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# **Optimal Solution with Low Computational Complexity for MIMO DF Relay Networks**

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**ABSTRACT:** In this paper, the optimal cooperative beam forming design for multiple input multiple output (MIMO) decode-and-forward relay channels. The source and relay node having multiple antennas and the destination node having single antenna. We derive the mathematical expression to identify the properties of optimal solution. We derive a low complexity explicit expression for the optimal beam forming vectors for specific scenario. Extensive simulation results can achieve the optimal beam forming design for the MIMO DF relay channel with low complexity.

**KEYWORDS:** SISO, MIMO, relay, optimal solution, beam forming vector.

## **I. INTRODUCTION**

In radio, multiple-input and multiple-output, or MIMO is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna technology. MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth or increased transmit power. It achieves this goal by spreading the same total transmit power over the antennas to achieve an array gain that improves the spectral efficiency (more bits per second per hertz of bandwidth) and/or to achieve a diversity gain that improves the link reliability (reduced fading). Because of these properties, MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wi-Fi), 4G, 3GPP Long Term Evolution, WiMAX and HSPA+. MIMO can be sub-divided into three main categories pre coding, spatial multiplexing, or SM and diversity coding. When the receiver has multiple antennas, the transmit beam forming cannot simultaneously maximize the signal level at all of the receive antennas, and pre coding with multiple streams is often beneficial.[1] Relay channel is used to communicate both the source and destination node. The use of relay is reliable communication, spectral efficiency improvement. Two types of relay protocols i) amplify-and-forward(AF), relay channel is amplify the signal and forwards the signal to destination, and ii)decode-and-forward(DF), the relay decodes the signals and then forward the re-encoded information to the destination [2]. The DF relay channel has greater signal processing capabilities than the AF relay channel.

## **II. SURVEY OF MIMO RELAY CHANNELS**

The MIMO relay channel is used to improve the network capacity. Some beam forming designs are based on AF channel and other was DF channel. In the previous scenarios source, relay, destination nodes are having single antenna. The linear pre coding techniques are used for balanced linear pre coders. Relay technologies is measured and considered in the consistency process of next invention communication systems such as 3GPP LTE-Advanced, IEEE 802.16j, and IEEE 802.16m. Three relay broadcast schemes are then summarized and evaluated in terms of transmission effectiveness under different radio channel conditions. [3]. Joint diversity is a communication technique, somewhere multiple terminals collection their resources to form a virtual antenna array that realizes spatial diversity gain in a distributed fashion. We observe the basic structure block of cooperative diversity systems, a simple fading relay channel where the source, destination, and relay terminals are each equipped with single antenna transceivers. The relay terminal operates in either the amplify-and-forward (AF) or decode-and-forward (DF) modes. For each protocol, we study the ergodic and outage capacity behavior under the AF and DF modes of relaying. We

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evaluate the spatial diversity performance of the various protocols and find that full spatial diversity (second-order in this case) is achieved by certain protocols provided that appropriate power control is employed [4]. In both standards, multiple-input multiple-output antenna technologies play an important role in meeting the 4G requirements. The function of MIMO technologies is one of the most essential distinctions between 3G and 4G. It not only enhances the conventional point-to-point link, but also enables new types of links such as downlink multiuser MIMO. A large family of MIMO techniques has been developed for various links and with various amounts of available channel state information in both IEEE 802.16e/m and 3GPP LTE/LTE-Advanced [5]. We investigate the design of the RD cooperative pre coder and derive an asymptotically optimal solution. We analytically show that, in the worst case, the proposed scheme is within  $\frac{1}{2}$  bit per transmit antenna of the asymptotic sum-capacity of the MIMO TWRC. [6]. Upper limits are derived from cut-set arguments, and lower limits track from an argument involving un coded transmission. A new example where a simple cut-set upper bound is achievable and one more example where encoded transmission achieves optimal performance. The findings are illustrated by geometric interpretations. This is a network joint source-channel coding problem, and it is well known that the source-channel separation theorem does not extend to this case [7]. Two users exchange information via a non-regenerative half-duplex two-way MIMO relay and each of the two users and the relay is equipped with multiple antennas. We study the design of the spatial source covariance matrices (or source matrices) at the two users and the spatial transformation matrix (or relay matrix) at the relay to maximize the achievable weighted sum rate of the system [8].

The diversity performance is a general cooperative transmission system prepared with non regenerative fixed gain relays in flat fading channels. Through outage possibility and diversity analysis, derive the diversity array of a two-hop cooperative transmission system when the relay has an arbitrary fixed gain. It is found that the end-to-end diversity order in such two-hop system is different from that of a non regenerative system with channel state information (CSI)-assisted relays. Simulation results are provided to verify our analytical results[9]. We evaluate secrecy rates in cooperative relay beam forming in the presence of imperfect channel state information (CSI) and multiple eavesdroppers. A source-destination pair aided by  $k$  out of  $M$  relays,  $1 \leq k \leq M$ , using decode-and-forward relay beam forming is considered. We compute the worst case secrecy rate with imperfect CSI in the presence of multiple eavesdroppers, where the number of eavesdroppers can be more than the number of relays[10]. The use of multiple antennas at both ends of a wireless link, popularly known as multiple-input multiple-output (MIMO) wireless, has been shown to offer significant improvements in spectral efficiency and link reliability through spatial multiplexing and space-time coding, respectively. It demonstrates that similar performance gains can be obtained in wireless relay networks employing terminals with MIMO capability.

