Scilab case study project on

The performance study of single-antenna and multi-antenna wireless communication systems using GUI

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Abstract:

Modern wireless communication systems demand higher data rates and more reliable connectivity. To address these needs, system designers continuously strive to enhance spectrum efficiency, link reliability, and network coverage. Space-time wireless technology, leveraging multiple antennas with advanced signaling and receiver techniques, has emerged as a key solution for improving wireless performance. While some aspects of this technology are already integrated into 3G standards, more sophisticated space-time methods are being developed for future wireless networks, including 5G, WLANs, and WANs. This study focuses on evaluating the performance of different antenna configurations—namely, single-input single-output (SISO), single-input multiple-output (SIMO), multiple-input single-output (MISO), and multiple-input multiple-output (MIMO) systems. A SCILAB-based graphical user interface (GUI) is designed to facilitate comparative analysis, with a particular emphasis on SISO and MIMO systems, highlighting their respective advantages in wireless communication.

Index terms: Capacity Analysis, SISO, MISO, SIMO, MIMO, GUI.

1 Introduction:

In Wireless communication, information can be transferred from one place to another without any sort of wire or electrical conductors. The rapid development of mobile users nowadays gives rise to a common problem for mankind: how the capacity and data rates of the users can be increased. The capacity limits dictate the maximum data rates that can be transmitted over wireless channels with asymptotically small error probability, assuming no delay constraints.

The use of multiple antennas at the transmitter and/or receiver in a wireless communication link opens a new dimension – space, which if leveraged correctly, can improve the data rate performance substantially. In many respects, the use of multiple antennas is the key technology to reach many of the aggressive system performance targets. Multiple antennas can be used in different ways for different purposes:

Diversity: Multiple receive antennas can be used for receive diversity. A multiple receive antennas is used to collect additional energy and suppress channel fading effect. Similarly, multiple transmit antennas at the base station can be used for transmit diversity and different types of beam-forming. The main goal of beam-forming is to improve the received signal-to-interference-and-noise ratio (SINR) and, eventually, improve system capacity and coverage.

Spatial multiplexing: By transmitting independent information on the parallel spatial channels, the data rate of transmission is increased. This effect is called spatial multiplexing. Spatial multiplexing results in an increased data rate, channel conditions permitting, in bandwidth-limited scenarios by creating several parallel "channels."

2. Problem Formulation

The capacity of multiantenna wireless communication systems is critically important as it directly determines the maximum achievable data rates in modern networks, enabling them to meet the exponentially growing demand for high-speed connectivity driven by applications like 4K/8K streaming, IoT, and AR/VR. By employing multiple antennas through techniques like MIMO, SIMO, and MISO, these systems overcome fundamental limitations of traditional SISO configurations by simultaneously enhancing spectral efficiency through spatial multiplexing, improving reliability via spatial diversity, and extending coverage via beamforming - all without requiring additional spectrum. As wireless systems face increasing pressure to deliver higher data rates within constrained spectrum and power budgets, understanding and maximizing multiantenna capacity remains essential for developing next-generation wireless communication systems. The capacity improvements from multiantenna systems form the technological foundation for 5G/6G mobile networks. In this case study, A SCILAB-based graphical user interface (GUI) is designed to facilitate comparative analysis of

SISO and MIMO systems over a flat fading AWGN channel and a fluctuating Rayleigh fading channel, highlighting their advantages in wireless communication.

3. Basic concepts related to the topic

Channel Configuration:

AWGN channel: The Additive White Gaussian Noise (AWGN) channel is a fundamental theoretical model in digital and analog communications. It characterizes the effect of random noise impairing a transmitted signal, providing a basis for analyzing system performance limits and designing robust modulation and coding schemes. Thus, understanding AWGN is essential for designing and evaluating communication systems before extending to more complex real-world scenarios.

Rayleigh fading channel: The Rayleigh fading channel is a statistical model used to describe the effect of multipath propagation in wireless communication systems, where a signal reaches the receiver via multiple paths due to reflections, diffractions, and scattering. The received signal is the sum of multiple reflected and scattered waves with random phases and amplitudes. This type of fading is common in environments without a dominant line-of-sight (LOS) component, such as urban areas or indoor wireless systems.

