (fitness function).
- The second part is the study of the importance of the different parameters of the function that allow us to calculate the BER

4.2. Overview of development tools

In this research theme uses several programming languages such as: PyCharm, WEKA.

4.2.1. PyCharm

PyCharm is an integrated development environment (IDE) used for programming in Python. It provides code analysis, a graphical debugger, an integrated unit tester, integration with version control systems, and supports web development with Django. PyCharm is developed by the Czech company JetBrains.

It is cross-platform, working on Microsoft Windows, macOS, and Linux. PyCharm has a Professional Edition, released under a proprietary license and a Community Edition released under the Apache License. PyCharm Community Edition is less extensive than the Professional Edition.

4.2.2. Weka

Weka: is an open source software that implements several learning algorithms accessible via a graphical interface or a Java library. This tool was developed by a team of researchers at Waikato University in New Zealand and is available free of charge (GNU license) at:

http://www.cs.waikato.ac.nz/ml/weka/

Objectives:

- The weka explorer allows to launch a method from an ARFF extension file.
- The results are put in the form of a standardized text file.

➢ Select the most suitable or effective method.

4.3. Preparation of Dataset

The dataset used in this work was randomly generated and is distributed as follows.

Attribut	Meaning	Values
M	Nomber of user	$\{10, 10^2, 10^3, 10^4, 10^5, 10^6\}$
N	Nomber of carriers	$N = 2^m, 0 \leq m \leq 7$
T_b	Symbol duration	CONST $T_b = 1$
ω	Fading Factor	$\{0.5, 1, 3, 170\}$
$\overline{P}^0$	Average power	$\overline{P}^0 \in [-20, 20] - \{0\}$; step= 1
$\overline{P}^m$	Total power	$\overline{P}^m \in [-20, 20]$; step = 1
N_0	One-sided noise power spectral density	$N_0 \in [-20, 20]$; step = 1

Table 1:The values of the different parameters.[43]

Parameter Explanation:

- **M**: Number of users, indicating the number of simultaneous transmissions or connections.
- **N**: Number of carriers, which depends on **m** and follows the formula **$N=2^m$**
- **T_b**: The duration of one symbol, given as a constant $T_b=1$.
- **ω**: The fading factor, representing the degree to which the signal is affected by fading.
- **P^0** : The average power of the useful signal, ranging from -20 to 20 but excluding 0, with increments of 1.
- **P^m** : The total power of interfering signals, also ranging from -20 to 20 with increments of 1.
- **N_0**: The one-sided noise power spectral density, ranging from -20 to 20 with increments of 1.

We added the class attribute that gives the configuration type. According to the experts a configuration can be good (bonne) or bad (mauvaise) and this according to the following values:

$$\text{Class}\big(\Pr(\text{error}|\overline{\text{P}}0,\overline{\text{P}}\text{m})\big) = \begin{cases} \text{good Configuration} & \text{, if } \text{BER} \leq 10^{-6} \\ \text{Bad Configuration,} & \text{else} \end{cases}$$

4.4. Experimentation

4.4.1. Genetic Algorithm parameters

The genetic algorithm was implemented with the following parameters:

Attribute	Meaning	Values
nbr_iteration	Number of iterations	{500, 700, 1000, 1500, 2000}
nbr_pop	Population size	{200, 400, 600, 800, 1000}
prob_croisement	Crossover probability	{0.1, 0.3, 0.5, 0.7, 0.9}
prob_mutation	Mutation Mutation probability	0.01
nbr_LesMeilleurConfigTable	containing the best configurations obtained during the execution	Nbr_pop / 2

Table 2:Implementation parameters of the GA.

