# IMPLEMENTATION OF STAIR MATRIX BASED MASSIVE MIMO DETECTION

***A Project Report On Submitted in partial fulfillment of the academic requirements for the award of degree***

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We, **RAJNANDINI BHUTADA (18011M2001), D VARUN (18011M2010), K MADHAV SAI ARYAN (18011M2017) , B SUMANTH (15011M2013)** hereby declare that the report of the U.G. Project work entitled under the guidance of Dr.M.ASHA RANI **Professor of ECE Department, JNTUH College of Engineering Hyderabad** is a bonafide work carried out by me. This is being submitted to JNTUH-CEH, in partial fulfilment of the requirements for the award of **Bachelor of Technology in ELECTRONICS AND COMMUNICATION ENGINEERING**. This is a bonafide report of the work carried out by me. The material contained in this report has not been submitted to any University or Institution for the award of any degree or diploma.

It is declared to the best of our knowledge that the work reported does not form part of any dissertation submitted to any other University or Institute for award of any degree.

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# ABSTRACT

Due to the increase in multimedia applications, people are demanding high data rate, high capacity and greater coverage. There is a need for effective utilization of available bandwidth as it is limited. Massive multi-input multi-output (m-gauss) technology uses special multiplexing and has a major impact to secure high data rate, high spectral efficiency and quality of service (QoS) [1]. This thesis aims to improve a few of the performance parameters of m-MIMO, BER (bit error rate) being an important parameter in determining efficiency of a MIMO system.

Approximate matrix inversion based methods are widely used for massive multi input multi output (m-MIMO) received symbol vector detection, these detectors usually use diagonally dominant channel matrix. In order to improve error-rate performance of m-MIMO detector, instead of a diagonal matrix a stair matrix is being used [2]. After carrying out simulations for various antenna configurations in MATLAB we could analyse that for antenna configuration of 95x38 there was an improvement of 99.35% in BER at constant SNR of 20db compared to other detection methods.

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| | |
|---|---|
| BER | Bit Error Rate |
| BS | Base Station |
| CG | Conjugate Gradient |
| GS | Gauss Seidel |
| MIA | Matrix Inversion Approximation |
| MIMO | Multi-Input Multi-Output |
| NSA | Neumann Series Approximation |
| RF | radio frequency |
| SNR | signal-to-noise ratio |
| SOR | Successive Over-Relaxation |
| ZF | zero- forcing |

# CHAPTER-1

# INTRODUCTION

## 1.1 Introduction

MIMO stands for multiple input and multiple output. It is a key technology used in 5G (fifth generation) systems and wireless communications to enhance the energy efficiency, coverage and mobility within the available radio spectrum.

Massive multiple-input multiple-output (m-MIMO) systems were firstly introduced in [3], and have drawn great interest form both academia and industry. In such systems, each base station (bs) is equipped with dozens to hundreds of antennas to serve tens of users in the same time-frequency resource. Therefore, this system can achieve significantly higher spatial multiplexing gains than conventional MIMO systems, which offers one of the most important advantages of massive MIMO (m-MIMO) systems, the potential capability to offer linear capacity growth without increasing power or bandwidth.[3]-[6]

Which was all the good side about MIMO. On the other hand, this system suffers from high computational complexity. Conventional MIMO uses inversion based linear detection. Implementing these method to massive MIMO increases the complexity in system detection. With use of conventional linear detectors such as zero forcing (ZF) and minimum mean square error (MMSE) we can achieve near-optimal BER performance but they require large matrix inversion which induces high computational complexity for symbol deception in such systems.

## 1.2 History behind MIMO

In order to know why MIMO was introduced we must look back at the antenna diversity. We can trace the routes of antenna diversity experiments conducted by RCA engineers Harold H. Beverage1 and Harold O. Peterson who noticed that radio broadcast signals at two stations located about a half mile apart had very different received signal strengths. To overcome this fading, which they came to understand was a result of multipath propagation, they developed a diversity system in which the audio outputs of two different receivers were combined to obtain improved audio quality, [11]-[12] , with experimental observations indicating that the two antennas needed to be separated by at least a wavelength for reliable operation. Later installations also used polarization diversity for situations where the large antenna separation was not feasible.

The main challenge with audio combining of diversity signals was that each antenna required a dedicated and costly receiver. Therefore, in 1941, a technique was proposed that used a single radio receiver with a switch that alternated between two antennas at a rate between 300 and 1000 Hz, effectively presenting an average signal to the receiver that provided some immunity to fading [13][21]. Finally, by 1959, with a mature understanding of signal processing enabled development of improved methods for single-receiver antenna diversity combining, algorithms were formed that laid the foundation of diversity communication systems for the following four decades [14][21]. It further set the stage for a huge volume of research focusing on the nature of multipath propagation and the proper design of antennas to enhance effective diversity performance [15]-[16] [21].

While antenna diversity represented a technology being employed in a large number of radio systems, it was limited to the number of receivers used due to effects of multipath fading. But the first paper at 1996, Foschini at Bell Laboratories wrote a paper [17][21] in which he showed that the communication capacity could be enabled by a system with MT transmit and MR receive antennas, under the assumption that the transmit radio knows nothing about the multi-antenna. His work was reinforced in 1998 not only by his own paper on the same topic but simultaneously by a paper from Raleigh and Cioffi that demonstrated even larger available capacities if the transmitter does know the channel [18][21]. The paper also provided a space-time coding structure aimed again at capturing some of the capacity available in the multipath, multi-antenna channel. Finally, a paper by Alamouti showed a transmit diversity scheme that provided optimal transmit precoding to exploit the multipath channel properties when the transmitter does not know H [19][21]. The paper by Raleigh and Cioffi made the strong connection between the available capacity and the singular values of H. This provided the understanding that the combination of multipath propagation with multi-antenna radios capable of transmitting a unique waveform from each antenna (or independently observing the signal on each receive antenna) creates a finite set of orthogonal communication modes, each of which can be used to independently communicate information. This understanding paved the way for a large volume of work focused on characterizing the properties of H for realistic propagation environments and different antenna designs [20]-[21]

A large number of other propagation studies have been conducted over the years, demonstrating the potential performance of MIMO systems over a wide range of practical environments. Many other studies have shown how to design compact MIMO antennas that offer strong performance in a variety of environments without suffering large performance degradation due to strong antenna mutual coupling.

The activities that have occurred over the past two decades has transformed MIMO communications from an academic concept to a major component of modern communication system and in turn has led to development of massive MIMO (m-MIMO) which is the main basis of 5G and will be used more in the future. [21]

### 1.3 Benefits of Massive MIMO

Many Some of the known benefits of massive MIMO (m-MIMO) are as follows:

1. Less Fading: Due to use of large antenna at the receiver end makes this technology less prone to fading [7].
2. Low Latency: Use of air interface reduces latency.
3. Reliability: with use of large number antenna it provides more diversity gain which in turn increases the link reliability [8]-[9].
4. Increased Security: Massive MIMO provides more physical security due to the orthogonal mobile station channels and narrow beams.
5. Increased Data Rate: array gain and spatial multiplexing used in Massive MIMO increases data rate and capacity.
6. Spectral Efficiency: Massive MIMO provides higher spectral efficiency by allowing its antenna array to focus narrow beams towards a user. Spectral efficiency more than ten times better than the current MIMO system used for 4G/LTE can be achieved.

## 1.4 Challenges of massive MIMO

There are still many issues that need to be studied to make massive MIMO systems a reality, Few of the challenges faced are as follows [10]:

1. Propagation Models: As the number of antennas grows, the individual user channels are still spatially uncorrelated and their channel vectors asymptotically become pairwise orthogonal under favourable propagation conditions.
2. TDD and FDD Modes: As research on massive MIMO systems is normally based on the TDD transmission mode due to channel estimation and feedback issues. There are several possible ways to enable FDD mode in massive MIMO systems. One way is to design an efficient precoding method.
3. Modulation: To construct a BS with a large number of antennas, low-cost power-efficient RF amplifiers are necessary, and problems with high PAPR can impede good performance OFDM.

4. Pilot Contamination: In a typical multi-cell massive MIMO system, users from neighbouring cells may use non-orthogonal pilots. The reason for this is very simple the number of orthogonal pilots is smaller than the number of users. The use of non-orthogonal pilots results in the pilot contamination problem.
5. Hardware Impairments: Only limited work has been done on the impact of hardware impairments on massive MIMO systems.

## 1.5 Overview of the Thesis

As the thesis proceeds we will discuss in Chapter 2 about the zero forcing model which is used to detect the transmitted vector. It is the basis for other detection models like Gauss-Seidel, Neumann series approximation and Conjugate-Gradient which will be discussed as the chapter proceeds.

In Chapter 3 we propose to implement a stair matrix based iterative model with an intention to give a better BER compared to the once discussed in the previous chapter and further describe the algorithm used.

In Chapter 4 simulation results carried out in MATLAB are presented to evaluate the percentage improvement in BER at a constant SNR between various detection models and the proposed Stair Matrix based model.

This thesis comes to conclusion in Chapter 5.

# CHAPTER-2

# LITERATURE REVIEW

## 2.1 Functions Of MIMO

MIMO functions can be divided into 3 categories namely precoding, spatial multiplexing and diversity coding

**Precoding**: The name itself says it is done before transmitting. It is a spatial processing that occurs at the transmitter. The same signal is emitted from each of the transmit antennas with appropriate phase and gain weighting such that the signal power is maximized at the receiver input.

**Spatial Multiplexing:** In spatial multiplexing a signal is split into multiple low rate streams and each is transmitted from a different transmit antenna in the same frequency channel. It is a very powerful technique for increasing channel capacity at higher Signal to Noise Ratio (SNR).

**Diversity Coding**: In diversity methods, a single stream is transmitted, but the signal is coded using techniques called space-time coding. Each antenna emits a signal with full or near orthogonal coding which exploits the independent fading in the multiple antennas to enhance signal diversity, this technique is employed when there is no channel knowledge at transmitter.

