Physical Layer Security using Massive MIMO and RIS technology

Capstone Report

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This project report was created on TexStudio editing platform using LaTeX. All the figures were drawn using draw.io online software tool.

Electrical and Computer Engineering
Nazarbayev University
http://www.nu.edu.kz

Title:
Enhancing Data Rates through Massive MIMO Beamforming

Theme:
Massive MIMO

Project Period:
Spring 2023

Project Group:
Lab's Name

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Copies: 1

Page Numbers: 21

Date of Completion:
April 25, 2024

Abstract:

Massive Multiple-Input-Multiple-Output (MIMO) systems and Reconfigurable Intellegent Surfaces (RIS) are considered to be the key technologies for next generations wireless communication, which are aimed to achieve higher data rates, massive connectivity and more secure data transmission. Combined use of these technologies together with artificial noise (AN) gives high hopes for strengthening Physical Layer Security (PLS) in wireless networks. This capstone work considers configuring phase shifts of RIS such that the impact of AN is maximized for illegitimate user, while its impact on legitimate user is not significant compared to the actual signal received from base station. In the proposed system model, some antennas is dedicated for AN and the rest are transmitting the actual data. The main objective of this model is to maximize Secrecy Capacity (SC) of the communication link, while satisfying the users' quality of service (QoS). To achieve that, we optimize the phase shifts of RIS and find the optimal number of base station antennas transmitting AN. Obtained results validate theoretical concepts and show that proposed RIS-assisted Massive MIMO incorporated with AN transmission can be an effecting tool for establishing and improving PLS in wireless communication.

Contents

1 Introduction **1**
1.1 Single-Input-Single-Output (SISO) Systems 2
1.2 Single-Input-Multiple-Output (SIMO) and Multiple-Input-Single-Output (MISO) Systems 3
1.3 Multiple-Input-Multiple-Output (MIMO) Systems 5
1.4 Massive MIMO 6
1.5 Reconfigurable Intelligent Surfaces 8
1.6 RIS-Aided Physical Layer Security 10

2 System Model **12**

3 Problem Formulation **14**

4 Numerical Results **15**

5 Conclusion **18**

Bibliography **19**

Chapter 1

Introduction

We live in an age when wireless communications are an integral part of our lives, but the notion of communicating and transferring data through wireless medium is more than a century old. Extensive research in this field started all the way at the end of the 19th century when Guglielmo Marconi showed how communication with sailing ships could be conducted via radio waves [1]. As of September 2023, according to GSMA (Global System for Mobile Communication), there are more than 11.8 billion cellular connections and more than 5.5 billion unique mobile subscribers worldwide, which is about 70 percent of the world population. With such high numbers of users present in cellular networks, there is a clear need to increase the quality of communications, that is, availability and data rates or capacity. During the last few decades, mobile communication evolved from data rates of 12Kbps in 2G to around 300-2000Kbps in 3G to 100Mbps in 4G [2] and to 10Gbps in the most recent 5G, which is promised to be achieved by implementing the massive Multiple-Input-Multiple-Output (MIMO) systems [1].

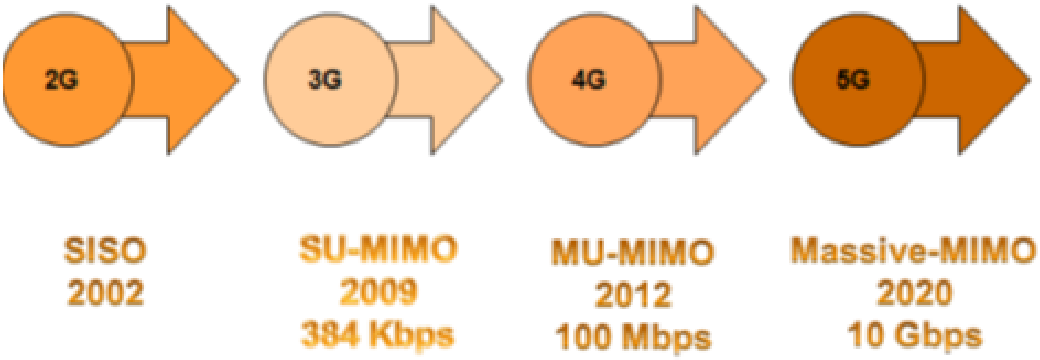

Figure 1.1: Evolving speed of wireless networks [1].

Massive MIMO systems give high hopes for better communication, but its practical implementation demands different approaches than of conventional MIMO systems. Otherwise it will be unfeasible due to high costs and power consumption. Therefore Massive MIMO is actively researched field of study. In [3], the wideband hybrid precoding approach and the limitations of previous works dedicated to it are addressed by introducing the new approach called Rank-Constrained Coordinate Ascent. In [4], authors review previously proposed precoding algorithms for mmWave massive MIMO hybrid systems and with aim to reduce computational complexity propose Learned-Sparse Bayesian Learning with Generalized Approximate Message Passing algorithm. In [5], the concept of Reference Signals (RS), which are important for channel estimation and helps more users to be served by one base station, is discussed and the use of random nonorthogonal RS in Massive MIMO is analyzed and shown to have advantages over orthogonal RS. In [6], Massive MIMO model with tightly-coupled antennas and the importance of mutual coupling effects were analyzed.Creating the optimal Massive MIMO detection technique is also a big subject of research in the field. MIMO detection refers to determining transmitted signal based on received signal [7]. In [8], a memristor-based analog circuit is introduced with the aim to fight high power consumption and computational complexity in the detection process.

In this work we explore massive MIMO communication, starting from basic SISO system and ending with RIS-aided massive MIMO system with investigation of its performance in terms of physical layer security.

1.1 Single-Input-Single-Output (SISO) Systems

Single-Input-Single-Output system consists only of one transmitting and one receiving antennas.

