NON-ORTHOGONAL MULTIPLE ACCESS FOR 5G AND BEYOND

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Overview

Introduction

- 5G Advancements: 5G represents a significant leap in mobile technology. It offers enhanced mobile broadband (eMBB) for blazing-fast internet. Enables massive machine type communication (mMTC) for connecting numerous devices.5G introduces ultra-reliable low latency communication (URLLC) which ensures fast and reliable data delivery, even in critical situations.[1]
- Millimeter Wave Technology: Millimeter wave technology in 5G offers faster data rates and reduced lag. Enables seamless data-intensive applications like AR and VR.[1]

4G Vs 5G

- 5G has significantly faster data rates with peak download speeds up to 20 Gbps, compared to 4G's maximum of 1 Gbps. This enables quick downloads, high-quality video streaming, and seamless gaming.
- 5G has much lower latency, typically between 1 to 10 milliseconds, making it ideal for real-time applications like augmented reality (AR), virtual reality (VR), and autonomous vehicles. Where as 4G has latency, usually around 30-50 milliseconds, which may cause delays in time-sensitive applications.
- 5G offers higher network capacity and can support a larger number of connected devices, making it better suited for the Internet of Things (IoT) and smart city applications. Where as 4G has limited network capacity and can become congested in densely populated areas.

Technology Used In 4G and Before

- **Othogonal Multiple Access :**
  OMA, or Orthogonal Multiple Access, is a wireless communication technique that enables multiple users to share the same channel without causing interference. It assigns unique resources to each user to ensure efficient and interference-free data transmission.
- **Types of OMA :**
  1. Frequency Division Multiple Access for 1G.
  2. Time Division Multiple Access for 2G.
  3. Code Division Multiple Access for 3G.
  4. Othogonal Frequency Division Multiple Access for 4G.

Technology Used In 5G

- **Non-Orthogonal Multiple Access**
  NOMA is a multiple access technique used in wireless communication systems that allows multiple users to share the same time-frequency resource without the constraint of orthogonality using different power levels or unique codes for data separation.
- NOMA achieves this by allocating varying power levels to different users or by assigning distinct spreading codes to each user's data. This innovative approach optimizes spectral efficiency and capacity in wireless networks.
- NOMA has higher **throughput** when compared to traditional OMA techniques.

- **Techniques Used By NOMA At Transmitter and Receiver respectively are:**
  1. Superposition Coding
  2. Successive Interference Cancellation

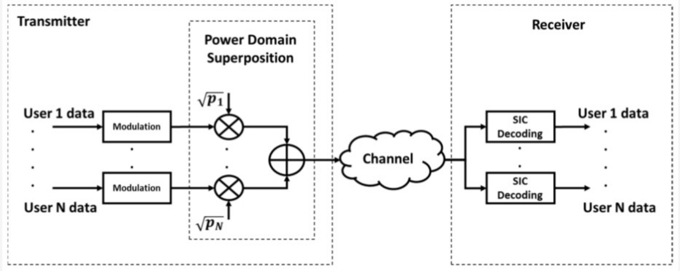

Figure: 1. Block Diagram Of SC and SIC [3]

Superposition Coding

- This is a method of concurrently transmitting information to various receivers by a particular source. In other words, it enables the transmitter to send data to multiple users at the same time. The different signals of several users are superimposed, and the resulting superimposed signal is conveyed over the channel (i.e., the same time/frequency resources)

Successive Interference Cancellation

SIC is a method employed at the receiver to decode multiple superimposed signals, one at a time, in a specific order. It works as follows:

- The receiver starts by decoding the signal of the user with the strongest signal quality or the highest power allocation. Once decoded, this signal is subtracted from the received data.
- After subtracting the first decoded signal, the receiver proceeds to decode the next strongest signal. This iterative process continues until all signals are successfully decoded or until a stopping criterion is met.
- By removing the contribution of previously decoded signals, SIC effectively separates and recovers each user's data stream from the superimposed signals.[2]

SYSTEM MODEL

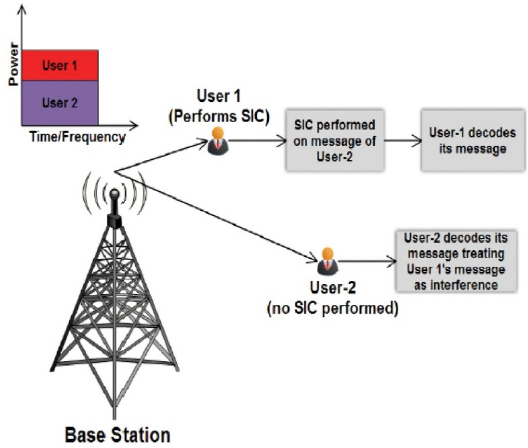

Figure: 2. Communication System in NOMA [1]