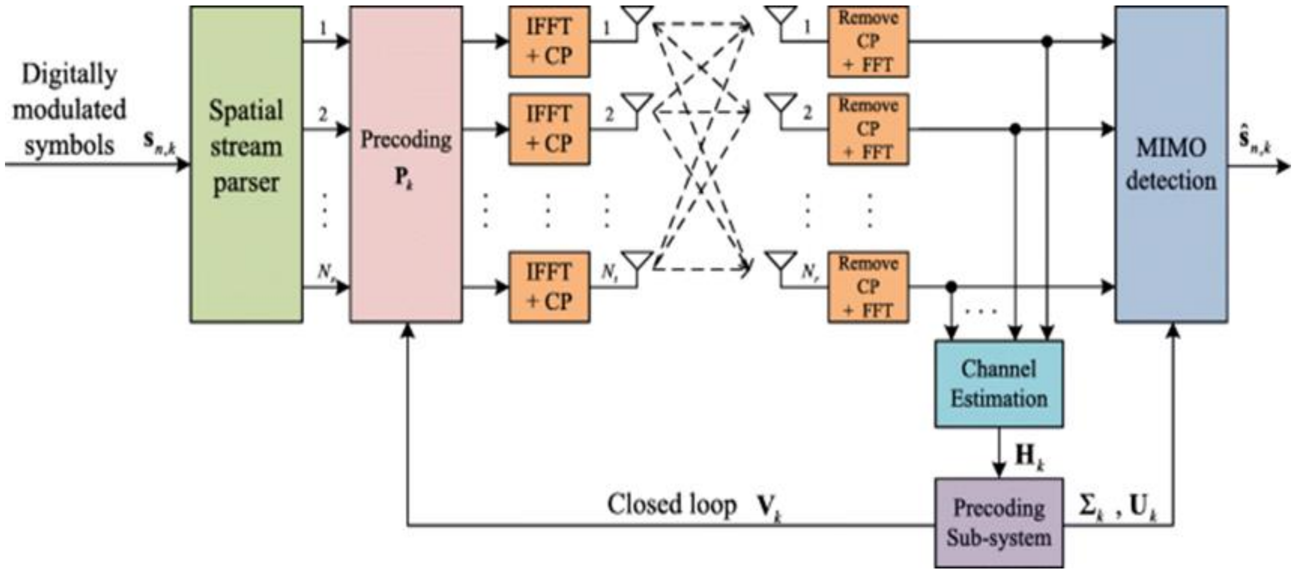



Figure 2.1 block diagram for MIMO detection

## 2.2 Zero Forcing System Model

The conventional linear detectors include zero force detection which uses z.f precoding at the downlink of massive MIMO (m-MIMO) as it balances the complexity and performance. A single cell is considered in which the base station is equipped with an array of ‘N’ number of transmitter antennas that serves the ‘J’ number of receiver antennas in the same cell. The vector for ‘J’ is given as [10]

$$S = [s_1\ s_2\ s_3 \ldots\ldots s_1]$$

Here $s_i$ ,i 1,2,....k is the data symbol corresponding to the i[th] user.

The vector $s \in C^{J\times 1}$ has to be transmitted over ‘N’ number of antennas, thus producing the transmitted data vector $x \in C^{N\times 1}$ as given below

$$x = Ws$$

where W is the mapping vector that transforms s into x , called as precoding weight matrix of size $N \times J$ . Here the precoder matrix W is given as

$$W = \begin{bmatrix} w_{11} & . & . & w_{1k} \\ . & . & & . \\ . & & . & . \\ w_{NJ1} & . & . & w_{NJ} \end{bmatrix}$$

(3)

Here the element $w_{ij}$ refers to weight of the link connecting $i^{th}$ transmitting antenna of the BS and antenna of the $i^{th}$ user. These elements are calculated in such a way that the transmitted data is received only by the intended user, causing minimal interference to other users.[10] The precoding matrix W is calculated for every user terminal by forcing every other to zero. It is represented as

$$W=H^H(HH^H)^{-1}$$

here $H \in C^{J\times N}$ is the channel matrix of dimension JxN this is obtained by uplink pilot transmission that acquires instantaneous channel state information at each base station the above equation can we written using gram matrix G as

$$W = H^H G^{-1}$$

from the above equation we can also write

$$x = H^H G^{-1} s$$

the vector x which is transmitted data is sent over the channel with white noise $n \in C^{J\times 1}$ is added that yields

$$y=Hx+n$$

here $y = [y_1\ y_2\ \ldots\ldots y_{k-1}\ y_k] \in C^{J\times 1}$ corresponds to the symbol vector received by the J user.

The below block figure (Figure 2.2) shows the steps involved in ZF precoding it involves a channel matrix 'H' which undergoes gram matrix computation after which it undergoes approximate matrix inversion and as a result we obtain a precoder matrix. These steps are less complex, but the inverse module is more complex as it requires division operation which is infeasible in hardware. Finding an inverse matrix is the challenging part in Zero forcing. [10]

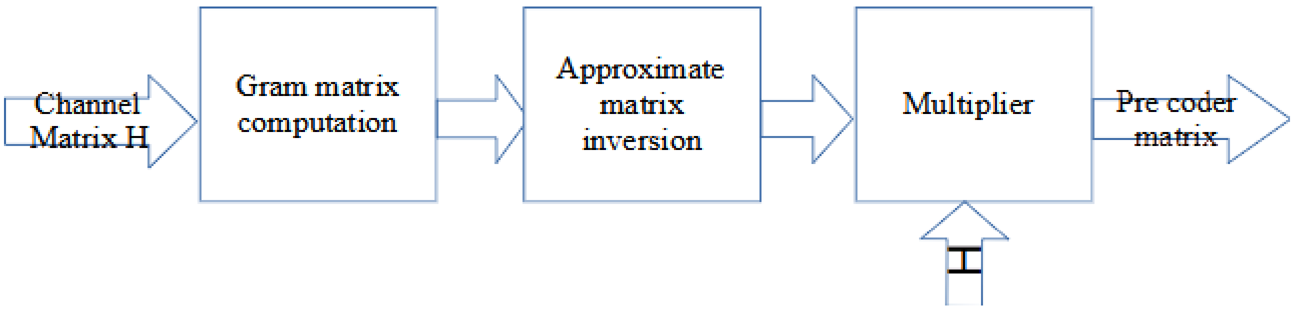



*Figure 2.2 block diagram of Zero Force precoder*

So, NS has been considered to carry out the matrix inversion approximation, because it is advantageous in hardware implementation and is suitable for massive MIMO systems, it can be written as

$$\mathbf{G}_N^{-1} \approx \sum_{n=0}^{N-1} (\mathbf{I}_K - \boldsymbol{\Theta}\mathbf{G})^n\, \boldsymbol{\Theta},$$

n denotes the number of items used in the NS, Θ is a K × K diagonal matrix

$$\lim_{n\to\infty} (I_k - \Theta G)^n$$

## 2.3 Neumann Series

This method is less complex when compared to the remaining methods. But it suffers from considerable performance loss when the ratio between antennas and user antenna is large. The gramian matrix G is decomposed into diagonal matrix E as G=X+E and the series approximation is given by below equation:

$$G^{-1}{}_{(N+1)} = \sum_{N=0}^{\infty} \quad (-X^{-1}E)^T X^{-1}$$

This method only uses inversions of diagonal matrix X which can be achieved with reciprocals of the diagonal elements as the iterations increase precision and complexity of the inversion increases[23].

## 2.4 Gauss–Seidel (GS)

This is an efficient iterative method and based on Successive Over-Relaxation Method in which the signal estimation depends on triangular matrix(L)

$$\hat{X}_{(N+1)} = (D - \frac{1}{\omega}L)^{-1}(Y_{Mf} + (1 - \frac{1}{\omega})D + D - \frac{1}{\omega}U)\ \hat{X}_{(N)}$$

Where W Is the relaxation parameter, the lower triangular matrix. When W = 1 in the above equation, the GS iterative method is obtained and the estimated signal can be written as:

$$\hat{X}_{(N+1)} = (D - L)^{-1}(Y_{Mf} + U\ \hat{X}_{(N)})$$

Generally, the GS method has a fast convergence rate. The initial estimation is Set as

$\hat{X}_{(0)} = D^{-1}Y_{Mf}$ and can be refined iteratively.[1]

## 2.5 Conjugate Gradient (CG)

This method outperforms the NS in performance and complexity. It requires a large number of iterations and include several divisions. The estimated signal $\hat{x}$ can be obtained by:

$$\hat{x}^{(n+1)} = \hat{x}^{(n)}\alpha^{(n+1)}p^{(n+1)}$$

where $p^{(n)}$ is the conjugate direction with respect to the gramian matrix A i.e.,

$$(p)^{(n)^H}\ Ap^{(j)} = 0, \qquad for\ \ n \neq\ j,$$

and

$$p^{(n)} = \hat{x}_{MF}{}^{(n)} + \frac{\hat{x}_{MF}{}^{(n)} .\ \hat{x}_{MF}{}^{(n)}}{\hat{x}_{MF}{}^{(n-1)} .\ \hat{x}_{MF}{}^{(n-1)}} p^{(n-1)}$$

and $\alpha^{(n)}$ is a Scalar Parameter

$$\alpha^{(n)} = \frac{\hat{x}_{MF}{}^{(n)} .\ \hat{x}_{MF}{}^{(n)}}{\hat{x}_{MF}{}^{(n-1)} .\ \hat{x}_{MF}{}^{(n-1)}}$$

This particular detection technique requires a lot of iterations to be done.

## 2.6 Motivation

Our motive is to relatively lower the Bit Error Rate (BER) observed in massive MIMO (m-MIMO) systems so that large number of transmitter antenna and receiver antenna can communicate with each without worrying about the loss of data or bits.

## 2.7 Problem Statement

The Problem with massive MIMO (m-MIMO) Detection is its high complexity. Due to which there is a problem in signal detection. Since massive MIMO (m-MIMO) works with a large number of transmitter antennas and receiver antennas there are high chances that antennas may experience fading and often the received data has few errors compared to transmitted data.

## 2.8 Objective

- To study about different massive MIMO(m-MIMO) detection techniques.
- To generate a Stair Matrix based algorithm for massive MIMO(m-MIMO) detection.
- To implement the detection techniques on MATLAB and plot there BER V/S average SNR plot and analysis the BER at particular SNR.
- To compare the improvement in the percentage of BER at an SNR for stair matrix over other detection techniques

# CHAPTER 3

# PROPOSED MODEL AND IMPLEMENTATION

## 3.1 Proposed Model

As seen in chapter 2 system model of any system model of MIMO is said to have a base station with ‘n’ antennas and assuming that a single antenna user is present near to the base station. The relationship between transmitted vector and received vector can be given by below equation

$$\mathbf{y = hx + n,}$$

where,

y = received signal vector and

x = the transmit symbol vector

h = the channel matrix and

n = additive white gaussian noise (AWGN)

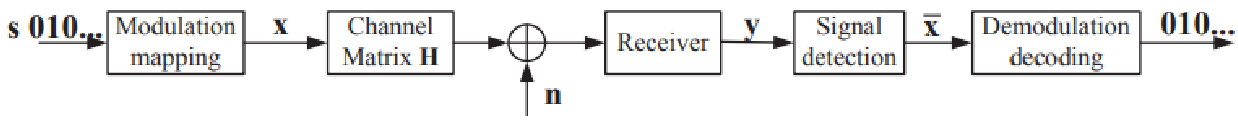



Figure 3.1 the structure of multiple-input-multiple-output (MIMO) signal detection

The Figure 3.1 block diagram represents the structure of multiple input multiple output signal detection. In which ‘s’ is the signal given which is modulation mapped to form the transmission matrix ‘x’, in order for each transmitter to react with multiple receiver there is formation of channel matrix ‘h’ taking place which when is then mixed with the noise when propagates in the air medium and reaches receiver antenna. Proper detection methods must be applied at the receiver end to detect signals transmitted.

This chapter deals with how the designing of a detection technique with help of stair matrix is going to be done in order to improve Bit Error Rate and will be compared with previously established detection technique which were briefly discussed in chapter 2.