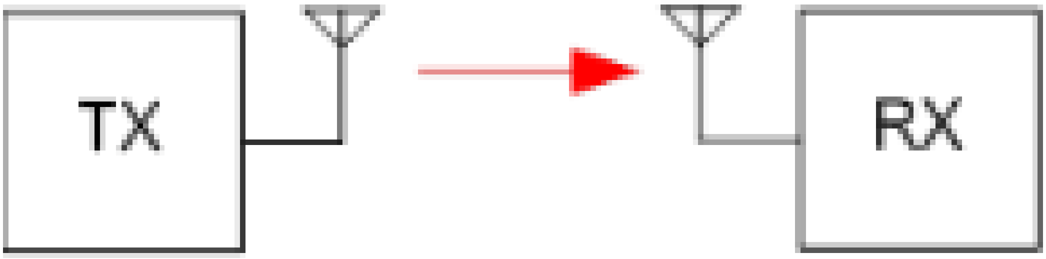

Figure 1.2: SISO communication system [2].

According to Shannon capacity theorem, the capacity of SISO is as follows:

$$C = B * log_2(1 + S/N), \tag{1.1}$$

where B is the bandwidth and S/N is the signal-to-noise ratio (SNR).

Although it is the simplest kind of wireless communication system, SISO is still used in Bluetooth, Wi-Fi, radio broadcasting, TV [1]. In fact, simplicity is the main advantage of SISO, but that is also the reason why SISO systems are not applicable everywhere and are not as reliable. In wireless communication, the signal is transmitted through space and the quality of link between transmitter and receiver is highly dependent on the propagation environment. Signal strength is degraded before it reaches the receiver because of multiple factors such as path loss which depends on the distance, physical obstacles which can block direct path, and changes in wireless channel parameters if any of the communication ends is mobile. Because of these factors, known as fading, it is not always sufficient to use simple Single-Input-Single-Output system, which uses only single antennas on both ends. The resulting SNR might be too low for proper communication. and to combat this problem, a technique called "diversity" was introduced, with the use of which more complicated systems with the use of multiple antennas on either the receiver end (SIMO), or transmitter end (MISO), or both ends (MIMO) were developed.

1.2 Single-Input-Multiple-Output (SIMO) and Multiple-Input-Single-Output (MISO) Systems

Diversity refers to the use of multiple copies of the same signal, so that even one copy of the signal happens to be of poor quality, the other copies will make up for it, so the overall communication quality is maintained. SIMO is a communication system, where a signal is transmitted by one antenna and multiple copies of that signal is received at multiple antennas. Such systems can be optimized by the use of receive diversity techniques: Selection Diversity, Equal Gain Combining and Maximum Ratio Combining. Let's consider a SIMO system with two receive antennas and one transmit antenna, as shown in fig. 1.3.

The signal transmitted is denoted by x and two copies of that signal are received at the receive antennas as y_1 and y_2. Then, the relationship between them is as follows:

$$y_1 = h_1x + n_1, y_2 = h_2x + n_2 \tag{1.2}$$

where h_1 and h_2 are channel coefficients and n_1 and n_2 are noise signals at the receivers. In case of Selection Diversity, the best of these two signals is chosen as the output:

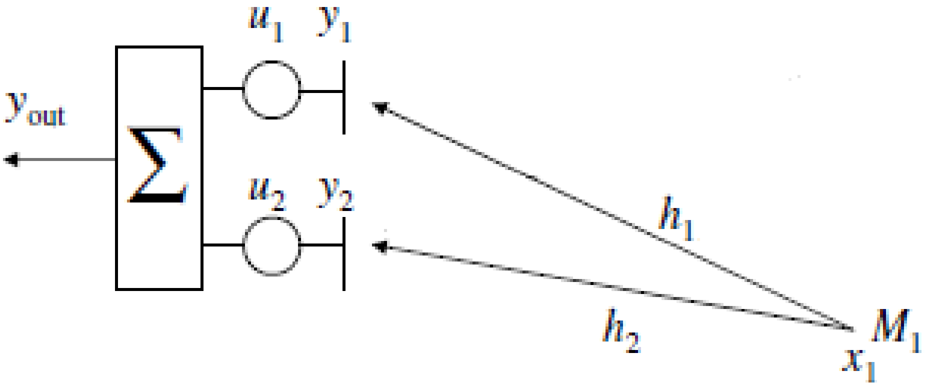

Figure 1.3: SIMO communication system [9].

$$y_{sel} = max(|h_1|, |h_2|)x + n_i \tag{1.3}$$

In case of Equal Gain Combining, these two copies are added, but before that their phases must be aligned. For that, the phase weights, u1 and u2, are applied:

$$y_{egc} = u_1y_1 + u_2y_2 = (u_1h_1 + u_2h_2)x + (u_1n_1 + u_2n_2) = (|h_1| + |h_2|)x + (u_1n_1 + u_2n_2) \tag{1.4}$$

If we assume that the two receive antennas are close to each other and the magnitude of channel coefficients are approximately the same, the equation for the output signal can be rewritten as $y_{equal} = 2|h|x$, which is twice as much as it would be with 1 receive antenna. In other words, this system has an array gain of 2, which is also known as a signal gain or beamforming gain.

In case of Maximum Ratio Combining, the copies of signals are added not just with the aligned phases, but these copies are also scaled so that the better ones will have more weight. For that, the weights are equal to the conjugates of channel coefficients. That is, $u_1 = h_1^*$ and $u_2 = h_2^*$. In such case the output signal is as follows:

$$y_{mrc} = u_1y_1 + u_2y_2 = (u_1h_1 + u_2h_2)x + (u_1n_1 + u_2n_2) = (|h_1|^2 + |h_2|^2)x + (h_1^*n_1 + h_2^*n_2) \tag{1.5}$$

It can be observed that the beamforming gain is increased even more now.

For the MISO systems, the MRC technique is still valid, if there is channel knowledge at the transmitter. It is effectively the same system, but with the multiple antennas at the transmitter end and single antenna at the receiver end.

Generally, applying weights to the transmitted or received signals creates a phenomenon called Beamforming. The weights are optimized such that phases of all signal copies are aligned to deliver the best signal to a specific location [9].

