Study on Non Orthogonal Multiple Access (NOMA)

Introduction:

Non-Orthogonal Multiple Access (NOMA) is a wireless communication technology that has gained significant attention as a key enabler for next-generation networks, including 5G and beyond. Unlike traditional multiple access techniques (e.g., Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), and Orthogonal Frequency Division Multiple Access (OFDMA)) that allocate orthogonal resources to users, NOMA allows multiple users to share the same time-frequency resources by superimposing their signals in a non-orthogonal manner. This enables higher spectral efficiency, massive connectivity, and improved system capacity, making it ideal for supporting the diverse demands of modern wireless communication systems.

Objectives:

- Understand the process of NOMA.
- Importance of NOMA.
- Understand the working process of Signal Interference Cancellation.
- Highlighting the advantages & disadvantages of NOMA.
- Highlighting the implementation challenges of NOMA.

Methodology:

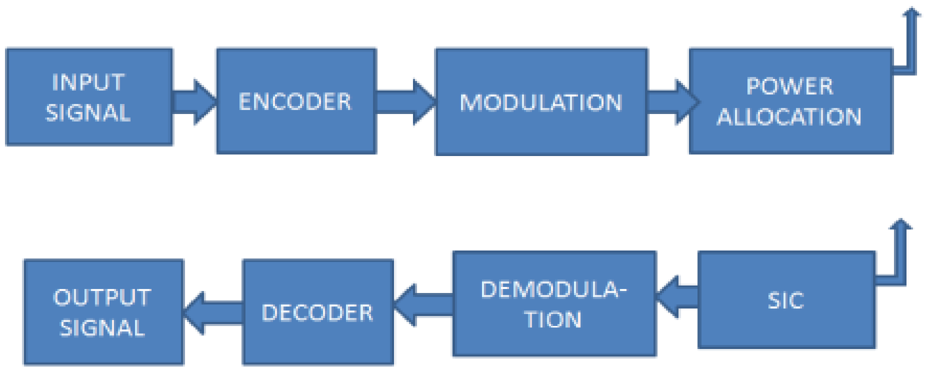

Figure-01: Working Procedure of NOMA

The basic block diagram of the simulation model is illustrated in Figure 01. In this diagram, superposition coding is employed as the encoding technique. Multiple signals to be transmitted are superimposed and sent through the physical downlink channel. Modulation schemes such as QPSK and 16-QAM are utilized. The channel is modelled with the addition of Additive White Gaussian Noise (AWGN). At the receiver, the signals undergo demodulation and decoding. While Successive Interference Cancellation (SIC) is commonly used for decoding, a sphere decoder is considered in this case, excluding SIC. NOMA is characterized by its ability to enhance spectral efficiency, support massive connectivity, and reduce transmission latency and signalling costs. Compared to Orthogonal Multiple Access (OMA), NOMA demonstrates superior multi-user capacity, as highlighted in earlier studies.

Theory:

1. **Super Position Coding:** NOMA uses superposition coding at the transmitter such that the successive interference cancellation (SIC) receiver can separate the users both in the uplink and in the downlink channels.
2. **Successive Interference Cancellation**: Successive Interference Cancellation (SIC) is a key signal processing technique used in Non-Orthogonal Multiple Access (NOMA) to separate signals superimposed in the power domain. It enhances spectral efficiency by allowing multiple users to share resources simultaneously.