## 3.2 Stair Matrix based model

In linear algebra, a matrix ‘D’ is called a diagonal matrix if elements outside the main diagonal are all zero. For instance, a $6 \times 6$ diagonal matrix can be expressed as:[1]

$$D = \begin{bmatrix} x & 0 & 0 & 0 & 0 & 0 \\ 0 & x & 0 & 0 & 0 & 0 \\ 0 & 0 & x & 0 & 0 & 0 \\ 0 & 0 & 0 & x & 0 & 0 \\ 0 & 0 & 0 & 0 & x & 0 \\ 0 & 0 & 0 & 0 & 0 & x \end{bmatrix}$$

In order to call a matrix ‘S’ as a stair matrix, its tridiagonal matrix where the off-diagonal entries on either the odd or the even row are zeros for example, a 6 x 6 stair matrix can be presented as:[1]

$$S = \begin{bmatrix} x & x & 0 & 0 & 0 & 0 \\ 0 & x & 0 & 0 & 0 & 0 \\ 0 & x & x & x & 0 & 0 \\ 0 & 0 & 0 & x & 0 & 0 \\ 0 & 0 & 0 & x & x & x \\ 0 & 0 & 0 & 0 & 0 & x \end{bmatrix} or\, S = \begin{bmatrix} x & 0 & 0 & 0 & 0 & 0 \\ x & x & x & 0 & 0 & 0 \\ 0 & 0 & x & 0 & 0 & 0 \\ 0 & 0 & x & x & x & 0 \\ 0 & 0 & 0 & 0 & x & 0 \\ 0 & 0 & 0 & 0 & x & x \end{bmatrix}$$

Above matrices can be represented by any of the below formulae as:

$$\mathrm{S}(\mathrm{i}, \mathrm{i}-1) = 0, \mathrm{S}(\mathrm{i}, \mathrm{i}+1) = 0 \text{ where } \mathrm{i} = 2, 4, \ldots, 2\frac{[K]}{[2]}$$

$$\mathrm{S}(\mathrm{i}, \mathrm{i}-1) = 0, \mathrm{S}(\mathrm{i}, \mathrm{i}+1) = 0 \text{ where } \mathrm{i} = 1, 3, \ldots, 2\frac{[k-1]}{[2]} + 1$$

### 3.2.1 Stair matrix for MIMO detection

This thesis makes use of stair matrix along with Jacobi (JA) and Gauss-Seidel (GS) methods to get lower Bit Error Rate (BER). Most of the existing iterative linear detectors are utilizing the diagonal matrix ‘D’ in estimating the initial vector because the equalization matrix is diagonally dominant, there are high chances that use of this matrix will show slow convergence or in some cases it may not even converge.

By use of stair matrix along with low complexity JA and GS methods there is chance to obtain fast convergence rate.

Equalization matrix (A) plays role in estimating the signal.

The initial solution is first computed based on the stair matrix as

$$x_{(0)} = s^{-1} y_{mf}$$

Then, for the first iteration Jacobi method is used and conducted as

$$x_{(1)} = D^{-1} (y_{mf} + (\mathrm{D} - \mathrm{A})\, x_{(0)})$$

There after for every iteration till end we use Gauss-Seidel method whose equation is given as

$$x_{(n+1)} = (D - L)^{-1} (y_{mf} + U x_n)$$

Where, in above equation

S = stair matrix

D = diagonal matrix

U = upper triangular matrix of channel matrix (H)

A = equalization matrix

$y_{mf}$ = Gram matrix

## 3.3 Signal to Noise Ratio (SNR)

The goal of any wireless system is to serve as many as users possible with highest data rate. In order to improve this data rate we must improve Signal-to-noise ratio (SNR). SNR is the ratio of the received signal power to the background noise power. The higher the ratio, the better the signal quality. In is can be written as

$$SNR = \frac{P_{signal}}{P_{noise}}$$

It is expressed in decibels(db).

In general case SNR value of 20 dB or more is recommended for data networks while SNR value of 25 dB or more is recommended for voice communication. Higher the SNR indicates higher is the signal strength compared to the noise levels.

## 3.4 Bit Error Rate (BER)

Bit Error Rate (BER) is a measure of telecommunication signal purity based on the quantity or percentage of transmitted bits that are received incorrectly. Essentially, the more incorrect bits, the greater the impact on signal quality. Bit error rate acts a parameter which is an effective indicator of full performance of the system because encompasses the receiver and transmitter as well as the media between them. Which is written as,

$$BER = \frac{Errors}{Total\ Number\ of\ Bits}$$

It is mainly used to characterise the performance in communication channels. BER can be evaluated using stochastic computer simulations. Bit error ratio of $10^{-9}$ is often considered the minimum acceptable BER for telecommunication while $10^{-13}$ is a more appropriate minimum BER for data transmission.

## 3.5 Relationship between Bit Error Rate (BER) and Signal to Noise ratio (SNR):

Bit Error Rate (BER) and Signal-to-noise ratio (SNR) are closely related to each other. High BER causes an increase in packet loss, increased in delay and increase in throughput. Since SNR is indicator of signal in the system it is usually accepted for it to be high.

The relationship between SNR and BER is that they are inversely proportional to each other.

In general any system must have as low BER as possible and SNR must be as high as possible.

$$BER \propto \frac{1}{SNR}$$

## 3.6 Implementation

MATLAB tool is used in this thesis in order to evaluate performance of various detection techniques massive MIMO (m-MIMO).

In MATLAB it is very easy to implement large number of antenna and initialise there arrays and subarrays, it is also useful in processing algorithms and channel models.

Detection techniques used along with our proposed model for comparison are:

- Neumann series approximation
- Gauss-Seidel
- Conjugate Gradient

It was required to install all the libraries which are required to write the code, debug and run it Error free.

The main step in writing the code or algorithm is to set all the default parameters like number of receiver antennas (MR), number of user terminals or transmitter antennas (MT), number of iterations, modulation scheme to be used and till which value of SNR simulation has to be carried out.

After setting all the default parameters, there must be need to initialise all the arrays, these arrays include

- Vector error rate
- Symbol error rate
- Bit error rate

The binary sequence input necessary to travel from MT to MR are generated in random manner using the MATLAB tool.

The channel matrix (H) is of size MR x MT.

The additive white gaussian noise (AWGN) channel is of size MR x 1.

Next it is required to set the detector functions whose inputs are channel matrix (H), transmit data (y), Variance of noise(N0).

These input values undergo necessary formulae transformations for respective detection techniques which are discussed in section 2.2, 2.3, 2.4, 2.5 and 3.2.1.

Later the bits are extracted and BER v/s average SNR plot is plotted for all detection techniques.

By conducting simulations for various antenna configurations conclusions are made and later discussed in chapter 4.

## 3.7 Algorithms

To simulate the above proposed models there are few algorithms used. These algorithms are not easy and readily available on MATLAB.

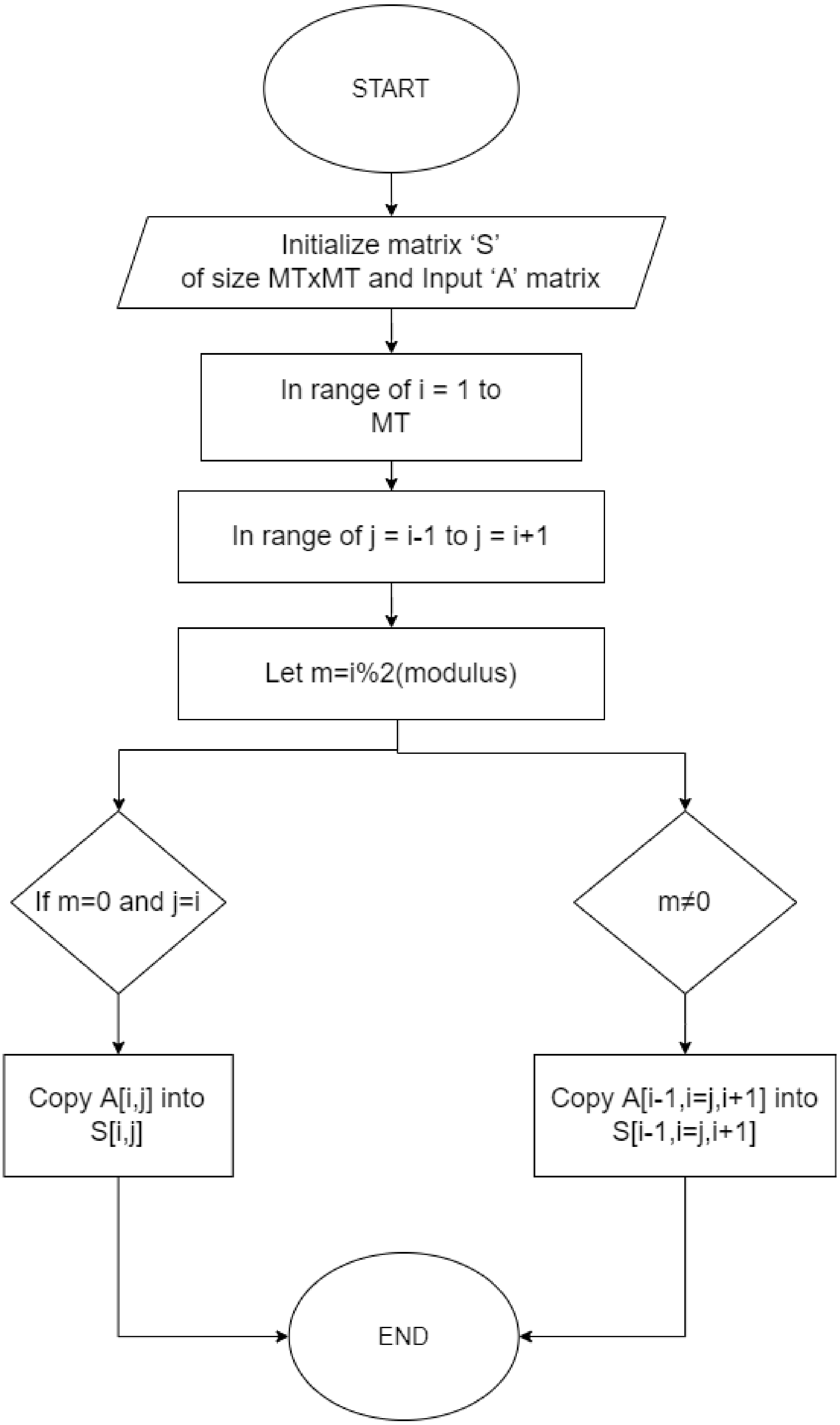
Section 3.7.1 focuses on how to generate a stair matrix from given channel matrix.

Section 3.7.2 focuses on how to generate inverse of the stair matrix as it is complicated for MATLAB to generate.