System Configuration:

In multiple antenna systems jargon, communication systems are broadly categorized into four categories with respect to the number of antennas in the transmitter (Tx) and the receiver (Rx), as listed below.

- SISO - single input single output system - 1 Tx antenna,1 Rx antenna
- SIMO - single input multiple output system - 1 Tx antenna, N Rx antennas (N > 1)
- MISO - multiple input single output system - M Tx antennas, 1 Rx antenna (M > 1)
- MIMO - multiple input multiple output system - M Tx antennas, N Rx antennas (M, N > 1)

Single-input single-output (SISO) system model:

The SISO radio communication systems contain one antenna at the transmitter and one at the receiver. Hence, the capacity of a SISO channel that is bandwidth limited to B Hz and average received power constrained to P Watts with noise power N_0, is given by

$C = B\log_2(1+P/N_0B)$ (AWGN) $C = B\log_2(1+|h|^2P/N_0B)$ (Rayleigh)

Single-input multiple-output (SIMO) system Model

A SIMO (Single-Input Multiple-Output) system consists of one transmit antenna and multiple receive antennas. This setup leverages receive diversity to combat fading and improve signal reliability without increasing transmit power. A SIMO system improves reliability and capacity over SISO by exploiting receive diversity.

$C = log2(1+ PNr/ N_0)$ (AWGN) $C = log2(1+N_0P\|\mathbf{h}\|2)$ (Rayleigh)

Multiple input single output (MISO) system Model

A MISO (Multiple-Input Single-Output) system consists of multiple transmit antennas and a single receive antenna. Unlike SIMO (which improves reliability via receive diversity), MISO focuses on transmit diversity and beamforming to enhance performance without increasing receive complexity.

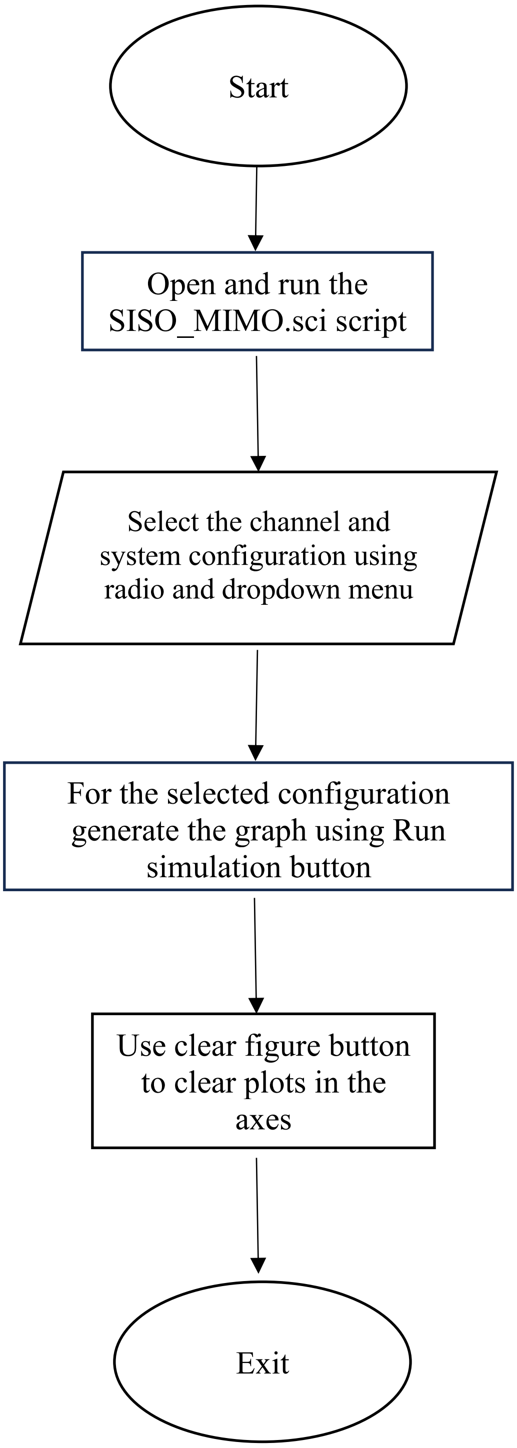
$C = log2(1+N_0P)$ (AWGN) $C = log2(1+ P\|h\|2/NtN_0)$ (Rayleigh)