1.3 Multiple-Input-Multiple-Output (MIMO) Systems

The evolution of wireless communication has not been stopped on the use of multiple antennas at only one end. With a goal to increase data rates with transmit power and frequency resources constraints, and to make the transmission of several data streams simultaneously, the concept of MIMO systems was introduced. MIMO is a communication system, where there are multiple antennas on both ends. Indeed, in previous SIMO example, it was shown that beamforming to one transmitter can be performed. But if there are more transmitters, it is possible to perform beamforming to each of them, transmitting several data streams at the same time.

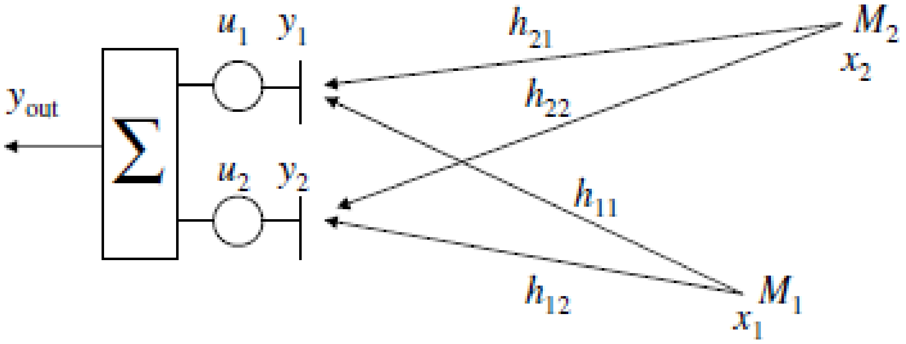

Figure 1.4: MIMO communication system [9].

Consider a basic 2x2 MIMO example shown in fig. 1.4. The output signal would be as follows:

$$y_{out} = (u_1 h_{11} + u_2 h_{12}) x_1 + (u_1 h_{21} + u_2 h_{22}) x_2 \tag{1.6}$$

where u_1 and u_2 are the weights added by the receiver. These weights can be set such that either x_1 or x_2 is ignored. For example, if $u_1 h_{11}$ + $u_2 h_{12}$ = 1 and $u_1 h_{21}$ + $u_2 h_{22}$ = 0, only x_1, signal from the first transmitted, is passed. And by applying another set of weights, only x_2 can be passed. The receiver essentially created two beams to each of transmitters such that their signals can still be distinguished. This basic example does not fully reflect the reality, but it nevertheless shows that MIMO is an improvement over SIMO and MISO systems in terms of data rates and the ability to serve multiple users simultaneously [9]. To sum up, MIMO systems make possible an increase in spectral efficiency, i.e. the amount of data transmitted over a given bandwidth, without increasing transmission power[10], while also being more reliable as it was shown to give a smaller Bit-Error-Rate (BER) value [11].

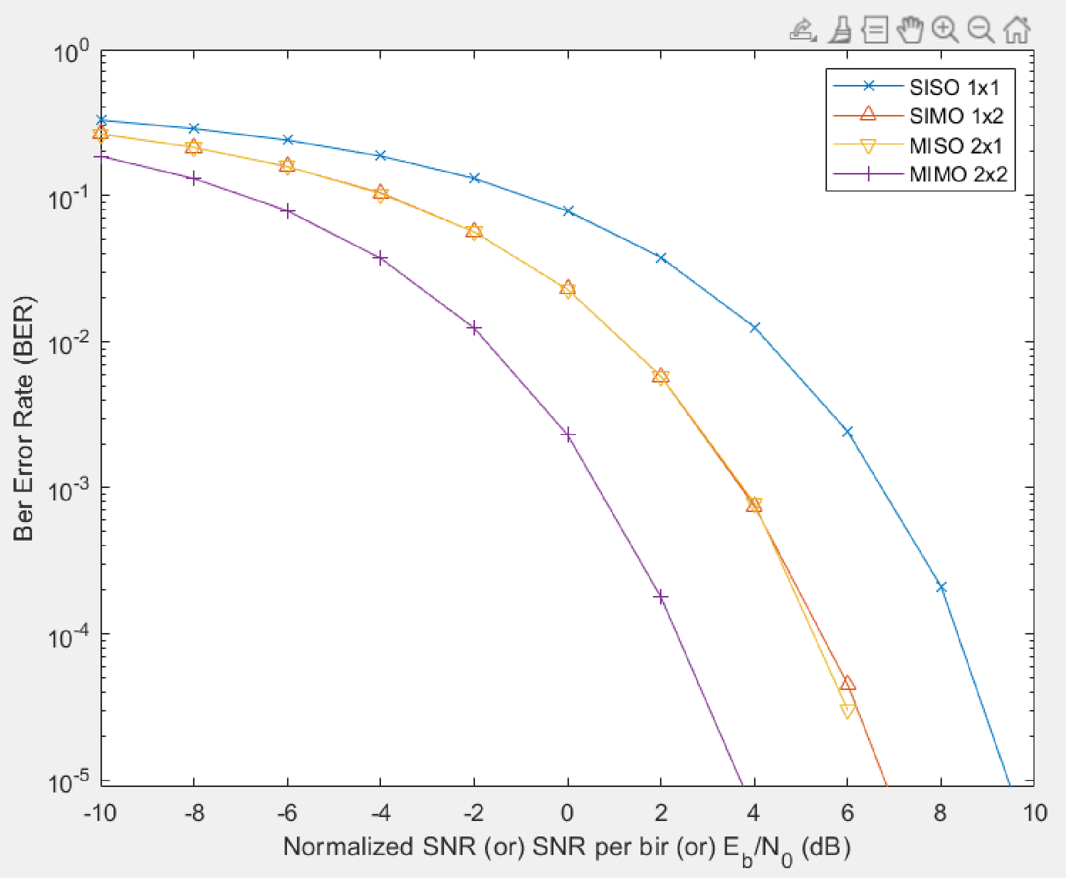

Figure 1.5: Bit-Error-Rate vs Eb/N0 for SISO, SIMO, MISO, MIMO.

