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Successive Interference Analysis for 5G System at Mid-Band and High-Band Frequency

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Abstract

This research study focuses on the impact of interference on different 5G system parameters such as modulation techniques (64-QAM, 256-QAM), channel models (AWGN, Rayleigh, and Rician), and MIMO (multiple input, multiple output) in terms of Bit Error Rate (BER). After the analysis of interference for each parameter, an analysis of interference by Short Range Devices (SRDs) on the 5G system network on the downlink channel is done. Finally, successive interference cancellation (SIC) for a 5G Non-Orthogonal Multiple Access (NOMA) system with Power Division Multiplexing (PDM) is applied. A 5G NOMA has higher spectral efficiency as compared to an Orthogonal Frequency Division Multiple Access (OFDMA), so it can fulfil the needs of the Internet of Things (IoT). SIC is implemented using PDM, where each user is assigned a certain power factor and generates a signal, the generated signal is superimposed and the New-Radio (NR) transmitter that transmits the superimposed signal. Finally, the signal is detected with and without SIC on the access side with SRDs as an interferer. After simulation and analysis of different 5G system parameters, it is found that the BER is decreased with an increase in the MIMO and is more applicable to the higher order modulation. With the SIC, the BER for the NOMA users decreased as compared to OFDMA users. The power coefficients for the stronger signal user (user 1) and weaker signal user (user 2) are 0.25 and 0.75 respectively.

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Keywords: BER, OFDMA, NOMA, PDM, SIC, IoT, Quadrature Amplitude Modulation (QAM), NR, Additive white Gaussian noise (AWGN), Rayleigh, Rician, MIMO, Signal-to-Interference-plus-Noise Ratio (SINR)

1. Introduction

There is a rapid growth in wireless technology from 1G to 4G, and 5G technology is rapidly in progress. Many developed countries have already deployed a 5G system, but in the least developed countries, the 5G system has not been implemented yet. The importance of 5G technology is increasing day by day due to rapid growth in mobile data traffic and high demand for IoT services using broadband internet services. A 5G system deploys for high data rates, improved quality of service (QoS), low latency, high coverage, and high reliability [1]. According to 3GPPs, the available frequency bands for 5G are described in Table 1.1

Table 1.1. Different Frequency Bands

Frequency Band	Frequency
Frequency range 1 (FR1)	Below 1GHz (Lower-Band)
Frequency range 2 (FR2)	Above 1 GHz up to 6 GHz (Mid-Band)
Frequency range 3 (FR3)	Above 24 GHz (High-Band)

SRDs are radio transmitters capable of unidirectional or bidirectional broadcasts, designed with minimum interference from other radio devices. SRDs find applications in wireless speech and video, alarms, building automation, wireless sensor systems, and remote keyless entry [17-19].

A signal that is being sent across a channel from source to destination may be altered or disrupted by adding undesired signals to the original signal, this phenomenon is known as interference. The channel's efficiency is hindered, diminished, or limited by interference [2].

High-definition applications and services, such as social networking, gaming, online browsing, and the simultaneous operation of a variety of machine-type communications, caused a huge increase in traffic. To fulfill traffic requirements, a 5G system for wireless communication has evolved with the challenges of managing interference. The interference in the 5G system is due to the presence of a dense heterogeneous network with relay nodes aiming to provide IoT services [3].

1.1. Contribution of Research Work

This research work focuses on interference analysis for 5G system parameters such as modulation and channel characteristics. Due to the rise in BER that accompanied the increase in modulation order, MIMO was introduced to reduce interference. Also, Successive Interference Cancellation (SIC) with PDM is used for the NOMA system to reduce the interference generated by SRDs and replace OFDMA. NOMA system helps in research and deployment for a 6G system in the future with increased spectral efficiency.

2. Related Work

The 5G technology is rapidly in progress; many developed countries have already deployed a 5G system, but in developing countries, the 5G system has not been implemented yet. A 5G system uses a higher order of modulation and higher frequencies to enhance data rates. Higher-order modulation is highly susceptible to noise, and higher frequencies are highly susceptible to blockage and absorption. So, an increased order of modulation leads to increased BER, so analysis for reducing BER with MIMO and path loss for Mid-Band and High-Band frequencies is needed. Not only do 5G system parameters introduce interference, but also SRDs introduce interference at the access end, so proper cancellation of interference is also needed. [20-23].

Wang et al. studied the co-existence between ES and FSS in China at 3400–3600 MHz frequency band interference. There are two different types of interference, which are co-channel interference and adjacent channel interference. Monte Carlo simulation and analysis results show that the LTE frequency offset from the edge of the FSS channel should be above 10 MHz for downlink and above 5 MHz for uplink in China [4].