Multiple-input multiple-output (MIMO) system Model

MIMO (Multiple-Input Multiple-Output) refers to wireless systems equipped with multiple antennas at both the transmitter and receiver. By exploiting spatial multiplexing, MIMO sends independent data streams in parallel to boost throughput, and by employing spatial diversity, it transmits the same information over different antenna paths to mitigate fading and improve link reliability. In rich multipath environments, MIMO can dramatically increase both capacity and spectral efficiency compared to SISO, SIMO, or MISO systems, though the actual gains depend on channel conditions, antenna correlations, and SNR.

$C = min(Nt,Nr)log2(1+ P/ N_0)$(AWGN) $C = log2det(I+ P/ NtN_0HH^H)$ (Rayleigh)

4 Flowchart


Start
Open and run the SISO_MIMO.sci script
Select the channel and system configuration using radio and dropdown menu
For the selected configuration generate the graph using Run simulation button
Use clear figure button to clear plots in the axes
Exit

5 Software/Hardware used

Operating System: Windows 11

Toolbox: None

Hardware: Personal Computer with 12th Gen Intel Core Processor, 16GB RAM

Software: Xcos, Scilab Version: 2025.1.0

6 Procedure of Execution

To generate the plots, follow these steps

- **Step 1:** Launch Scilab on your computer and type editor in the Scilab console.

- **Step 2:** Open the SISO_MIMO.sci file

- **Step 3:** Run the file by selecting the triangular icon of "start" in the toolbar.

- **Step 4:** Select the channel and system configuration using radio and dropdown menu in the GUI interface.

- **Step 5:** Now hit Run simulation button to generate desired results. Each plot will display the simulated behavior according to the configuration selected. To test different scenarios, modify the channel and system parameters in the GUI interface before running.

- **Step 6:** Use the clear figure button to clear plots in the axes

- **Step 7:** The Exit button closes the GUI window.