4.4.2. Fitness function *[43]*

Our fitness function is the one that calculates the **BER** in the case of the

«Up Link» :

$$\Pr(\text{error}|\overline{\text{P}}0,\overline{\text{P}}\text{m}) \cong \frac{1}{2}\,\text{erfc}\big(\sqrt{\text{h}}\big) \dots \dots \dots \dots \dots \dots \dots \text{(I)}$$

Where the parameter **"h"** represents the **"SNR"** and is calculated by:

$$h = \frac{\bar{P}0\,Tb}{(2\frac{\bar{P}0\ Tb}{N\omega} + \left(\frac{M-1}{N}\right) + \bar{P}m\ Tb\ + N0)} \ldots\ldots\ldots\ldots\ldots (II)$$

4.4.3. The best results

After several experimental tests, the best results obtained are as follows:

1) For 100 user with (Any configuration):

The results obtained is presented in the following extract:

P0	N	ω	Pm	N0	BER
15	44	68	0.554	-2	3.1187278784435554e-60
13	47	8	0.554	-2	7.227796796138867e-184
12	45	92	3.826	-5	2.548746064116617e-265
18	57	158	-14.216	12	0
. . .	. . .	. . .	. . .	. . .	. . .
13	47	8	3.826	-5	0
13	47	7	3.826	-5	0
16	47	92	3.826	-5	0
. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
13	47	8	3.826	-5	0
13	47	8	11.052	-13	0
15	47	8	3.826	-5	0

Table 3:Best Configurations for 100 user.

2) **For 1000 user with (Any configuration):**

The results obtained is presented in the following extract:

P^0	N	ω	P^m	N_0	BER
-19	110	100	2	-11	3.231109026216812e-40
-19	110	100	2	-11	3.231109026216812e-40
-19	110	149	2	-11	2.0590321461351876e-40
-19	109	128	2	-11	1.3990858950384117e-41
-19	109	128	2	-11	1.3990858950384117e-41
-19	109	149	2	-11	1.1932010020233996e-41
-19	109	18	2	-11	4.151522493827196e-46
-19	109	18	2	-11	4.151522493827196e-46
-19	109	18	2	-11	4.151522493827196e-46
-19	109	12	2	-11	2.765444513247167e-48
-19	109	12	2	-11	0
-19	109	12	2	-11	0
-19	109	12	2	-11	0
-19	109	12	2	-11	0
-19	109	3	2	-11	0
-19	109	3	2	-11	0
-19	109	3	2	-11	0
. . . .	. . .	. . .	. . .	. . .	. . .
-19	109	3	2	-11	
-19	109	1	2	-11	0
-19	109	1	2	-11	0
-19	109	1	2	-11	0

Table 4: Best results for 1000 user.

3) For 10000 User:

- **Best configuration:**

Population size	200
Number of iterations	1000
Crossover rate	0.4
Mutation rate	0.01

- **Best Results**

P0	**N**	ω	**Pm**	**N0**	**BER**
19	124.	0.5	-19	-19	5.0030323809836764e-12
19	124	0.5	-19	-19	5.0030323809836764e-12
19	124	0.5	-19	-19	5.0030323809836764e-12
19	124	0.5	-19	-19	5.0030323809836764e-12
19.	124	0.5	-19	-19	5.0030323809836764e-12
19	124	0.5	-19	-19	5.0030323809836764e-12
19	124	0.5	-19	-19	5.0030323809836764e-12
19	124	0.5	-19	-19	5.0030323809836764e-12
19	124	0.5	-19	-19	5.0030323809836764e-12
19	124	0.5	-19	-19	5.0030323809836764e-12
19	124	0.5	-19	-19	5.0030323809836764e-12
19	124	0.5	-19	-19	5.0030323809836764e-12
19	124	0.5	-19	-19	5.0030323809836764e-12

Table 5: Best Configurations for 10000 users.

4.5. Study of Importance of Parameter

4.5.1. Dataset Description

The table below shows the characteristics of the our dataset (randomly generated)

Name	Number of instance	Number of attributes	Attribute type	Number of classes
UplinkBer_BenchmarkFinal. Arff	201633	5	Numeric	2 (good, bad)

Table 6:Characteristics of the data tables UplinkBer_BenchmarkFinal.arff .

In this file (UplinkBer_BenchmarkFinal.arff), there are 201633 instances with 5 attributes (Number of carriers, The fading factor, The average power, The total power, The one-sided noise power). All of these attributes are used to calculate the BER, which is used to determine whether or not the result is a good or bad configuration.