M. Adhikari and D. S. Baral's research on interference analysis of 5G in a coexistence scenario with SRD in the 850 MHz band with a reference frequency of 868 MHz and taking SRDs in the frequency range of 863–870 MHz, Monte-Carlo (MC)-based SEAMCAT simulation for finding the probability of interference or bitrate degradation, suggests ensuring service availability greater than 95% [5].

Palizban et al. studied the mm-wave for outdoor coverage in dense urban areas and found that mm-waves are more sensitive to blockage, and the presence of line of sight (LoS) is needed and provides the coverage solution for large cities with dense BS [6].

S. Liu, Y. Wei, and S.-H. Hwang studied the necessity of guard band protection for the coexistence of 5G satellite earth stations (Ess) and base station (BS) and also investigated the power control scheme to handle the interference between BS and ES [7].

A. Gachhadar, R. K. Maharjan, S. Shrestha, N. B. Adhikari, and F. Qamar studied the interference cancellation in multi-tier heterogeneous networks and analyzed the performance of users based on coverage probability, success probability, ergodic capacity, throughput gain, and outage probability [8].

N. Iswarya and L. Jayashree conducted a survey on SIC for 5G NOMA using code domain and power domain techniques. NOMA can improve capacity in terms of higher spectral efficiency, massive connectivity, and low latency as compared to traditional OFDMA multiple access, so it can support a large number of users with higher spectral efficiency, massive connectivity, and low latency [9].

Md. Golam Sadeque studied the BER performance of different modulations (BPSK, QPSK, and 16-QAM) with an AWGN channel between the transmitter and receiver using MATLAB Simulink, and found that BER increases with an increase in the modulation order [10].

3. Proposed Work

The proposed work consists of the analysis of interference by the 5G parameters (modulation and channel characteristics) with MIMO for the reduction of BER and the analysis of BER with the presence of SRDs for NOMA and OFDMA.

3.1. 5G Downlink System

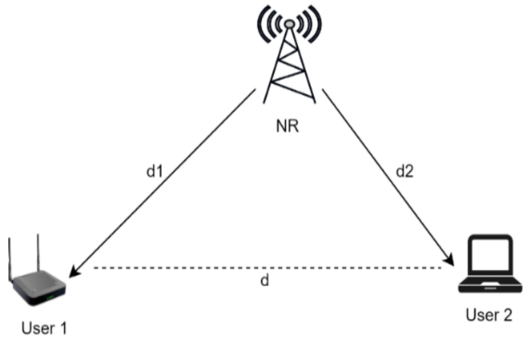
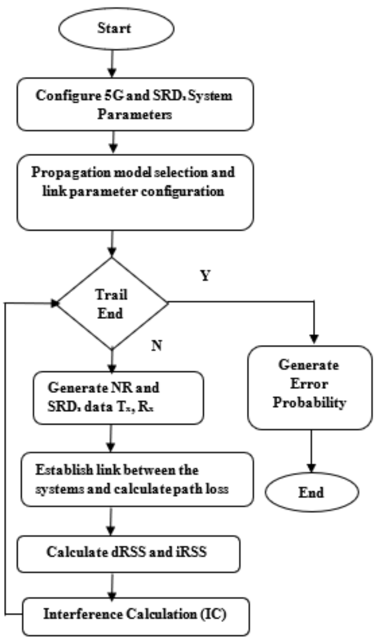


Figure 3.1. 5G Downlink System with Two Users

In Figure3.1user 1 and user 2 are stronger and weaker signals at a distance of d1 and d2 from the NR transmitter, respectively, and d is the distance between user 1 and user 2.

3.2. Flowchart



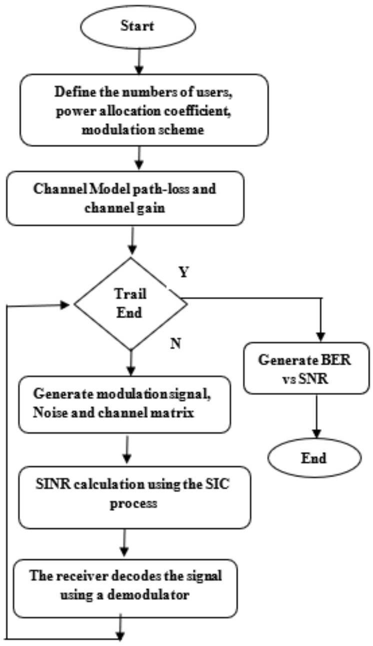


Figure 3.2. Analysis of Interference by SRDs using SEAMCAT for varying Interferer Tx power [5]

Figure 3.3. Analysis of BER for NOMA SIC System using MATLAB

Trail End is the completion of the iteration, in this analysis. The number of iteration is assumed as 20,000. The flowchart in Figure 3.2 and Figure 3.3 presents the process in the analysis of interference by SRDs using SEAMCAT for varying interferer transmitting power and the analysis of BER for NOMA SIC system using MATLAB respectively.