7 Results and Discussion

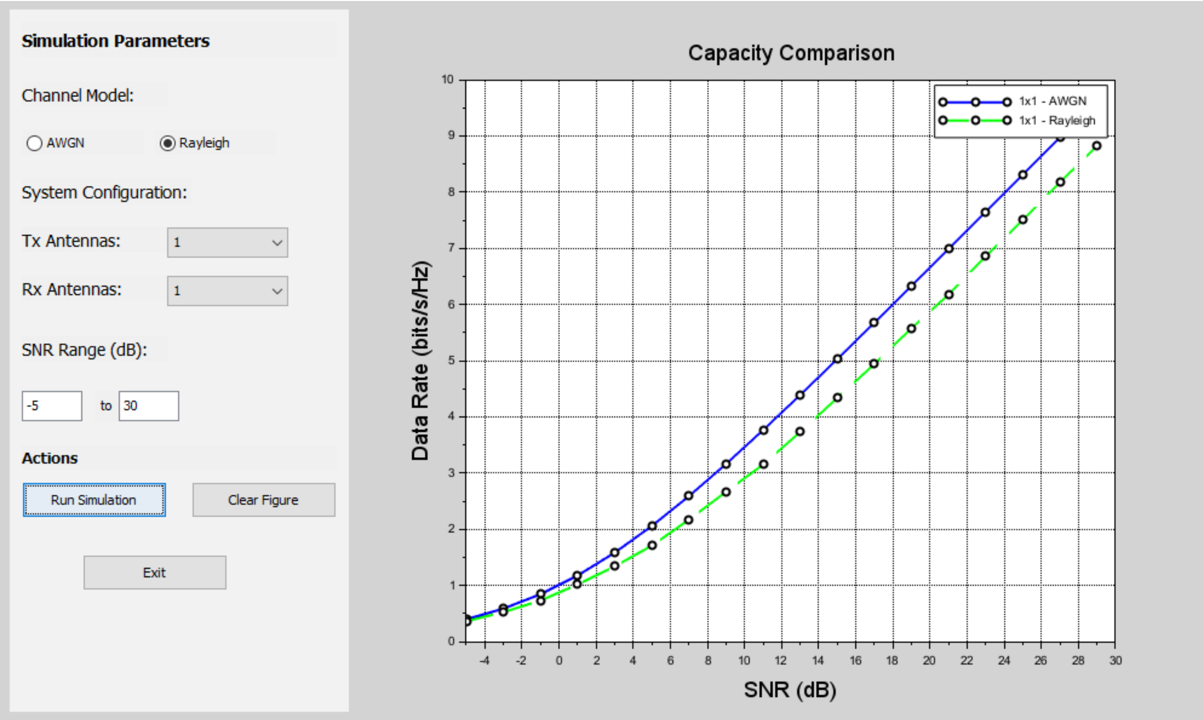


Figure 1: Capacity comparison of SISO System over AWGN and Rayleigh Fading Channel

Figure 1 illustrates the capacity comparison of a SISO system over AWGN and Rayleigh fading channels across a range of SNR values from -5 dB to 30 dB. From the graph, it is evident that the capacity of the system under the AWGN channel is consistently higher than that under the Rayleigh fading channel for the same SNR values. This difference is due to the unpredictable fluctuations and deep fades in signal amplitude caused by Rayleigh fading, which leads to a reduction in the overall data rate. In contrast, the AWGN channel maintains a relatively stable transmission environment, allowing for better utilization of the available SNR. As the SNR increases, both curves exhibit a logarithmic growth in capacity, but the gap between AWGN and Rayleigh remains noticeable, emphasizing the detrimental effect of fading on wireless communication performance.

