School of Electrical Engineering and Computing

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Optimal Robust Transceiver Designs for Non-regenerative Multicasting MIMO Relay Communication Systems

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Signature:

Date: 15/1/2017

To

My parents, My wife Hauwa'u and children Abubakar and Umar

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Abstract

This research work considers a robust transceiver design of two-hop non-regenerative multicasting multiple-input multiple-output (MIMO) relay systems. The proposed research work aims to minimize the maximal mean-squared error (MSE) between the transmitter and the receiver with further signal processing. In the proposed research, an optimal weighting matrix called relay matrix or precoding matrix is considered as a Wiener filter with singular vectors of the channels matrices at the relay station.

Initially, an optimal structure of the relay precoding matrix is derived to minimize the maximal mean-squared error (MSE) in the signal waveform estimation, with the assumption that the relay knows the channel covariance information (CCI) of the relay-destination and the source-relay links. The proposed scheme is closer to the conventional relay algorithms in terms of both MSE and bit-error-rate (BER). In the existing design, the estimated MSE at the receiver nodes is optimum when the channel state information (CSI) of the transmitters to relay link and relay to receivers link are known at the relay node. However, in practice, the actual CSI is not available and it has to be approximated. Hence, due to estimate of the CSI, a channel mismatch is always between the actual and estimated CSI. Hence, a robust transceiver design can improve the performance of the MIMO relay system by taking the channel mismatch into account. Therefore, the robust transceiver design is important and useful for real-time applications.

Finally, the problem of robust transceiver design is investigated for a non-regenerative multicasting MIMO relay system, where linear signal processing is applied at the relay node to minimize the maximal MSE of the symbol estimation at the receivers.The optimization problem is non-convex in nature. Hence, the proposed optimization problem cannot be solved directly. Therefore, an optimal algorithm is developed to optimize the transmitters, relay, and receivers precoder matrices by converting the non-convex optimization problem into convex optimization problem using the semi-definite programming (SDP) technique. Simulation results show that the proposed algorithm outperforms the full CSI based algorithms.

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Abbreviations

AF	amplify and forward
3G	Third Generation (wireless communications standard)
AWGN	additive white Gaussian noise
BER	bit error rate
CCI	Channel Covariance information
CSI	Channel state information
DF	decode and foward
FDMA	Frequency Division Multiple Access
ITU	International Telecommunication Union
LTE	Long Term Evolution
LMMSE	Lnear minimamal mean square error
MI	mutual information
MIMO	multiple-input multiple-output
MISO	multiple input single output
MMSE	minimal mean square error
MSE	mean square error
NMSE	normalized MSE
MUI	multiuser interference
QoS	quality of service
QPSK	quadrature phase shift keying
SIMO	single input multiple output
SINR	Signal-to-noise Interference Ratio
SISO	Single Input Single Output
SDP	semidefinite programming
SNR	signal-to-noise ratio

Chapter 1

Introduction

1.1 Background of the Study

Wireless relay is necessary to provide wide coverage area extension, cost-effective and reliable for wireless networks in various applications. Hence a relay node can be implemented in wireless environments where there are strong fading and shadowing effects due to the presence of scatters like tall buildings and thick trees, and also to get good quality of service(QoS) as well as coverage in indoor environments. In order to reduce transmission power to the neighbour nodes, for example in ad-hoc networks, relay plays an important role essentially to mitigate the fading and shadowing effects. For strategic applications, deployment of the relay is desirable to enhance the networks reliability, availability, robustness and minimize the interception by unwanted users.

If the distance between the source and the receiver is large, it is important to have a relay in between to reduce the attenuation of the unguided channel. In [1, 2], a two-hop relay channel model was investigated in the 1970s. More recent studies on relays are reported in [3]-[6] and [7]. In [1, 2, 5,8], a system of single-antenna relay was considered as the primary focus of previous research.

Depending on the role played by the relay node, there are two classifications of the relay schemes categorically for cooperative communication system: the amplify-and-forward (AF) scheme and the decode-and-forward (DF) relay scheme, proposed in [6], [9], [10]. In DF scheme, the relay has to decode the information which is obtained from the transmitter and retransmits the encoded information to the receiver. Whereas in AF scheme, the relay amplifies the received information from the transmitter and retransmits the amplified information to the receiver. When compared with the DF scheme, the AF scheme has a reduced computational complexity and it is easier to incorporate into the cooperative communication networks.

The performance of the two relay schemes is compared in [11] for single antenna relay system. It was concluded in [11] that the AF relay scheme outperforms the DF relay scheme in terms of diversity order with the similar multiplexing gain, although the two relay schemes may outshine each other in terms of the mutual information (MI) depending on the channel type.

It is a known fact that higher data rate transmission can be provided by a multiple-antenna system than a single-antenna system under a scattered environment. Mutual messages of single user multiple-input multiple-output (MIMO) relay system was well documented in [12] and [13]. In [12] and [13], formulas were derived for ergodic capacities and interference exponents of such channels, and computational procedures were formulated to solve such problems and it was shown that the efficient gain of such multi-antenna systems over single antenna systems is rather large under independent assumptions. Recently, MIMO relay scheme has been proposed in [14] where a regenerative MIMO relay is considered. In [14], it is stated that the relay node can receive and retransmit information concurrently at a same frequency, but in reality, it is not possible because the power of the source signal arrived at the relay node typically overshadows the power of the desired signal at the relay node.

For a non-regenerative MIMO relay system, it is often assumed that two links exist between the transmitter and the receiver nodes, the source-relay-destination link and the direct source-destination link, respectively. There are many research studies on the optimal relay precoding matrix for the source-relay-destination channel. Recently in [16] and [18], a relay precoding scheme was proposed for a non-regenerative MIMO relay system to increase the MI between the source to destination link. In the proposed algorithm, the relay node amplifies the received signal by a linear signal processing at the relay and the amplified signal is retransmitted to the destination.

In references [16]-[18], optimal relay matrix is obtained for enhancing the capacity between the transmitter and the receiver when the full CSI for the source-relay and relay-destination links is available at the relay node.

In [19] and [20], a relay precoding scheme was proposed to minimize the mean-squared-error (MSE) of the estimated signal at the destination node. In [20], an optimization problem was derived with respect to the signal-to-noise ratio (SNR) criterion. A unified framework was proposed in [21] to optimize the source and relay precoding matrices for a wider class of objective functions. The direct source-destination link was not considered in all these works.

In reality, the direct source to destination link should not be ignored because it gives valuable spatial diversity to the system. The proposed methods in [16], [17] and [19] - [20] are not optimal, if the source-destination link is included in the proposed design schemes.

In [16], the relay precoding matrix structure was derived for maximizing ergodic capacity in between the source-to-destination link in which the direct link is considered. However, the proposed relay precoding scheme is not optimal, since the structure of the transmission power constraint is not considered at the relay. Recently, it was investigated in [22] that with the direct source-destination link, the optimal relay precoding matrix has a general beamforming structure.

In [23], an alternative design algorithm was proposed to optimize both the source and relay precoding matrices. However, the proposed design scheme in [23] is strictly suboptimal and requires high computation, since the optimal beamforming structure of the relay amplifying matrix is not exploited.

1.2 Overview of the MIMO Relay System

1.2.1 Introduction

MIMO antenna technique is commonly used in wireless radio communication system in the state of art telecommunication system these days. This technique of antenna diversity that can improve performance by using multiple antennas arrangement which leads to a better beamforming technique. Hence, in the latest communication standards, WiMAX 802.16m and 3GPP LTE-Advanced, have adapted this technique reported in [4]. Some detailed information of the different MIMO relay multicasting from multiple sources is explained in the section below.

1.2.2 Types of MIMO system

Different arrangements of antennas are possible to achieve the desired level of system performance in the current wireless radio communication system. This could be single-input single-output (SISO) antenna arrangement system, in this case both the transmitter and the receiver have only one antenna. In single-input and multiple-output (SIMO) antenna arrangement system, the transmitter has only one antenna and the receiver has more than one antenna. There is also multiple-input and single-output (MISO) arrangement where the transmitter has more than one antenna and the receiver has only one antenna. In MIMO arrangement, both the transmitter and the receiver have more than one antenna. The SISO, SIMO, MISO and MIMO systems arrangements are shown in Fig. 1.1 - 1.4.

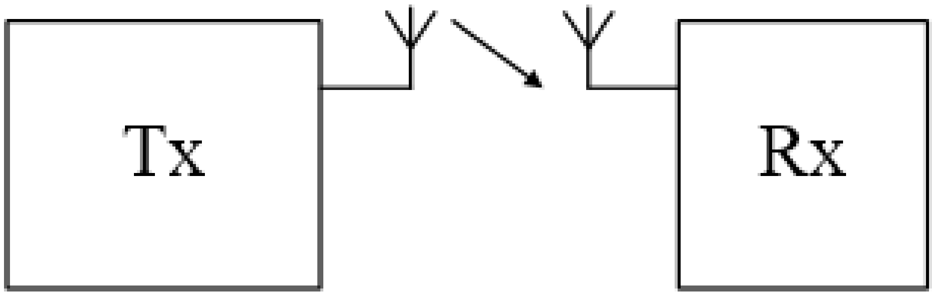

Figure 1.1: SISO

MIMO technique has the highest advantage and received much interest in wireless communication as it has a better antenna diversity gain and essential multiplexing gain [6]. In the MIMO technique, the advantage of antenna diversity is utilised as the stream of signals with different content of information which is transmitted simultaneously to the intended receivers. With this, a great wireless system performance is achieved and wireless communication link is stabilised, wireless link reliability is improved and error is minimised as expressed in [7]. With such essential diversity, it can be concluded that MIMO antenna arrangement is more reliable as explained in [5]. The advantage of multiplexing gains of the system has huge potential in wireless communication which is explained as throughput of MIMO technique and multiplexing gains [6]. As multiple of the same signals is transmitted to the intended receiver, system diversity is applied. These could lead to proper wireless link stability and the principle can greatly

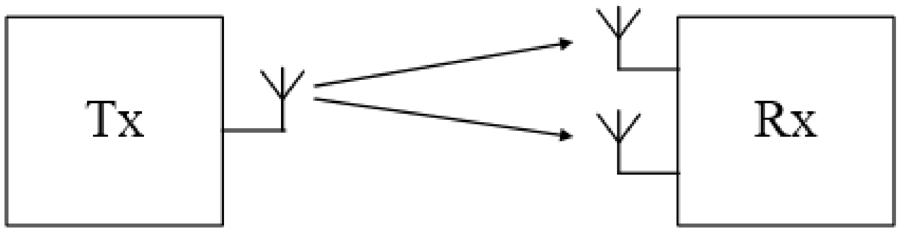

Figure 1.2: SIMO

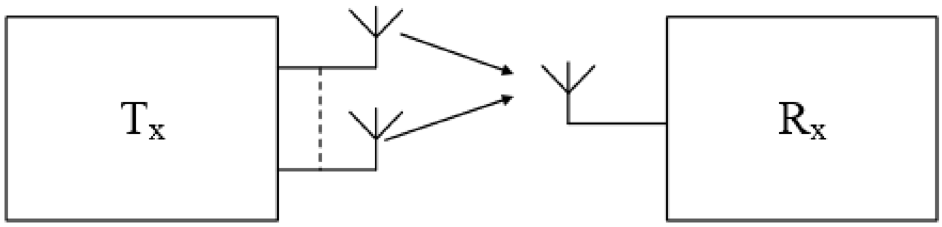

Figure 1.3: MISO

improve the wireless system performance by reducing error rate as the probability of the received signal symbols is very high.

1.2.3 Cooperative relay transmission

The cooperative relay transmission in wireless communication has a lot of potential and this area attracts a lot of research interest in recent time. It has a lot of benefits as shown by some mobile communication standards such as Long-Term Evolution (LTE) advanced where it has been used for coverage extension, capacity enhancement and high data rate throughput as discussed in [9].

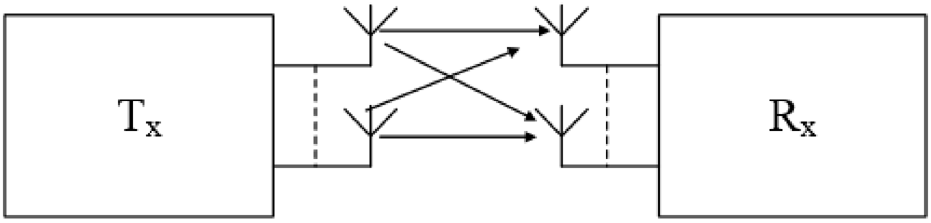

Figure 1.4: MIMO

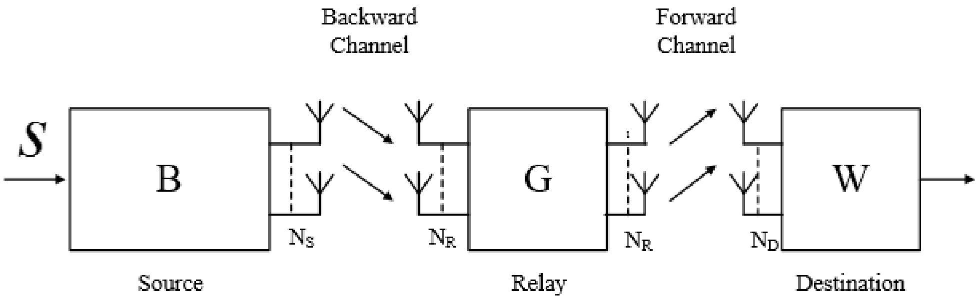

Figure 1.5: MIMO relay system

Furthermore, due to long distance between the transmitter and the receiver nodes, the transmitted signal undergoes large path fading when compared with the link through the relay node as in [10]. Due to its simplicity, half duplex mode relay is considered in this research.

1.3 Objectives of the research

The main aim of the research is to design a robust transceiver for non-regenerative multicasting MIMO relay system with Gaussian random channel uncertainties between the transmitters to the receivers. Distinctively, the objectives of the research are to:

- develop new and innovative robust MSE based design schemes for the multicasting MIMO relay system with theoretical justifications using computationally efficient convex optimization algorithms.
- verify and validate the effectiveness of the proposed robust MSE transceiver design schemes using numerical analysis and computer simulations.

1.4 Significance of the research

The proposed research focuses on non-regenerative multicasting MIMO relay system design for wireless cooperative communications which will be able to compete with the current high demand of wireless applications by minimizing the maximal MSE of the wireless systems and exploiting the spectral efficiency. The derived precoding matrix will lead to the development of the system with the minimal outage and maximal MSE, which will, therefore, improve the spectral efficiency. To summarize, the innovation and the key benefits of the proposed research on non-regenerative multicasting MIMO relay design for cooperative communication are as follows

- By designing optimal precoding matrix of transmitters and relay, MSE of the estimated symbol at the receivers will be minimized and a comparison can be made with the existing single source non-regenerative multicasting MIMO relay strategies.
- By improving the existing approach, the maximal minimum MSE between the transmitters and the receivers can be minimized.
- By minimizing the maximal minimum MSE under transmit power constraints at both the transmitters and the relay node, cost effective result

can be achieved which will provide better performance in terms of Bit error rate (BER) and minimum MSE.

Chapter 2

Literature Review

2.1 Introduction

Wireless medium has a multicasting behaviour in nature, hence it is highly useful for multicasting applications. However, the channel fading and shadowing effects may degrade the performance of the wireless systems. The channel shadowing effect can be reduced in [24] by implementing multiple antennas and beamforming techniques at the transmitters and the receivers. The multiple antennas and beamforming techniques have already been incorporated in the latest wireless standards such as WIMAX 802.16m and 3gpp LTE which enable a better multicasting in [25]. Multi-antenna multicasting system's channel capacity limits have been investigated in [24] and [26]. In [27] and [28], multicasting transceiver design schemes have been investigated with the assumptions that the full channel state information (CSI) is available at the relay node.

In [29], a non-regenerative multicasting MIMO relay system was investigated in which one transmitter broadcasts a common message to multiple receivers with the aid of a relay. Recently in [30], two-hop multicasting MIMO relay system is considered where a group of transmitters multicast their messages to multiple receivers through a relay node. It is noticed that the transmitters, the relay node, and the receivers have multiple antennas. In [30], it was assumed that the full CSI of the transmitters-relay and relay-receivers links are known at the relay node. It can be noted that due to the multiple users, the transmitters and relay matrices optimization problem becomes much more complex than that for the single-transmitter systems.