The results of simple MATLAB simulation of all discussed above examples is shown in fig. 1.5. It demonstrates how the system reliability is improved by using beamforming with multiple antennas on one or both ends, as the possibility of receiving error bit is smaller for MIMO, larger for SIMO/MISO and even larger for SISO system on the same normalized SNR level. Perfect channel knowledge is assumed in the simulation.

1.4 Massive MIMO

Massive MIMO is a version of MIMO system with much larger number of antennas on base station (tens, hundreds or even thousands) with the ability to serve higher amount of users with data rate sufficient for good communication. Unlike conventional MIMO systems, Massive MIMO does not require complicated signal processing. Also, the channel knowledge is not required on terminals, only the base station needs to learn it. These features make Massive MIMO scalable with respect to base station antennas number and are explained by the phenomenon known as channel hardening[12], which greatly simplifies resource allocation in Massive MIMO [13]. Channel hardening occurs when the number of base station antennas is large enough to make fast-fading decrease and to bring the effective gain close to its expected value. When it happens, the channel behaves almost deterministically, thus simplifying the channel estimation and reducing the resources spent on it[14].

Implementing Massive MIMO leads to improvement of energy efficiency and to more than 10 times larger capacity [15], as any increase in number of antennas positively impacts the capacity [16]. Even increasing the number of antennas on only one end is shown to improving SNR of the system and thus the capacity[17].

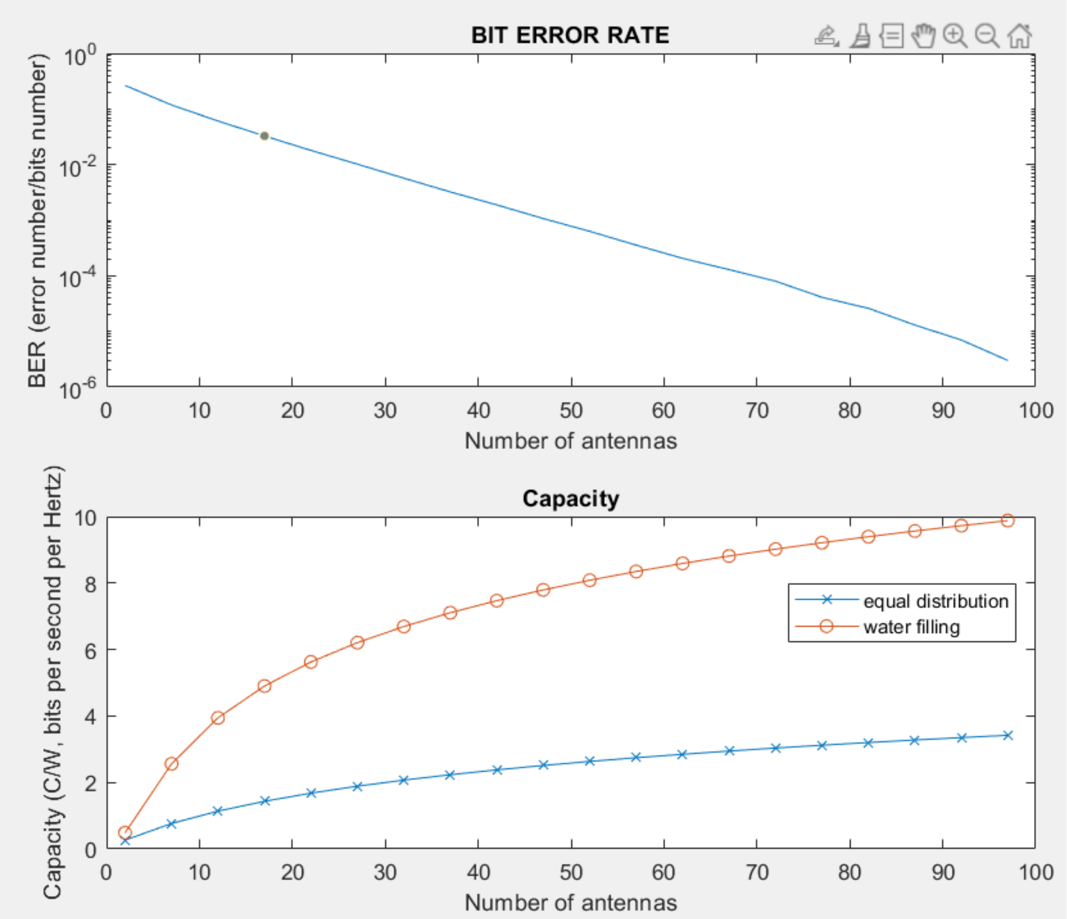

Figure 1.6: BER and Capacity vs Number of Antennas (NxN).

Figure above shows negative correlation of antennas number with BER, and positive correlation with the capacity. Unlike in previous simulation, this example focuses only on MIMO model, and with each iteration the antennas number is increased on both communication ends. Also, the normalized SNR and transmit power are fixed here. For the sake of demonstration they are fixed on -10dB and 20dBm respectively.

1.5 Reconfigurable Intelligent Surfaces

Massive MIMO is considered to be the key technology for 5G communication, where achieved data rates can be more than 1Gbps[18]. However, implementing the simple transmitter-to-receiver communication is not the only way and might not be the best way for implementing Massive MIMO. In Non-Line-of-Sight (NLoS) situations, where some obstacle blocks the direct link between the transmitter and receiver, the quality of communication can be drastically degraded. One way to address this problem is to build more base stations transmitting signals so that one could receive direct signal anywhere. However, in reality it is not feasible due to costs, high energy consumption, and severe interference issues[19]. Reconfigurable Intelligent Surface (RIS) or Intelligent Reflecting Surface is the innovative technology which is believed to be an important part of the next generation wireless communication systems[20]. RIS consists of very large number of near passive reflective elements that can be controlled in real time to manipulate incoming signal waves reflecting them in a desired direction[21], essentially performing beamforming in pseudo Line-of-Sight (LoS) propagation environment. Because of the passive nature of RIS elements, deploying it between transmitter and receiver is more energy and cost efficient approach to mitigate the shadowing effect created by the obstacle. The underlying concept of RIS is that each element can shift the phase of incident electromagnetic waves and the degree of these shifts can be dynamically reconfigured so that the beams can be formed in direction of the user.