Section 3.7.3 focuses on how to implement the proposed detection model which is based on joint JA, GS and stair matrix

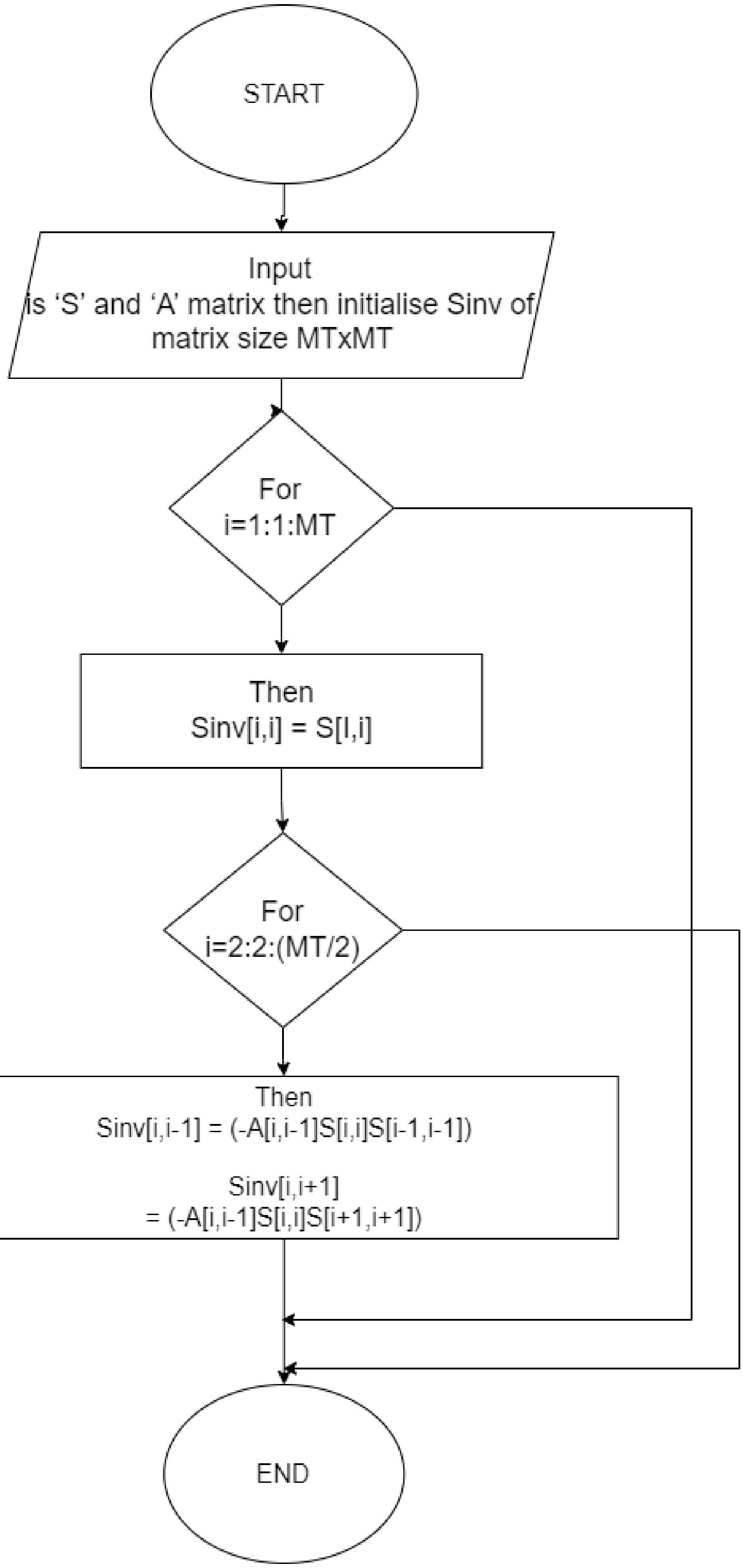
### 3.7.1 Algorithm to extract stair elements

In this MT = number of transmitter antenna, A = equalization matrix and S= stair matrix

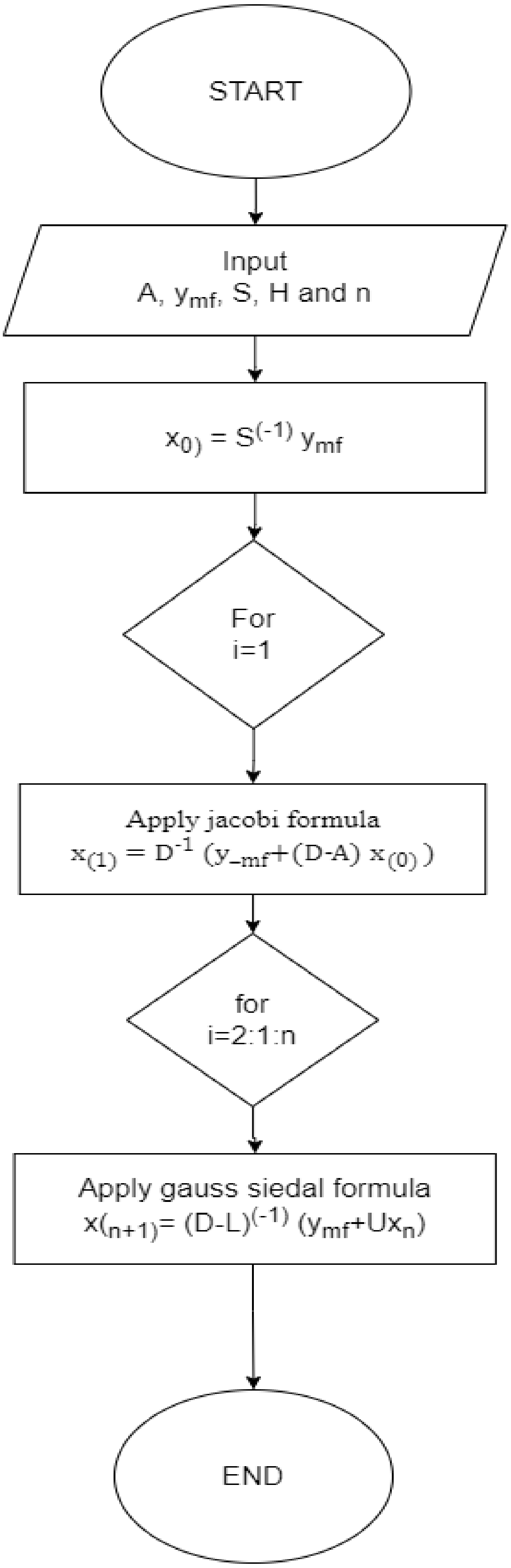


### 3.7.2 Algorithm to extract Inverse of a stair matrix

In this MT = number of transmitter antenna, A = equalization matrix, S = Stair matrix and Sinv = inverse of stair matrix



### 3.7.3 Algorithm for the detection method based on joint JA, GS, and a stair matrix



# CHAPTER 4

# SIMULATION RESULTS

## 4.1 Previously implemented models for massive MIMO detection

In below graphs x-axis represents average SNR per receiver antennas in decibels (db) and y-axis represents Bit Error Rate (BER). In all the graphs MR is number of receiver antenna and MT is number of transmitter antenna.

Figure 4.1illustrates antenna configuration of 120x50, we can conclude that in Gauss-seidel method BER value is less compared to others at constant value of SNR=20db. The Neumann graph is almost converging while there is slight improvement in Conjugate-Gradient compared to Neumann.

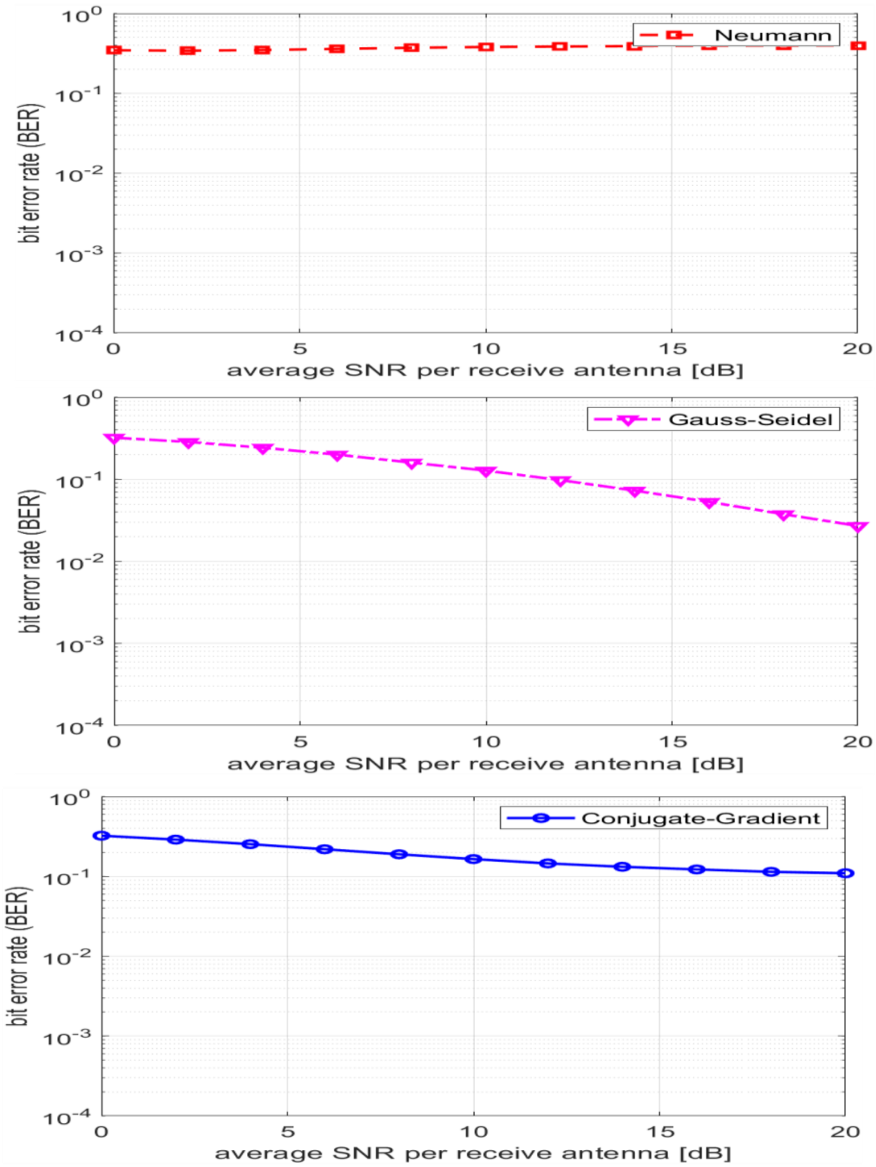



Figure 4.1 MR=120; MT=50

Figure 4.2 illustrates antenna configuration of 120x60, initially all the graphs start at same point but as SNR keeps on increasing at SNR=10db, BER of Neumann model is less compared to that of other two models but at SNR=20db BER value of Gauss-Seidel is less than Conjugate-Gradient.