3.3. Analysis of Interference by SRDs using SEAMCAT

3.3.1. Configure 5G and SRD_s System Parameter

Configure the 5G and SRD parameters on SEAMCAT; the parameters are antenna pointing (azimuth and elevation), antenna height, radiation pattern, antenna gain, and transmitter emission characteristics such as power distribution, emission mask, transmitting power, operating frequency, system bandwidth, etc. are all examples of transmitter distribution parameters. Antenna pattern, antenna pointing, antenna height, antenna gain, and receiver characteristics like noise floor, blocking mode, blocking mask, reception bandwidth, sensitivity, etc. are examples of receiver input parameters.

3.3.2. Establish a Link between the Systems and Calculate the Path Loss Propagation model selection depends on operating frequency, so according to the ITU-R propagation model used, it is P.452-14. For link parameter configuration, there is a victim system (Tx and Rx), an interference link, and the required input parameters for event generation for simulation.

3.3.3. Calculate dRSS and iRSS

The desired (wanted) received signal strength and interfering (unwanted) received signal strength is calculated as

$$dRSS = P(V_t) + G(V_t) - PL(V_t \to V_r) + G(V_r) - A(V_r) \quad (3.1)$$

$$iRSS = P(I_t) + G(I_t) + G(V_r) + PC(I_t) - PL(I_t \to V_r) - A(V_r) \quad (3.2)$$

Where, P (V_t) = Maximum power of victim (desired) transmitter antenna

G (V_t) = Gain of the victim transmitter (V_t)

PL ($V_t \to V_r$) = Path loss between the victim transmitter (V_t) and the victim receiver (V_r)

$G(V_r)$ = Gain of victim receiver (V_r)

$A(V_r)$ = Attenuation by Victim receiver (V_r)

$P(I_t)$ = Power of Interfering transmitter (I_t)

$G(I_t)$ = Gain of Interfering transmitter (I_t)

$PC(I_t)$ = Power control of interfering transmitter (I_t)

$PL(I_t \rightarrow V_r)$ = Path loss between interfering transmitter (I_t) and victim receiver (V_r) [11] .

3.3.4. Interference Calculation (IC)

Interference calculation is done by calculating the carrier-to-interference ratio C / (N + I). It is expressed as C / (N + I) = dRSS / iRSS equivalent to dRSS - iRSS in dB and compared with the C / (N + I) threshold value.

If C / (N+I) < C/ (N+I) threshold, then the probability of error is 1, and if the received signal is less than the sensitivity of the receiver, the probability of error is 1.

3.4. Analysis of BER for NOMA SIC system using MATLAB

3.4.1. NOMA Overview

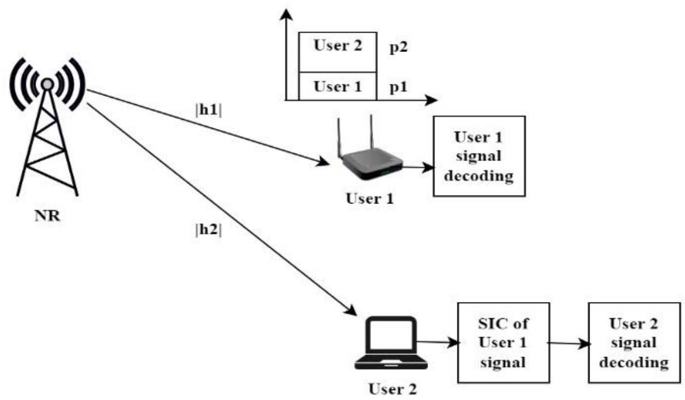


Figure 3.4. 5G Downlink System with PDM NOMA

SIC is an interference cancellation technique to reduce interference in multi-user circumstances and, finally, increase the communication system's capacity and reliability by decoding and eliminating interference from many users or sources successively. It consists of two steps for two receivers. If M users are considered in the networks that interfere with each other, it will take M steps to decode the weakest signal at one node or user to achieve the desired signal.

- In the first step, SIC treats weaker signals as noise and decodes the strongest signal.
- In the second step, SIC regenerates the most powerful signal and removes it from the received signal.