However, in practice, the true CSI is not available and it has to be derived from the estimated signal at the receivers. Due to estimating the signal at the receivers, there is always a channel mismatch between the actual and the estimated CSI due to quantization errors, outdated channel information, and channel noise. Hence, in practice, it is assumed that only partial information of the relay-destination channel is available at the relay node. In [53] and [54], a transceiver design has been proposed for maximizing the ergodic capacity of a relay node with the assumption that the channel covariance information (CCI) of the relay-destination channel is available at the relay node. In [55], [56][57], minimum MSE (MMSE)-based transceiver designs have been proposed with the assumption that the CCI of the relay-destination link and the full CSI of the source-relay link are available at the relay nodes.

Hence, the performance of the proposed algorithm in [29], will be degraded due to such channel mismatch. By taking the channel estimation errors into consideration, a robust transceiver design can improve the performance of the multicasting MIMO relay system. Hence, the robust design has great importance and is highly useful for practical applications in [31]. MIMO channel essentially depends on the degree of channel state information available at the transmitter and the receiver for its best performance and utilization.

The channel state information is traditionally obtained via training sequence, pilot symbols at the receiver which gives the details of the channel behaviour. Blind method, which does not require pilot symbols, is also used to obtain the CSI at the receiver but it requires the knowledge of the whole channel which consumes a lot of resources in [13]. CSI at the transmitter can only be obtained via a feedback from the receiver and this technique makes the channel to slowly vary and this leads to the decrease in spectral efficiency. Due to this fact, some of the bandwidths are required to send the feedback to the transmitter. To transmit the CSI by taking whatever possible from the reciprocity that allows the channel to infer from measurement received previously in [10]. Most of the research works is generally assumed that the CSI is available at the receiver. However, in practice, it is more realistic to consider partial or imperfect CSI at the transmitter in [13]. Hence, in this research, it is assumed that the CSI at the relay is estimated from the second hop.

There are global and individual solutions for multiple transmitters quality of service to optimize the MSE of the data stream. In this research work, the individual MSE optimization metric is considered to design a robust system. The individual quality of service depends on the zero forcing (ZF) constraints to optimize the weighted matrix, the weighted matrix precoding depends on the choice of these constrains. However, it is shown that the optimal solution is independent of the transmitted power function or the quality of service under zero forcing constraints in [21] and [24] because the design of linear receiver is based on individual quality of service that the received composites signal is completely uncoupled and the trade-off is not noticeable among the MSEs. It makes possible to simultaneously optimize the substream without affecting one another in [13]. Simultaneously minimising all the individual MSEs leads to obtaining linear minimum MSE (LMMSE) receiver, also known as Wiener filter [24]. This filter removes all the errors presents in the received signals. There are different types of metric for quality of service in wireless communication which are minimizing MSE, minimizing the bit error rate (BER) and maximizing signal to interference and noise ratio (SINR) in [13]. In this research work, minimizing MSE among multiple transmitters is considered because it can be expressed in terms of the other metrics.

Robust designs can be divided into two categories such as worst-case robust design in [35] and Bayesian robust design in [31]. It is proposed in [33] that for linear channel estimations, the channel mismatch can be modelled as random with a Gaussian distribution. In [34], a simplified robust design scheme has been proposed for non-regenerative multicasting MIMO relay systems.

In this research work, it is aimed to minimize the maximal MSE of the estimated signal among all receivers with respect to power constraints at the transmitters and the relay node. The proposed problem is highly non-convex and the proposed optimization problem cannot be solved directly. Hence, the non-convex problem will be converted into convex optimization problem using the standard semi-definite programming (SDP) technique under some mild approximation.

In practice, the multiple sources multicasting MIMO relay system provides valuable spectral diversity and full exploration of the spectral efficiency of the wireless system and hence reduces MSE of the proposed system to meet the necessary demand. In this research work, the following design problems will be considered:

- A robust design of non-regenerative multicasting MIMO relays with multiple sources is proposed under different optimization criteria as for instance maximal MSE for a given available transmit power.
- The optimal structure of the relay precoding matrix is derived to minimize the maximal MSE between the transmitters and the receivers which are robust against the CSI mismatch.

2.1.1 Notations

In this thesis, notations used are as follows: Scalers are denoted as lowercase letters e.g. s,n while vectors are denoted by lowercase bold face e.g. $\mathbf{s}, \mathbf{n}$. Matrices are denoted by bold face uppercase letters e.g $\mathbf{S}, \mathbf{N}$. For matrices like $(.)^H, (.)^{-1}$ and $(.)^+$ denote transpose, conjugate, Hermitian transpose, inverse, and pseudo-inverse operations respectively. $tr(.)$ denotes the trace of a matrix and $E[.]$ represents the statistical expectation and blkdiag(.) stands for a block-diagonal matrix and $\mathbf{I}_N$ represents N dimensional identity matrix.

Chapter 3

Covariance Feedback Based Transceiver Design For Single Source Multicasting MIMO Relay System

3.1 Introduction

In this chapter, the optimal source, relay and receive matrix design are analysed for single source multicasting MIMO relay cooperative communication system with the assumption that the covariance information of the source-relay and relay-receiver links are available at the relay node. In Section 3.2, the system model description is introduced. In Section 3.3, the joint source and relay optimization problem is demonstrated and the solution to highly nonconvex optimization problem is provided to make the problem as a simple which is solved by the CVX tool box. In Section 3.4, the performance of the proposed scheme is verified through computer simulations.

3.2 System Model

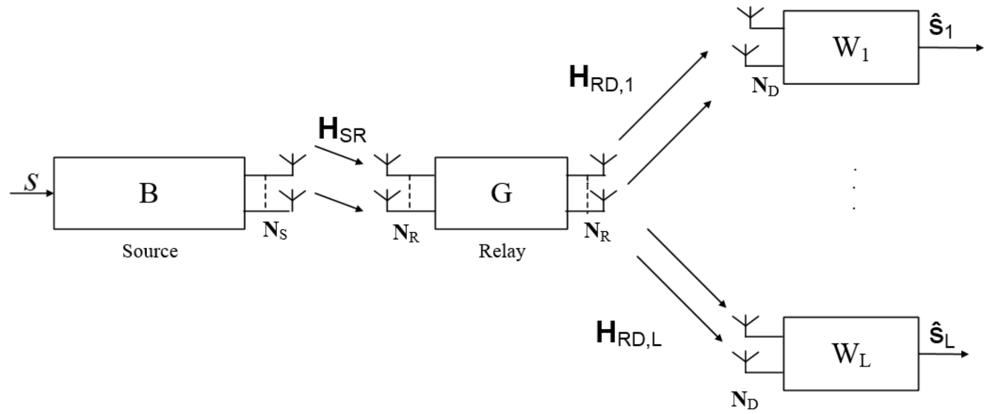

Figure 3.1: Multiuser Multicasting MIMO relay system

Fig. 3.1 shows two-hop single transmitter multicasting MIMO relay system. The signal transmission between the source and receivers nodes is carried out in dual hops. During the first-hop, the source node transmits the precoded signal vector $\mathbf{x} = \mathbf{Bs}$ to the relay node. The $N_B \times 1$ for $N_B \leq \min\,(N_S, N_R, N_d)$ modulated signal vector is linearly precoded by $N_S \times N_B$ source precoding matrix $\mathbf{B}$. It is assumed that $E[\mathbf{ss}^H] = \mathbf{I}_{N_B}$ is the source covariance matrix. Where N_S, N_R, N_D are the number of source, relay and destination antennas respectively. The received signal at the relay node can be expressed as

$$\mathbf{y}_r = \mathbf{H}_{SR}\mathbf{Bs} + \mathbf{n}_r \tag{3.1}$$

In the second-hop, relay node transmits the precoded signal vector $\mathbf{x}_r = \mathbf{Gy}_r$ which is received at the destination nodes. It is assumed that during the second hop, the source node does not transmit. The received signal vector $\mathbf{y}_r$ at the relay node is now linearly amplified by the precoded matrix $N_R \times N_R$.

$\mathbf{H}_{SR}$ is the first-hop $N_R \times N_B$ channel matrix and added the additive Gaussian noise vector $\mathbf{n}_r$ at the relay node. The amplified and precoded signal vector by the relay node can be expressed as

$$\mathbf{x}_r = \mathbf{G}\mathbf{y}_r \tag{3.2}$$

with (3.1) and (3.2), the arrived signal at the ith destination node is retrieved and formulated as

$$\begin{aligned} \mathbf{y}_{d,i} &= \mathbf{H}_{RD,i}\mathbf{G}\mathbf{H}_{SR}\mathbf{B}\mathbf{s} + \mathbf{H}_{RD,i}\mathbf{G}\mathbf{n}_r + \mathbf{n}_{d,i} \\ &\triangleq \mathbf{A}_i\mathbf{s} + \mathbf{n}_i, i = 1, ...L \end{aligned} \tag{3.3}$$

where $\mathbf{H}_{RD,i}$ is the $N_D \times N_R$ for second channel hop matrix and $\mathbf{n}_{d,i}$ is the $N_D \times 1$ additive Gaussian noise vector that is added at the ith destination node. Whereas $\mathbf{A}_i \triangleq \mathbf{H}_{RD,i}\mathbf{G}\mathbf{H}_{SR}\mathbf{B}$ represents the source to the relay first-hop channel matrix node and $\mathbf{n}_i = \mathbf{H}_{RD,i}\mathbf{G}\mathbf{n}_r + \mathbf{n}_{d,i}$ represents the noise vector added at the receiver. It is assumed that the whole noise have zero means and unit variance. But in practical, the perfect CSI is not available at the relay node and it has to be estimated, but there is always difference between the estimated and the actual CSI which results to the channel mismatch. Thus, the estimated channel matrices $\mathbf{H}_{SR}$ and $\mathbf{H}_{RD,i}$ are assumed as partial CSI during the first and the second time slots and can be modelled as

$$\mathbf{H}_{SR} = \mathbf{H}_{wSR}\mathbf{\Sigma}_{SR}^{1/2} \tag{3.4}$$

$$\mathbf{H}_{RD,i} = \mathbf{H}_{wRD,i}\mathbf{\Sigma}_{RD,i}^{1/2} \tag{3.5}$$

where $\mathbf{H}_{wSR}$ and $\mathbf{\Sigma}_{SR}^{1/2}$ are source to relay channel and covariance matrices respectively and $\mathbf{H}_{wRD,i}$ and $\mathbf{\Sigma}_{RD,i}^{1/2}$ are for the relay to destination channel and covariance matrices respectively.

3.3 Problem Formulation

Linear MMSE estimator $\mathbf{W}_i$ is employed to retrieve the original propagated signal $\mathbf{s}$. Hence, the signal received at the ith destination is expressed as

$$\tilde{\mathbf{s}} = \mathbf{W}_i\mathbf{y}_{d,i}, i = 1, ..., L \tag{3.6}$$

Assume that P_s and P_r acting as the upper bond of the transmitter and relay power limits respectively. Hence, the power constraints on the source node and the relay node can be expressed as

$$p(\mathbf{B}) = tr(\mathbf{B}\mathbf{B}^H) \leq P_s \tag{3.7}$$

$$p(\mathbf{G}, \mathbf{B}) = tr\left[\mathbf{G}\left(\mathbf{H}_{SR}\mathbf{B}\mathbf{B}^H\mathbf{H}_{SR}^H + \mathbf{I}_{N_R}\right)\mathbf{G}^H\right] \leq P_r \tag{3.8}$$

By using (3.3) and (3.6), the MSE of the propagated signal estimation is obtained as

$$E_i = tr\bigg((\mathbf{W}_i\mathbf{A}_i - \mathbf{I}_{N_B})(\mathbf{W}_i\mathbf{A}_i - \mathbf{I}_{N_B})^H + \mathbf{W}_i\mathbf{C}_i\mathbf{W}_i^H\bigg) \tag{3.9}$$

$$i = 1, ..., L$$

from (3.9), $\mathbf{C}_i$ represents the noise covariance matrix which can be expressed as

$$\mathbf{C}_i = \mathbf{H}_{RD,i}\mathbf{G}\mathbf{G}^H\mathbf{H}_{RD,i}^H + \mathbf{I}_{N_D} \tag{3.10}$$

where $\mathbf{W}_i$ is scaled matrix that minimize MSE from (3.1) which can be formulated as

$$\mathbf{W}_i = (\mathbf{A}_i\mathbf{A}_i^H + \mathbf{C}_i)^{-1}\mathbf{A}_i \tag{3.11}$$

By substituting (3.11) into (3.9) and then applying the matrix inversion lemma the MSE can be expressed as

$$E_i = tr\left(\left[\mathbf{I}_{N_B} + \mathbf{A}_i^H\mathbf{C}_i^{-1}\mathbf{A}_i\right]^{-1}\right), i = 1, ..., L \tag{3.12}$$

Thus, from (3.12), the problem of linear transceiver design optimization problem is then expressed as

$$\min_{\{\mathbf{B}\}\mathbf{G}} \max_i tr\left(\left[\mathbf{I}_{N_B} + \mathbf{A}_i^H\mathbf{C}_i^{-1}\mathbf{A}_i\right]^{-1}\right) \tag{3.13}$$

$$s.t\ tr\left(\mathbf{G}\left(\mathbf{H}_{SR}\mathbf{B}\mathbf{B}^H\mathbf{H}_{SR}^H + \mathbf{I}_{N_R}\right)\mathbf{G}^H\right) \leq P_r \tag{3.14}$$

$$tr\left(\mathbf{B}\mathbf{B}^H\right) \leq P_s \tag{3.15}$$

The relay optimal precoding matrix $\mathbf{G}$ as expressed in (3.14) will be used in solving the complex function of E_i

$$\mathbf{G} = \mathbf{T}\mathbf{D}^H \tag{3.16}$$

where $\mathbf{D} = \Big(\mathbf{H}_{SR}\mathbf{B}\mathbf{B}^H\mathbf{H}_{SR}^H + \mathbf{I}_{N_R}\Big)^{-1}\mathbf{H}_{SR}\mathbf{B}$ is the linear MMSE estimator weight matrix for the received signal at first hop and $\mathbf{T}$ is the source precoding matrix for the second-hop. By employing optimal precoding relay matrix $\mathbf{G}$, the MSE in (3.13) can be expressed into the different sum of the two separate MSE functions as

$$\begin{aligned} E_i = tr\Bigg(\Big[\mathbf{I}_{N_B} + \mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}\Big]^{-1}\Bigg) + \\ tr\Bigg(\Big[\mathbf{R}^{-1} + \mathbf{T}^H\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\mathbf{T}\Big]^{-1}\Bigg), i = 1, ..., L \end{aligned} \tag{3.17}$$

The first part represents $tr\Bigg(\Big[\mathbf{I}_{N_B} + \mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}\Big]^{-1}\Bigg)$ in (3.17) as the MSE of estimated propagated signal waveform vector
$\mathbf{s}$ from (3.1) $tr\Bigg(\Big[\mathbf{R}^{-1} + \mathbf{T}^H\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\mathbf{T}\Big]^{-1}\Bigg)$ at the first hop relay node by applying the weight matrix $\mathbf{D}$. The remaining second term of (3.17) is the increments response of MSE in second-hop and $\mathbf{R}$ is expressed as

$$\mathbf{R} = \mathbf{B}^H\mathbf{H}_{SR}^H\Big(\mathbf{H}_{SR}\mathbf{B}\mathbf{B}^H\mathbf{H}_{SR}^H + \mathbf{I}_{N_R}\Big)^{-1}\mathbf{H}_{SR}\mathbf{B} \tag{3.18}$$

From the optimal precoding matrix of the relay $\mathbf{G}$ in (3.14), the power taken by the relay node is expressed as $tr\Big(\mathbf{T}\mathbf{R}\mathbf{T}^H\Big)$ while the term
$tr\Bigg(\Big[\mathbf{I}_{N_B} + \mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}\Big]^{-1}\Bigg)$ from (3.17) take the powers $tr(\mathbf{B}\mathbf{B}^H)$ for the covariance matrix of the signal transmitted by the source. Hence, the (3.13)-(3.15) can be expressed as

$$\begin{aligned} \min_{\{\mathbf{B}\},\mathbf{T}} \max_i tr\Bigg(\Big[\mathbf{I}_{N_B} + \mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}\Big]^{-1}\Bigg) + \\ tr\Bigg(\Big[\mathbf{R}^{-1} + \mathbf{T}^H\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\mathbf{T}\Big]^{-1}\Bigg) \end{aligned} \tag{3.19}$$

$$s.t.\ tr\left(\mathbf{TRT}^H\right) \le P_r \tag{3.20}$$

$$s.t.\ tr\left(\mathbf{BB}^H\right) \le \mathbf{P}_s \tag{3.21}$$

Applying matrix invasion lemma, $(\mathbf{A} + \mathbf{BCD})^{-1} = \mathbf{A}^{-1} - \mathbf{A}^{-1}\mathbf{B}(\mathbf{DA}^{-1}\mathbf{B} + \mathbf{C}^{-1})^{-1}\mathbf{DA}^{-1}$ on (3.18), $\mathbf{R}$ can be expressed as

$$\mathbf{R} = \mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}\left(\mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B} + \mathbf{I}_{N_B}\right)^{-1} \tag{3.22}$$