The basic example of advantageous implementing transmitter-RIS-receiver communication concept is shown in fig 1.7, where the direct communication link is blocked by a building, but there is another building with RIS on it, thus reflecting the signal directly to the receiver instead of being just a random scatterer. Assume this is MIMO system with Nt antennas on the transmitter and Nr antennas on the receiver. And number of RIS elements is M. Assuming a narrowband flat-fading wireless propagation, the received signal can be written as[22]

$$y = \sqrt{G_d} H_{env} x + \sqrt{G_r} H_{ris} x + n \tag{1.7}$$

where x is the transmitted signal vector, n is is the additional white Gaussian noise at receiver obeying the distribution $n \sim \mathcal{CN}(0, \sigma^2)$, $\sqrt{Gd}$ and $\sqrt{Gr}$ represent large scale gain of the H_{env} and H_{ris} respectively. H_{ris} is controllable channel be-

Figure 1.7: An illustration of the basic RIS-assisted communication scenario [21].

tween transmitter and receiver that goes through RIS, while H_{env} is uncontrollable channel which includes all of the other links. H_{ris} can be representes as[22]

$$H_{ris} = H_2 * Q * H_1 \tag{1.8}$$

where H1 is M x Nt matrix representing transmitter-to-RIS channel and H2 is Nr x M matrix representing RIS-to-receiver channel, whereas Q is M x M matrix of the reflecting coefficients of all surface elements, which can be described as[22]

$$Q = diag(\beta_1 e^{i\theta_1}, ..., \beta_M e^{i\theta_M}) \tag{1.9}$$

where $\beta_i \in [0, 1]$ is amplitude reflection coefficient and $\theta_i \in [0, 2\pi)$ is phase shift of i RIS element that can be manipulated and optimized in order to maximized the channel gain. Fig 1.8 demonstrates how the use of optimized RIS improves the quality of communication. Capacity versus SNR curves of 4 by 4 MIMO system assisted by 20 elements ideal RIS are plotted for 2 cases: when phase shifts of RIS elements are optimized, and when they are random. Particle Swarm Optimization (PSO) algorithm, which was first proposed in[23] is applied. PSO is widely used in various fields, and its implementation in RIS phase shifts optimization is investigated and discussed in great detail in[24].

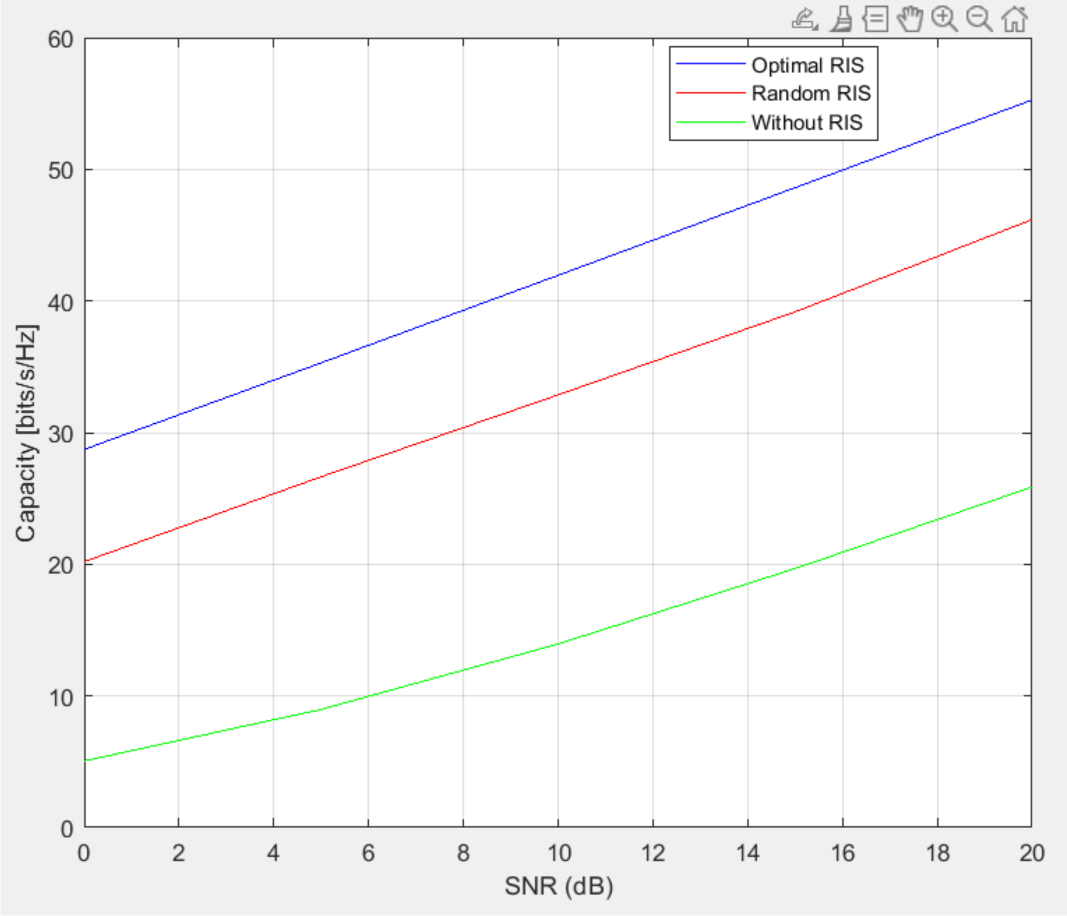

Figure 1.8: Capacity vs SNR with and without phase shifts optimization.

As discussed above, RIS is an excellent technology for mitigating the shadowing effect and for increasing stability and data rates in urban areas. However, researchers have high hopes for RIS potential in many other application scenarios including Physical Layer Security (PLS)[21].