4.5.2. Features Selection Methods

- **GainRatioAttributeEval :** aims to assess the worth of attributes by considering their ability to contribute to the differentiation of instances based on the class labels. The gain ratio for an attribute measures how well it distinguishes between classes by taking into account both the purity of the splits (entropy) and the intrinsic information content of the attribute.

- The attributes are ranked based on their Gain Ratio scores:

Attributes	Gain	Ranking
P^m	0.08197	4
N_0	0.07676	5
NP	**0.02223**	**1**
P^0	0.00756	3
ω	0.00276	2

Table 7: Result of method of GainRatioAttributeEval.

- **ClassifierAttributeEval**

This method evaluates the importance of each feature by training a classifier (such as Decision Trees, Random Forests, SVMs, etc.) on the dataset and measuring how well the classifier performs using each individual feature.

Result:

Attributes	N_0	ω	P^0	P^m	**NP**
Ranking	5	2	3	4	**1**

Table 8:Result of method of ClassifierAttributeEval.

- **CfsSubsetEval:** is a technique used to assess the importance of features in a dataset by evaluating their impact on the performance of a classifier. It helps in selecting the most relevant features for building accurate machine learning models, thereby improving efficiency and interpretability.

Result:

Attributes	**NP**	P^m	N_0
Ranking	**1**	2	5

Table 9:Results of method of CfsSubsetEval.

4.5.3. Discussion

This study demonstrates that the number of carriers in MC_CDMA systems directly influences BER performance by influencing SNR. It is a critical parameter that network planners and engineers must consider carefully in order to achieve optimal performance and efficiency in wireless communication systems.

4.6. Conclusion

Through this chapter, We have acquired many optimal configurations (BER < 10^{-6}) for every user class (100, 1000, and 10,000) . Through a number of tests, we were able to show how genetic algorithms can be used in optimization of multiple access protocols.

We were able to generate multiple configurations for a minimum BER (absolute 0) by using GA to this problem. In the second section, we use the feature selection methods to examine the significance of the parameters, or attributes.

General conclusion

In the realm of communication systems, evaluating the performance of various Multiple Access Protocols (MAC) through the lens of Bit Error Rate (BER) is an essential step towards achieving optimal functionality. BER serves as a critical metric, quantifying the likelihood of errors creeping into data transmissions. By meticulously analyzing BER under the influence of different MAC protocols, engineers gain valuable insights into how these protocols manage channel access and mitigate collisions. This knowledge is paramount for selecting the most fitting protocol for a specific application's needs. Protocols that excel in minimizing collisions will demonstrably exhibit a lower BER, translating to more reliable data transmission. This meticulous evaluation process safeguards the efficient utilization of the shared channel, ultimately ensuring the delivery of high-quality data. Furthermore, it paves the way for advancements in communication technologies, such as the exploration of Multi-Carrier Code Division Multiple Access (MC-CDMA) systems for 4Gand 5G networks. By leveraging decision trees and genetic algorithms, researchers can delve deeper into optimizing the performance of these advanced systems

After a theoretical study, we found that most (if not all) performance evaluation work uses simulation with MATLAB within limited intervals, for example, the number of users does not exceed 500 users. Consequently, the objective of this work is to use evaluate the performance of MC-CDMA. In this part, we provide an overview of the work of this thesis as well as future perspectives.

1. **Optimization:** The goal of this part is to optimize the BER calculation function to find the best possible configurations.
2. **Study of Parameter Importance:** Using features selection methods .

After several experiments, we found that the application of genetic algorithms for performance evaluation of the MC-CDMA multiple access technique is very significant. We were able to obtain several configurations ensuring a minimal BER (absolute 0) with a reduced execution time. The Study of Parameter Importance demonstrates that the number of carriers in MCCDMA systems directly influences BER performance. It is a critical parameter that network planners and engineers must consider carefully in order to achieve optimal performance and efficiency in wireless communication systems.

As future perspectives, we plan to validate the obtained results through practical simulation (compare with practical BER) and study other multiple access techniques such as MC-DS-CDMA, MT-CDMA, etc.

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