It can be noticed from (3.22) that the increase of the first-hop SNR makes the term $\mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}$ to approach infinity. However, at an acceptable high SNR case, $\mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B} \gg \mathbf{I}_{N_B}$, thus $\mathbf{R}^{-1}$ is approximated as $\mathbf{I}_{N_B}$. With such approximation result, the optimization problem from (3.19)-(3.21) can be expressed as

$$\min_{\mathbf{B},\mathbf{T}} \ \max_i tr\left(\left[\mathbf{I}_{N_R} + \mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}\right]^{-1}\right) + tr\left(\left[\mathbf{I}_{N_B} + \mathbf{T}^H\mathbf{H}_{RD}^H\mathbf{H}_{RD}\mathbf{T}\right]^{-1}\right) \tag{3.23}$$

$$s.t.\ tr\left(\mathbf{TT}^H\right) \le P_r \tag{3.24}$$

$$s.t.\ tr\left(\mathbf{BB}^H\right) \le P_{s,} \tag{3.25}$$

Hence, it can be seen that the amplifying matrix of the relay $\mathbf{T}$ is not dependent on transmitter covariance matrix $\mathbf{B}$. Therefore, the optimization problem can be further split into transmitter precoding matrix optimization problem

$$\min_{\{B\},} tr\left(\left[\mathbf{I}_{N_B} + \mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}\right]^{-1}\right) \tag{3.26}$$

$$s.t.\ tr\left(\mathbf{BB}^H\right) \le P_s,$$

and relay amplifying matrix optimization problem

$$\min_{\mathbf{T}} \max_i tr\left(\left[\mathbf{I}_{N_B} + \mathbf{T}^H\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\mathbf{T}\right]^{-1}\right) \tag{3.27}$$

$$s.t.\ tr\left(\mathbf{TT}^H\right) \le P_{r,} \tag{3.28}$$

3.3.1 Optimization of B

It can be observed from (3.26) that the problem is minimized to find the optimal precoding matrix $\mathbf{B}$ to minimize the MSE of the signal received at the relay node. Using the channel model from (3.4), the lower bound of the objective function could be minimized which can be expressed as

$$E_{\mathbf{H}_{SR}}M(\mathbf{B}) \succeq tr\left(\left[\mathbf{I}_{N_R} + \mathbf{B}^H E_{\mathbf{H}_{SR}}(\mathbf{H}_{SR}^H\mathbf{H}_{SR})\mathbf{B}\right]^{-1}\right)$$
$$= tr\left(\left[\mathbf{I}_{N_B} + \mathbf{N}_S(\mathbf{B}^H\mathbf{\Sigma}_{SR}\mathbf{B})\right]^{-1}\right) \quad (3.29)$$

where $E_{\mathbf{H}_{SR}}(\mathbf{H}_{\omega SR}^H\mathbf{H}_{\omega SR}) = N_S\mathbf{I}_{N_S}$. Using (3.29), the transmitter precoding matrix optimization problem can be written as

$$\min_{\{\mathbf{B}\},} tr\left(\left[\mathbf{I}_{N_B} + \mathbf{N}_S(\mathbf{B}^H\mathbf{\Sigma}_{SR}\mathbf{B})\right]^{-1}\right) \quad (3.30)$$
$$s.t.\ tr\left(\mathbf{B}\mathbf{B}^H\right) \leq P_s,$$

Let introduce the singular value decomposition (SVD) of $\mathbf{\Sigma}_{SR}$ which can be expressed as

$$\mathbf{\Sigma}_{SR} = \mathbf{V}_{\Sigma SR}\mathbf{\Lambda}_{\Sigma SR}\mathbf{V}_{\Sigma SR}^H \quad (3.31)$$

where $\mathbf{\Lambda}_{\Sigma SR} = \text{diag}\{\mathbf{\Lambda}_{\Sigma SR,1}, ..., \mathbf{\Lambda}_{\Sigma SR,NR}\}$ with $\mathbf{\Lambda}_{\Sigma SR,1} \geq ... \geq \mathbf{\Lambda}_{\Sigma SR,NR}$ and the dimension of $\mathbf{V}_{\Sigma SR}$, $\mathbf{\Lambda}_{\Sigma SR}$ and $\mathbf{V}_{\Sigma SR}$ are $N_R \times N_R$, $N_R \times N_S$ and $N_S \times N_R$.

The main diagonal elements of $\mathbf{\Lambda}_{\Sigma SR}$ are taken from the highest to the lowest from Lemma 2 in [46], the transmitter optimization problem has a closed form solution for $\mathbf{B}$ which can be expressed as

$$\mathbf{B} = \mathbf{V}_{\Sigma SR}\mathbf{\Lambda}_B^{1/2} \quad (3.32)$$

where $\mathbf{V}_{\Sigma SR}$ has the leftmost columns of $\mathbf{V}_{\Sigma SR}$ and $\mathbf{\Lambda}_B^{1/2}$ is the diagonal of $N_B \times N_B$ matrix. By substituting (3.31) and (3.32) into (3.30), the objective function in

(3.30) can be formulated as optimization problem with scalar variables

$$\min_{\{\lambda_{B,i}\},} \sum_{i=1}^{N_B} \frac{1}{1+N_S(\lambda_{B,i}\lambda_{\Sigma SR,i})} \tag{3.33}$$

$$s.t. \sum_{i=1}^{\mathbf{N}_B} \lambda_{B,i} \leq P_s \tag{3.34}$$

$$\lambda_{B,i} \geq 0, i = 1, ..., N_B \tag{3.35}$$

where $\lambda_{B,i}$ and $\lambda_{\Sigma SR,i}$ are the ith diagonal elements of $\mathbf{\Lambda}_B$ and $\mathbf{\Lambda}_{\Sigma,SR}$ respectively. The problem in (3.33)-(3.35) has the solution from water-filling [47]

$$\lambda_{B,i} = \frac{1}{\lambda_{\Sigma SR,i}}\left(\sqrt{\frac{\lambda_{\Sigma SR,i}}{\mu_l}} - 1\right)^+ \tag{3.36}$$

where $(x)^+ = max(x, 0)$, and $\mu > 0$ satisfy the condition of

$$\sum_{1}^{N_B} \frac{1}{\lambda_{\Sigma SR,i}}\left(\sqrt{\frac{\lambda_{\Sigma SR,i}}{\mu_l}} - 1\right)^+ = P_s \tag{3.37}$$

3.3.2 Optimization of T

The amplifying matrix of the optimal relay $\mathbf{T}$ from (3.23) is applied to min-max MSE of the received signal waveform at the receiver nodes, and the channel error estimation model as expressed in (3.5) and the matrix inversion Lemma 2 [48] the objective function can be expressed as

$$\begin{aligned} &E_{\mathbf{H}_{RD,i}}\left\{tr\left(\left[\mathbf{I}_{N_B} + \mathbf{T}^H\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\mathbf{T}\right]^{-1}\right)\right\} \\ &\geq tr\left(\left[\mathbf{I}_{N_B} + \mathbf{T}^H E_{\triangle RD,i}\{\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\}\mathbf{T}\right]^{-1}\right) \end{aligned} \tag{3.38}$$

Now the problem is reduced to find the optimal precoder matrix $\mathbf{T}$ and the second-hop channel matrix subject to power constraint (3.26) and (3.27).The channel matrix $\mathbf{H}_{RD}$ can be modelled as

$$\mathbf{H}_{RD,i} = \tilde{\mathbf{H}}_{wRD,i}\mathbf{\Sigma}_{RD,i}^{1/2} \tag{3.39}$$

where $\mathbf{H}_{RD,i} \triangleq \tilde{\mathbf{H}}_{wRD,i}\mathbf{\Lambda}_{RD,i}^{1/2}\mathbf{V}_{RD,i}^{H}$ and $\tilde{\mathbf{H}}_{wRD,i}$ has the same distribution as $\mathbf{H}_{RD,i}V_{RD,i}\mathbf{\Lambda}_{RD,i}^{1/2} = \tilde{\mathbf{H}}_{wRD,i}\mathbf{V}_{RD,i}$. The singular value decomposition of $\mathbf{\Sigma}_{RD,i}$ can be expressed as

$$\mathbf{\Sigma}_{RD,i} = \mathbf{V}_{\Sigma RD,i}\mathbf{\Lambda}_{\Sigma RD,i}\mathbf{V}_{\Sigma RD,i}^{H} \tag{3.40}$$

where $\mathbf{\Lambda}_{\Sigma RD,i} = \text{diag}\{\mathbf{\Lambda}_{\Sigma RD,1}, ..., \mathbf{\Lambda}_{\Sigma RD,NR}\}$ with $\mathbf{\Lambda}_{RD,1} \geq ... \geq \mathbf{\Lambda}_{\Sigma RD,NR}$. Using $E_{\mathbf{H}_{wSR}}[\mathbf{H}_{wSR}^{H}\mathbf{H}_{wSR}] = E_{\mathbf{H}_{wRD,i}}[\mathbf{H}_{wRD,i}^{H}\mathbf{H}_{wRD,i}] = N_D\mathbf{I}_{N_R}$ [52], trace property and substituting (3.40) into (3.38) the objective function from (3.38) can be expressed as

$$tr\left(\left(\mathbf{I}_{N_B} + \mathbf{T}^{H}\tilde{\mathbf{H}}_{2,i}\mathbf{T}\right)^{-1}\right) \tag{3.41}$$

where $\tilde{\mathbf{H}}_{2,i} = \mathbf{N}_D\mathbf{V}_{\Sigma RD,i}\mathbf{\Lambda}_{\Sigma RD,i}\mathbf{V}_{\Sigma RD,i}^{H}$ and hence, the problem of the relay precoding matrix optimization from (3.27) can be expressed as

$$\begin{aligned} \min_{\mathbf{T}} \max_{i} tr\left(\left(\mathbf{I}_{N_B} + \mathbf{T}^{H}\tilde{\mathbf{H}}_{2,i}\mathbf{T}\right)^{-1}\right) \\ s.t\; tr\left(\mathbf{T}\mathbf{T}^{H}\right) \leq P_r \end{aligned} \tag{3.42}$$

By using the matrix identity, $tr([\mathbf{I}_n + \mathbf{C}_{m\times n}\mathbf{D}_{n\times m}]^{-1}) = tr([\mathbf{I}_n + \mathbf{D}_{n\times m}\mathbf{C}_{m\times n}]^{-1}) + m - n$ the min-max optimization problem from (3.42) can be expressed as

$$\begin{aligned} \min_{\mathbf{M}} \max_{i} tr\left(\left[\mathbf{I}_{N_D} + \tilde{\mathbf{H}}_{2,i}^{1/2}\mathbf{M}\tilde{\mathbf{H}}_{RD,i}^{1/2}\right]^{-1}\right) + \mathbf{N}_B - \mathbf{N}_D \\ s.t.\; tr(\mathbf{M}) \leq P_r \\ (\mathbf{M}) \succcurlyeq 0 \end{aligned} \tag{3.43}$$

where $\mathbf{M} = \mathbf{T}\mathbf{T}^{H}$ and $\mathbf{M}$ is a positive semi-definite(PSD) matrix as given by $\mathbf{M} \succcurlyeq 0$. By bringing a PSD matrix $\mathbf{Z}_i$ with $\mathbf{Z}_i \geq \left[\mathbf{I}_{N_D} + \tilde{\mathbf{H}}_{2,i}^{1/2}\mathbf{M}\tilde{\mathbf{H}}_{2,i}^{1/2}\right]^{-1}, i = 1, ..., L$ and a real valued slack variable q. Employing the Schur complement, the precoding matrix of the relay optimization problem from (3.43) can be expressed as

$$\begin{aligned} &\min_{\mathbf{q},\mathbf{M},\mathbf{Z}_i} q \\ &s.t\ tr(\mathbf{Z}_i) \leq P_r\ i = 1, ..., L \\ &tr(M) \leq P_r \\ &\begin{pmatrix} \mathbf{Z}_i & \mathbf{I}_{N_D} \\ \mathbf{I}_{N_D} & \left[\mathbf{I}_{N_D} + \tilde{\mathbf{H}}_{2,i}^{1/2}\mathbf{M}\tilde{\mathbf{H}}_{2,i}^{1/2}\right] \end{pmatrix} \succcurlyeq 0, i = 0, ..., L \\ &\mathbf{M} \succcurlyeq 0 \end{aligned} \tag{3.44}$$

Convex programming toolbox CVX is used to solve the semidefinite programming (SDP) problem in (3.44).

3.4 Simulation Results

In this section, the performance of the proposed scheme is verified by using numerical analysis.The simulation for the proposed non-regenerative multicasting MIMO relay system is carried out using the following parameters.The source, relay and destination links are equipped with same number of antennas as $N_S = N_R = N_D = 4$. Quadrature Phase Shift Keying(QPSK) modulation constellation is used to generates the symbols, and the entries of the channel matrices of $\mathbf{H}_{wSR}$, $\mathbf{H}_{wRD,i}$, $\mathbf{\Sigma}_{SR}$ and $\mathbf{\Sigma}_{RD,i}$ are generated as complex Gaussian variables having zero means and unit variance. Bessel function of first kind $\mathbf{\Sigma}_{i,j} = j_0(\triangle\pi|i-j|)$ is used to generate the elements of the covariance matrix $\mathbf{\Sigma}_{SR}$ of $\mathbf{H}_{wSR}$ and $\mathbf{\Sigma}_{RD,i}$ of $\mathbf{H}_{wRD,i}$ in reference [49] where $j_0(.)$ is the zeroth order of the Bessel function of first kind and $\triangle$ is the angle of fading spread. The angle of spread is set as $\triangle_1 = 10^0, \triangle_2 = 20^0$ and $\triangle_3 = 30^0$ for the first-hop and second-hop. Performance comparison between the partial CSI (PCSI) and Full CSI (FCSI) design schemes for BER versus SNR with different number of users is shown in Fig. 3.2. The two algorithms are simulated under the same condition, and the transmit signals are

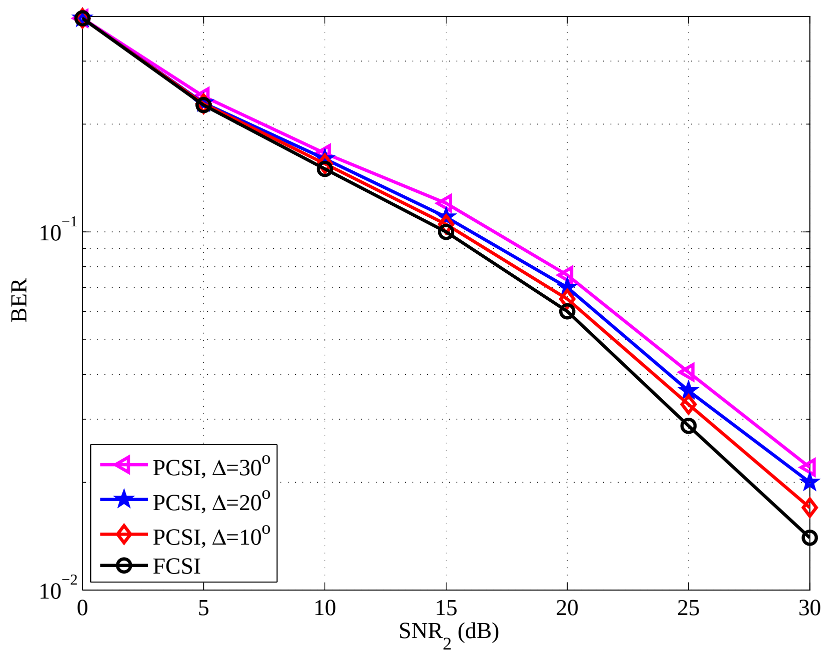

Figure 3.2: BER versus SNR for PCSI and FCSI design schemes

modulated using QPSK signal constellations, then transmitted to the destination nodes. With $L = 4$ where L is the number of receivers, each of the nodes is equipped with number of multiples antennas.The performance of the two algorithms, based on the BER, is plotted against the SNR between the relay and the destination nodes. It can be noticed from Fig.3.2 that the BER increases as the $\triangle$ increases for the PCSI scheme.