In Figure 3.4, a strong signal at user 1 has a channel gain of $|h1|$ and a power coefficient of α_1, whereas a weaker signal at user 2 has a channel gain of $|h2|$ and a power coefficient α_2, such that $|h2| > |h1|$ and $\alpha_1 > \alpha_2$. In NOMA, multiple users share the same time-frequency resources and superimpose their signals before sending them to the base station, and P (t) is the total power transmitted. where $\alpha_1 + \alpha_2 = 1$. Now, the signal transmitted from the NR transmitter is given by

$$x = \sqrt{\alpha 1 \text{ P (t)}}\, \text{s1} + \sqrt{\alpha 2 P(t)}\, \text{s2} \quad (3.3)$$

The desired received signal through the AWGN channel is given by

$$y(t) = h(t) * \sum_{i=1}^{M} \sqrt{\alpha_i P(t)} s_i(t) + n(t) \quad (3.4)$$

where, α_i represents the power coefficient, P (t) is the total transmitted power, si (t) is transmitted, and n (t) is the additive white Gaussian noise.

3.4.2. NOMA SIC Receiver Architecture

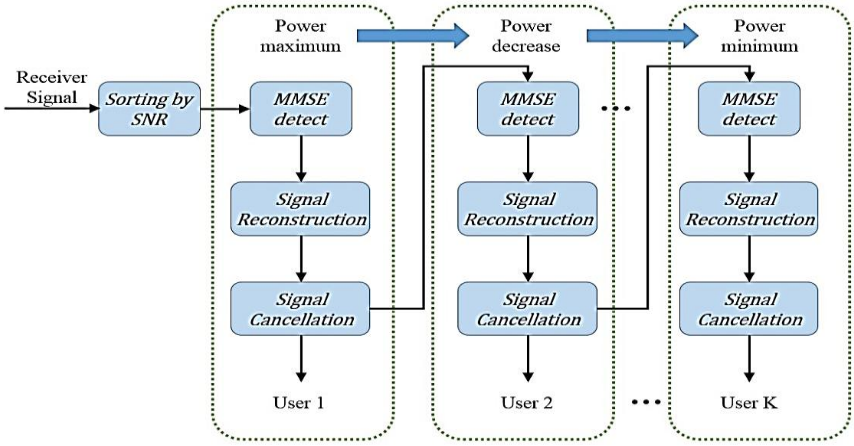


Figure 3.5. SIC Receiver Architecture [12]

As shown in Figure 3.5, with the SIC receiver architecture, the data rate can be achieved by decoding multiple signals in descending order of SNR. Let p1, p2, ... pk transmit power for k users, where $p1 > p2 > ... > pk$, where user 1 with the strong signal is decoded directly whereas the signal from other users is treated as noise. Based on Shannon's capacity theorem or formula, the data rate for different users is described as

$$R_1 = B * \log_2 \left(1 + \frac{p1|h_1|^2}{\sum_{i=2}^{k} pi|h_1|^2 + N_0}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

Similarly, R_2, ..., R_k is calculated. Consider R_K as the weakest signal is decoded last and is given by,

$$R_k = B * \log_2 \left(1 + \frac{pk|h_k|^2}{N_0}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

Now the total data rates, or system throughput, are given by $S_T = R_1 + \ldots + R_k$.

If the OFDMA channel is used, the B/k for k users, where B is channel bandwidth. To make NOMA applicable, consider the challenges in managing the interference between the SRD users.

3.4.3. BER Calculation

BER is used to express how likely it is that there will be errors when sending bits from the transmitter to the receiver. Finally, the BER assesses the quality and reliability of a communication network link. Mathematically, BER is given by:

$$BER = \frac{\text{Number of Incorrectly Received Bits}}{\text{Total Number of Transmitted Bits}} \ldots\ldots (3.7)$$

The demodulator decodes the received bits, and BER in terms of SNR is given by:

$$\text{BER} = \frac{1}{2} \cdot \text{erfc}\left(\frac{\text{SNR}}{\sqrt{2}}\right) \ldots\ldots (3.8)$$

, erfc is a complementary error function. From the above equation 3.8, the higher the value of SNR lower the BER, and vice-versa.

In the presence of interference, SINR is given by:

$$\text{SINR} = \frac{\text{Received Signal Power}}{\text{Noise Power} + \text{Interference Power}} \ldots\ldots (3.9)$$

If an interferer is present, SINR in terms of SNR is given by:

$$\text{SINR} = \frac{\text{SNR}}{\text{Interference}} \ldots\ldots (3.10)$$

so, equation 3.10 shows that SINR < SNR, then BER due to the presence of interferer increases.

3.4.4. Power Allocation

NOMA SIC employs proportional fairness for balanced spectral efficiency, allocating power proportionally based on user channel conditions while transmitting the signal. Power Division Multiplexing (PDM) uses superposition coding. In this system, the transmitter transmits different types of information using Power Division Multiplexing (PDM). Power allocation to different users by pairing in the clusters [13]. If pairing more than two users, then fixed power allocation cannot be effective in preventing dominance by stronger users. On such cases the water drop filling algorithms can be used [14].