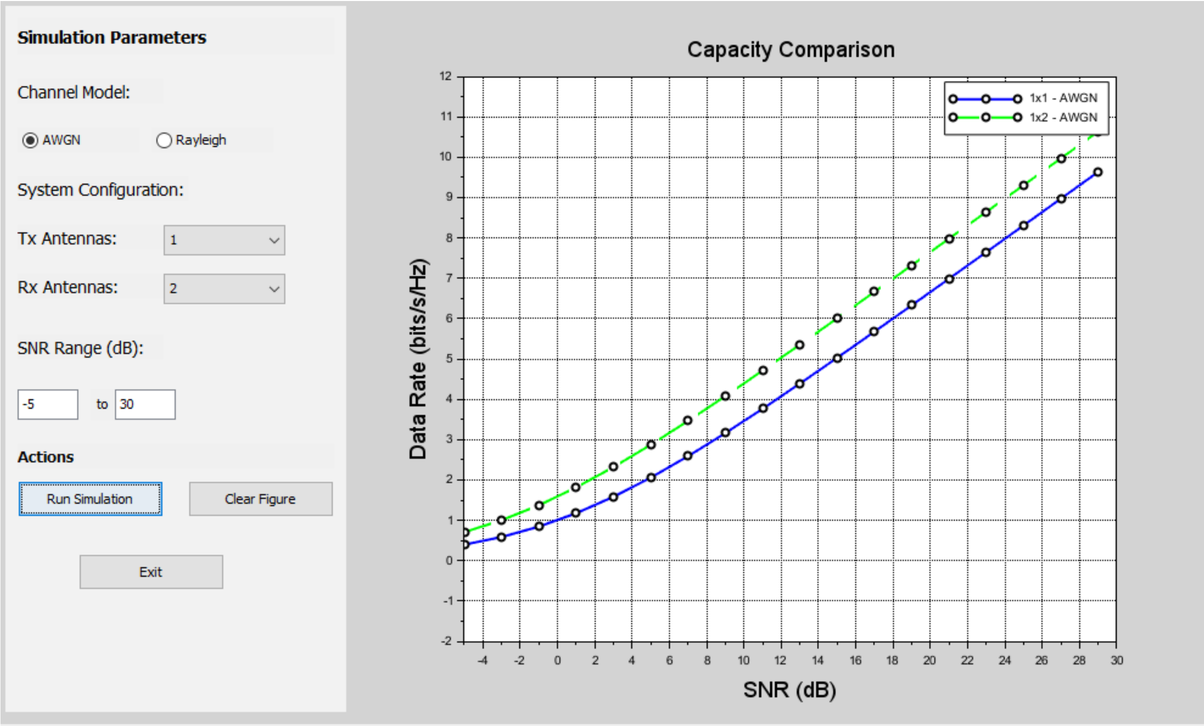


Figure 2: Capacity comparison of SISO and SIMO systems

Figure 2 presents a capacity comparison between SISO (1x1) and SIMO (1x2) systems over an AWGN channel across a range of SNR values from -5 dB to 30 dB. The graph clearly shows that the SIMO configuration achieves a higher data rate than the SISO system for the same SNR values. This improvement is due to the use of multiple receive antennas in the SIMO system, which provides receive diversity and enhances signal reliability by mitigating the effects of noise and channel impairments. As a result, the SIMO system is able to extract more useful information from the transmitted signal, thus improving the overall capacity. The increasing gap between the 1x1 and 1x2 curves with rising SNR further highlights the advantage of employing multiple antennas at the receiver in terms of performance gain in AWGN environments.

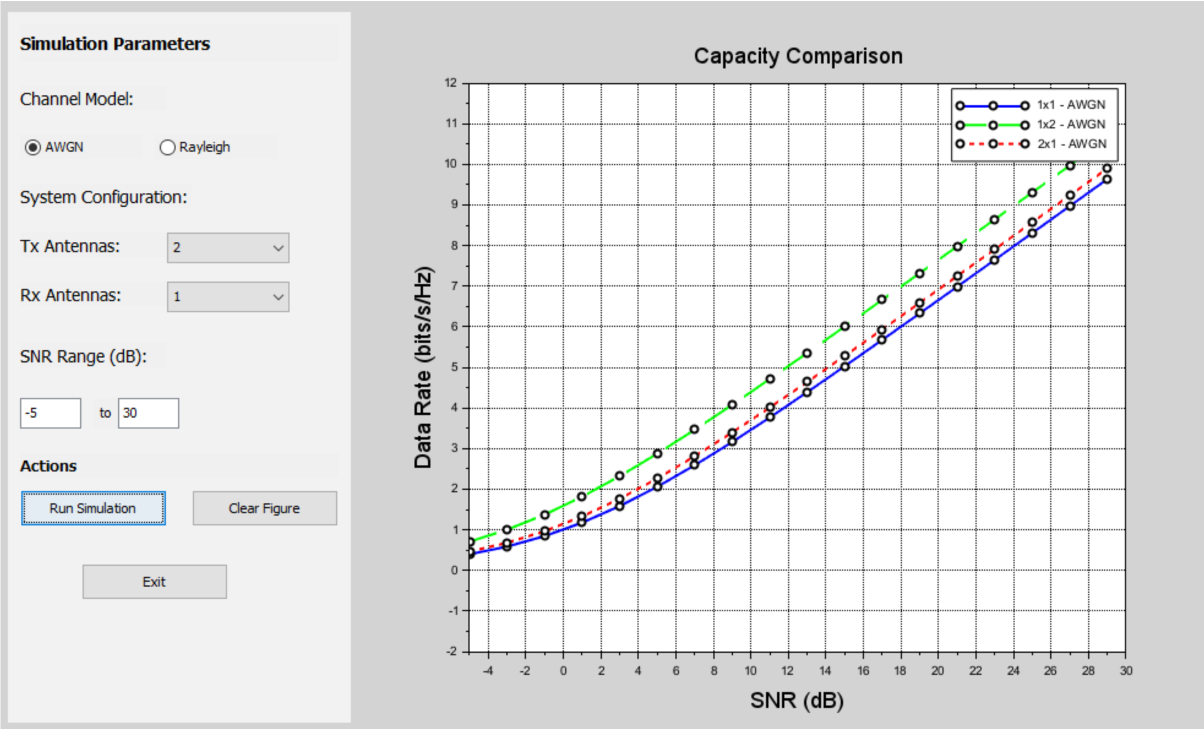


Figure 3: Capacity comparison of SISO, MISO, and SIMO systems

The given plot compares the channel capacity of SISO (1x1), SIMO (1x2), and MISO (2x1) systems over an AWGN channel across a wide SNR range. It is evident that both SIMO and MISO systems outperform the basic SISO configuration, offering higher data rates for the same SNR values. Among them, the SIMO (1x2) system demonstrates the best performance due to receive diversity, which provides a greater ability to combat noise and enhance signal detection. The MISO (2x1) system also shows improvement over SISO, leveraging transmit diversity to enhance reliability. However, SIMO slightly outperforms MISO, especially at higher SNR values, due to the better capability of multiple receive antennas to effectively process and combine the incoming signals. Overall, the use of multiple antennas—either at the transmitter or receiver—significantly improves capacity in AWGN channels, with receive diversity offering a marginally higher benefit.