In Fig.3.3, the performance of BER for the PCSI scheme is plotted, and the signals are generated using QPSK constellations. The BER performance of the PCSI and FCSI is plotted against the SNR between the relay node and the destination nodes for different angles of the antenna orientation which are used to check for its correlation.The angles are $\triangle_1 = 10^0$, $\triangle_2 = 20^0$ and $\triangle_3 = 30^0$. It can be observed from the Fig.3.3 that BER increases as the the number of destination nodes increases, this because the relay destination channels are chosen among all the destination nodes as worse case scenario. It can be noticed from the Fig.3.3 that the performance of the proposed PCSI scheme is closer to the FCSI scheme.

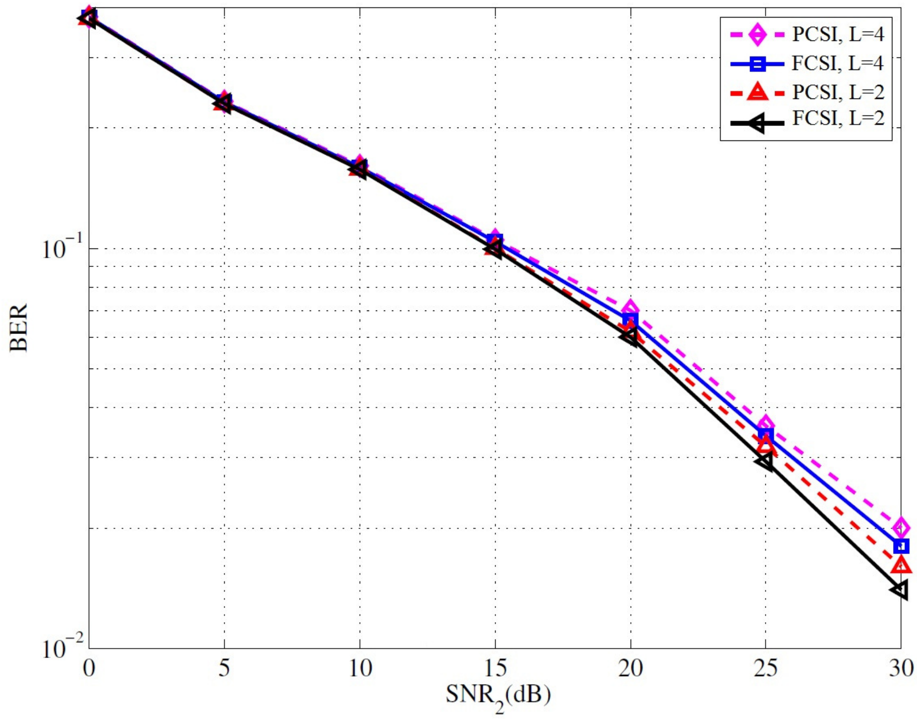

Figure 3.3: Performance of BER versus SNR with different number of receivers

The result of NMSE performance between PCSI and FCSI designs is shown in Fig. 3.4, the simulated results are under the same condition for both algorithms. The signal is sent to destination nodes $L = 4$, and each node is equipped with the same number of antennas $N_S = N_R = N_D = 4$. The performance of the NMSE of the two algorithms is plotted against the SNR between relay and the destination nodes. From Fig.3.4, it is observed that the performance of the proposed PCSI scheme is closer to the FCSI scheme.

3.4.1 Summary of the chapter

In this chapter, PCSI based transceiver design is studied for multicasting MIMO relay from single source. The optimal source, relay and receives precoder matrices are derived. A solution to highly nonconvex optimization problem is proposed

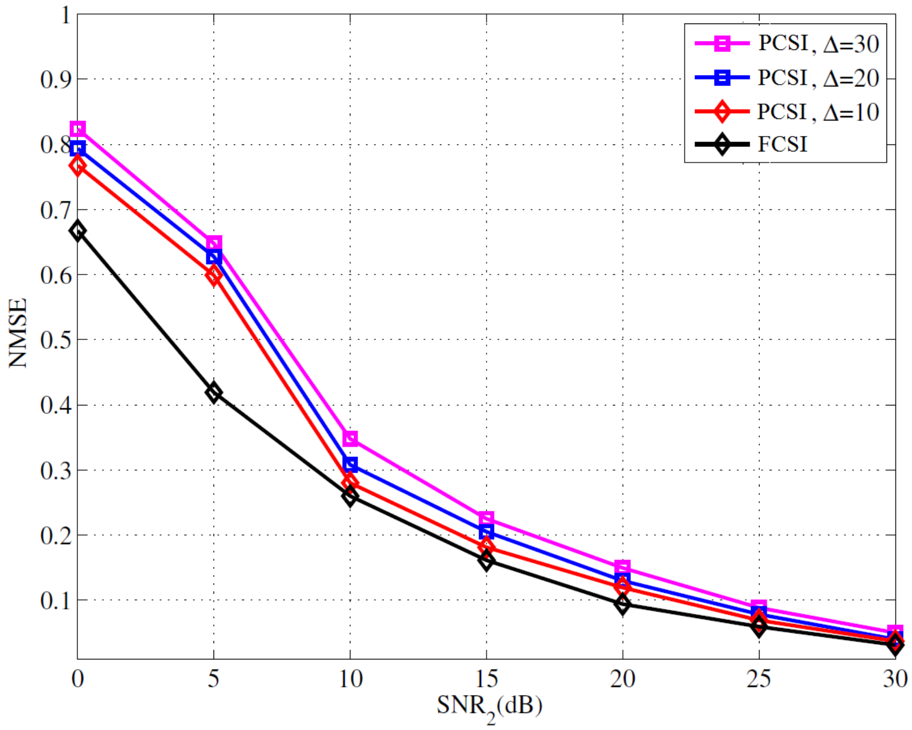

Figure 3.4: Normalised MSE versus SNR of PCSI and FCSI designs

to make the problem simple. Using CVX programming tool box, the problem is solved. Numerical analysis showed that the performance of the proposed PCSI scheme is closer to the FCSI scheme.

Chapter 4

Partial CSI Based Transceiver Design for Multicasting MIMO Relay System from Multiple Sources

4.1 Introduction

In this chapter, PCSI based transceiver design is proposed for multicasting MIMO relay system from multiple sources. In the proposed design scheme, the optimal source, relay and receiver precoder matrices are derived with the assumption that the channel information is unknown and has to be estimated with partial information. In Section 4.2, joint source and relay optimization problem is demonstrated and the solution to highly nonconvex optimization problem is provided to make the problem as simple and noncomplex which could be solved by a CVX programming tool box. In Section 4.3, the result of the proposed scheme is verified by using numerical analysis.

4.2 System Model

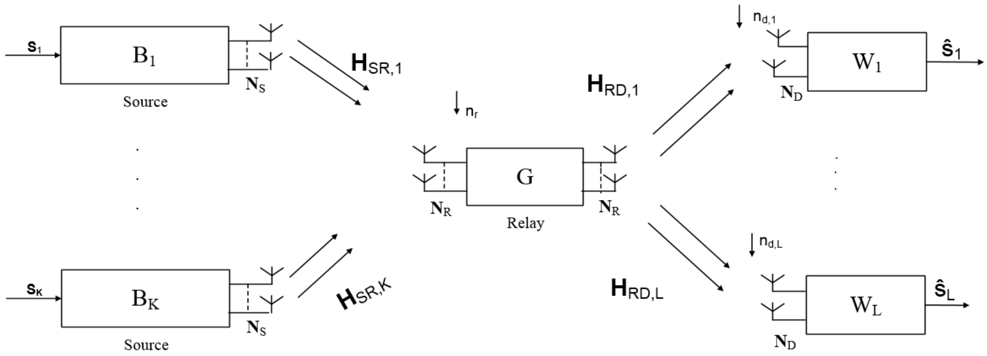

Figure 4.1: Multiuser Multicasting MIMO relay system

In this section, a two hop non-regenerative Multi user multicasting MIMO relay system with L receivers as shown in Fig 4.1, is considered. The transmitters and the relay are equipped with N_S and N_R antennas respectively. To simplify the analysis, it is assumed that each receiver node has N_D antennas. It is also assumed that there is no direct link between the transmitters and receivers. The transmission of data takes place via two time slots. During the first time slot, $N_{S,k} \times 1$ modulated signal vector $\mathbf{S}_k$ is linearly precoded by kth source node with $N_{S,k} \times N_{S,k}$ precoding matrix $\mathbf{B}_k$. The precoded signal is then transmitted to the relay nodes. The total number of independent data streams from the source is denoted as $N_B = \sum_{k=1}^{K} N_{S,k}$ and the statistical signal expectation of the received signal to be given as $E[\mathbf{S}_k\mathbf{S}_k^H] = \mathbf{I}_{Ns,k}$. From Fig.4.1, the propagated information at relay node can be retrieved as

$$\mathbf{y}_r = \sum_{k=1}^{K} \mathbf{H}_{SR,k}\mathbf{B}_k\mathbf{s}_k + \mathbf{n}_r \triangleq \mathbf{H}_{SR}\mathbf{B}\mathbf{s} + \mathbf{n}_r \tag{4.1}$$

where $\mathbf{y}_r$ is the $N_R \times 1$ retrieved information at the relay destination, $\mathbf{H}_{SR,k}$ is, $N_R \times N_{S,k}$, the kth channel matrix of the first-time slot between the kth transmitter and relay nodes, $\mathbf{H}_{SR} = [\mathbf{H}_{SR,1}, ..., \mathbf{H}_{SR,K}]$, $\mathbf{B} \triangleq blkdiag(\mathbf{B}_1, ...\mathbf{B}_K)$,

$\mathbf{s} \triangleq [\mathbf{s}_1^T, ...\mathbf{s}_K^T]^T$ and $\mathbf{n}_r$ is the additive Gaussian noise vectors that is observed at the relay node.

At the second-time slot, the retrieved signal $\mathbf{y}_r$ is linearly amplified by the $N_R \times N_R$ relay precoding matrix $\mathbf{G}$. The precoded signal is then propagated to the receiving nodes.

$$\mathbf{X}_r = \mathbf{G}\mathbf{y}_r \tag{4.2}$$

with (4.1) and (4.2), the arrived signal at the ith destination node is retrieved and formulated as

$$\begin{aligned} \mathbf{y}_{d,i} = \mathbf{H}_{RD,i}\mathbf{G}\mathbf{H}_{SR}\mathbf{B}\mathbf{s} + \mathbf{H}_{RD,i}\mathbf{G}\mathbf{n}_r + \mathbf{n}_{d,i} \\ \triangleq \tilde{\mathbf{A}}_i\mathbf{s} + \mathbf{n}_i, i = 1, ...L \end{aligned} \tag{4.3}$$

where $\mathbf{H}_{RD,i}$ represents $N_D \times N_R$ for second hop channel matrix and $\mathbf{n}_{d,i}$ is the additive Gaussian noise vector obtained at the ith receiver node. Whereas $\tilde{\mathbf{A}}_i \triangleq \mathbf{H}_{RD,i}\mathbf{G}\mathbf{H}_{SR}\mathbf{B}$ represents the source channel matrix node and $\mathbf{n}_i = \mathbf{H}_{RD,i}\mathbf{G}\mathbf{n}_r + \mathbf{n}_{d,i}$ represents the noise vector at the destination. It is assumed that the whole noises have zero means and unit variance. But, in practical the perfect CSI is not available at the relay node and it has to be estimated, but there is a gap between the estimated and the actual CSI which results into the channel mismatch. Thus, the channel precoding matrices $\mathbf{H}_{SR,k}$ and $\mathbf{H}_{RD,i}$ can be modelled and expressed as

$$\mathbf{H}_{SR,k} = \mathbf{H}_{wSR}\mathbf{\Sigma}_{SR}^{1/2}, k = 1, ..., K \tag{4.4}$$

$$\mathbf{H}_{RD,i} = \mathbf{H}_{wRD}\mathbf{\Sigma}_{RD}^{1/2}, i = 1, ..., L \tag{4.5}$$

4.3 Problem Formulation

Linear MMSE estimator $\mathbf{W}_i$ is employed to retrieve the actual propagated signal $\mathbf{s}$. Hence, the signal received at the ith destination is expressed as

$$\tilde{\mathbf{s}} = \mathbf{W}_i\mathbf{y}_{d,i}, i = 1, ..., L \tag{4.6}$$

It is assumed that P_s and P_r are the upper bound of the transmitter and relay powers limits respectively, Hence, the power constraints on the source and the relay nodes can be expressed as.

$$p(\mathbf{B}) = tr(\mathbf{B}_k\mathbf{B}_k^H) \leq P_{s,k}, k = 1, ..., K \tag{4.7}$$

$$p(\mathbf{G}, \mathbf{B}) = tr\Bigg(\mathbf{G}\Bigg(\mathbf{H}_{SR}\mathbf{B}\mathbf{B}^H\mathbf{H}_{SR}^H + \mathbf{I}_{N_R}\Bigg)\mathbf{G}^H\Bigg) \leq P_r \tag{4.8}$$

By using (4.3) and (4.8), the MSE of the propagated signal estimation is obtained as

$$E_i = tr\Bigg((\mathbf{W}_i\tilde{\mathbf{A}}_i - \mathbf{I}_{N_B})(\mathbf{W}_i\tilde{\mathbf{A}}_i - \mathbf{I}_{N_B})^H + \mathbf{W}_i\mathbf{C}_i\mathbf{W}_i^H\Bigg) \tag{4.9}$$
$$i = 1, ..., L$$

where $\mathbf{C}_i$ represents the expected noise depending on matrix which can be expressed as

$$\mathbf{C}_i = \mathbf{H}_{RD,i}\mathbf{G}\mathbf{G}^H\mathbf{H}_{RD,i}^H + \mathbf{I}_{N_D} \tag{4.10}$$

where $\mathbf{W}_i$ is scale matrix that minimizes the MSE from (4.9) which can be formulated as

$$\mathbf{W}_i = (\tilde{\mathbf{A}}_i\tilde{\mathbf{A}}_i^H + \mathbf{C}_i)^{-1}\tilde{\mathbf{A}}_i \tag{4.11}$$

Substituting (4.11) into (4.9) and then applying the matrix inversion lemma the MSE can be expressed as

$$E_i = tr\Bigg(\Bigg[\mathbf{I}_{N_B} + \tilde{\mathbf{A}}_i^H\mathbf{C}_i^{-1}\tilde{\mathbf{A}}_i\Bigg]^{-1}\Bigg), i = 1, ..., L \tag{4.12}$$

Thus, from (4.12), the problem of linear transceiver design optimization problem can be expressed as

$$\min_{\{\mathbf{B}_k,\}\mathbf{G}} \max_i tr\Bigg(\Bigg[\mathbf{I}_{N_B} + \tilde{\mathbf{A}}_i^H\mathbf{C}_i^{-1}\tilde{\mathbf{A}}_i\Bigg]^{-1}\Bigg) \tag{4.13}$$

$$s.t. \; tr\Bigg(\mathbf{G}\Bigg(\mathbf{H}_{SR}\mathbf{B}\mathbf{B}^H\mathbf{H}_{SR}^H + \mathbf{I}_{N_R}\Bigg)\mathbf{G}^H\Bigg) \leq P_r \tag{4.14}$$

$$tr\Bigg(\mathbf{B}_k\mathbf{B}_k^H\Bigg) \leq P_{s,k}, \; k = 1, ..., K \tag{4.15}$$

The relay optimal precoding matrix $\mathbf{G}$ as expressed in (4.13) will be used in solving the complex function of E_i

$$\mathbf{G} = \mathbf{T}\mathbf{D}^H \tag{4.16}$$

where $\mathbf{D} = \left(\mathbf{H}_{SR}\mathbf{B}\mathbf{B}^H\mathbf{H}_{SR}^H + \mathbf{I}_{N_R}\right)^{-1}\mathbf{H}_{SR}\mathbf{B}$ is the linear MMSE estimator scale matrix for the expected signal at first- hop and $\mathbf{T}$ is the source precoding matrix for the second-hop. By employing optimal precoding relay matrix $\mathbf{G}$, the MSE in (4.9) can be expressed into the sum of the separate MSE function

$$\begin{aligned} E_i = tr\left(\left[\mathbf{I}_{N_B} + \mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}\right]^{-1}\right) + \\ tr\left(\left[\mathbf{R}^{-1} + \mathbf{T}^H\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\mathbf{T}\right]^{-1}\right), i = 1, ..., L \end{aligned} \tag{4.17}$$