Receiving the signals from users on the basis of the pattern of the received signal is called Pattern Division Multiple Access (PDMA) [15]. The transmitted superimpose signal is given in equation 3.3.

Finally, the transmitter transmits a signal using Power Division Multiplexing (PDM), whereas receiving by Pattern Division Multiple Access (PDMA).

3.5. Different 5G Parameters

3.5.1. Transmit Signal using Modulation

To transmit data at higher rates for the 5G system, 64 QAM and 256 QAM modulations are used. Each symbol in 64-QAM corresponds to eight bits of digital data streams, $2^6 = 64$ potential permutations. The constellation diagram's 64 possible amplitude and phase combinations are used to encode these eight bits. The constellation diagram for 64-QAM is on an 8x8 grid. Each symbol in 256-QAM corresponds to eight bits of digital data streams, $2^8 = 256$ potential permutations. The constellation diagram's 256 possible amplitude and phase combinations are used to encode these eight bits. The constellation diagram for 256-QAM is on a 16x16 grid. The transmit signal symbol is denoted by x. For BPSK two bits, 64-QAM six bits, and 256-QAM eight bits at a time are generated from the transmitter to the receiver.

3.5.2. Channel Noise

Additive White Gaussian Noise (AWGN) in communication systems is simulated noise with constant power spectral density and a Gaussian probability distribution. Its impact on a signal is typically assessed by considering either the power or variance of the noise. The Power Spectral Density (PSD) is given by:

$$No = k \cdot T \quad (3.11)$$

The total noise power (N) is given by:

$$N = No \cdot B \quad (3.12)$$

k is Boltzmann's constant, equal to $(1.380649 \times 10^{-23})$ Joules per Kelvin (J/K), T is the absolute temperature in Kelvin (K), B is Bandwidth in Hz.

3.5.3. Channel Matrix

Channel matrix (H) is different for Rayleigh, Rican, and AWGN channel models; the channel matrix is used to define the channel gain or attenuation from the transmitter to the receiver. Higher channel gain signifies increased signal amplification, reducing path loss, and enhancing communication efficiency by mitigating signal attenuation through the medium and overcoming obstacles. Inversely, lower channel gain implies higher path loss, indicating diminished signal strength due to increased attenuation and obstacles in the communication channel. In the case of MIMO, multiple transmitters transmit the signal to a single user in order to reduce BER by increasing the channel gain and reducing the impact of path loss. The effective channel matrix with path-loss is given by:

$$H_{\text{eff}} = \sqrt{L(d)} \cdot H \quad (3.13)$$

The desired received signal is given by:

$$Y = H_{\text{eff}} \cdot x + N \quad (3.14)$$

4. Results and Discussion

The result and discussion cover simulation tools for the analysis of the interference and for the following Scenario

- Analysis of BER with different 5G parameters (modulation, channel characteristics) with MIMO
- Analysis of interference by SRDs for a transmitter-receiver system with one interferer by applying SIC

4.1. Simulation Parameters and Tools

4.1.1. Simulations Tools

SEAMCAT: It is a Monte Carlo-based simulator for interference analysis software, which is developed by CEPT.

MATLAB: It is a matrix-based language simulator, used to analyze the real-world mathematical problem. Tasks performed by MATLAB are Numerical Calculation, Programming, Matrix Manipulation, and Error analysis.

4.1.2. Simulation Parameters

The Table. 4.1 shows the simulation parameter used for the base station (NR) and short-range devices.

Table 4.1. Simulation Parameters for BS (NR) and SRDs **[**16]

Parameters	**Values**
Operating Frequency	2.3 GHz, 2.6 GHz, 3.4 GHz, 28 GHz
System Bandwidth	45 MHz, 100 MHz, 200 MHz, 2GHz
Modulation	BPSK, 64 QAM, 256 QAM
MIMO	8 * 8 antenna array
Receiver Sensitivity	-93.7 dBm
BS (NR) Transmit Power	43 dBm
Channel Model	AWGN, Rician, Rayleigh fading channel
Propagation Model	ITU-R P.452-14
BS (NR) height	30 m
Receiver height (SRDs)	1.5 m
BS (NR) Antenna Gain	15 dB
Protection Criteria (C/(N+I))	10 dBm
SRDs Bandwidth	200 KHz
SRDs Gain	9 dB

4.2 Analysis of BER with different 5G Parameters

Analysis of BER for different modulation techniques BPSK, 64-QAM, and 256-QAM, with and without MIMO, and finally analysis of BER for different channel models (AWGN, Rayleigh, and Rician). In this analysis, one ideal transmitter and receiver are considered without SRDs; only the impact of the parameter is studied and analyzed. The BER analysis for different modulation is shown in the Figure 4.1 below.