System Model Continuation

In Figure 2, a Base Station (BS) in a 5G network strategically selects two users:

- User 1 is near to the Base station and User 2 is far from the base station.
- As User 1 is near , **channel gain** of user 1 is high when compared to channel gain of user 2 which is low as it is far.
- So the Base station employs an efficient power allocation strategy, assigning low power to the User 1 and high power to the User 2.
- Now Superposition Coding allows multiple signals to be transmitted on the same frequency at the same time by encoding each user's data stream which is combined with the data of other users in a way that they can be transmitted together without causing interference.

System Model Continuation

- User 1 detects User 2's signal first due to because of its high power, leading to interference. User 1 employs SIC that subtracts this interference to recover its own data.
- This interference cancellation by User 1 effectively removes User 2's interference. Subsequently, User 1 decodes its data from the remaining signal.
- User 2, with a weaker signal, cannot effectively cancel out the interference caused by User 1, as the interference from User 1 is stronger and interferes with User 2's signal.

System Model Continuation

- Let x1 , x2 be Users 1 and 2's signals respectively and P1 , P2 be the transmission powers by base station for User 1 and User 2. Then the superimposed signal will be:

$$x = \sqrt{P_1}x_1 + \sqrt{P_2}x_2$$

- With this , the received signal at User 1 will be:

$$y_1 = h_1 x + w_1$$

  Where h1 is the channel gain and w1 is the Gaussian Noise.

- Let N be the Power Density or Noise Power of w.

System Model Continuation

- The effectiveness of SIC relies on the order in which decoding takes place, a key factor for achieving interference cancellation. This decoding Order is given by:

$$(h_i)^2/N_i$$

  where h is the channel gain and N is the power density of w. This is Signal To Noise Ratio (SNR).

- Taking the above 2 User case , if

$$(h_1)^2/N_1 > (h_2)^2/N_2$$

  , it indicates that User 1 has a higher signal-to-noise ratio (SNR) than User 2 , signifying better signal quality for User 1. Users with stronger SNR are decoded first. Therefore, User 1, with the higher SNR, is decoded before User 2, while User 2 may experience extra interference and be decoded after User 1's signal separation. This prioritization optimizes signal separation and decoding efficiency.

Outage

- SIC involves a sequential decoding process where each user's signal is decoded and interference is removed. This process can introduce some latency, so it's crucial for users to transmit their information at a rate that accounts for this latency while maintaining high spectral efficiency
- Claude Shannon's theorem defines the capacity (C) of a channel in terms of the Signal-to-Noise Ratio (SNR) as follows:

$$C = \log_2(1 + SNR) bits/sec/Hz \quad ([1])$$

where C is the capacity of the channel, which represents the maximum data rate that can be reliably transmitted over the channel.

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Outage Continuation

- If the actual information rate (transmission rate) in a system exceeds the channel's capacity (as defined by Shannon), it can lead to an **"outage"**. Outage occurs when the system cannot maintain reliable communication due to excessive information rates.
- Let Rb be the transmission rate.
  1. If Rb is much greater than (1 + SNR) : it indicates that the system has a significant margin of data transmission capacity and that the signal is robust, relative to noise, allowing for a reliable data rate.
  2. If Rb is slightly greater than (1 + SNR) : it suggests that the system is operating close to its capacity, and data transmission is relatively less robust but still possible.

Outage Continuation

- **3. If Rb is less than (1 + SNR) :** it implies that the data rate is insufficient to maintain reliable communication in the presence of noise. In such cases, there may be data transmission errors or an inability to maintain a connection.

Problem Formulation In NOMA

- **Receiver Complexity in Hardware:** The hardware complexity of receivers, mainly due to Successive Interference Cancellation (SIC), is a big problem in NOMA. SIC requires a lot of computing power and can drain the battery quickly, which is a significant issue for devices with limited power.[1][2]
- To tackle this problem, NOMA can group users with similar characteristics and allocate power effectively. Finding the right balance between performance and energy efficiency is crucial for using NOMA in various communication scenarios.

Conclusion

In conclusion, NOMA is proved to be a transformative technology in 5G communication, prioritizing users with better connections and significantly enhancing spectral efficiency, aligning with the goals of 5G for speed, efficiency, and reliability.
As 5G networks evolve, NOMA's role becomes pivotal, revolutionizing the way data is transmitted and received, making it a cornerstone technology for the future of interconnected communication.

References

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Thank you