The first part in (4.17) represents $tr\left(\left[\mathbf{I}_{N_B} + \mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}\right]^{-1}\right)$ as the MSE of estimated propagated signal waveform vector $\mathbf{s}$ from (4.1) at the first-hop relay node by applying the weigh matrix $\mathbf{D}$. The remaining second term of equation (4.17) is the increments response of MSE in second-hop and $\mathbf{R}$ is expressed as

$$\mathbf{R} = \mathbf{B}^H\mathbf{H}_{SR}^H\left(\mathbf{H}_{SR}\mathbf{B}\mathbf{B}^H\mathbf{H}_{SR}^H + \mathbf{I}_{N_R}\right)^{-1}\mathbf{H}_{SR}\mathbf{B} \tag{4.18}$$

From the optimal precoding matrix of the relay $\mathbf{G}$ in (4.14), the power taken by the relay node is expressed as $tr\left(\mathbf{T}\mathbf{R}\mathbf{T}^H\right)$. Hence, (4.15) can be written as

$$\begin{aligned} \min_{\{\mathbf{B}\},\mathbf{T}} \max_i tr\left(\left[\mathbf{I}_{N_R} + \sum_{k=1}^{K}\mathbf{B}_k^H\mathbf{H}_{SR,k}^H\mathbf{H}_{SR,k}\mathbf{B}_k\right]^{-1}\right) + \\ tr\left(\left[\mathbf{R}^{-1} + \mathbf{T}^H\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\mathbf{T}\right]^{-1}\right) \end{aligned} \tag{4.19}$$

$$s.t.\ tr\left(\mathbf{T}\mathbf{R}\mathbf{T}^H\right) \leq P_r \tag{4.20}$$

$$s.t.\ tr\left(\mathbf{B}_k\mathbf{B}_k^H\right) \leq P_s, k = 1, ..., K \tag{4.21}$$

Applying matrix invasion lemma on (4.18), the following can be obtained

$$\mathbf{R} = \mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}\left(\mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B} + \mathbf{I}_{N_B}\right)^{-1} \tag{4.22}$$

From (4.19), it is noticed that the increase of the SNR in the first-hop makes the term $\mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}$ to approach infinity. However, at an acceptable high SNR case, $\mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B} \gg \mathbf{I}_{N_B}$, thus $\mathbf{R}^{-1}$ is approximated by $\mathbf{I}_{N_B}$. With such assumption result, the optimization problem from (4.19) can be rewritten as

$$\begin{aligned}\min_{\mathbf{B},\mathbf{T}} \max_i tr\left(\left[\mathbf{I}_{N_B} + \sum_{k=1}^{K} \mathbf{B}_k^H\mathbf{H}_{SR,k}^H\mathbf{H}_{SR,k}\mathbf{B}_k\right]^{-1}\right)+ \\ tr\left(\left[\mathbf{I}_{N_R} + \mathbf{T}^H\mathbf{H}_{2,i}^H\mathbf{H}_{2,i}\mathbf{T}\right]^{-1}\right)\end{aligned} \tag{4.23}$$

$$s.t.\ tr\left(\mathbf{T}\mathbf{T}^H\right) \leq P_r \tag{4.24}$$

$$tr\left(\mathbf{B}_k\mathbf{B}_k^H\right) \leq P_{s,k},\ k = 1, ..., K \tag{4.25}$$

Hence, it can be seen that the amplifying matrix of the relay $\mathbf{T}$ is not dependent on transmitter covariance matrix $\mathbf{B}_k$.Therefore, the optimization problem can be further split into transmitter precoding matrix optimization problem

$$\min_{\{\mathbf{B}\},} tr\left(\left[\mathbf{I}_{N_R} + \sum_{k=1}^{K} \mathbf{B}_k^H\mathbf{H}_{SR,k}^H\mathbf{H}_{SR,k}\mathbf{B}_k\right]^{-1}\right) \tag{4.26}$$

$$s.t.\ \mathrm{tr}\left(\mathbf{B}_k\mathbf{B}_k^H\right) \leq P_s, \mathbf{J}_k = 0,\ k = 1, ..., K$$

and relay amplifying matrix optimization problem

$$\min_{\mathbf{T}} \max_i \mathrm{tr}\left(\left[\mathbf{I}_{N_B} + \mathbf{T}^H\mathbf{H}_{2,i}^H\mathbf{H}_{2,i}\mathbf{T}\right]^{-1}\right) \tag{4.27}$$

$$tr\left(\mathbf{T}\mathbf{T}^H\right) \leq P_{r,} \tag{4.28}$$

It can be seen that transmitter covariance matrix optimization problem in (4.26) is minimized to find the optimal source precoding matrix $\mathbf{B}_k$ to minimize the MSE of the estimated signal received at the relay node. Meanwhile, the optimal $\mathbf{B}_k$ can not be determined unless $\mathbf{H}_{SR,k}$ is known. But, by using $\tilde{\mathbf{H}}_{SR,k}$, we can get $\mathbf{B}_k$ which will result in a great system performance degradation because of the mismatch between $\mathbf{H}_{SR,k}$ and $\mathbf{H}_{\omega SR,k}$. With $M(\mathbf{B}_k) = tr\Bigg(\Bigg[\mathbf{I}_{N_R} +$

$\sum_{k=1}^{K} \mathbf{B}_k^H \mathbf{H}_{SR,k}^H \mathbf{H}_{SR,k} \mathbf{B}_k \Big]^{-1} \Big)$ minimizing $E\{M(\mathbf{B}_k)\}$ while the statistical expectation is over the distribution of $\mathbf{H}_{SR,k}$ for finding optimal $\mathbf{B}_k$. The channel matrix $\mathbf{H}_{SR,k}$ can be modeled as

$$\mathbf{H}_{SR,k} = \tilde{\mathbf{H}}_{\omega SR,k} \mathbf{\Sigma}_{SR,k}^{1/2} \tag{4.29}$$

where $\mathbf{H}_{SR,k} \triangleq \tilde{\mathbf{H}}_{wSR,k} \mathbf{\Lambda}_{\Sigma SR,k}^{1/2} \mathbf{V}_{SR,k}^H$ and $\tilde{\mathbf{H}}_{wSR,k}$ has the same distribution as $\mathbf{H}_{\omega SR,k} \mathbf{V}_{\Sigma SR,k}$. The singular value decomposition of $\mathbf{\Sigma}_{SR,k}$ can be expressed as

$$\mathbf{\Sigma}_{SR,k} = \mathbf{V}_{\Sigma SR,k} \mathbf{\Lambda}_{\Sigma SR,k} \mathbf{V}_{\Sigma SR,k}^H \tag{4.30}$$

where $\mathbf{\Lambda}_{\Sigma SR,k} = \text{diag}\{\mathbf{\Lambda}_{\Sigma SR,1}, ..., \mathbf{\Lambda}_{\Sigma SR,NR}\}$ with $\mathbf{\Lambda}_{SR,1} \geq ... \geq \mathbf{\Lambda}_{\Sigma SR,NR}$. By substituting (4.29) and (4.30) into (4.26) and using trace property, and the matrix identity property $tr([\mathbf{I}_n + \mathbf{C}_{m\times n}\mathbf{D}_{n\times m}]^{-1}) = tr([\mathbf{I}_n + \mathbf{D}_{n\times m}\mathbf{C}_{m\times n}]^{-1}) + m - n$ the optimization problem from (4.26) can be expressed as

$$\min_{\{\mathbf{J}_k\},} tr\left(\left[\mathbf{I}_{N_R} + N_S \sum_{k=1}^{K} \mathbf{V}_{\Sigma SR,k}^H \mathbf{\Lambda}_{\Sigma SR,k}^{1/2} \mathbf{J}_k \mathbf{V}_{\Sigma SR} \mathbf{\Lambda}_{\Sigma SR}^{1/2}\right]^{-1}\right) + N_B - N_R \tag{4.31}$$
$$s.t. \ \text{tr}\big(\mathbf{J}_k\big) \leq P_s, \mathbf{J}_k = 0, k = 1, ..., K$$

where $E\{\tilde{\mathbf{H}}_{\omega SR,k}^H \tilde{\mathbf{H}}_{\omega SR,k}\} = N_S \mathbf{I}_{N_S}$, $\mathbf{J}_k = \mathbf{B}_k \mathbf{B}_k^H$ is a PSD matrix and $\mathbf{Y}_k$ is introduced with a real valued slack variable p. Hence, the min-max problem can be converted as

$$\min_{p,\mathbf{J}_k \mathbf{Y}_k} p$$
$$s.t. \ tr\mathbf{Y}_k \leq p, k = 1, ..., K$$
$$tr(\mathbf{J}_k) \leq P_s, \mathbf{J}_k \succcurlyeq 0, k = 1, ..., K \tag{4.32}$$
$$\begin{pmatrix} \mathbf{Y}_k & \mathbf{I}_{N_R} \\ \mathbf{I}_{N_R} & [\mathbf{I}_{N_R} + N_S \sum_{k=1}^{K} \tilde{\mathbf{\Sigma}}^H \mathbf{J}_k \tilde{\mathbf{\Sigma}}] \end{pmatrix} \succcurlyeq 0, \ k = 1, ..., K$$
$$\mathbf{J}_K \succcurlyeq 0$$

where $\tilde{\mathbf{\Sigma}} = \mathbf{V}_{\Sigma SR,k} \mathbf{\Lambda}_{\Sigma SR,k}^{1/2}$. Convex programming toolbox CVX can be used to solve the semi-definite (SDP) problem from (4.32).

The amplifying matrix of the optimal relay $\mathbf{T}$ from (4.27) is applied to min-max MSE of the received signal waveform at the receiver nodes and using the channel estimation model which is expressed in (4.31), the objective function can be expressed as

$$\begin{aligned} & E\Big\{tr\Big(\big[\mathbf{I}_{N_B}+\mathbf{T}^H\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\mathbf{T}\big]^{-1}\Big)\Big\} \\ & \geq tr\Big(\big[\mathbf{I}_{N_B}+\mathbf{T}^H E\{\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\}\mathbf{T}\big]^{-1}\Big) \end{aligned} \tag{4.33}$$

Now the problem is reduced to find the optimal precoder matrix $\mathbf{T}$ and the second-hop channel matrix subject to power constraint (4.28). The singular value decomposition of $\mathbf{\Sigma}_{RD,i}$ can be expressed as

$$\mathbf{\Sigma}_{RD,i} = \mathbf{V}_{\Sigma RD,i}\mathbf{\Lambda}_{\Sigma RD,i}\mathbf{V}_{\Sigma RD,i}^H \tag{4.34}$$

where $\mathbf{\Lambda}_{\Sigma RD,i} = \text{diag}\{\mathbf{\Lambda}_{\Sigma RD,1},...,\mathbf{\Lambda}_{\Sigma RD,NR}\}$ with $\mathbf{\Lambda}_{RD,1} \geq ... \geq \mathbf{\Lambda}_{\Sigma RD,NR}$. The channel matrix can be modelled as

$$\mathbf{H}_{RD,i} \triangleq \tilde{\mathbf{H}}_{\omega RD,i}\mathbf{\Lambda}_{\Sigma RD,i}^{1/2}\mathbf{V}_{\Sigma RD,i}^H \tag{4.35}$$

where $\tilde{\mathbf{H}}_{RD,i} \triangleq \mathbf{H}_{\omega RD,i}\mathbf{V}_{\Sigma RD,i}$ and $\tilde{\mathbf{H}}_{\omega RD,i}$ has the same distribution as $\mathbf{H}_{\omega RD,i}\mathbf{V}_{\Sigma RD,i}$. Now substituting (4.35) into (4.33), and using trace property,the objective function in (4.33) can be expressed as

$$tr\Big(\Big(\mathbf{I}_{N_B}+\mathbf{T}^H\tilde{\mathbf{H}}_{2,i}\mathbf{T}\Big)^{-1}\Big) \tag{4.36}$$

where $E\{\tilde{\mathbf{H}}_{\omega RD,i}^H\tilde{\mathbf{H}}_{\omega RD,i}\} = N_D\mathbf{I}_{N_D}$, $\tilde{\mathbf{H}}_{2,i} = \mathbf{N}_D\mathbf{V}_{\Sigma RD,i}\mathbf{\Lambda}_{\Sigma RD,i}\mathbf{V}_{\Sigma RD,i}^H$ and hence, the problem of the relay precoding matrix optimization in (4.27)-(4.28) can be expressed as

$$\begin{aligned} & \min_{\mathbf{T}}\max_{i} tr\Big(\Big(\mathbf{I}_{N_B}+\mathbf{T}^H\tilde{\mathbf{H}}_{2,i}\mathbf{T}\Big)^{-1}\Big) \\ & \qquad s.t\ tr\Big(\mathbf{T}\mathbf{T}^H\Big) \leq P_r \end{aligned} \tag{4.37}$$

By using the matrix identity, (4.29) the min-max optimization problem in (4.37) can be written as

$$\min_{\mathbf{M}} \max_{i} tr\left(\left[\mathbf{I}_{N_D} + \tilde{\mathbf{H}}_{2,i}^{1/2}\mathbf{M}\tilde{\mathbf{H}}_{2,i}^{1/2}\right]^{-1}\right) + N_B - N_D \qquad s.t.\ tr(\mathbf{M}) \leq P_r \tag{4.38}$$

where $\mathbf{M} = \mathbf{T}\mathbf{T}^H$ and $\mathbf{M}$ is a positive semidefinite (PSD) matrix as given by $\mathbf{M} \succcurlyeq 0$. By bringing a PSD matrix $\mathbf{Z}_i$ with $\mathbf{Z}_i \geq \left[\mathbf{I}_{N_D} + \tilde{\mathbf{H}}_{2,i}^{1/2}\mathbf{M}\tilde{\mathbf{H}}_{2,i}^{1/2}\right]^{-1}, i = 1, ..., L$ and a real valued slack variable q. Employing the Schur complement, the precoding matrix of the relay optimization problem in (4.38) can be expressed as

$$\begin{aligned} &\min_{\mathbf{q},\mathbf{M},\mathbf{Z}_i} q \\ &s.t.\ \mathrm{tr}(\mathbf{Z}_i) \leq P_r\ i = 1, ..., L \\ &tr(\mathbf{M}) \leq P_r \\ &\begin{pmatrix} \mathbf{Z}_i & \mathbf{I}_{N_D} \\ \mathbf{I}_{N_D} & \left[\mathbf{I}_{N_D} + \tilde{\mathbf{H}}_{2,i}^{1/2}\mathbf{M}\tilde{\mathbf{H}}_{2,i}^{1/2}\right] \end{pmatrix} \succcurlyeq 0, i = 0, ..., L \\ &\mathbf{M} \succcurlyeq 0 \end{aligned} \tag{4.39}$$

Convex programming toolbox CVX can be used to solve the SDP problem which is expressed by (4.39).

4.4 Simulation Results

In this section, the performance of the proposed scheme is verified by using numerical simulation. The simulation for the proposed non-regenerative multicasting MIMO relay system is carried out using the following parameters.The source, relay and destination links are equipped with the same number of antennas as $N_S = N_R = N_D = 4$. QPSK modulation constellation is used to generate the symbols, the entries of the channel matrices of $\mathbf{H}_{wSR,k}, \mathbf{H}_{wRD,i}$, and $\mathbf{\Sigma}_{SR,k}$ are generated as complex Gaussian variables having zero mean and unit variance.