4.2.1 BER Analysis for different Modulation

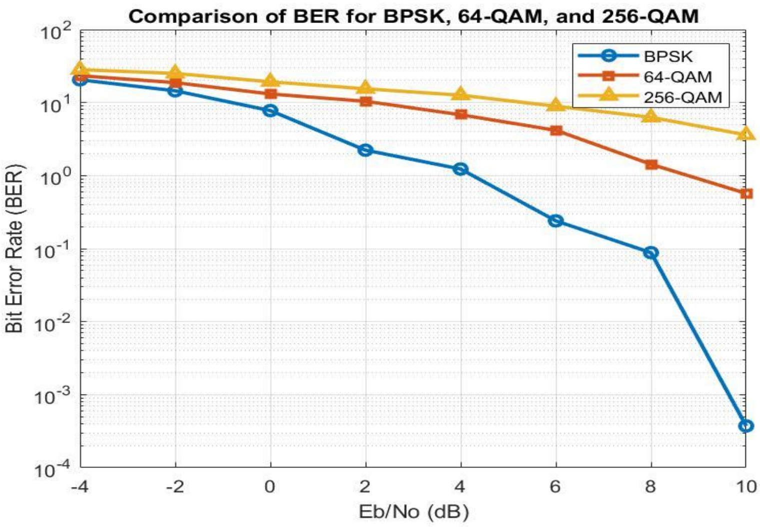


Figure 4.1. Comparison of BER for BPSK, 64-QAM, and 256-QAM

Table 4.2. Comparison of BER for BPSK, 64-QAM, and 256-QAM

Eb/No (dB)	BER for BPSK (%)	BER for 64-QAM (%)	BER for 256-QAM (%)
-4	20.5	23.33	28.25
-2	14.5	18.75	25.063
0	7.77	13.11	19.25
2	2.23	10.42	15.438
4	1.23	6.81	12.625

6	0.24	4.17	8.917
8	0.088	1.43	6.281
10	0.000373	0.57	3.609

Table 4.2 shows that BER for 256-QAM > 64-QAM > BPSK, whereas the higher-order 256-QAM can produce larger data rates, although it is more susceptible to noise and interference since constellation points are closer to one another in the complex plane. BER decreases with increases SNR values.

4.2.2 BER Analysis for different Modulation with MIMO

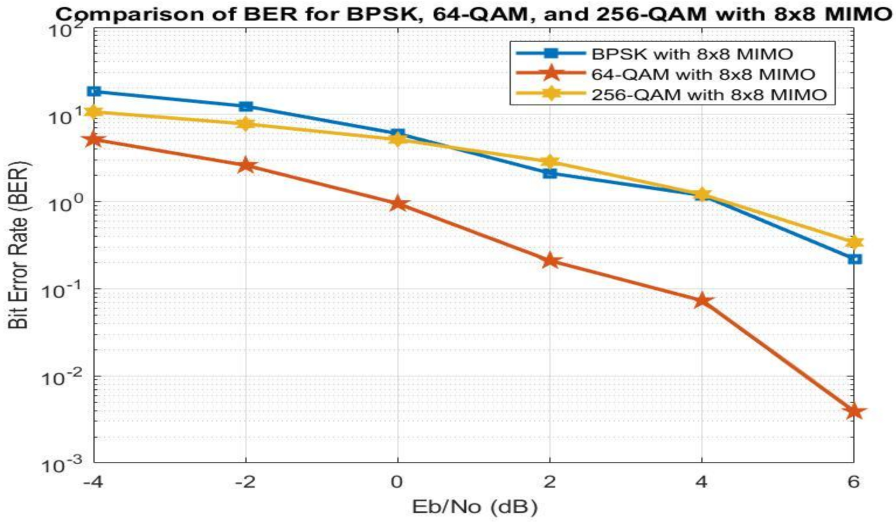


Figure 4.2. Comparison of BER for BPSK, 64-QAM, and 256-QAM with 8 * 8 MIMO

The BER analysis for for BPSK, 64-QAM, and 256-QAM with 8 * 8 MIMO is shown in Figure 4.2