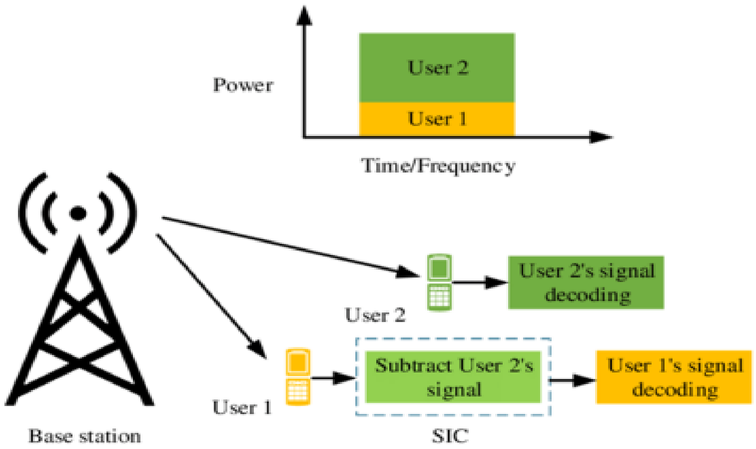

Figure-02: NOMA Wireless Communication

Working Procedure of SIC:

1. Superposition Coding: Signals for multiple users are combined at the transmitter.

2. Signal Reception: Composite signal received by users.

3. Successive Decoding: Stronger signal decoded first and removed. Weaker signal is then decoded.

4. Iterative Interference Cancellation: Process repeats for additional signals.

Figure 2 show the antenna transmits the unipolar real signals $x1$ and $x2$ to $U1$ and $U2$, respectively. Since $U2$ is closer to the transmitting and thus has a higher channel gain, the access point assigns a lower power level to $x2$. The two signals are then superimposed and transmitted simultaneously as $s = P1x1 + P2x2$, where $P1 > P2$ and the sum of these assigned power values is equal to the total transmitting power. The same principle applies for a higher number of users, where the allocated power values are determined based on the channel gains of the different users.

The dominant component in the combined received signal in Figure 02 & Figure 03 is $P1x1$ $U1$ can directly decode its signal considering the interference from the other user's signal as noise, $U2$, however, needs to decode $x1$ first, and then subtract it from the combined signal in order to isolate $x2$ from the residue. This process is called SIC (signal interference cancellation), where users are ordered according to their respective signal strengths so that each receiving terminal decodes the strongest signal first, subtracts it, and repeats the process until it decodes its desired signal.

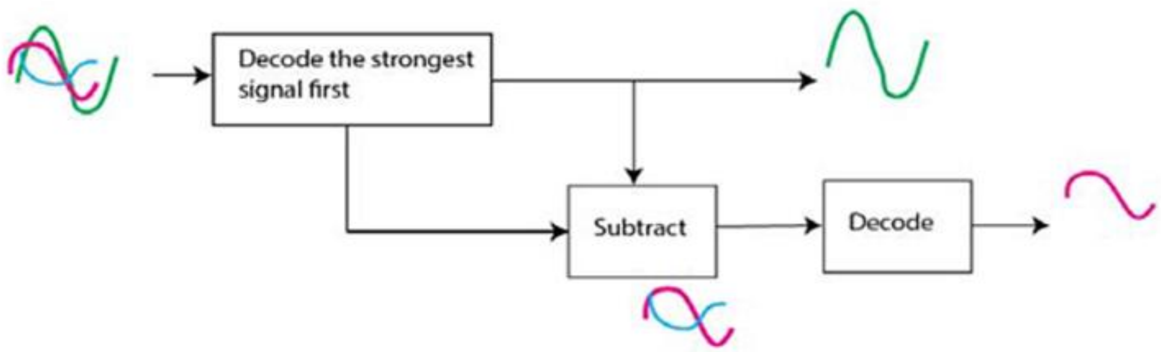

Figure-03: Successive Interference Cancellation

Figure 02 NOMA Wireless Communication with two users. It is recalled that NOMA allocates more power to users with worse channel conditions, while less power is allocated to those with better channel conditions. A key issue is to allocate appropriate power levels for the different users in order to facilitate Successive interference Cancellation (SIC) and to achieve better trade-off between throughput and fairness. The simplest power allocation strategy is the so-called fixed power allocation (FPA), in which users are sorted in an ascending order according to channel gain values.