Bessel function of first kind $\mathbf{\Sigma}_{i,j} = j_0(\triangle\pi|i-j|)$ is used to generate the elements of the covariance matrix $\mathbf{\Sigma}_{SR,k}$ of $\mathbf{H}_{SR,k}$ and $\mathbf{\Sigma}_{RD,i}$ of $\mathbf{H}_{RD,i}$ [49] where $j_0(.)$ is the zeroth order of the Bessel function of first kind and $\triangle$ is the angle of fading spread. The angles of spread are set as $\triangle_1 = 10^0, \triangle_2 = 20^0$ and $\triangle_3 = 30^0$ for the first-hop and second- hop. The result of comparison of performance between

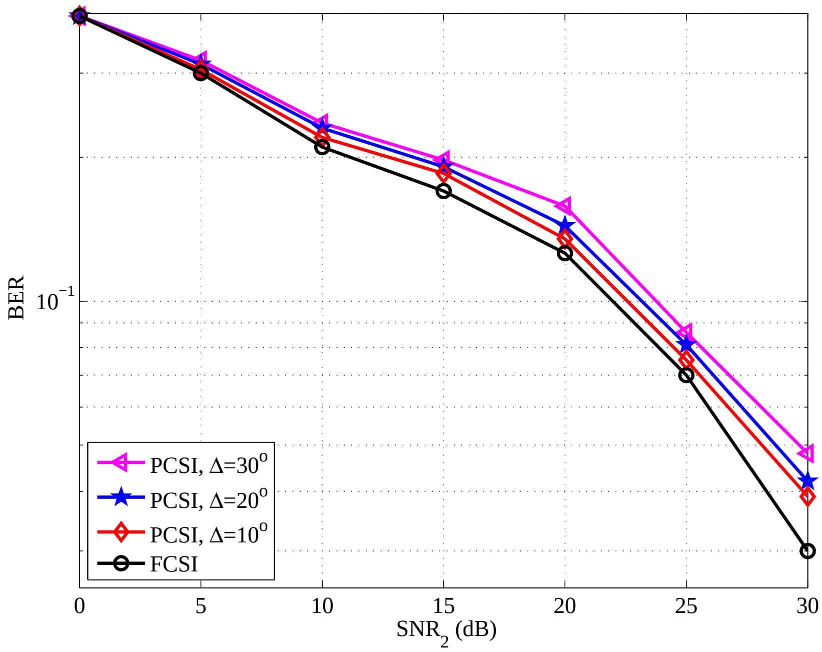

Figure 4.2: BER versus SNR(dB) in partial CSI and full CSI design for different spreads angles

PCSI scheme and FCSI scheme for BER versus SNR for various angles of spread is shown in Fig. 4.2. The two algorithms are simulated under the same condition, and the transmit signals are modulated using QPSK signal constellations, then transmitted to the destination nodes. The BER performance of the two algorithm is plotted against the SNR between the relay and destination nodes for different angle of antenna orientation, $\triangle_1 = 10^0, \triangle_2 = 20^0$ and $\triangle_3 = 30^0$. It can be observed from Fig.4.2 that the BER increases as the number of user increases for both the full CSI and the partial CSI (PCSI) schemes.

In Fig. 4.3, the performance of BER for the PCSI design for multiple sources

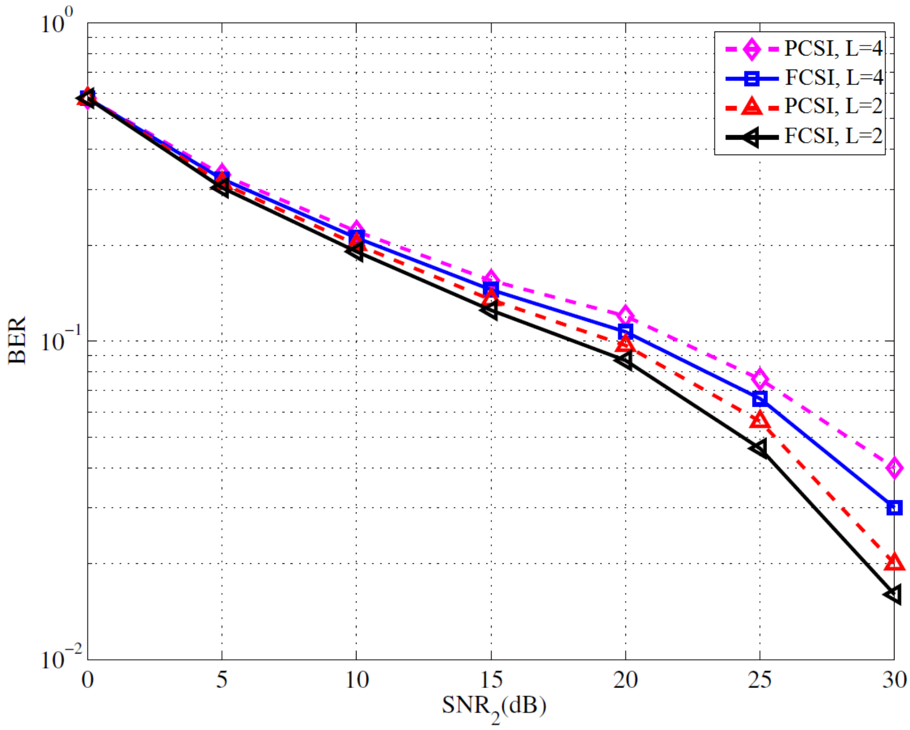

Figure 4.3: BER versus SNR(dB) in partial CSI and full CSI design for multiusers

is plotted, and the signals are generated using QPSK constellations. The BER performance of the PCSI and FCSI is plotted against the SNR between the relay and the destination nodes for two number of users , $L = 2$ and $L = 4$. It can be observed from Fig 4.3 that BER increases as the the number of destination nodes increases. It can be noticed from Fig.4.3 that the proposed PCSI scheme is closer to the FCSI scheme.

The NMSE performance between PCSI and FCSI design schemes is shown in Fig. 4.4. The simulated results are under the same condition for the both algorithms. In the simulation, destination nodes are set at $L = 4$, and each node is equipped with the same number of antennas $N_S = N_R = N_D = 4$. The performance of the NMSE of the two algorithms is plotted against the SNR between relay and the destination nodes for various of the spread angles namely $\Delta = 10^o$,

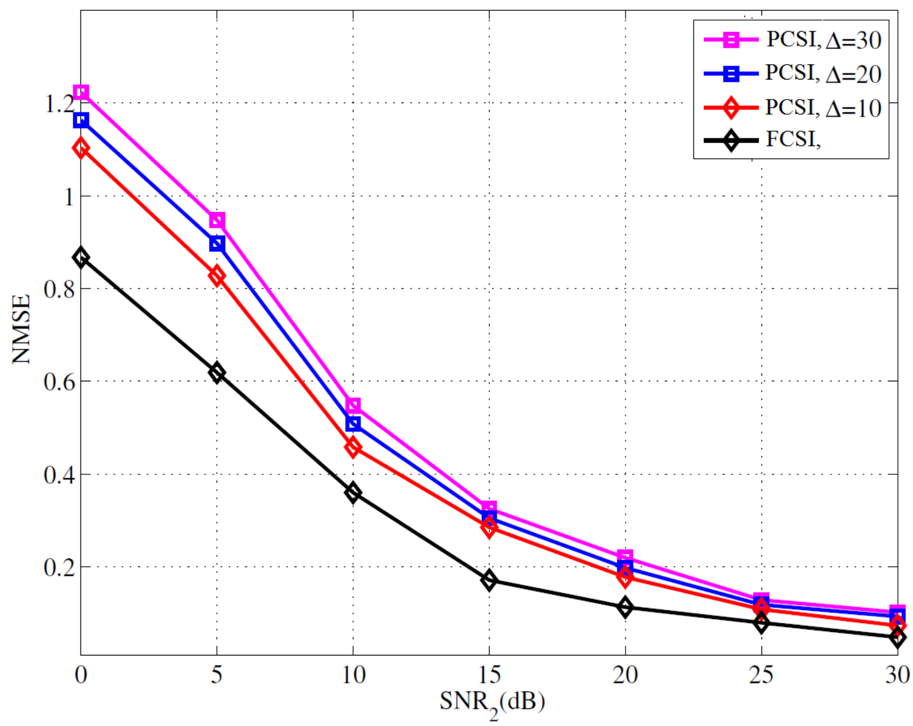

Figure 4.4: NMSE versus SNR(dB) in PCSI and FCSI designs for different spreads angles

$\Delta = 20^o$ and $\Delta = 30^o$. It can be observed from Fig. 4.4 that the PCSI scheme is closer to the FCSI scheme.

4.4.1 Summary of the chapter

In this chapter, the relay and receiver matrices are derived for covariance feedback based multiple source multicasting MIMO relay system and jointly derived the matrices under source and relay powers limit bound and the proposed scheme is solved by using CVX programming tool box. Numerical examples are used to verify the performance of the the proposed scheme. It can be noticed from the numerical examples that the proposed design scheme is closer to the FCSI scheme.

Chapter 5

Robust Designs for Multicasting MIMO Relay System from Multiple Sources

In this chapter, a robust transceiver design is proposed for multicasting MIMO relay system from multiple sources. In the proposed design scheme, the optimal source, relay and receiver precoder matrices are derived with the assumption that the channel information is unknown and estimated with partial information. In Section 5.1, the system model description is introduced. In Section 5.2, the joint source and relay optimization problem is demonstrated and the solution to highly nonconvex optimization problem is provided to simplify the problem which could be solved by CVX programming tool box. In Section 5.3, the numerical results of the proposed scheme is validated with the FCSI scheme.

5.1 System Model

In this section, a two hop non-regenerative Multiuser multicasting MIMO relay system with L receivers as shown in Fig 5.1, is considered. The transmitters and

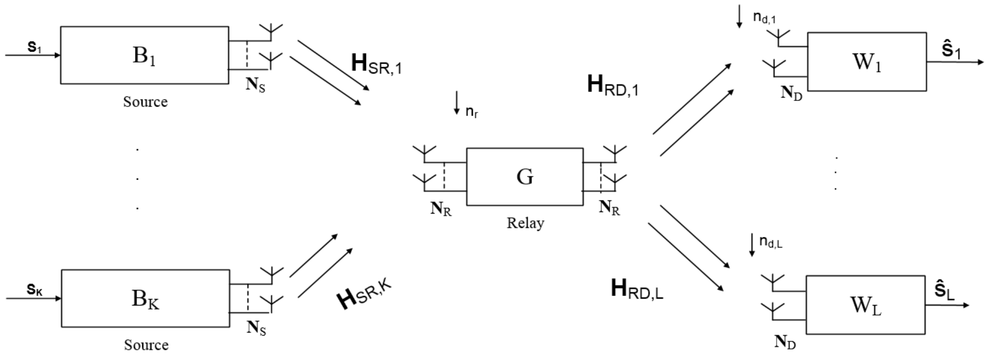

Figure 5.1: Multi-source Multicasting MIMO relay system

the relay are equipped with N_S and N_R respectively. To simplify the analysis, its assumed that each receiver node is equipped with N_D antennas. It is also assumed that there is no direct link between the transmitter and receivers. The transmission of data takes place via two time slots. During the first time slot, $N_{Sk} \times 1$ modulated signal vector $\mathbf{s}_k$ is linearly precoded by Nth source node with $N_{Sk} \times N_{Sk}$ precoding matrix $\mathbf{B}_k$. The precoded signal is then propagated to the relay nodes. The total number of composite data streams from the source is denoted as $N_B = \sum_{k=1}^{K} N_{S,k}$ and the statistical signal expectation of the received signal to be given as $E[\mathbf{S}_k \mathbf{S}_k^H] = \mathbf{I}_{Ns,k}$. From Fig.5.1, the propagated information at relay node can be retrieved as

$$\mathbf{y}_r = \sum_{k=1}^{K} \mathbf{H}_{SR,k} \mathbf{B}_k \mathbf{s}_k + \mathbf{n}_r \triangleq \mathbf{H}_{SR} \mathbf{B} \mathbf{s} + \mathbf{n}_r \tag{5.1}$$

where $\mathbf{y}_r$ is the $N_R \times 1$ retrieved information at the relay destination, $\mathbf{H}_{SR,k}$ is $N_R \times N_{S,k}$ kth channel matrix of the first time slot between the kth source node and the relay node, $\mathbf{H}_{SR,k} = [\mathbf{H}_{SR,1}, ...\mathbf{H}_{SR,K}]$, $\mathbf{B} \triangleq blkdiag(\mathbf{B}_1, ...\mathbf{B}_K)$, $\mathbf{s} \triangleq [\mathbf{s}_1^T, ...\mathbf{s}_K^T]^T$ and $\mathbf{n}_r$ is the Guassian additive noise vectors that is observed at the relay node.

At the second time slot, the retrieved signal $\mathbf{y}_r$ is linearly amplified by the $N_R \times N_R$ antenna precoding matrix $\mathbf{G}$ as expressed from (5.2). The precoded signal is then propagated to the receiving nodes.

$$\mathbf{x}_r = \mathbf{G}\mathbf{y}_r \tag{5.2}$$

with (5.1) and (5.2), the arrived information at the ith receive node is formulated as

$$\begin{aligned}\mathbf{y}_{d,i} &= \mathbf{H}_{RD,i}\mathbf{G}\mathbf{H}_{SR,k}\mathbf{B}\mathbf{s} + \mathbf{H}_{RD,i}\mathbf{G}\mathbf{n}_r + \mathbf{n}_{d,i} \\ &\triangleq \tilde{\mathbf{A}}_i s + \mathbf{n}_i, i = 1, ...L\end{aligned} \tag{5.3}$$

where $\mathbf{H}_{RD,i}$ represents $N_D \times N_R$ for relay to receive node channel hop matrix and $\mathbf{n}_{d,i}$ is the additive Gaussian noise vector obtained at the ith receive node. Whereas $\tilde{\mathbf{A}}_i \triangleq \mathbf{H}_{RD,i}\mathbf{G}\mathbf{H}_{SR}\mathbf{B}$ represents the source channel matrix node and $\mathbf{n}_i = \mathbf{H}_{RD,i}\mathbf{G}\mathbf{n}_r + \mathbf{n}_{d,i}$ represents the noise vector at the destination. It is assumed that the whole noises have zero mean and unit variance. But, in practice, the full CSI is not available at the relay node and it has to be estimated, but there is a gap between the estimated and the actual CSI which results into channel mismatch. Thus, the channel precoding matrices $\mathbf{H}_{SR,i}$ and $\mathbf{H}_{RD,i}$ can be modelled and expressed as

$$\mathbf{H}_{SR,k} = \hat{\mathbf{H}}_{SR,k} + \tilde{\triangle}_{SR,k}, k = 1, ..., K \tag{5.4}$$

$$\mathbf{H}_{RD,i} = \hat{\mathbf{H}}_{RD,i} + \tilde{\triangle}_{RD,i}, i = 1, ..., L \tag{5.5}$$

where $\hat{\mathbf{H}}_{SR,k}$ and $\hat{\mathbf{H}}_{RD,i}$ are considered as the estimated transmitter-relay link and relay-receiver link channels matrices, $\tilde{\triangle}_{SR,k}$ and $\tilde{\triangle}_{RD,i}$ represent the channel estimation errors with Gaussian random variables and zero mean. But $\tilde{\triangle}_{SR,k}$ and $\tilde{\triangle}_{RD,i}$ are the estimated channel error matrices that depend only on the channel estimation algorithm. Therefore, the probability density function of $\tilde{\triangle}_{SR,k}$ and $\tilde{\triangle}_{RD,i}$ can be modelled as [48]

$$\tilde{\Delta}_{SR,k} \sim CN(0, \mathbf{\Sigma}_{SR,k} \otimes \mathbf{\Psi}^T_{SR,k}) \tag{5.6}$$

$$\tilde{\Delta}_{RD,i} \sim CN(0, \mathbf{\Sigma}_{RD,i} \otimes \mathbf{\Psi}^T_{RD,i}) \tag{5.7}$$

where $\mathbf{\Sigma}_{SR,k}$ stands for the row and $\mathbf{\Psi}_{SR,k}^T$ stands for the column matrices of $\tilde{\triangle}_{SR,k}$ while $\mathbf{\Sigma}_{RD,i}$ and $\mathbf{\Psi}_{RD,i}^T$ are the entries of row and entries of the column matrices of $\tilde{\triangle}_{RD,i}$. $\tilde{\triangle}_{SR,k}$ and $\tilde{\triangle}_{RD,i}$ are assumed to be the noise complex gaussian distribution with zero mean.