Table 4.3. Analysis of BER for Different Modulation with and without MIMO

Eb/No (dB)	-4	-2	0	2	4	6
BER for BPSK (%)	20.5	14.5	7.77	2.23	1.23	0.24
BER for BPSK with 8*8 MIMO (%)	18.35	12.45	6.03	2.12	1.18	0.22
BER for 64-QAM (%)	23.33	18.75	13.11	10.42	6.82	4.17
BER for 64-QAM with 8*8 MIMO (%)	5.17	2.61	0.95	0.21	0.073	0.0039
BER for 256-QAM (%)	28.25	25.06	19.25	15.43	12.62	8.91
BER for 256-QAM with 8*8 MIMO (%)	10.72	7.8	5.15	2.87	1.21	0.34

Table 4.3 shows that BER decreases with an increase in the MIMO. For the lower order Modulation (BPSK) technique, MIMO is less applicable but for the higher modulation (64-QAM,256-QAM) technique, MIMO is more applicable to decrease the BER.4.2.3. BER Analysis for different Channel Models

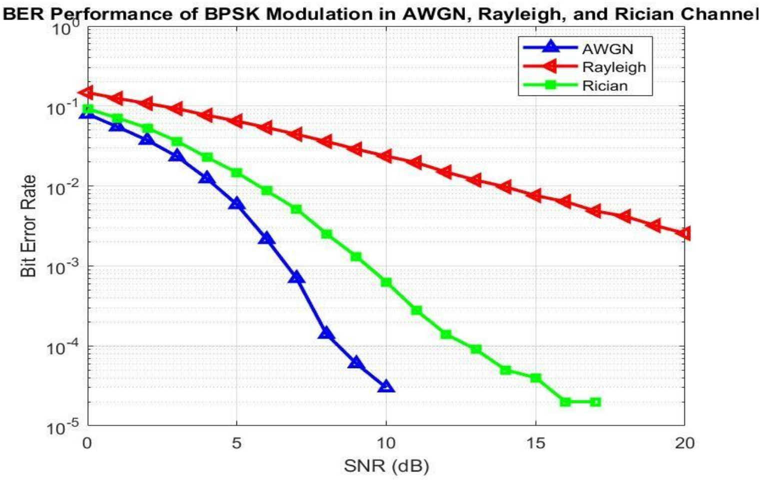


Figure 4.3. BER vs SNR for BSPK with different channel

Figure 4.3 shows that BER decreases with an increase in SNR, comparing the different channel models: BER, Rayleigh > Rician > AWGN, since the Rayleigh channel considers the fading whereas AWGN is the ideal channel.

4.2.3 Analysis of Path-loss for Different Frequency

Path-loss analysis utilizing the ITU-R-recommended P.452-14 propagation model for mid-band and high-band frequencies. Utilizable at a distance of 10,000 km and in the frequency range of 0.7 GHz to 50 GHz. The path-loss for different frequencies at different distance is shown in the Table 4.4

Table 4.4. Path-loss for different Frequencies at different Distances

Frequency Band	Distance in meters (d)	Path-loss (dB)
2300 MHz	20	65.76
2600 MHz	20	66.83
3400 MHz	20	69.16
28 GHz	20	87.57
2300 MHz	500	93.72
2600 MHz	500	94.79
3400 MHz	500	97.12
28 GHz	500	115.53

4.2. Transmitting Power of Interferer

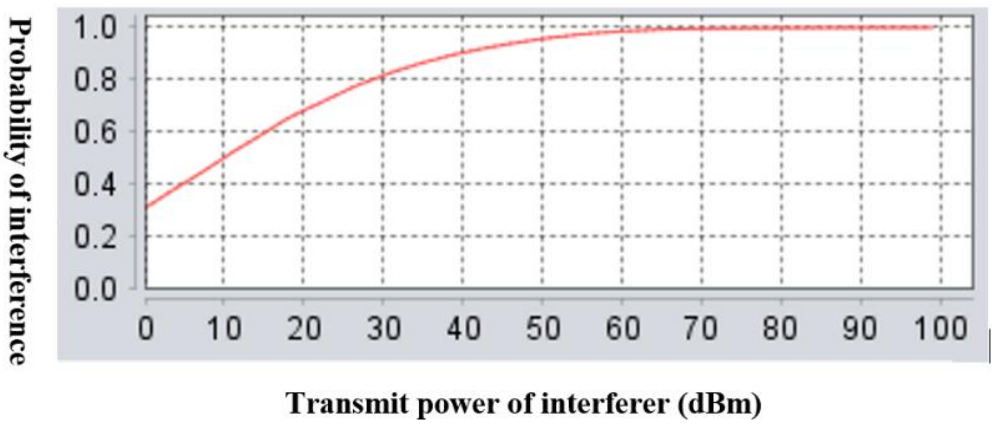


Figure 4.4. Transmitting Power of Interferer using SEAMCAT

Figure 4.4 shows that the probability of error increases with increases in the transmitting power of the interferer and exceeds the threshold at 60 dBm.