1.6 RIS-Aided Physical Layer Security

Communication security in wireless networks is always an issue because of its broadcast nature. And in some spheres such as banking it is of especial importance. Besides traditional encryption methods, there is an interest in physical layer security that is aimed to secure data transmission based on physical properties of wireless channel [25]. In [26],[27],[28],[29], RIS is shown to significantly enhance the PLS of the system by jointly optimizing the active transmit beamforming and the passive reflect beamforming of the IRS. In[30], the idea of using transmit jamming with artificial noise (AN) in RIS-aided communication system is investigated and proved to be an effective tool for improving secrecy rate of the system.

We propose optimizing RIS such that it maximizes the effect of AN on the received signal by eavesdropper to the extent no actual data can be retrieved, while still maintaining relatively good quality communication for legitimate user.

Chapter 2

System Model

This work presents a RIS-aided (Rose) communication system with massive MIMO base station (Alice) transmitting real signal from some portion of antennas while also transmitting AN from other portion of antennas. On the receiving end there are a legitimate user (Bob) to whom the signal conveying confidential data is intended and a malicious eavesdropper (Eve) who tries to intercept the signal. The idea is to mess up the received signal on Eve's end by aiming the AN to them through Rose, while still transmitting quality signal to the Bob.

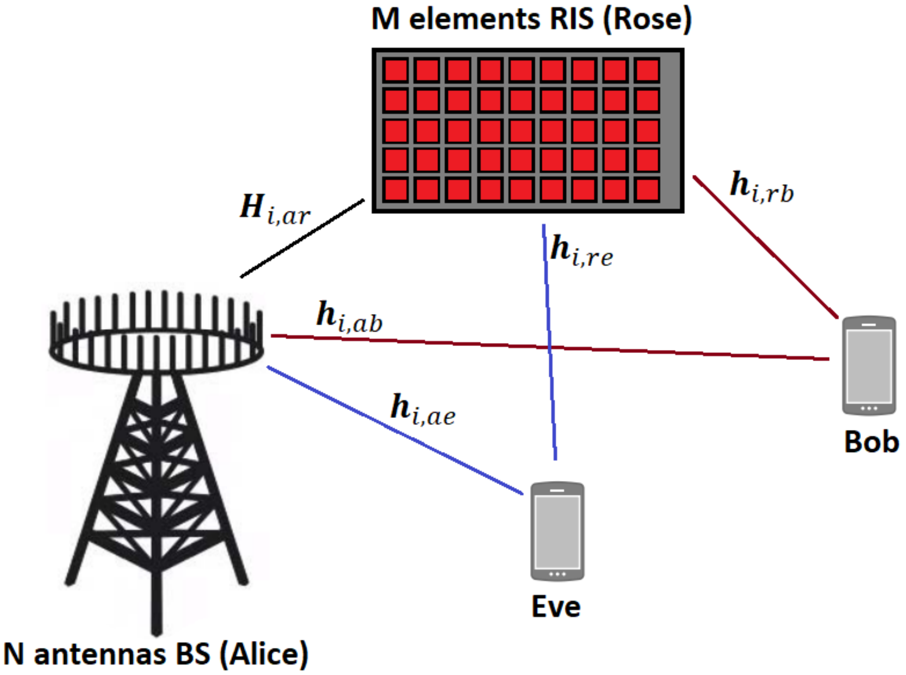

Figure 2.1: System Model.

We consider both Bob and Eve to have a single receiving antenna, Rose to have M number of reflecting elements, and Alice to have N number of transmitting antennas, which are divided into two portions N_s and N_{an}, dedicated for transmitting the signal (s) and AN (an) respectively. The total transmit power at Alice is $\mathrm{P}_t = \mathrm{P}_s + P_{an}$, where P_s and P_{an} is the power allocated for s and an respectively. The channels from Alice to Rose are denoted by $\boldsymbol{H}_{s,ar} \in \mathbb{C}^{M \times N_s}$ and $\boldsymbol{H}_{an,ar} \in \mathbb{C}^{M \times N_{an}}$; from Alice to Bob and Eve are $\boldsymbol{h}_{s,au} \in \mathbb{C}^{1 \times N_s}$ and $\boldsymbol{h}_{an,au} \in \mathbb{C}^{1 \times N_{an}}$, where $\forall u \in \{b, e\}$; from Rose to Bob and Eve are $\boldsymbol{h}_{s,ru} \in \mathbb{C}^{1 \times M}$ and $\boldsymbol{h}_{an,ru} \in \mathbb{C}^{1 \times M}$, where $\forall u \in \{b, e\}$. For this scenario, equation (1.7) of the received signal can be rewritten as

$$\begin{aligned} y_u = &\sqrt{P_s}\left[\sqrt{G_{au}}\boldsymbol{h}_{s,au} + \sqrt{G_{aru}}\boldsymbol{h}_{s,ru}\boldsymbol{Q}\boldsymbol{H}_{s,ar}\right] s \\ &+ \sqrt{Pan}\left[\sqrt{G_{au}}\boldsymbol{h}_{an,au} + \sqrt{G_{aru}}\boldsymbol{h}_{an,ru}\boldsymbol{Q}\boldsymbol{H}_{an,ar}\right] an + n, \end{aligned} \tag{2.1}$$

where $\sqrt{G_{au}}$ and $\sqrt{G_{aru}}$ are large-scale gains, which are essentially path losses of Alice-User(Bob or Eve) and Alice-Rose-User links respectively, and can be expressed as[22]

$$G_{au} = \frac{1}{d_{au}^{\tau_1}}, \tag{2.2}$$

$$G_{aru} = \frac{1}{(d_{ar}d_{ru})^{\tau_2}}, \tag{2.3}$$

where d_{au}, d_{ar}, d_{ru} are distances between Alice and Users, Alice and Rose, and Rose and Users respectively, and τ is the path loss exponent. Since an is treated as an interference, equation for the resulting SINR on the Users can be written as

$$\gamma_u = \frac{P_s\left|\sqrt{G_{au}}\boldsymbol{h}_{s,au} + \sqrt{G_{aru}}\boldsymbol{h}_{s,ru}\boldsymbol{Q}\boldsymbol{H}_{s,ar}\right|^2}{P_{an}\left|\sqrt{G_{au}}\boldsymbol{h}_{an,au} + \sqrt{G_{aru}}\boldsymbol{h}_{an,ru}\boldsymbol{Q}\boldsymbol{H}_{an,ar}\right|^2 + \sigma_u^2}, \tag{2.4}$$

where σ_u^2 is the noise power at the receivers. As was mentioned earlier, Q is the matrix containing all the reflecting coefficients of Rose and the ultimate goal is to bring SINR of Eve under certain threshold to stop them from stealing data, while maintaining good quality of service (QoS) of Bob. In order to achieve it, we maximize the interference on Eve by optimizing Q for $\boldsymbol{h}_{an,re}\boldsymbol{H}_{an,ar}$ cascaded channel, without dedicating too much of Alice's antennas on transmitting an so that SINR on Bob is still sufficiently high.