5.2 Problem Formulation

MMSE estimator $\mathbf{W}_i$ is employed to retrieve the actual propagated signal $\mathbf{s}$ at the ith receiver. Hence, the signal received at the ith destination could be expressed as

$$\tilde{\mathbf{s}} = \mathbf{W}_i \mathbf{y}_{d,i}, i = 1, ..., L \tag{5.8}$$

Assume that P_s and P_r are the upper bond of the transmitter and relay powers respectively. Hence, the power constraints on the source and the relay nodes can be expressed as

$$p(\mathbf{B}) = tr(\mathbf{B}\mathbf{B}^H) \leq P_{s,k} \tag{5.9}$$

$$p(\mathbf{G}, \mathbf{B}) = tr\Big(\mathbf{G}\Big(\mathbf{H}_{SR}\mathbf{B}\mathbf{B}^H\mathbf{H}_{SR}^H + \mathbf{I}_{N_R}\Big)\mathbf{G}^H\Big) \leq P_r \tag{5.10}$$

from (5.3) and (5.8), MSE of the propagated signal is obtained as

$$E_i = tr\Big((\mathbf{W}_i\tilde{\mathbf{A}}_i - \mathbf{I}_{N_B})(\mathbf{W}_i\tilde{\mathbf{A}}_i - \mathbf{I}_{N_B})^H + \mathbf{W}_i\mathbf{C}_i\mathbf{W}_i^H\Big), \tag{5.11}$$

$$i = 1, ..., L$$

where $\mathbf{C}_i$ represents the expected noise depending on matrix which could be expressed as

$$\mathbf{C}_i = \mathbf{H}_{RD,i}\mathbf{G}\mathbf{G}^H\mathbf{H}_{RD,i}^H + \mathbf{I}_{N_D} \tag{5.12}$$

where $\mathbf{W}_i$ is scale matrix to minimizing MSE from (5.11) and can be formulated as

$$\mathbf{W}_i = (\tilde{\mathbf{A}}_i\tilde{\mathbf{A}}_i^H + \mathbf{C}_i)^{-1}\tilde{\mathbf{A}}_i \tag{5.13}$$

Substituting (5.13) into (5.11) and then applying the matrix inversion lemma, MSE is obtained as

$$E_i = tr\left(\left[\mathbf{I}_{N_B} + \tilde{\mathbf{A}}_i^H \mathbf{C}_i^{-1} \tilde{\mathbf{A}}_i\right]^{-1}\right), i = 1, ..., L \tag{5.14}$$

Thus, from (5.14), the problem of linear precoder design is then expressed as

$$\begin{aligned} \min_{\{\mathbf{B}_k,\}\mathbf{G}} \max_i \; & tr\left(\left[\mathbf{I}_{N_B} + \tilde{\mathbf{A}}_i^H \mathbf{C}_i^{-1} \tilde{\mathbf{A}}_i\right]^{-1}\right) \\ s.t. \; & tr\left(\mathbf{G}\left(\mathbf{H}_{SR,k}\mathbf{B}\mathbf{B}^H\mathbf{H}_{SR,k}^H + \mathbf{I}_{N_R}\right)\mathbf{G}^H\right) \le P_r \\ & tr\left(\mathbf{B}_k\mathbf{B}_k^H\right) \le P_{s,k} k = 1, ..., K \end{aligned} \tag{5.15}$$

The relay optimal precoding matrix $\mathbf{G}$ as expressed in (5.16) will be used in solving the complex function of E_i

$$\mathbf{G} = \mathbf{T}\mathbf{D}^H \tag{5.16}$$

where $\mathbf{D} = \left(\mathbf{H}_{SR,k}\mathbf{B}\mathbf{B}^H\mathbf{H}_{SR,k}^H + \mathbf{I}_{N_R}\right)^{-1}\mathbf{H}_{SR,k}\mathbf{B}$ is the well known linear MMSE estimator scaled matrix for the expected signal at first-hop and $\mathbf{T}$ is the source precoding matrix for the second-hop. By employing optimal precoding relay matrix $\mathbf{G}$, the MSE in (5.14) can be expressed into the sum of the separate two MSE functions

$$\begin{aligned} E_i = & tr\left(\left[\mathbf{I}_{N_B} + \mathbf{B}^H\mathbf{H}_{SR,k}^H\mathbf{H}_{SR,k}\mathbf{B}\right]^{-1}\right) + \\ & tr\left(\left[\mathbf{R}^{-1} + \mathbf{T}^H\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\mathbf{T}\right]^{-1}\right), i = 1, ..., L \end{aligned} \tag{5.17}$$

The first part represents $tr\left(\left[\mathbf{I}_{N_B} + \mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}\right]^{-1}\right)$ as the MSE of estimated propagated signal waveform vector $\mathbf{S}$ from (5.1) at the first-hop relay node by applying the weight matrix $\mathbf{D}$. The remaining second term of equation (5.17) is the increment response of MSE in second-hop and $\mathbf{R}$ is expressed as

$$\mathbf{R} = \mathbf{B}^H\mathbf{H}_{SR,k}^H\left(\mathbf{H}_{SR,k}\mathbf{B}\mathbf{B}^H\mathbf{H}_{SR,k}^H + \mathbf{I}_{N_R}\right)^{-1}\mathbf{H}_{SR,k}\mathbf{B} \tag{5.18}$$

From the optimal precoding matrix of the relay $\mathbf{G}$ from (5.16), power taken by relay node is expressed as $tr\Big(\mathbf{TRT}^H\Big)$ while the term $tr\Big(\Big[\mathbf{I}_{N_B} + \mathbf{B}^H\mathbf{H}_{SR}^H\mathbf{H}_{SR}\mathbf{B}\Big]^{-1}\Big)$ from (5.17) can now be rewritten as $tr\Big(\Big[\mathbf{I}_{N_B} + \sum_{k=1}^{K}\mathbf{H}_{SR,k}\mathbf{B}_k\mathbf{B}_k^H\mathbf{H}_{SR,k}^H\Big]^{-1}\Big) + N_B - N_R$ where $\mathbf{B}_k$ is the precoded matrix of the signal transmitted by the k^{th} source. Hence, (5.15) can be formulated as

$$\begin{aligned} \min_{\{\mathbf{B}\},\mathbf{T}} \max_{i} \; & tr\Bigg(\Bigg[\mathbf{I}_{N_R} + \sum_{k=1}^{K}\mathbf{H}_{SR,k}\mathbf{B}_k\mathbf{B}_k^H\mathbf{H}_{SR,k}^H\Bigg]^{-1}\Bigg) + N_B - N_R + \\ & tr\Bigg(\Bigg[\mathbf{R}^{-1} + \mathbf{T}^H\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\mathbf{T}\Bigg]^{-1}\Bigg) \end{aligned} \tag{5.19}$$

$$s.t.\; tr\Big(\mathbf{TRT}^H\Big) \le P_r$$

$$s.t.\; tr\Big(\mathbf{B}_k\mathbf{B}_k^H\Big) \le P_{s,k}, k = 1, 2, ..., K$$

Let us introduce the following matrix identity

$$(\mathbf{A} + \mathbf{BCD})^{-1} = \mathbf{A}^{-1} - \mathbf{A}^{-1}\mathbf{B}(\mathbf{DA}^{-1}\mathbf{B} + \mathbf{C}^{-1})^{-1}\mathbf{DA}^{-1} \tag{5.20}$$

Applying the matrix inversion lemma (5.20) into (5.18), $\mathbf{R}$ can be rewritten as

$$\mathbf{R} = \mathbf{B}^H\mathbf{H}_{SR,k}^H\mathbf{H}_{SR}\mathbf{B}\Big(\mathbf{B}^H\mathbf{H}_{SR,k}^H\mathbf{H}_{SR}\mathbf{B} + \mathbf{I}_{N_B}\Big)^{-1} \tag{5.21}$$

From (5.21), it is noticed that the increase SNR in the first-hop makes the term $\mathbf{B}^H\mathbf{H}_{SR,k}^H\mathbf{H}_{SR,k}\mathbf{B}$ to approach infinity. However, at an acceptable high SNR state, $\mathbf{B}^H\mathbf{H}_{SR,k}^H\mathbf{H}_{SR,k}\mathbf{B} \gg \mathbf{I}_{N_B}$, thus $\mathbf{R}^{-1}$is approximated as $\mathbf{I}_{N_B}$. With such assumption result, the optimization problem from (5.19) could be expressed as

$$\begin{aligned} \min_{\mathbf{B}_k,\mathbf{T}} \max_{i} \; & tr\Bigg(\Bigg[\mathbf{I}_{N_R} + \sum_{k=1}^{K}\mathbf{H}_{SR,k}\mathbf{B}_k\mathbf{B}_k^H\mathbf{H}_{SR,k}^H\Bigg]^{-1}\Bigg) + \\ & tr\Bigg(\Bigg[\mathbf{I}_{N_B} + \mathbf{T}^H\mathbf{H}_{2,i}^H\mathbf{H}_{2,i}\mathbf{T}\Bigg]^{-1}\Bigg) \end{aligned} \tag{5.22}$$

$$s.t.\; tr\Big(\mathbf{TT}^H\Big) \le P_r$$

$$tr\Big(\mathbf{B}_k\mathbf{B}_k^H\Big) \le P_{s,k}, \quad k = 1, ..., K$$

Hence, it can be seen that the amplifying matrix of the relay $\mathbf{T}$ is not dependent on transmitter matrix $\mathbf{B}_k$. Therefore, the optimization problem can be further split into transmitter precoding matrix optimization problem

$$\min_{\{\mathbf{B}_k\},} tr\left(\left[\mathbf{I}_{N_R} + \sum_{k=1}^{k} \mathbf{H}_{SR,k}\mathbf{B}_k\mathbf{B}_k^H\mathbf{H}_{SR,k}^H\right]^{-1}\right) \tag{5.23}$$
$$s.t.\ \mathrm{tr}\left(\mathbf{B}_k\mathbf{B}_k^H\right) \leq P_s, k = 1, ..., K$$

and relay amplifying matrix optimization problem as

$$\min_{\mathbf{T}} \max_{i} tr\left(\left[\mathbf{I}_{N_B} + \mathbf{T}^H\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\mathbf{T}\right]^{-1}\right) \tag{5.24}$$
$$tr\left(\mathbf{T}\mathbf{T}^H\right) \leq P_{r,}$$

It can be seen that the optimization problem in (5.22) can be minimized to find the optimal source precoding matrix $\mathbf{B}_k$ to minimize the MSE of the expected signal received at the relay node. Meanwhile, the optimal $\mathbf{B}_k$ cannot be determined unless the value of $\mathbf{H}_{SR,k}$ is known. But, by using $\hat{\mathbf{H}}_{SR,k}$, $\mathbf{B}_k$ which will result into a great system performance degradation because of the mismatch between $\mathbf{H}_{SR,k}$ and $\hat{\mathbf{H}}_{SR,k}$. With $M(\mathbf{B}_k) = tr\left(\left[\mathbf{I}_{N_R}+\sum_{k=1}^{K} \mathbf{H}_{SR,k}\mathbf{B}_k\mathbf{B}_k^H\mathbf{H}_{SR,k}^H\right]^{-1}\right)$ minimizing $E_{\triangle SR,k}\{M(\mathbf{B}_k)\}$ while the statistical expectation is over the distribution $\triangle_{SR,k}$ to get the optimal $\mathbf{B}_k$, could be acheived by finding the channel expectation. The objective function from (5.22) using matrix identity can be expressed as

$$E_{\triangle_{SR,k}}\{M(\mathbf{B}_k)\} \geq tr\left(\left[\mathbf{I}_{N_R} + \sum_{k=1}^{K} \mathbf{B}_k^H E_{\triangle SR,k}\{\mathbf{H}_{SR,k}^H\mathbf{H}_{SR,k}\}\mathbf{B}_k\right]^{-1}\right) + N_B - N_R \tag{5.25}$$

$$= tr\left(\left[\mathbf{I}_{N_R} + \sum_{k=1}^{K} \tilde{\mathbf{H}}_{1,k}^{1/2}\mathbf{J}_k\tilde{\mathbf{H}}_{1,k}^{1/2}\right]^{-1}\right) + 2N_B - 2N_R$$

where $E_{\triangle SR,k}\{\mathbf{H}_{SR,k}^H\mathbf{H}_{SR,k}\} = \tilde{\mathbf{H}}_{1,k} = \hat{\mathbf{H}}_{SR,k}\hat{\mathbf{H}}_{SR,k}^H + \mathrm{tr}\left(\mathbf{\Sigma}_{SR,k}\right)\mathbf{\Psi}_{SR,k}$ is derived from the channel estimation error modeled in (5.5) and $\mathbf{J}_k = \mathbf{B}_k\mathbf{B}_k^H$.

Let $\mathbf{J}_k$ is a PSD matrix and $\mathbf{Y}_k$ is introduced with $\Big[\mathbf{I}_{N_R}+\sum_{k=1}^{K}\tilde{\mathbf{H}}_{1,k}^{1/2}\mathbf{J}_k\tilde{\mathbf{H}}_{1,k}^{1/2}\Big]^{-1}, k = 1, ..., K$ and a real valued slack variable p is introduced. Hence, the min-max problem could be rewritten as

$$\min_{p,\mathbf{J}_k\mathbf{Y}_k} p$$
$$s.t.\ tr(\mathbf{Y}_k) \leq p, k = 1, ..., K$$
$$tr(\mathbf{J}_k) \leq P_s, \mathbf{J}_k \succcurlyeq 0, k = 1, ..., K \tag{5.26}$$

$$\begin{pmatrix} \mathbf{Y}_k & \mathbf{I}_{N_R} \\ \mathbf{I}_{N_R} & [\mathbf{I}_{N_R} + \sum_{k=1}^{k}\tilde{\mathbf{H}}_{1,k}^{1/2}\mathbf{J}_k\tilde{\mathbf{H}}_{1,k}^{1/2}] \end{pmatrix} \succcurlyeq 0, k = 0, ..., K$$
$$\mathbf{J}_k \succcurlyeq 0$$

Amplifying matrix of the optimal relay $\mathbf{T}$ from (5.24) is applied to min-max MSE of the retrieved signal waveform at the receiver end. Using channel error estimation model from (5.4) and the matrix inversion Lemma, the lower bound of $E_{\triangle RD,i}\Big\{tr\Big(\big[\mathbf{I}_{N_B} + \mathbf{T}^H\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\mathbf{T}\big]^{-1}\Big)\Big\}$ could be formulated as

$$\begin{aligned} &E_{\triangle RD,i}\Big\{tr\Big(\big[\mathbf{I}_{N_B} + \mathbf{T}^H\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\mathbf{T}\big]^{-1}\Big)\Big\} \\ &\geq tr\Big(\big[\mathbf{I}_{N_B} + \mathbf{T}^H E_{\Delta RD,i}\{\mathbf{H}_{RD,i}^H\mathbf{H}_{RD,i}\}\mathbf{T}\big]^{-1}\Big) \\ &= tr\Big(\big[\mathbf{I}_{N_B} + \mathbf{T}^H\mathbf{H}_{2,i}\mathbf{T}\big]^{-1}\Big) \end{aligned} \tag{5.27}$$

where $\tilde{\mathbf{H}}_{2,i} = \hat{\mathbf{H}}_{RD,i}^H\hat{\mathbf{H}}_{RD,i} + tr(\mathbf{\Sigma}_{RD,i})\mathbf{\Psi}_{RD,i}$. Hence, the precoding matrix of the relay optimization problem can be expressed as

$$\begin{aligned} \min_{\mathbf{T}}\max_{i} tr\Big(\Big(\mathbf{I}_{N_B} + \mathbf{T}^H\tilde{\mathbf{H}}_{2,i}\mathbf{T}\Big)^{-1}\Big) \\ s.t.\ tr\Big(\mathbf{T}\mathbf{T}^H\Big) \leq P_r \end{aligned} \tag{5.28}$$

Applying the matrix identity (4.29), the min- max optimization problem from (5.28) can be expressed as

$$\min_{\mathbf{M}}\max_{i} tr\Big(\big[\mathbf{I}_{N_D} + \tilde{\mathbf{H}}_{2,i}^{1/2}\mathbf{M}\tilde{\mathbf{H}}_{2,i}^{1/2}\big]^{-1}\Big) + N_B - N_D \tag{5.29}$$

$$s.t.\; tr(\mathbf{M}) \leq P_r$$

where $\mathbf{M} = \mathbf{T}\mathbf{T}^H$ and $\mathbf{M}$ being PSD matrix that is given by $\mathbf{M} \succcurlyeq 0$. By bringing a PSD matrix $\mathbf{Z}_i$ with $\mathbf{Z}_i \geq \left[\mathbf{I}_{N_D} + \tilde{\mathbf{H}}_{2,i}^{1/2}\mathbf{M}\tilde{\mathbf{H}}_{2,i}^{1/2}\right]^{-1}, i = 1, ..., L$ where q real valued slack variable. Employing the Schur complement, the precoding matrix of the relay optimization problem in (5.29) can be expressed as

$$\begin{aligned} &\min_{q,\mathbf{M}\mathbf{Z}_i} q \\ &s.t\; tr(\mathbf{Z}_i) \leq P_r \; i = 1, ..., L \\ &tr(\mathbf{M}) \leq P_r \\ &\begin{pmatrix} \mathbf{Z}_i & \mathbf{I}_{N_D} \\ \mathbf{I}_{N_D} & \left[\mathbf{I}_{N_D} + \tilde{\mathbf{H}}_{2,i}^{1/2}\mathbf{M}\tilde{\mathbf{H}}_{2,i}^{1/2}\right]^{-1} \end{pmatrix} \succcurlyeq 0, i = 0, ..., L \\ &\mathbf{M} \succcurlyeq 0 \end{aligned} \tag{5.30}$$

Convex problem from (5.30) is resolved by using CVX programming toolbox.