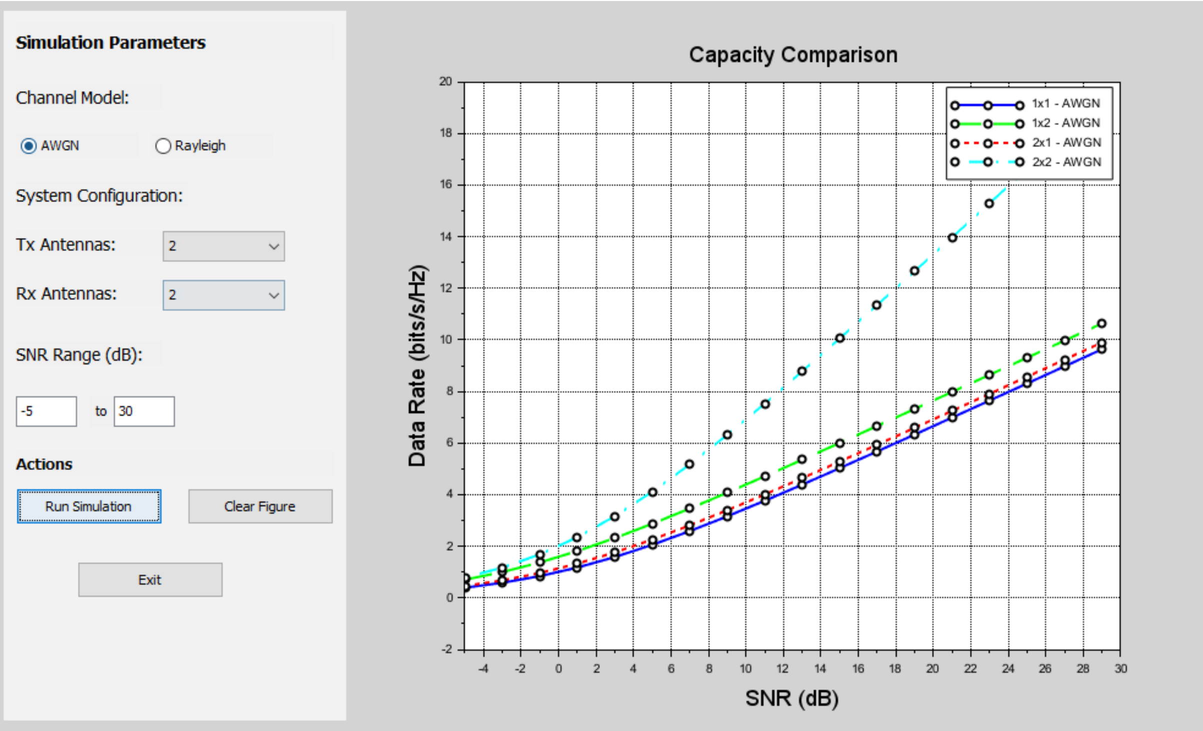


Figure 4: Capacity comparison of SISO, MISO, SIMO, and MIMO systems

Figure 4 provides a comprehensive capacity comparison of SISO (1x1), SIMO (1x2), MISO (2x1), and MIMO (2x2) systems over an AWGN channel for an SNR range of -5 dB to 30 dB. As expected, the MIMO system (2x2) significantly outperforms all other configurations, achieving the highest data rates due to spatial multiplexing gains from multiple transmit and receive antennas. SIMO (1x2) and MISO (2x1) systems also exhibit improved capacity compared to the baseline SISO system, owing to diversity gains. Notably, SIMO performs slightly better than MISO across the SNR range due to more effective signal combination at the receiver. The capacity increase becomes more pronounced with rising SNR, highlighting the advantage of employing multiple antennas. Overall, this comparison clearly demonstrates that using both transmit and receive diversity in a MIMO configuration offers the greatest capacity improvement in AWGN environments.