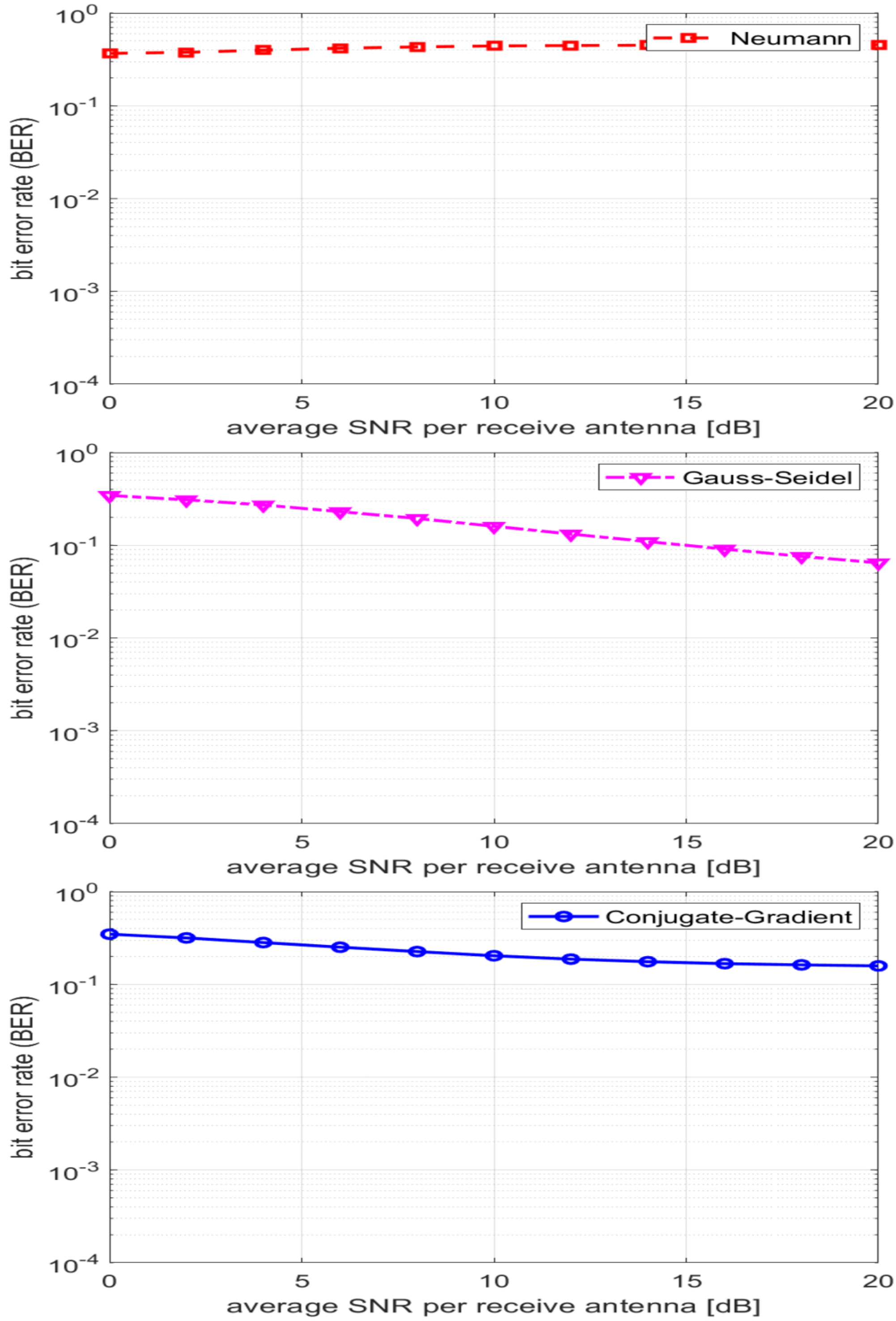



Figure 4.2 MR=120; MT=60

Figure 4.3 is for antenna configuration of 100x70, initially all graphs start from same point and as SNR keeps on increasing BER keeps on decreasing and Gauss-Seidel performs better than others. It can also be observed from Figure 4.2 that for configuration of 120x60 there is more decrease in BER.

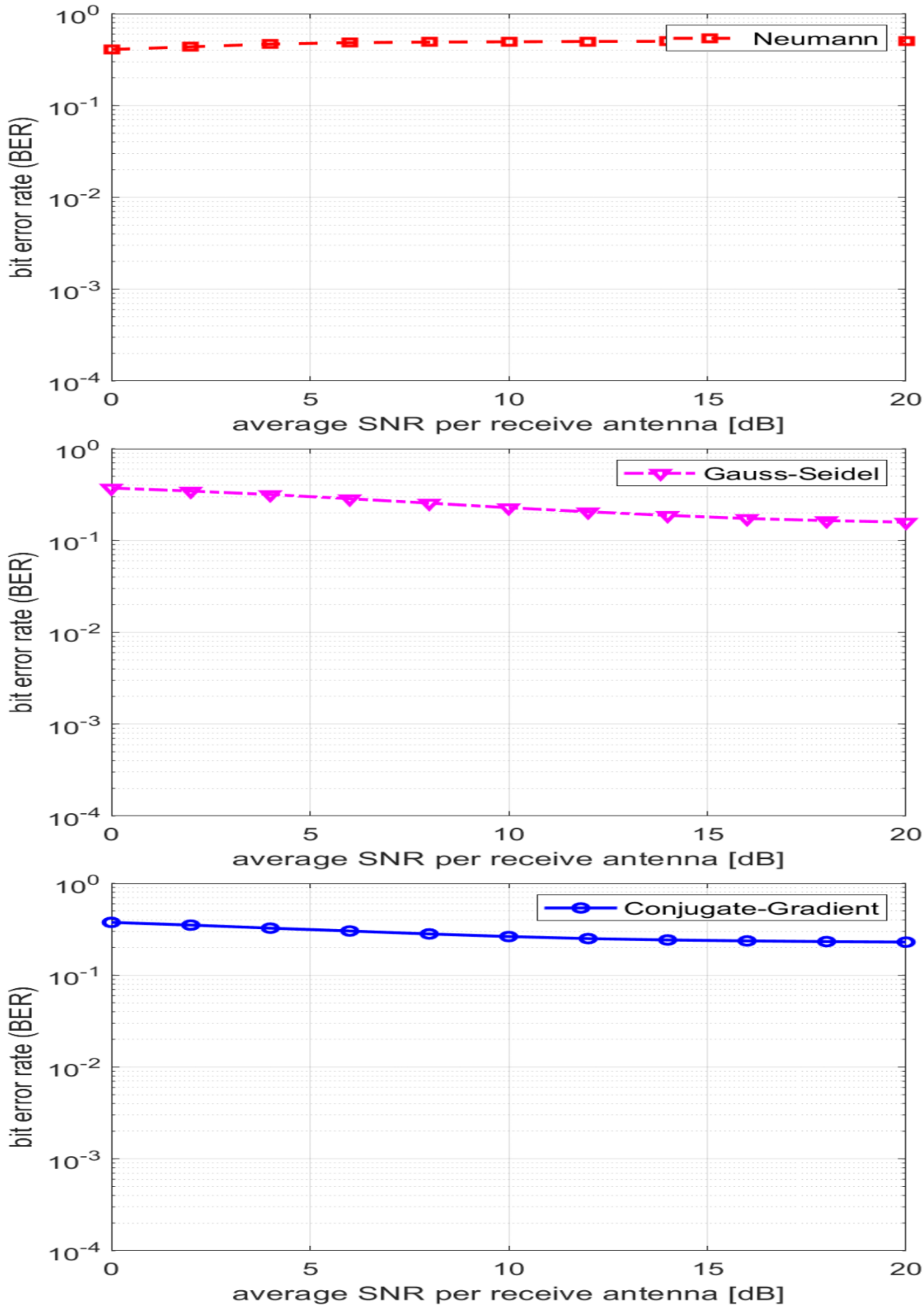



Figure 4.3 MR=100; MT=70

Figure 4.4 is illustrated for antenna configuration of 95x35. From the graph we can say that at SNR=5db BER of Gauss-Seidel and Conjugate Gradient is same while Neumann is about to converge. As SNR keeps on increasing there is significant amount of decrease in BER in Gauss-Seidel method when compared to Conjugate i.e., at SNR=20db BER value for Gauss-seidel is $10^{-2}$ and for Conjugate Gradient is $10^{-1}$.

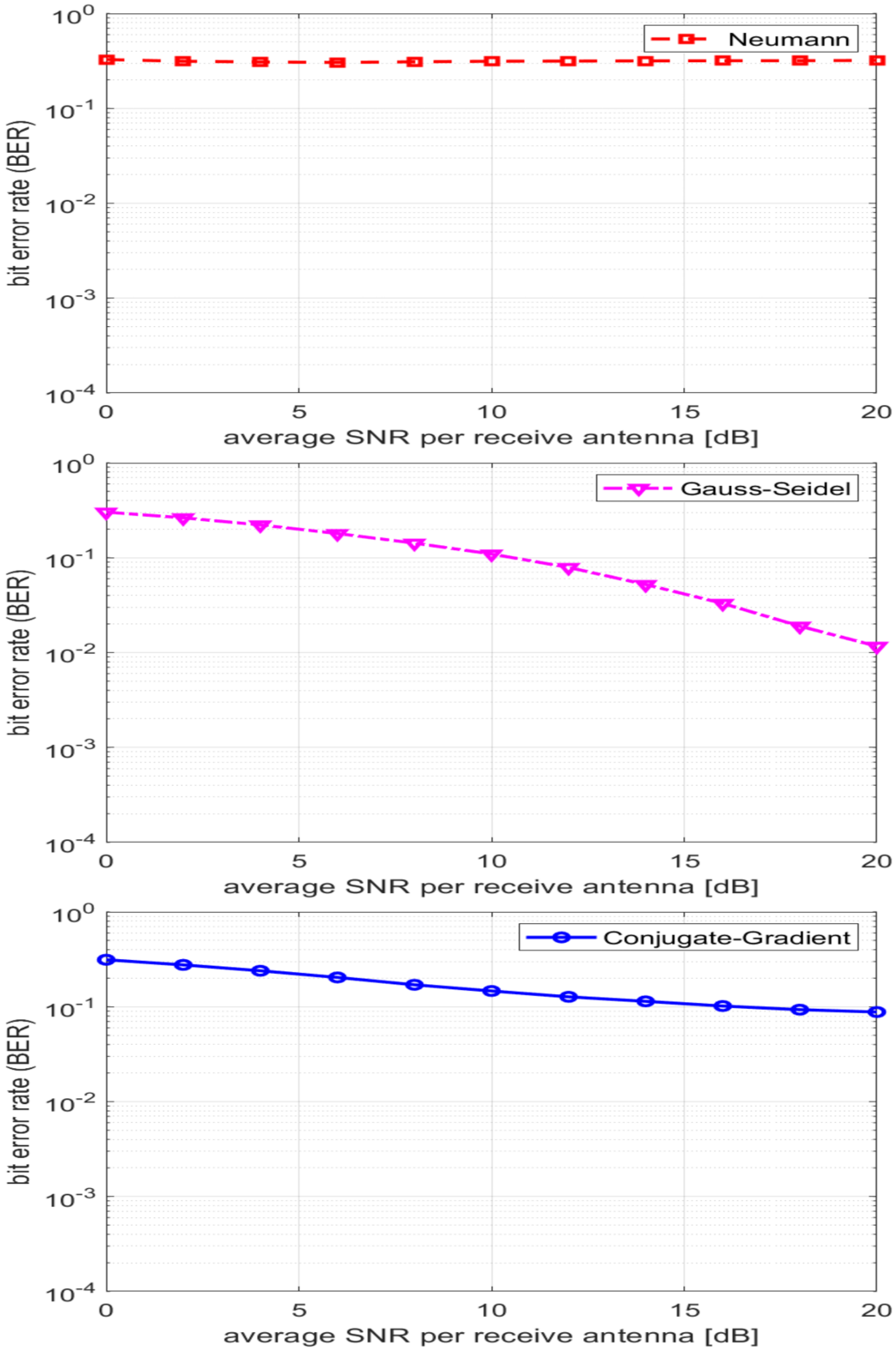



Figure 4.4 MR=95; MT=35

Figure 4.5 has antenna configuration of 95x23, Comparing this graph with previous graphs it can clearly be seen that there is significant improvement in BER at SNR=20db for Neumann model. The BER value for Gauss-Seidel is $10^{-4}$ which is most obtained in any of the simulations while Conjugate Gradient is nearly $10^{-2}$.