5.3 Simulation Results

In this section, numerical simulations are used to demonstrate and verify the performance of the proposed algorithm. The correlation matrices of the channel estimation error are generated using the following channel model as in [50]

$$\mathbf{\Psi}_{SR,k} = \mathbf{\Psi}_{RD,i} = \begin{pmatrix} 1 & \alpha & \alpha^2 & \alpha^3 \\ \alpha & 1 & \alpha & \alpha^2 \\ \alpha^2 & \alpha & 1 & \alpha \\ \alpha^3 & \alpha^2 & \alpha & 1 \end{pmatrix}, k = 1, ..., K, i = 1, ..., L$$

$$\mathbf{\Sigma}_{SR,k} = \mathbf{\Sigma}_{RD,i} = \begin{pmatrix} 1 & \beta & \beta^2 & \beta^3 \\ \beta & 1 & \beta & \beta^2 \\ \beta^2 & \beta & 1 & \beta \\ \beta^3 & \beta^2 & \beta & 1 \end{pmatrix}, k = 1, ..., K, i = 1, ..., L$$

Here it is assumed that the coefficients of correlation are given as $0 \leq \alpha, \beta \leq 1$ and σ_e^2 is taken as a measurement for the variance of the channel error estimation reference . While the correlation of channel matrix estimation error for the first and the second hop $\tilde{\mathbf{H}}_{SR,k}$ and $\tilde{\mathbf{H}}_{RD,i}$, respectively, are generated using (5.6) and (5.7). The result of the performance of the proposed robust min-max algorithm is compared with non robust min-max MSE in [51]. For the first simulation example, the performance of the proposed algorithm is investigated with different value of variance against the BER and in the second with number of users and the third NMSE with different levels of SNR.

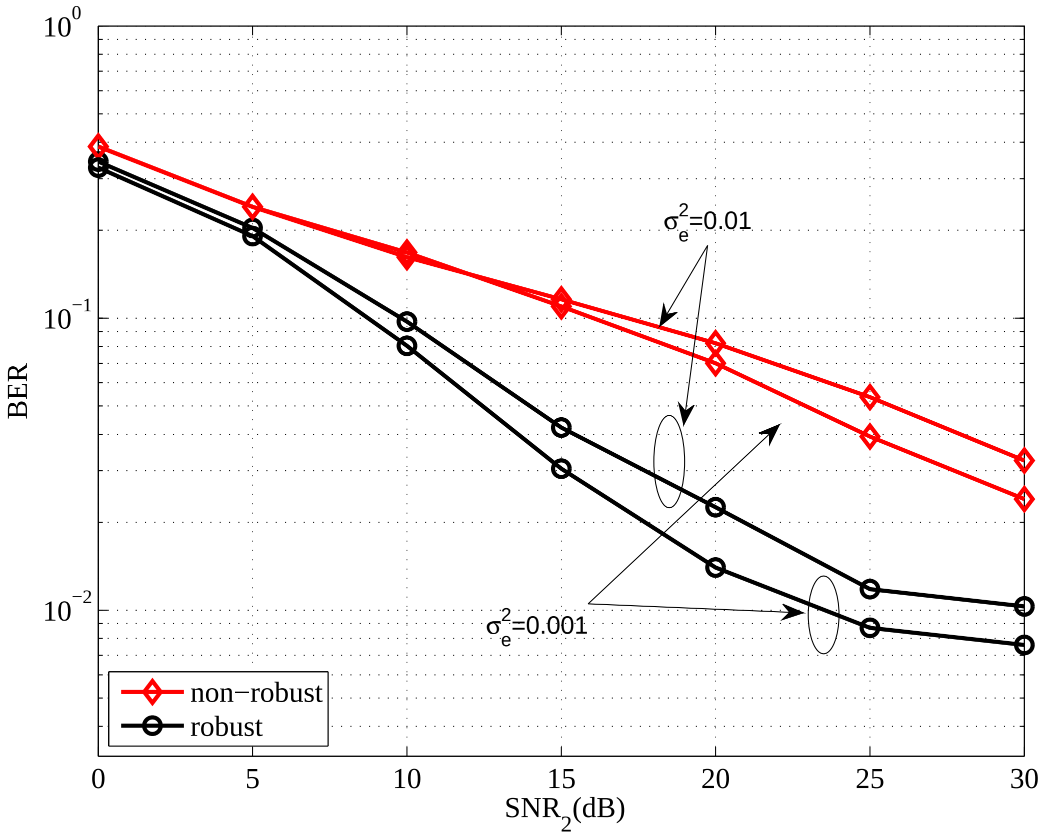

Figure 5.2: BER versus SNR (dB) for Non-robust and robust design performance comparison with $SNR_1 = 30dB$, $N_S = N_R = N_D = 4$, and K=2 and L=4.

Fig.5.2 shows the result of the performance based on BER for the non-robust and robust design algorithm using 30dB SNR and $\sigma_e^2 = 0.001$ and 0.01.

The source, relay destination are provided with same number of antennas as $N_S = 4, N_R = 4$, and $N_D = 4$. The number of source is $K = 2$ and the number of destination receiver node is $L = 4$. Based on the results obtained, it shows that the robust design algorithms outperforms the non-robust in term of BER while higher variance of estimation error result in higher BER. Therefore it can be concluded that proposed algorithm has a better performance than the traditional algorithm.

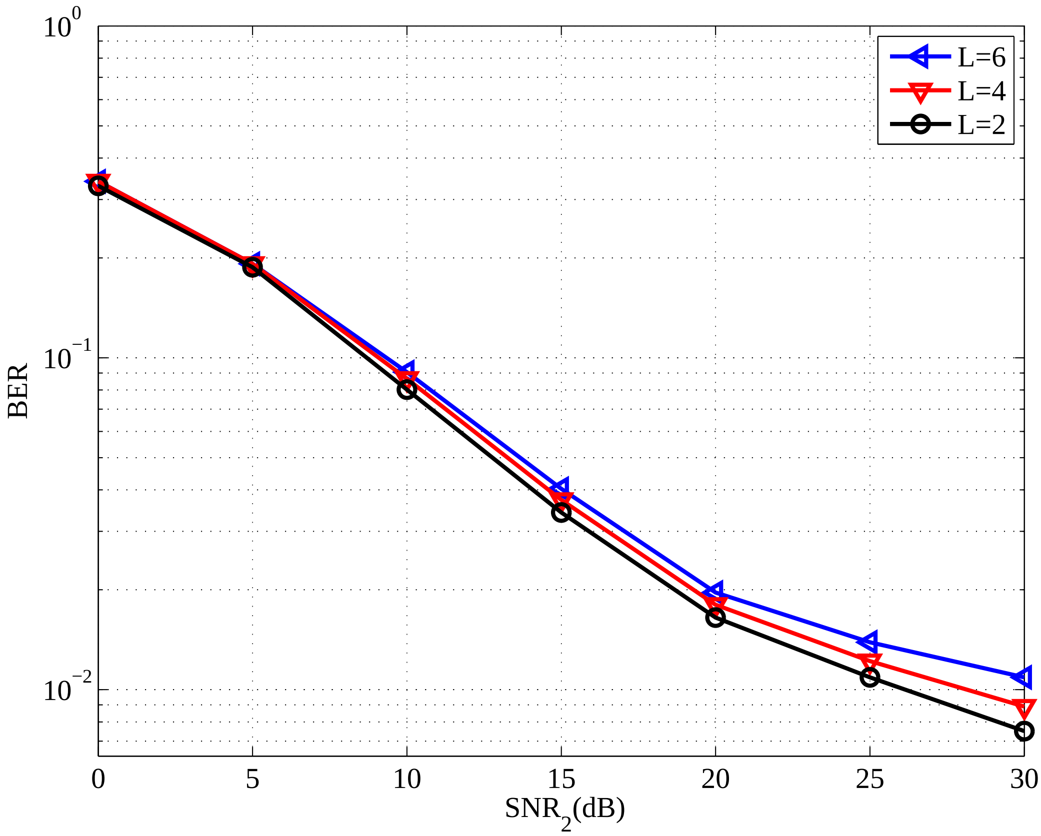

Figure 5.3: BER performance versus SNR_2 with $SNR_1 = 30dB$, $N_S = N_R = N_D = 4$, and K=2.

Fig. 5.3 illustrates the response of numerical example of robust design method with $L = 2, 4$, and 6. The SNR of first-hop is at 30 dB and source, relay and receiver are equipped with same number of antennas $N_S = 4, N_R = 4$, and $N_D = 4$ and the number of transmitter is set at $K = 2$. In Fig.5.3, the BER levels of the proposed robust design method is plotted against the SNR in the second-hop. It is noticed that as the number of the receiver nodes is increased the BER also increased because the objective function from (5.29) is optimized to find the minimum MSE of the desired receiver end for worse case scenario system.

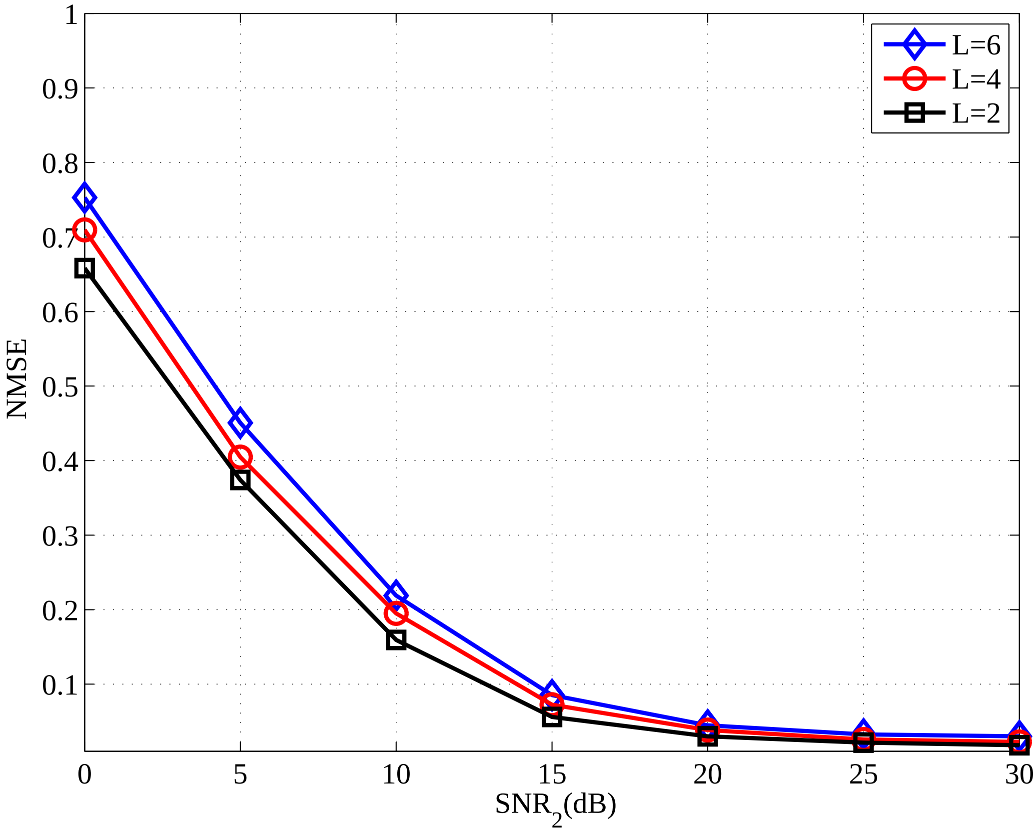

Figure 5.4: NMSE performance versus SNR_2 with $SNR_1 = 30dB$, $N_S = N_R = N_D = 4$, and K=2.

Fig.5.4 shows the result of performance based on NMSE for the robust design algorithm using 30dB SNR and $\sigma_e^2 = 0.001$ and 0.01 at the first-hop both the source, relay destination are equipped with same number of antennas as $N_S = 4, N_R = 4$, and $N_D = 4$. The number of transmitter node is set at $K = 2$ and the destination receiver node $L = 3$. In the second-hop, the NMSE response of the proposed robust design algorithm is plotted. Based on the observation of the results obtained, it shows that the NMSE of the robust design algorithm increases with increasing the number of the destination.

5.3.1 Summary of the chapter

In this chapter, a robust transceiver design for non-regenerative multicasting MIMO relay system from multiple sources is investigated and optimal transmitter, relay and receiver precoding matrices are derived with the assumption that the CSI is unknown and has to be estimated. Numerical simulations are used to verify the proposed design scheme with the FCSI scheme. The simulation results show that the proposed scheme outperforms the existing FCSI scheme.

Chapter 6

Conclusions and Future Work

In the next generation wireless network, both transmitters and users equipment will be equipped with multiple antennas to meet the future demand of mobile internet and achieve better coverage and wireless link reliability for multiple sources multicasting communication systems. In this research, advanced signal processing algorithms are developed for multiple source multicasting with unknown CSI being taken into consideration and numerical analysis is used to validate the proposed transceiver design scheme.

6.1 Conclusions

Suboptimal transceiver design for non-regenerative multicasting MIMO relay system is investigated under channel uncertainties. In Chapter 3, the suboptimal relay and receiver design problem has been considered for the non-regenerative MIMO relay communication system based on MMSE criterion. In the proposed design, it is assumed that channel uncertainty condition is considered between the source-relay and relay-destination links. In the proposed design, nonconvex problem is converted into convex problem using SDP and the problem is solved by conventional optimization tool. Simulation results demonstrate the effectiveness of the proposed design.

Then in Chapter 4, linear non-regenerative multiple source multicasting MIMO relay technique is proposed to minimize the MSE of the signal waveform estimation at the destination node. In the proposed design, the existing results are generalized on the structure of the optimal relay amplifying matrix. In the proposed design, it is assumed that channel uncertainty condition is considered between the relay-destination link and the source-destination link. In the proposed design algorithm, the nonconvex optimization problem is converted into convex optimization problem and solved by CVX programming tool box. Simulation results show that the proposed algorithm performance closes to the existing full CSI algorithm.

Finally in Chapter 5, robust multicasting optimization problem is considered in the uplink and downlink multiuser MIMO relay system where one transmitter multicasts common message to multiple receivers through a relay node. Joint source and relay precoding design problem is investigated for multicasting non-regenerative MIMO relay system. In the proposed design scheme, the transmitter, relay, and receiver matrices are jointly optimized to minimize the maximal MSE of the signal waveform estimation among all receivers subject to power constraints at the transmitter and relay node. Due to the computation complexity of the proposed design scheme, a low complexity design scheme is proposed with moderate approximation. In particular, it is shown that under (moderately) high source-relay link SNR assumption, both proposed transceiver design schemes are formulated as standard SDP problems and are efficiently solved using existing solvers.

6.2 Future Works

In this thesis, a few advanced signal processing algorithms have been developed for non-regenerative multicasting MIMO relay systems with the assumption that the wireless channels undergo channel uncertainty conditions such as partial CSI and channel estimation errors. However, there are still many possibilities for extending this research work. In Chapter 3, the optimal structure of the non-regenerative MIMO relay precoding matrix has been derived with the assumption that the relay knows the CCI of all the links. However, in the study, optimization of the receiver matrix has been omitted. Hence, in the future work, the omitted parameters can be incorporated to obtain a closed form solution.

It will also be interesting to investigate the performance of the non-regenerative multicasting MIMO relaying algorithm in Chapter 4 with the assumption that the relay knows the mean and covariance information of all the channel links. Further, in the Chapter 3 and 4, it has been assumed that there is no direct link between the source and destination nodes. In future work, it can be assumed that the direct link between the source and destination nodes can be considered in the proposed transceiver design.

Recently, there has been a growing interest on beamforming problems for multicasting in the non-regenerative MIMO relay systems. The existing dual-hop non-regenerative multicasting MIMO relay scheme has been extended to investigate under robust channel model for mitigating the channel estimation errors in Chapter 5. The challenging issue of robust transceiver optimization has been investigated for multicasting MIMO relay systems when there is mismatch between the true and estimated channel matrices. The min-max MSE problem has been solved for multicasting multiple data streams. However, the min-max rate problem for multiple-stream multicasting still remains open as a challenging problem.

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