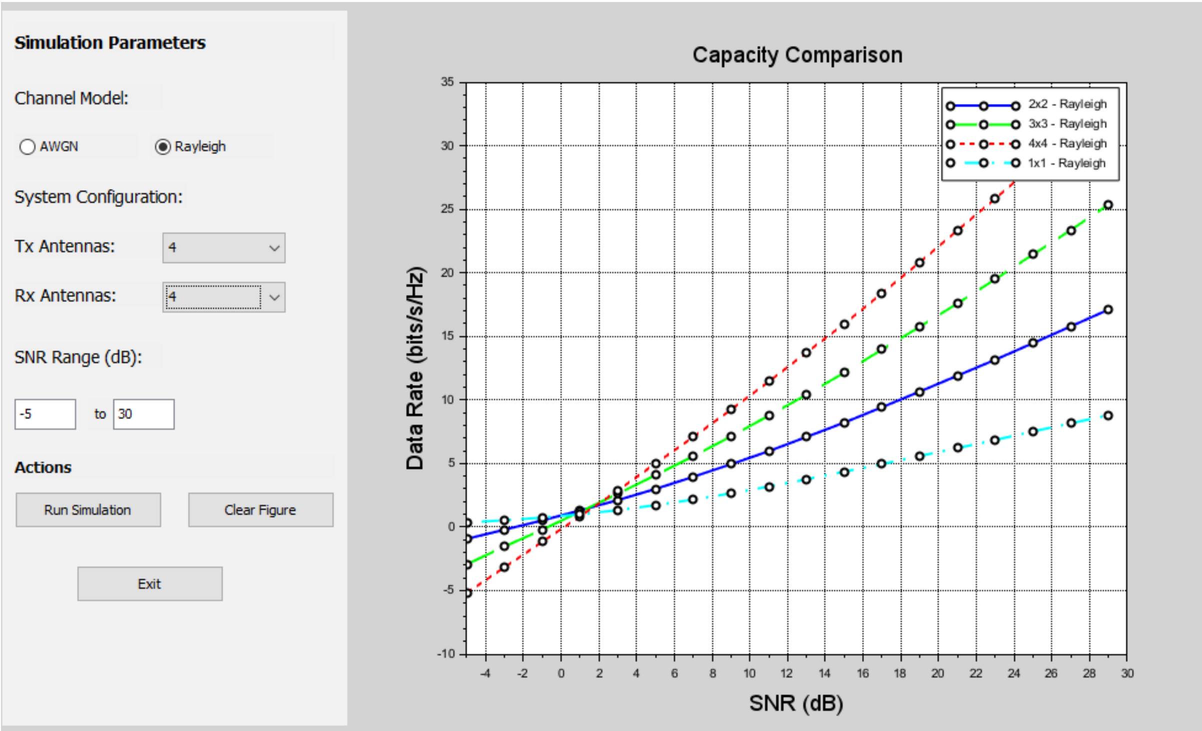


Figure 5: Capacity Comparison between SISO and Various Antenna Configurations of MIMO Systems

Figure 5 illustrates the capacity comparison of SISO (1x1) and various MIMO configurations (2x2, 3x3, and 4x4) over a Rayleigh fading channel across an SNR range of -5 dB to 30 dB. It is evident that as the number of antennas increases at both the transmitter and receiver, the channel capacity improves significantly. The 4x4 MIMO system achieves the highest data rate, demonstrating the power of spatial multiplexing and diversity gain in overcoming the severe multipath effects of Rayleigh fading. The capacity curves show a near-linear increase with SNR for higher antenna configurations, in contrast to the relatively slow growth seen in the SISO system. This indicates that MIMO systems can exploit the rich scattering environment of Rayleigh channels to dramatically enhance throughput. Thus, the inference is clear: employing more antennas in a MIMO setup substantially boosts capacity and resilience in fading environments, making it a highly effective technique for modern wireless communication systems.

8 References

[1] Bala, Diponkor, G. M. Waliullah, M. Hena, M. Abdullah, and M. Hossain. "Study the Performance of Capacity for SISO, SIMO, MISO and MIMO in Wireless Communication." Journal of Network and Information Security 8, no. 1&2 (2020): 01-06.