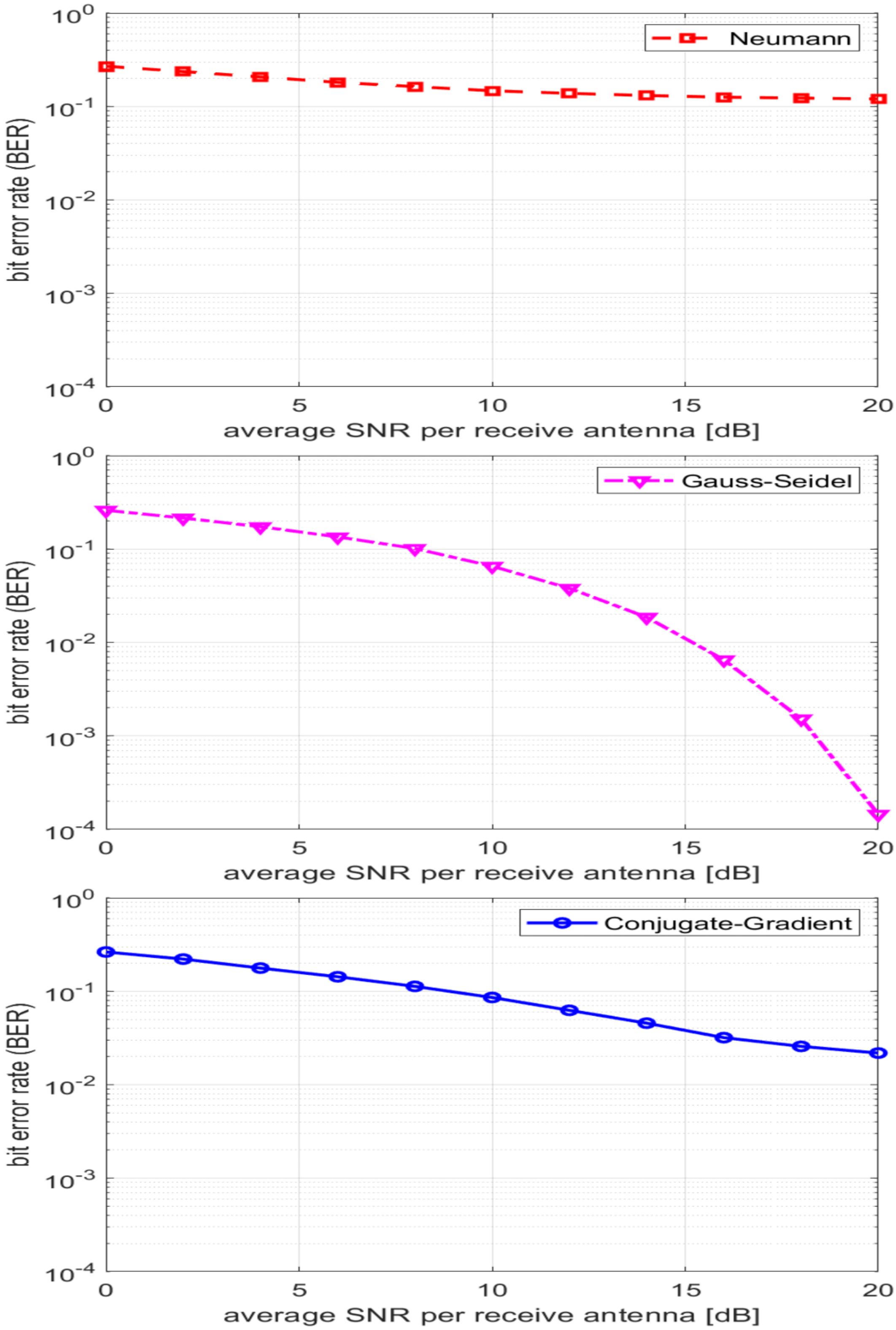



Figure 4.5 MR=95; MT=23

In Figure 4.6 configuration of antenna is 116x38. From SNR=0db to SNR=10db BER of Gauss-Seidel and Conjugate is same and as SNR increases at SNR=20db we can notice that BER for Gauss-Seidel is less compared BER for Conjugate Gradient.

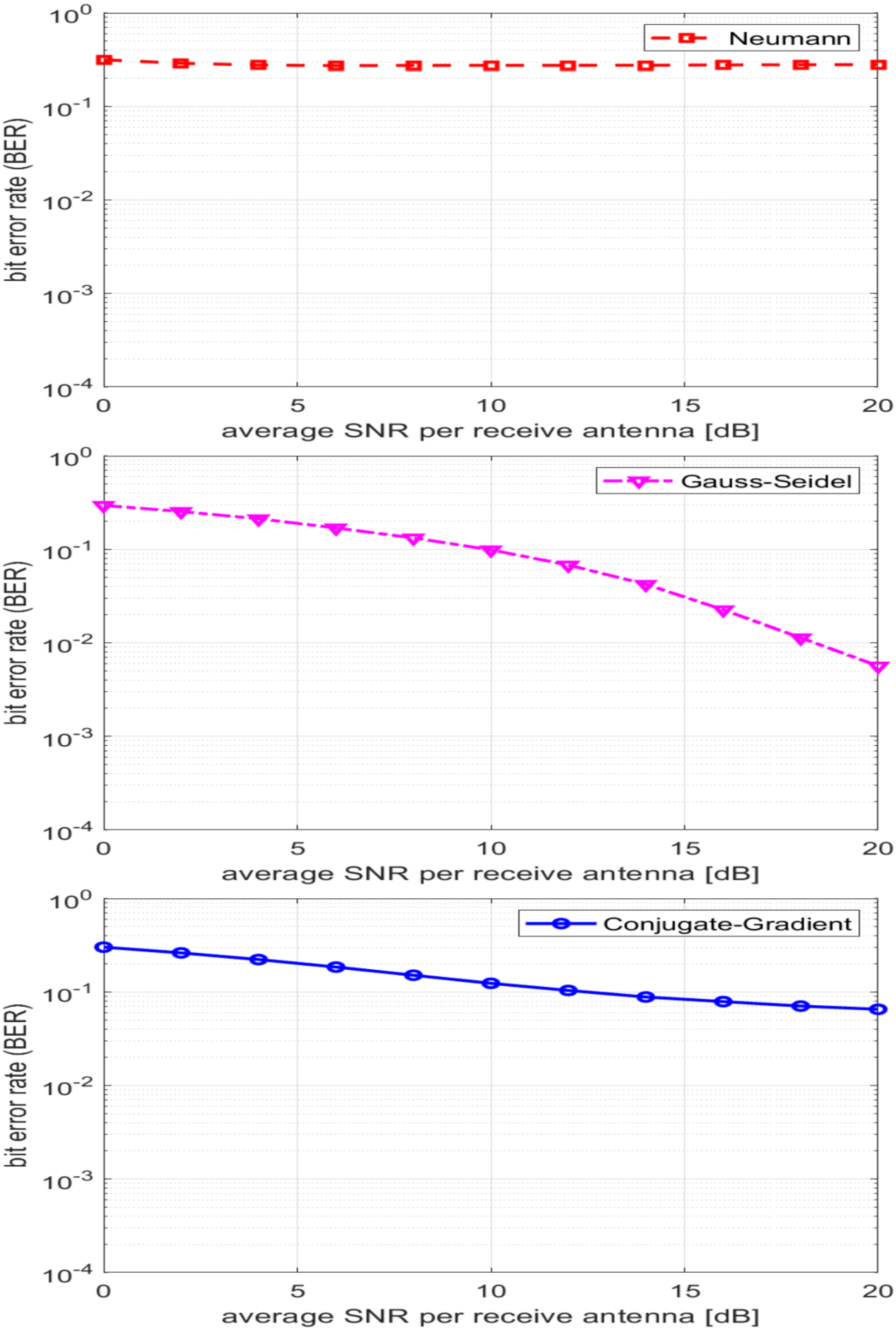



Figure 4.6 MR=116; MT=38

From all the above simulations we can conclude that highest improvement in BER at constant SNR=20db is for Gauss-Seidel model then comes Conjugate Gradient model and last is Neumann Series model. Gauss-Seidel and Conjugate Gradient have same SNR till 5db~10db and then Gauss-seidel shows more improvement compared to Conjugate Gradient. Neumann series model is converging in almost all cases except for one antenna configuration i.e., 95x23.
These all models will now be compared in section 4.2 and percentage improvement will be tabulated in section 4.3

## 4.2 Simulation of stair matrix proposed model and Its comparison with other detection techniques

Figure 4.7 illustrates the comparison of the proposed model with other models for antenna configuration of 120x50 and number of iteration n=6. It can clearly be seen that till SNR=10db Gauss-Seidel and Stair matrix have same BER. As SNR keeps on increasing there is improvement in BER for SNR=20db. While Neumann Series is almost converging and BER of Conjugate gradient is less than that of Gauss-Seidel and Stair Matrix.

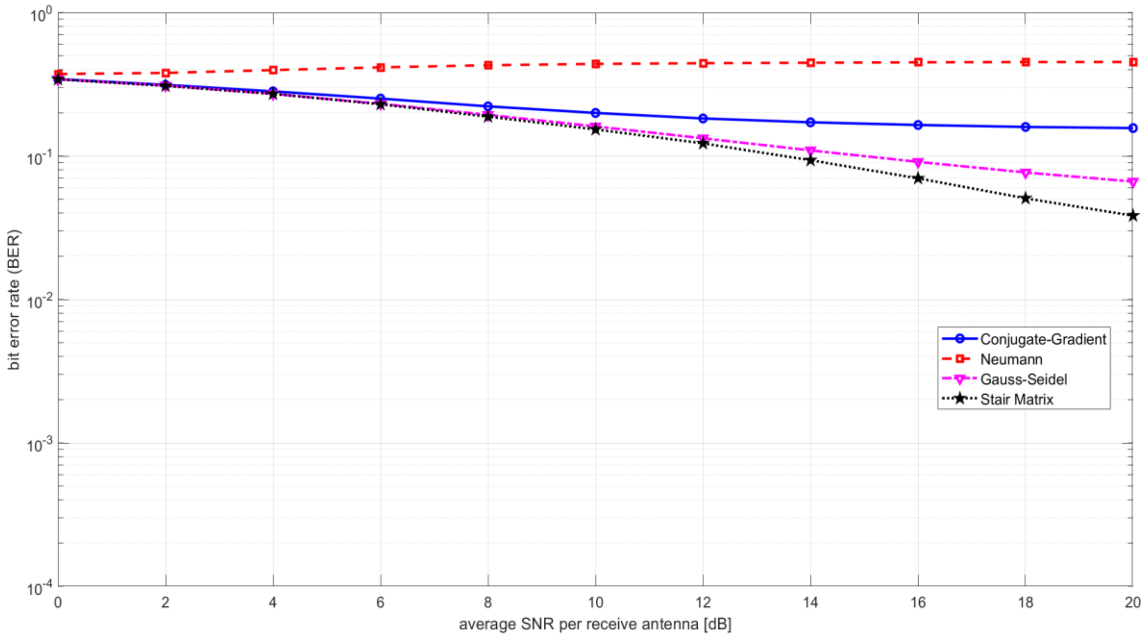



Figure 4.7 MR=120; MT=50; n=6

Figure 4.8 is illustrated for antenna configuration of 120x50 and number of iterations are n=6. From below figure we can see that till SNR=12db Stair Matrix and Gauss-Seidel have same BER of $10^{-1}$. As SNR is increasing BER is $10^{-2}$ for proposed Stair Matrix method while for Gauss-seidel it is less than $10^{-2}$. As usual Neumann Series converges and BER for SNR=20db in Conjugate Gradient is less compared to other two models. It can also be seen that till SNR=6db BER for Stair Matrix model, Gauss-Seidel model and Conjugate Gradient model is same.