The ultimate metric of the system performance in terms of security is Secrecy Capacity (SC), which is defined as the difference in capacities of Bob and Eve.

$$SC = R_b - R_e, \tag{2.5}$$

where $R_u = B\log_2\left[1 + \gamma_u\right], \forall u \in \{b, e\}$, and B is the channel bandwidth.

Chapter 3

Problem Formulation

To maximize SC we can maximize SINR of Bob and/or minimize SINR of Eve. In this work we use both options, however mainly focus on the second. We try to maximize SC while maintaining data rate for Bob above certain value, QoS_b, and under certain value for Eve, QoS_e, by optimizing Q - phase shifts of Rose to maximize the interference on Eve, N_{an} - number of antennas dedicated to *an* transmission, and consequently power distribution - P_s and P_{an} to minimize the impact of *an* on Bob. The problem can be formulated as

$$\begin{aligned}
\mathrm{P}_1 : \quad & \max_{Q, N_{an}, P_s, P_{an}} \quad SC \\
& \text{s.t.} \\
\mathrm{C}_1^1\text{:} \quad & \gamma_b \geq \bar{\gamma}_b \\
\mathrm{C}_1^2\text{:} \quad & \gamma_e \leq \bar{\gamma}_e \\
\mathrm{C}_1^3\text{:} \quad & P_s + P_{an} = P_t \\
\mathrm{C}_1^4\text{:} \quad & N_s + N_{an} = N \\
\mathrm{C}_1^5\text{:} \quad & \theta_m \in (0, 2\pi],
\end{aligned} \tag{3.1}$$

where $\bar{\gamma}_b = 2^{\mathrm{QoS}_b} - 1$ and $\bar{\gamma}_e = 2^{\mathrm{QoS}_e} - 1$, so C_1^1 and C_1^2 are data rate constraints. C_1^3 constraint indicates that combined power dedicated to s and *an* transmission must be equal to the total transmitting power. Similarly, C_1^4 requires the combined number of both types of Alice's antennas to be equal to the total number of antennas. C_1^5 indicates that phase shifts of each Rose's element must be in the range $(0, 2\pi]$. The matrix of optimal phase shifts Q for Eve's SINR minimizing is obtained by using PSO algorithm, which was discussed earlier. Then, the optimal N_{an}, which gives maximum data rate for Bob while satisfying the constraints, is found by iterating the N_{an} from 1 to $N - 1$ and calculating the SINR values on each iteration. Consequently, the optimal P_s, P_{an} is calculated.

Chapter 4

Numerical Results

Finally, in this chapter, the numerical parameters that were used to simulate the system and results of the simulation is presented. The channel bandwidth B is set to be 10MHz; the total transmit power P_t is 30dBm; the thermal noise power on the receivers $sigma_u^2$ is approximately -100dBm. We consider scenario where Eve is situated closer to Alice: $d_{ab} = 100m$, $d_{ae} = 50m$, $d_{ar} = 10m$, $dr_{rb} = 50m$, $dr_{re} = 50m$ are Alice-Bob, Alice-Eve, Alice-Rose, Rose-Bob and Rose-Eve distances respectively. We consider the medium of propagation of Alice-Rose-User links to be free space, so the path loss exponent $\tau_2 = 2$, while direct links Alice-User are assumed to have obstacles causing shadowing effect so τ_1 is believed to be higher and set to 3.5. The minimum data rate for Bob QoS_b is set to 10Mb/s and the maximum data rate for Eve QoS_e is set to 0.1Mb/s. Both Bob and Eve are considered to have one receiving antenna each; number of transmitting antennas on Alice $N = 20$; and number of reflective elements on Rose $M = [80 : 10 : 120]$ for simulation purposes. It was intended to use higher number of both N and M, but we failed to do so due to time constraints and the amount of time the simulation takes.

In Fig. 4.1, the correlation between number of RIS elements and transmit antennas dedicated for an. As we can see, a system with 80 or 90 RIS elements needs 13 Alice's antennas to transmit an in order to maintain γ_e under its threshold value $\bar{\gamma}_e$. However, as we increase number of RIS elements, the an transmit antennas decreases. As we can see, for 100, 110 or 120 RIS elements, N_{an} is decreased to 12. So, now N_{an} is smaller, which means N_s is larger and consequently the strength of an actual signal s is increased and thus γ_b is also increased, while, let's not forget, γ_e still does not exceed $\bar{\gamma}_e$. Basically, by optimizing N_{an} we maximize data rate of Bob. The more RIS elements - the worse is Eve's SINR - the less antennas is needed to be dedicated on an - and the more antennas will transmit the signal for Bob, increasing its SINR.