Advantages:

1. **Higher Spectral Efficiency:** This process allows multiple users to share the same time frequency resources by differentiating them in power domain leading better spectrum utilization.
2. **Higher Connection Density**: It helps simultaneously communicate with large number of devices making it appropriate for IOT networks.
3. **Enhanced User Fairness**: Allocate higher power to users with poor channel conditions, NOMA ensure fairness while maintaining system.
4. **Lower Latency**: Enables simultaneous transmission reducing delays.

5. **Flexible User Pairing**: It can pair with different channel conditions, optimizing resource usage and performance across device scenarios.

Disadvantages:

1. **Receiver Complexity:** Successive Interference Cancellation (SIC) at the receiver requires significant computational power, increasing the complexity of user equipment.
2. **Error Propagation:** Errors in decoding one user's signal during SIC can propagate, affecting the decoding accuracy of other users' signals
3. **Accurate Channel State Estimation:** It requires precise channel state information for optimal power allocation which is difficult in dynamic environments.
4. **Energy Inefficiency:** Allocating high power to users with poor channel condition increases energy consumption will be concern for battery sensitive applications.
5. **Security:** Superposition of multiple users signals may expose unauthorized interception.

Applications:

1. **5G and Beyond Wireless Networks:**

- Enhanced Mobile Broadband (eMBB): High-speed internet for applications like video streaming and virtual reality.
- Massive Machine-Type Communication (mMTC): Connecting a vast number of IoT devices.
- Ultra-Reliable Low-Latency Communication (URLLC): Supporting mission-critical services like autonomous vehicles and remote surgery.

2. **Internet of Things(IoT):**

- Massive Connectivity: NOMA efficiently supports the large number of IoT devices in smart homes, cities, and industries.
- Energy Efficiency: Power-domain multiplexing helps IoT devices with limited energy resources share the same resources efficiently.

3. **Vehicular Communication Systems:**

- NOMA enables **vehicle-to-everything (V2X)** communication, which requires low latency and high reliability for autonomous driving, traffic management, and collision avoidance.

4. **Satellite Communication:**

- NOMA enhances the capacity and connectivity of satellite systems, making it suitable for remote areas and global communication services.

5. **Drones and UAV Communication:**

- NOMA supports **unmanned aerial vehicles (UAVs)** by enabling simultaneous communication with multiple drones, crucial for applications like disaster management and delivery systems.

6. **Healthcare Systems:**

- NOMA is crucial in **e-health** applications, such as telemedicine and remote patient monitoring, where multiple devices need to transmit data con currently with low latency.

7. **Public Safety Networks:**

- In emergency scenarios, NOMA supports simultaneous communication for multiple first responders, ensuring efficient coordination and data sharing.

8. **Industrial Automation:**

- NOMA is applied in **Industry 4.0** for factory automation, where numerous machines and sensors require real-time communication for efficient operation.

9. **Maritime and Underwater Communication:**

- NOMA is suitable for connecting multiple vessels and underwater sensors simultaneously, improving maritime navigation and environmental monitoring.