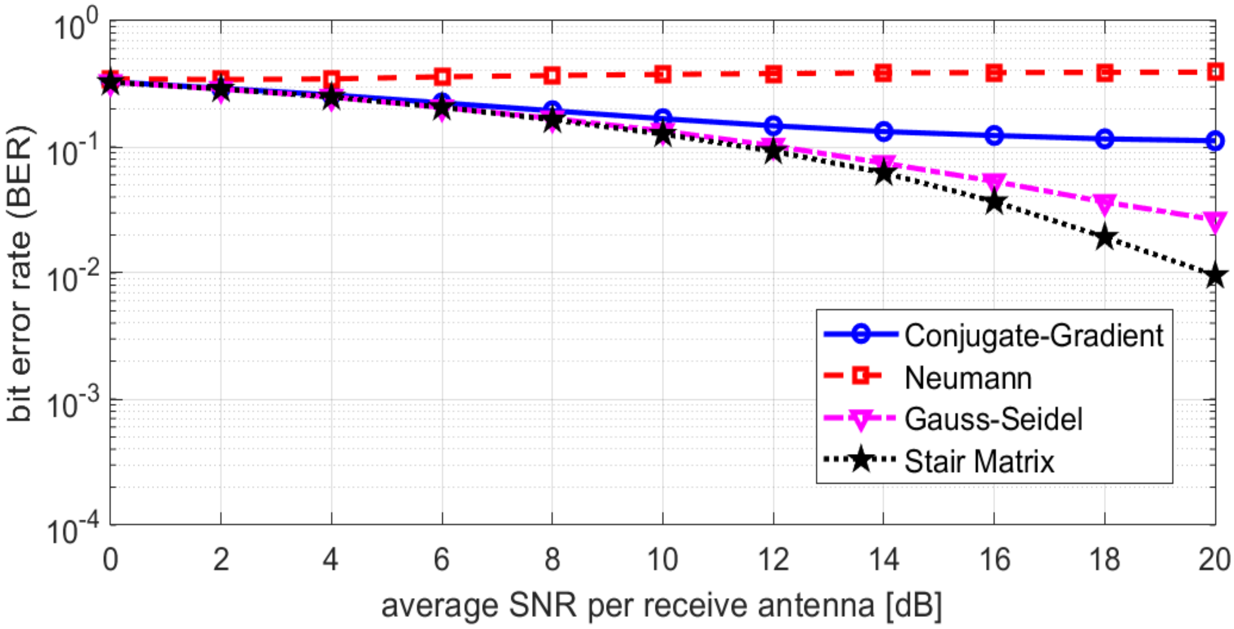



Figure 4.8 MT=120; MR= 50; n=6

Figure 4.9 shows performance comparison for antenna configuration of 100x70 with number of iterations n=10. It can be told from the graph that till SNR=8db BER for proposed Stair matrix model, Gauss-Seidel model and Conjugate-Gradient is same. But for SNR=20db we can see that there is very slight difference between BER of Conjugate-Gradient and Gauss-Seidel compared to Stair Matrix model and obviously value of BER for Stair matrix is less.

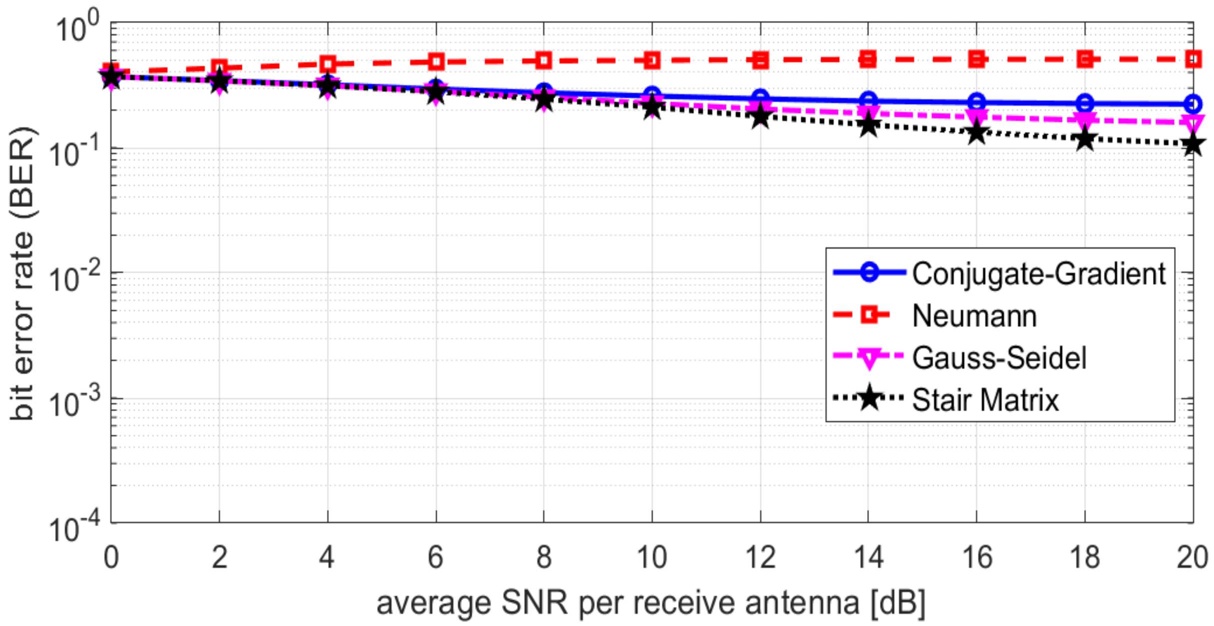



Figure 4.9 MR=100; MT=70; n=10

Figure 4.10 is for antenna configuration of 95x35 with number of iterations n=5. It can be noticed that till SNR=12db Stair Matrix proposed method and Gauss-seidel have same BER and it can also be seen that there is very slight improvement in BER for SNR=20db. If the number of iterations were less than 5 then there are chances for Gauss-Seidel to have more BER. As usual Neumann Series converges.

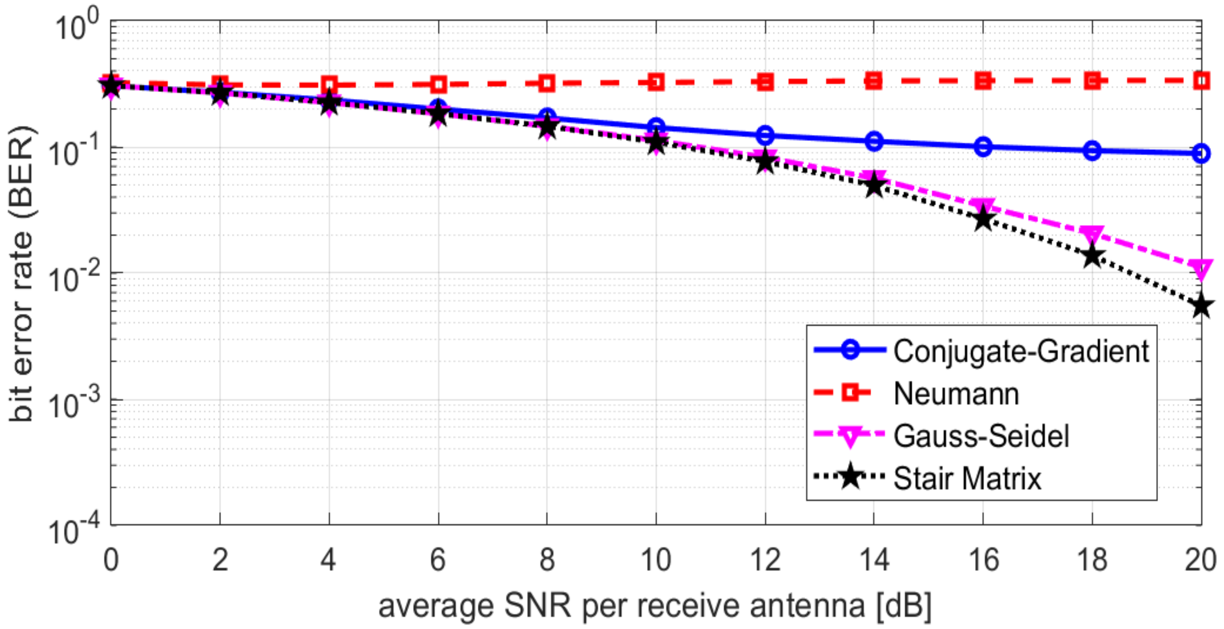



Figure 4.10 MR=95; MT=35; n=5

Figure 4.11 illustrates antenna configuration of 95x23 with number of iterations n=4. It can be seen that till SNR=14db Stair Matrix proposed model and Gauss-Seidel has BER same again at SNR=18db BER is same and at SNR=20db BER for Stair Matrix proposed method is lower than Gauss-Seidel model. At SNR=20db BER for Stair Matrix Proposed model is ≈ $10^{-4}$. As Neumann model converges the improvement in BER for Stair matrix model when compares is 99.9% at SNR=20db. While the graph for Conjugate-Gradient model is almost linear.