4.3. Analysis of Interference for User 1 and User 2

In this section of research, we analyze the BER for OFDMA and NOMA SIC with varying power coefficients for the two users, considering user 1 as the stronger signal and user 2 as the weaker signal.

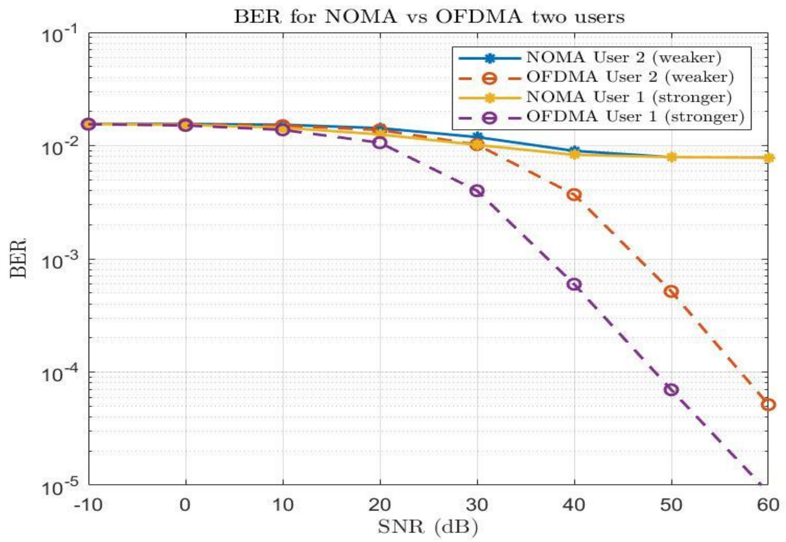


Figure 4.5. BER for NOMA and OFDMA for Power Coefficients 0.5 and 0.5

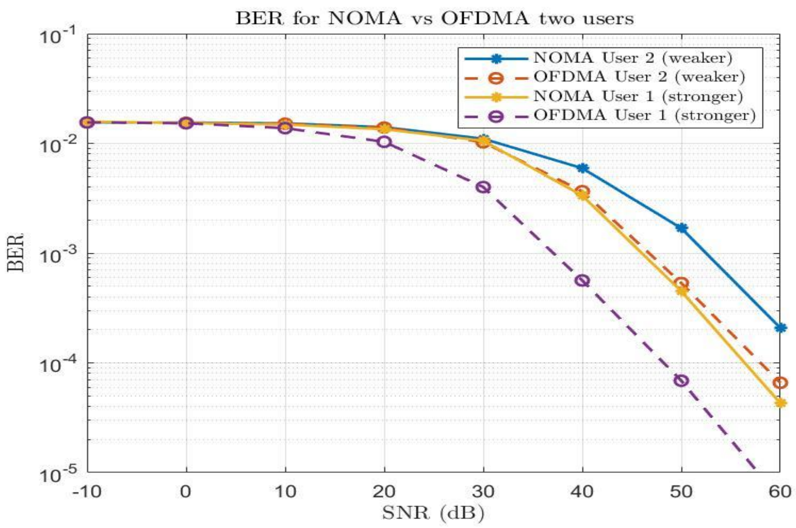


Figure 4.6. BER for NOMA and OFDMA for Power Coefficients 0.25 and 0.75

Analysis of BER from Figures 4.5 and 4.6 shows that increasing the power coefficient, BER, for NOMA users is decreased as compared to OFDMA users. Therefore, BER for NOMA SIC can be decreased by optimizing power using various methods. Additionally, by pairing more than two users, deep learning algorithms can be used for real-world deployment of 5G NOMA systems in the future, helping to meet the demand for IoT with improved spectral efficiency.

5. Conclusion

The research demonstrates that in a 5G system, factors such as modulation techniques, channel models, and MIMO significantly impact the Bit Error Rate (BER). The analysis of interference by SRDs on the downlink channel with implementing SIC for a 5G Non-Orthogonal Multiple Access NOMA system using Power Division Multiplexing (PDM) reduces the BER. The study finds that BER decreases with increased MIMO and is highly applicable for higher-order modulation, and analysis shows BER is reduced by assigning an appropriate power coefficient between the SRD users. The results demonstrates that BER is equivalent to SIC systems for OFDMA and NOMA. . Therefore, 5G NOMA with SIC employing PDM is required to meet future IoT needs with high spectrum efficiency. Additionally, numerous researchers are investigating the viability of a 6G system that incorporates NOMA, indicating that 5G NOMA can be important to the deployment of 6G. Also, 5G NOMA can be implemented by pairing more than two users, and the allocation of power coefficients will be done by using deep learning algorithms.

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