Code:

```
% NOMA Simulation Parameters
numSymbols = 10^5;        % Number of symbols per user
Pt = 1;                   % Total transmit power
alpha = 0.8;              % Power allocation coefficient for User 1
beta = 0.15;              % Power allocation coefficient for User 2
gamma = 1 - alpha - beta; % Power allocation coefficient for User 3
EbN0_dB = 0:2:30;         % Eb/N0 range in dB

% BPSK Modulation (Symbol Mapping)
data1 = randi([0 1], 1, numSymbols);  % Random binary data for User 1
data2 = randi([0 1], 1, numSymbols);  % Random binary data for User 2
data3 = randi([0 1], 1, numSymbols);  % Random binary data for User 3
x1 = 2 * data1 - 1;                   % BPSK for User 1
x2 = 2 * data2 - 1;                   % BPSK for User 2
x3 = 2 * data3 - 1;                   % BPSK for User 3

% Transmit signal with power allocation for each user
s = sqrt(alpha * Pt) * x1 + sqrt(beta * Pt) * x2 + sqrt(gamma * Pt) * x3;

% Initialize BER results
BER_User1 = zeros(1, length(EbN0_dB));
BER_User2 = zeros(1, length(EbN0_dB));
BER_User3 = zeros(1, length(EbN0_dB));

for idx = 1:length(EbN0_dB)
    % Noise and Channel
    EbN0 = 10^(EbN0_dB(idx)/10);
    N0 = Pt / ( EbN0);      % Noise spectral density
    noise = sqrt(N0/2) * (randn(1, numSymbols) + 1i * randn(1, numSymbols));
    h = (randn(1, numSymbols) + 1i * randn(1, numSymbols)) / sqrt(2); % Rayleigh fading
```

```
  % Generation of Received signal
   y = h .* s + noise;
   % Channel equalization
   y_equalized = y ./ h;

   % Successive Interference Cancellation (SIC) for User 1
   y_User1 = y_equalized / sqrt(alpha * Pt);  % Normalize for User 1
   detected_x1 = real(y_User1) > 0;          % BPSK Detection for User 1
   BER_User1(idx) = sum(detected_x1 ~= data1) / numSymbols;

   % Remove User 1's signal for User 2 decoding
   y_User2 = y_equalized - sqrt(alpha * Pt) * x1; % SIC to cancel User 1's signal
   y_User2 = y_User2 / sqrt(beta * Pt);         % Normalize for User 2
   detected_x2 = real(y_User2) > 0;            % BPSK Detection for User 2
   BER_User2(idx) = sum(detected_x2 ~= data2) / numSymbols;

   % Remove User 2's signal for User 3 decoding
   y_User3 = y_User2 - sqrt(beta * Pt) * x2;     % SIC to cancel User 2's signal
   y_User3 = y_User3 / sqrt(gamma * Pt);        % Normalize for User 3
   detected_x3 = real(y_User3) > 0;            % BPSK Detection for User 3
   BER_User3(idx) = sum(detected_x3 ~= data3) / numSymbols;
end

% Plot results
figure;
semilogy(EbN0_dB, BER_User1, 'b-o', 'LineWidth', 2);
hold on;
semilogy(EbN0_dB, BER_User2, 'r-*', 'LineWidth', 2);
semilogy(EbN0_dB, BER_User3, 'g-^', 'LineWidth', 2);
grid on;
xlabel('Eb/N0 (dB)');
ylabel('Bit Error Rate (BER)');
legend('User 1 (High Power)', 'User 2 (Medium Power)', 'User 3 (Low Power)');
title('NOMA BER Performance with 3 Users');
 % Power Allocation vs Frequency Spectrum Plot
frequency = linspace(0, 1, 100);        % Normalized frequency spectrum
power1 = alpha * ones(size(frequency));  % Power allocated to User 1
power2 = beta * ones(size(frequency));   % Power allocated to User 2
power3 = gamma * ones(size(frequency));  % Power allocated to User 3
figure;
 hold on;
area(frequency, power1, 'FaceColor', 'b', 'DisplayName', 'User 1 Power');
area(frequency,power2, 'FaceColor', 'r', 'DisplayName', 'User 2 Power');
area(frequency,  power3, 'FaceColor', 'g', 'DisplayName', 'User 3 Power');
grid on;
xlabel('Normalized Frequency');
ylabel('Power Allocation');
title('Power Allocation vs Frequency Spectrum');
legend('show');
hold off;
```

Result Analysis:

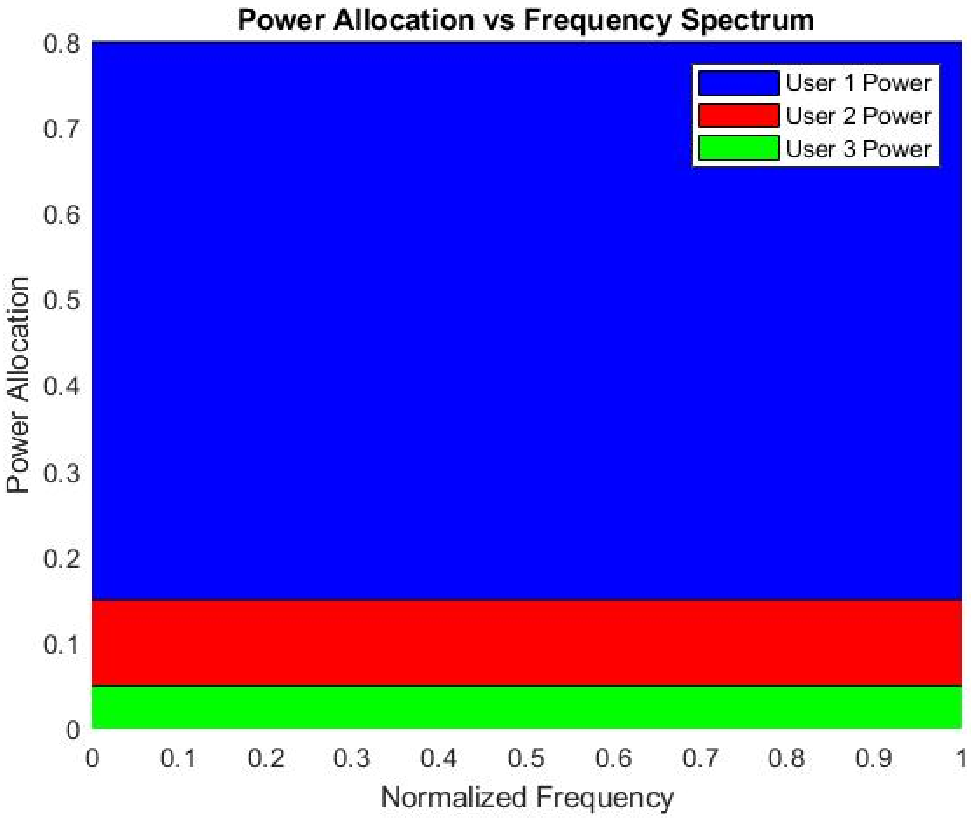

Figure-04: Power Allocation Vs Frequency

The graph represents the distribution of power allocation among three users across the normalized frequency spectrum. The x-axis denotes the normalized frequency, ranging from 0 to 1, while the y-axis represents the power allocated to each user from 0 to 0.8. The total power allocation is shown as a stacked area plot, where each layer corresponds to a specific user. The blue region, which dominates the plot, represents User 1, who has the highest power allocation across the entire spectrum. Below this, the red region corresponds to User 2, with a moderate power allocation. Finally, the green region at the bottom represents User 3, with the smallest power allocation. The graph effectively illustrates the relative distribution of power among the users, highlighting the dominance of User 1 and the comparatively lower allocations for Users 2 and 3. From the graph it is depicted that for user 1 who is far away receiver needs more power to receive the signal.