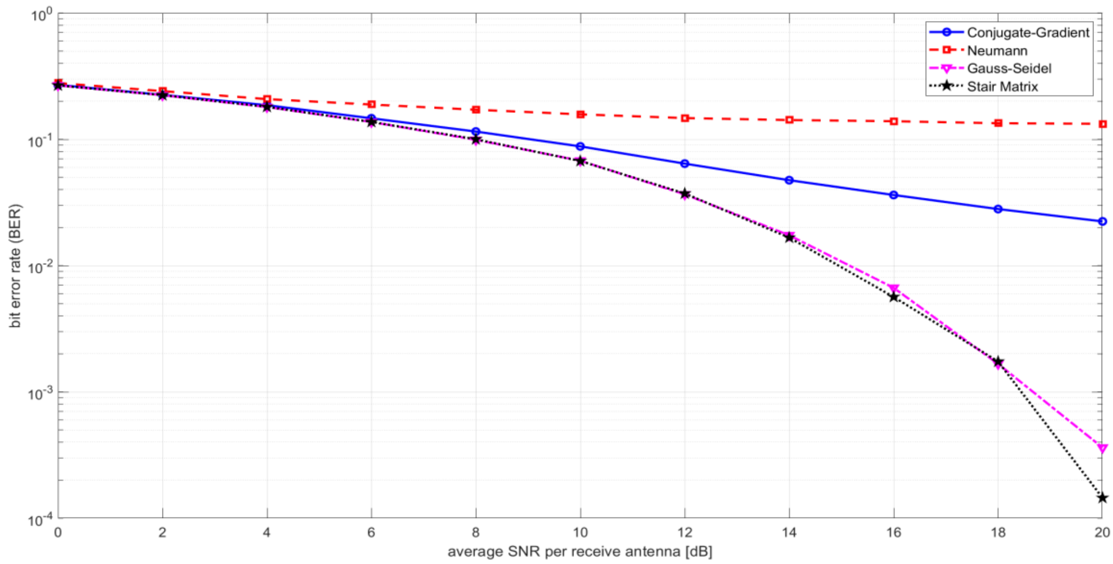



Figure 4.11 MR=95; MT=23; n=4

Figure 4.12 is illustrated for antenna configuration of 116x38 with number of iterations n=7. In this graph the percentage improvement in Conjugate-Gradient model and Stair Matrix proposed model is about 50% at SNR=16db. At SNR=20db we can observe that BER is slightly less $10^{-3}$ for Stair Matrix proposed model.

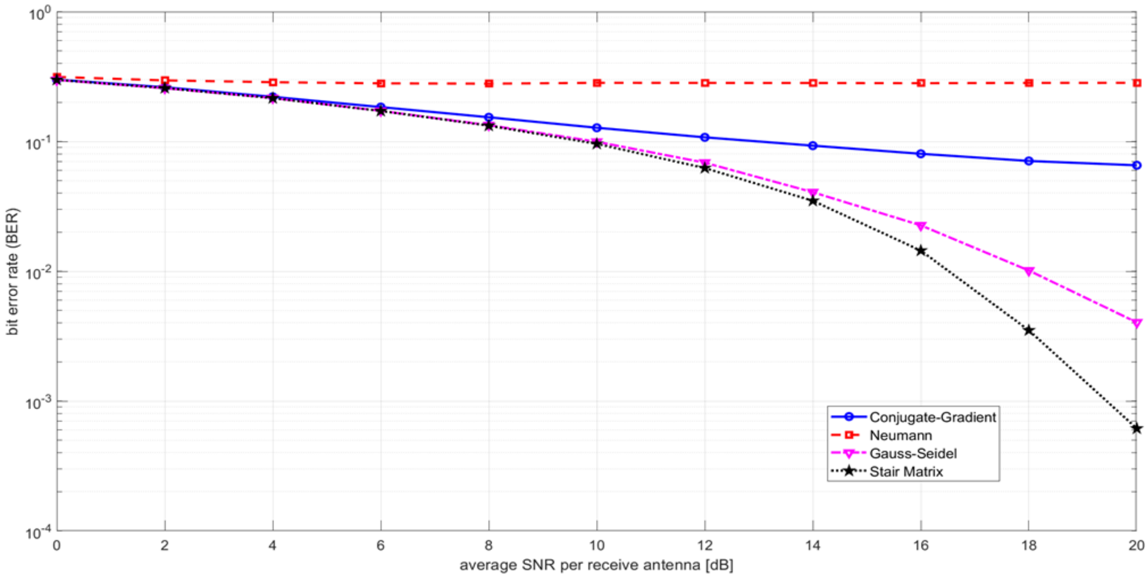



Figure 4.12 MR=116; MT=38; n=7

Now, the percentage improvement in BER at constant value of SNR=20db for all the models which include Neumann Series model, Conjugate-Gradient model, Gauss-Seidel model and Stair Matrix based proposed model will be calculated and the tabulated results will be shown in section 4.3.

It can also be said that it is desirable that the graph plotted between BER v/s average SNR must be decreasing. If curve is more negative it indicates that BER should also be decreasing.

## 4.3 Performance evaluation table

This table shows the percentage improvement in BER at constant SNR=20db for all other models and the proposed stair matrix method.

Here,

MR = number of receiver antenna

MT = number of transmitter antenna

n = number of iterations

Table 4.3 Performance of massive MIMO detection methods

| **Stair matrix specification** | **Neumann** | **Gauss-Seidel** | **Conjugate-Gradient** |
|---|---|---|---|
| MR=120; MT=50; n=6 | 97.55% | 91.44% | 63.76% |
| MR=120; MT=60; n=6 | 91.52% | 75.50% | 42.193% |
| MR=100; MT=70; n=10 | 78.9% | 51.77% | 32.42% |
| MR=95; MT=35; n=5 | 98.36% | 93.78% | 50.42% |
| MR=95; MT=23; n=4 | 99.89% | 99.35% | 59.9% |
| MR=116; MT=38; n=7 | 99.744% | 98.83% | 83.65% |

# CHAPTER 5

# CONCLUSION AND FUTURE SCOPE

## 5.1 Conclusion:

This thesis proposes a massive MIMO detector which utilises stair matrix along with Jacobi method (JS) and Gauss-Seidel. This proposed method was compared with other massive MIMO detectors like Neumann Series, Gauss–Seidel (SG) and Conjugate Gradient (CG) to evaluate the improvement in BER at constant SNR.

Conclusion made from above simulations and percentage improvement table is that when antenna configuration was 95x23 with iterations n=4 we are getting the highest improvement of 98.89% in the Stair Matrix proposed model when compared to the Neumann series model for detecting BER at constant SNR=20db. For the same configuration of antenna of 95x23 with iterations n=4 there is an improvement of about 99.35% in BER for SNR=20db when compared to the Gauss-Seidel model. When there is a huge difference between the number of receivers and transmitters like in the case of antenna configuration of 116x38 with iterations n=7 there is about 83.65% improvement in the BER when compared to that of Conjugate-Gradient model.

Major limitation in using the MATLAB tool for plotting BER V/S average SNR plot is that it does not allow the number of transmitters to be more or equal to the number of receivers. Due to which it becomes difficult to compute values to plot and due to this high complexity we cannot get the appropriate graph. It is observed that whenever this case is applied all the models Stair Matrix based model, Neumann Series model, Conjugate-Gradient model and Gauss-Seidel model graphs converge at zero.

# REFERENCES


[1] Albreem, Mahmoud A., Mohammed H. Alsharif, and Sunghwan Kim. 2020. "A Robust Hybrid Iterative Linear Detector for Massive MIMO Uplink Systems" *Symmetry* 12, no. 2: 306. https://doi.org/10.3390/sym12020306

[2] S. Shahabuddin, M. A. Albreem, M. S. Shahabuddin, Z. Khan and M. Juntti, "FPGA Implementation of Stair Matrix based Massive MIMO Detection," 2021 IEEE 12th Latin America Symposium on Circuits and System (LASCAS), 2021, pp. 1-4, doi: 10.1109/LASCAS51355.2021.9459171

[3] T. L. Marzetta, “Noncooperative Cellular Wireless with Unlimited Numbers of Base Station Antennas,” IEEE Trans. Wireless Commun., vol. 9, no. 11, pp. 3590–3600, Nov. 2010.

[4] F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, T. L. Marzetta, O. Edfors, and F. Tufvesson, “Scaling up MIMO: Opportunities and Challenges with Very Large Arrays,” IEEE Signal Process. Mag., vol. 30, no. 1, pp. 40–46, Jan. 2013.

[5] E. G. Larsson, F. Tufvesson, O. Edfors, and T. L. Marzetta, “Massive MIMO for Next Generation Wireless Systems,” IEEE Commun. Mag., vol. 52, no. 2, pp. 186–195, Feb. 2014.

[6] J. Hoydis, S. Brink, and M. Debbah, “Massive MIMO in the UL/DL of Cellular Networks: How Many Antennas Do We Need?” IEEE Sel. Areas Commun., vol. 31, no. 2, pp. 160–171, Feb. 2013.

[7]Nguyen, M. Massive MIMO: A Survey of Benefits and Challenges. ICSES Trans. Comput. Hardw. Electr. Eng. 2018, 4, 1–4.

[8]Marzetta, T.L. Noncooperative cellular wireless with unlimited numbers of base station antennas. IEEE Trans. Wirel. Commun. 2010, 9, 3590–3600.

[9] Popovski, P.; Stefanovi´c, C.; Nielsen, J.J.; De Carvalho, E.; Angjelichinoski, M.; Trillingsgaard, K.F.; Bana, A.S. ˇ Wireless Access in Ultra-Reliable Low-Latency Communication (URLLC). IEEE Trans. Commun. 2019, 67, 5783–5801

[10] D.Subitha, J.M.Mathana, J.S.Leena Jasmine ,R.Vani “Modified Conjugate Gradient Algorithms for Gram Matrix Inversion of Massive MIMO Downlink Linear Precoding”international Journal of Recent Technology and Engineering (IJRTE), Volume-8, Issue-2S11, September 2019

[11] J. E. Brittain, “Electrical Engineering Hall of Fame: Harold H. Beverage,” Proc. IEEE, vol. 96, pp. 1551–1554, Sep. 2008.

[12] H. H. Beverage and H. O. Peterson, “Diversity receiving system of R.C.A. Communications, Inc., for radiotelegraphy,” Proc. IRE, vol. 19, pp. 529–561, Apr. 1931.

[13] F. A. Bartlett, “A dual diversity preselector,” QST, vol. XXV, pp. 37–39, Apr. 1941.

[14] D. G. Brennan, “Linear diversity combining techniques,” Proc. IRE, vol. 47, pp. 1075–1102, Jun. 1959

[15] R. G. Vaughan and J. B. Andersen, “Antenna diversity in mobile communications,” IEEE Trans. Veh. Technol., vol. VT-36, pp. 147–172, Nov. 1987.

[16] M. A. Jensen and Y. Rahmat-Samii, “Performance analysis of antennas for hand-held transceivers using FDTD,” IEEE Trans. Antennas Propag., vol. 42, pp. 1106–1113, Aug. 1994.

[17] G. J. Foschini, “Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas,” Bell Labs Technical Journal, pp. 41–59, Autumn 1996.

[18] G. G. Raleigh and J. M. Cioffi, “Spatio-temporal coding for wireless communication,” IEEE Trans. Commun., vol. 46, pp. 357–366, Mar. 1998

[19] S. M. Alamouti, “A simple transmit diversity technique for wireless communications,” IEEE J. Selected Areas Commun., vol. 16, pp. 1451– 1458, Oct. 1998.

[20] M. A. Jensen and J. W. Wallace, “A review of antennas and propagation for MIMO wireless communications,” IEEE Trans. Antennas Propag., vol. 52, pp. 2810–2824, Nov. 2004.

[21]M. A. Jensen, "A history of MIMO wireless communications," *2016 IEEE International Symposium on Antennas and Propagation (APSURSI)*, 2016, pp. 681-682, doi: 10.1109/APS.2016.7696049

[22] Robin Chataut and Robert Akl Massive MIMO Systems for 5G and beyond Networks—Overview, Recent Trends, Challenges, and Future Research Direction sensors 2020, 20, 2753

[23] Shahriar Shahabuddin, Muhammad Hasibul Islam, Mohammad Shahanewaz Shahabuddin,Mahmoud A. Albreem, Markku Juntti Matrix Decomposition for Massive MIMO Detection