Fig 4.2 shows that SINR constraints are met, so Bob receives good quality signal, while Eve is struggling to retrieve any data with such a low data rate. It is also clear

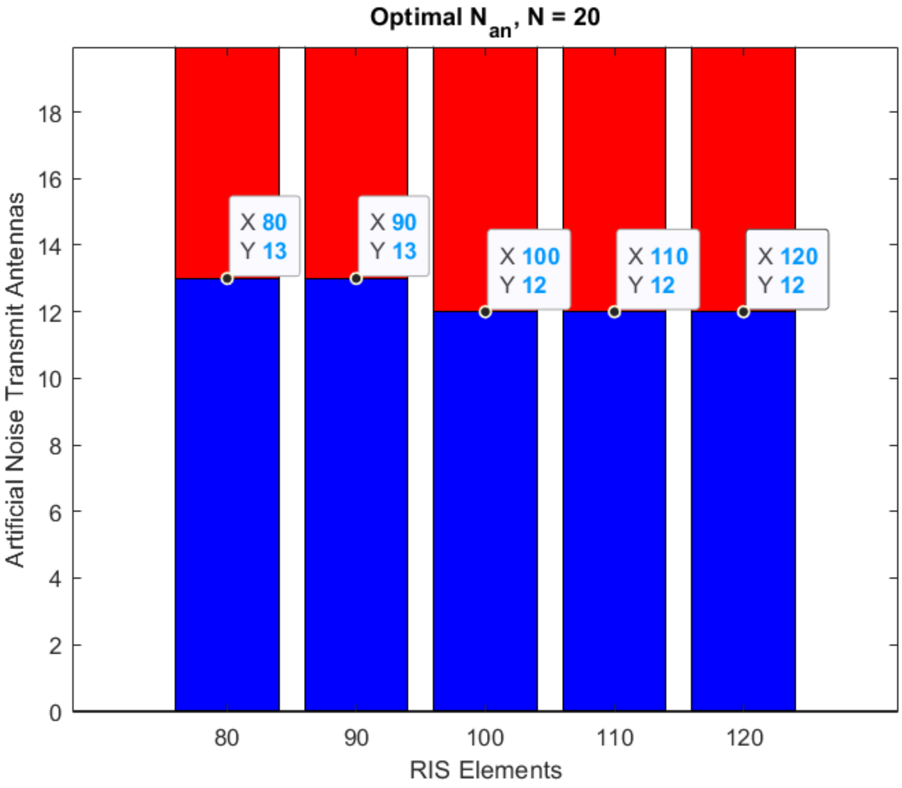

Figure 4.1: Results of the simulation. Optimal N_{an}.

that the SC is almost as high as the capacity of Bob, indicating the communication is secure. However, the curves are not smoothly going up, as they theoretically should be. It can be explained by the small number of iterations and small number of Alice antennas. Because of the randomness of the channel gains, the expected trend can only be achieved with very large number of iterations, thousands or even millions, while this model was only simulated for 50 times. Also, the number of Alice antennas should be higher in order to get even more optimized N_{an} and thus improve the Bob capacity. All of these takes a lot of time even on powerful computers, and due to time limitations of this project improved more accurate results was not obtained.

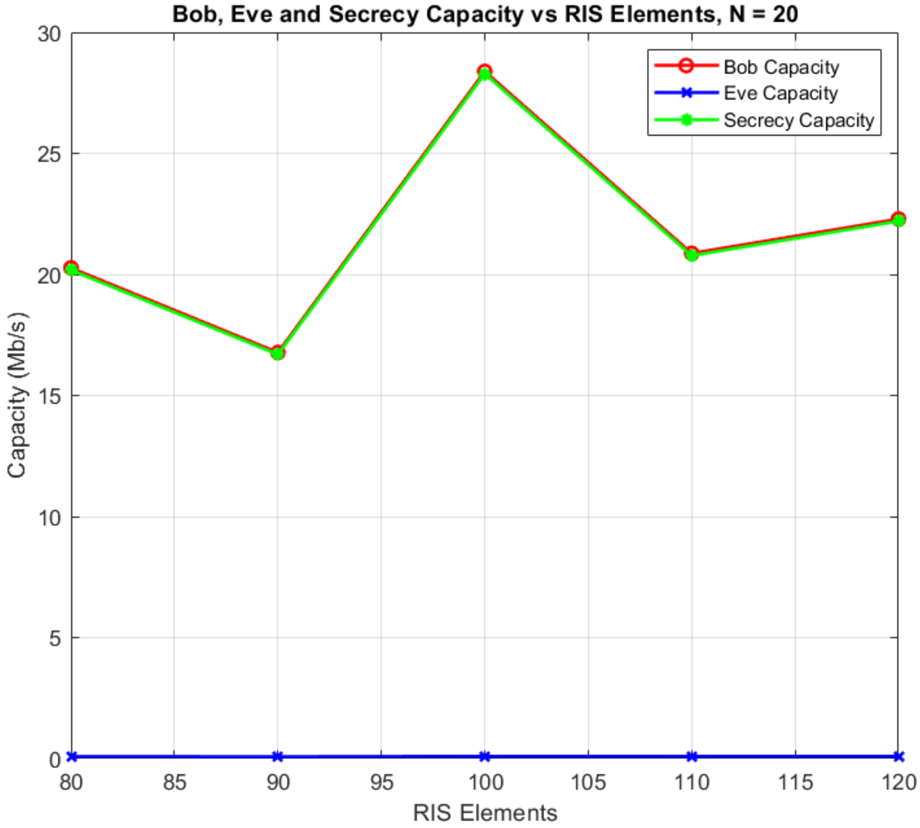

Figure 4.2: Results of the simulation. Bob, Eve, Secrecy Capacities.

Chapter 5

Conclusion

The need for quality and secure wireless communication is always increasing. Massive MIMO and RIS are one of the most promising technologies for the future development of wireless communication. In this project, RIS-assisted Massive MIMO was considered in terms of Physical Layer Security, and was shown to be an effective tool for ensuring secure and quality wireless communication. We propose a system model, which uses some portion of base station antennas for transmitting artificial noise to jam the signal for malicious eavesdropper, while RIS is used to reflect this artificial noise directly to the eavesdropper, maximizing its effect on them. The secrecy capacity of the system was maximized by optimizing RIS phase shift and number of dedicated for artificial noise transmit antennas. Despite the simulation was conducted not ideally due to time constraints, the results show that this model achieves sufficient SC for secure communication by improving data rate on Bob and keeping data rate on Eve under the threshold level. Further research with different scenarios such as multiple Bobs and/or Eves, and with better conducted simulations are encouraged.

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