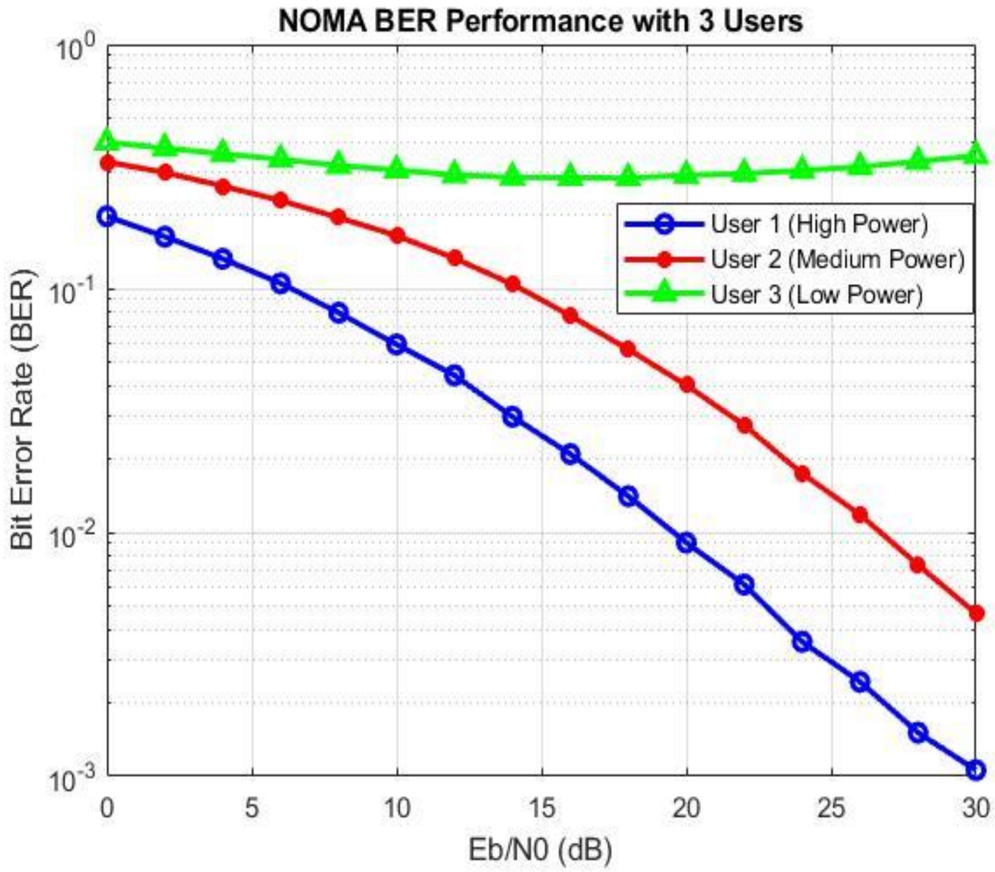

Figure-05: Bit Error Rate Performance Vs SNR

The graph illustrates the Bit Error Rate (BER) performance of a Non-Orthogonal Multiple Access (NOMA) system for three users under varying signal-to-noise ratio (SNR) conditions, represented as E_b/N_0 (in dB) on the x-axis. The y-axis, plotted on a logarithmic scale, shows the Bit Error Rate. The performance curves are categorized by power levels allocated to each user. User 1 (high power), represented by blue circles, demonstrates the best performance, with BER decreasing significantly as E_b/N_0 increases. User 2 (medium power), represented by red squares, shows moderate performance, with a slower decline in BER compared to User 1. User 3 (low power), represented by green triangles, maintains a consistently higher BER, indicating poorer performance even as E_b/N_0 increase. The graph highlights the trade-off in BER performance among users with different power allocations in a NOMA system, where higher power users achieve better error rate performance.

Discussion:

Non-Orthogonal Multiple Access (NOMA) represented a paradigm shift in wireless communication, enabling significant advancements for next-generation networks, including 5G and beyond. Unlike traditional orthogonal multiple access schemes such as TDMA, FDMA, and OFDMA, which assign distinct time, frequency, or code resources to different users to avoid interference, NOMA allows multiple users to simultaneously access the same time-frequency resources. This was achieved by leveraging the power domain or code domain to distinguish users, with signals superimposed and separated using advanced signal processing techniques such as Successive Interference Cancellation (SIC) at the receiver. By accommodating multiple users in a single resource block, NOMA significantly enhances spectral efficiency, allowing networks to support massive connectivity—a critical requirement for applications such as the Internet of Things (IoT), smart cities, and machine-to-machine communications. Furthermore, NOMA improves system capacity and user fairness by dynamically allocating power levels based on users' channel conditions, enabling stronger signals for users with poor channels and ensuring robust communication. This ability to meet diverse Quality of Service (QoS) requirements makes NOMA an indispensable technology for modern communication systems, paving the way for efficient, scalable, and future-proof network deployments.

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