We consider a setup where a designated source terminal communicates with a designated destination terminal, both equipped with  $M$  antennas, assisted by  $K$  single-antenna or multiple-antenna relay terminals using a half-duplex protocol [11]. For a decode-and-forward (DF) multiple-input-multiple-output (MIMO) relay channel, propose a new partial-information relaying scheme that adaptively controls the number of streams to be forwarded to the destination. In the first transmission phase, a source broadcasts data streams it consist of non forwarding and forwarding streams. In the second transmission phase, a relay forwards only forwarding streams to the destination, and a destination node decodes both non forwarding and forwarding streams by consecutive interference cancellation. Consider the two possible scenarios according to the ease of use of the channel-state information (CSI) at the source. The first state is that no CSI is presented at the source, and therefore, a source node broadcasts data streams with equal power allocation. In this state, the number of data streams to be forwarded by the relay is determined according to the available CSI at the relay. For the second scenario, where the perfect CSI is available at the source, we propose a linearly combined pre coding matrix for that rate maximization.

### III. ZERO FORCING PRECODER FOR MIMO DF RELAY CHANNEL

Precoding is a generalization of beamforming to support multi-stream (or multi-layer) transmission in multi-antenna wireless communications. In conventional single-stream beamforming, the same signal is emitted from each of the transmit antennas with appropriate weighting (phase and gain) such that the signal power is maximized at the receiver output. When the receiver has multiple antennas, single-stream beamforming cannot simultaneously maximize the signal level at all of the receive antennas. In order to maximize the throughput in multiple receive antenna systems,

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multi-stream transmission is generally required. In point-to-point systems, precoding means that multiple data streams are emitted from the transmit antennas with independent and appropriate weightings such that the link throughput is maximized at the receiver output. In multi-user MIMO, the data streams are intended for different users (known as SDMA) and some measure of the total throughput (e.g., the sum performance or max-min fairness) is maximized. In point-to-point systems, some of the benefits of precoding can be realized without requiring channel state information at the transmitter, while such information is essential to handle the inter-user interference in multi-user systems. Precoding in the downlink of cellular networks, known as network MIMO or coordinated multipoint (CoMP) is a generalized form of multi-user MIMO that can be analyzed by the same mathematical techniques.

There are three types in linear precoding technique

1. MMSE precoding,
2. MRT precoding, and
3. ZF precoding.

## A. Precoding For Multi User MIMO System

In multi-user MIMO, a multi-antenna transmitter communicates simultaneously with multiple receivers (each having one or multiple antennas). This is known as space-division multiple access (SDMA). From an implementation perspective, precoding algorithms for SDMA systems can be sub-divided into linear and nonlinear precoding types. The capacity achieving algorithms are nonlinear, but linear precoding approaches usually achieve reasonable performance with much lower complexity. Linear precoding strategies include maximum ratio transmission (MRT), zero-forcing (ZF) precoding, and transmit Wiener precoding. There are also precoding strategies tailored for low-rate feedback of channel state information, for example random beamforming. Nonlinear precoding is designed based on the concept of dirty paper coding (DPC), which shows that any known interference at the transmitter can be subtracted without the penalty of radio resources if the optimal precoding scheme can be applied on the transmit signal. While performance maximization has a clear interpretation in point-to-point MIMO, a multi-user system cannot simultaneously maximize the performance for all users. This can be viewed as a multi-objective optimization problem where each objective corresponds to maximization of the capacity of one of the users. The usual way to simplify this problem is to select a system utility function; for example, the weighted sum capacity where the weights correspond to the system's subjective user priorities. Furthermore, there might be more users than data streams, requiring a scheduling algorithm to decide which users to serve at a given time instant.

## B. Linear Precoding With Full Channel State Information

This suboptimal approach cannot achieve the weighted sum rate, but it can still maximize the weighted sum performance (or some other metric of achievable rates under linear precoding). The optimal linear precoding does not have any closed-form expression, but it takes the form of a weighted MMSE precoding for single-antenna receivers. The precoding weights for a given user are selected to maximize a ratio between the signal gain at this user and the interference generated at other users (with some weights) plus noise. Thus, precoding can be interpreted as finding the optimal balance between achieving strong signal gain and limiting inter-user interference. Finding the optimal weighted MMSE precoding is difficult, leading to approximate approaches where the weights are selected heuristically. A common approach is to concentrate on either the numerator or the denominator of the mentioned ratio; that is, maximum ratio transmission (MRT)<sup>[7]</sup> and zero-forcing (ZF) precoding. MRT only maximizes the signal gain at the intended user. MRT is close-to-optimal in noise-limited systems, where the inter-user interference is negligible compared to the noise.

ZF precoding aims at nulling the inter-user interference, at the expense of losing some signal gain. ZF precoding can achieve performance close to the sum capacity when the number of users is large or the system is interference-limited (i.e., the noise is weak compared to the interference). A balance between MRT and ZF is obtained by the so-called regularized zero-forcing (also known as signal-to-leakage-and-interference ratio (SLNR) beamforming and transmit Wiener filtering). All of these heuristic approaches can also be applied to receivers that have multiple antennas. Also for multiuser MIMO system setup, another approach has been used to reformulate the weighted sum rate optimization problem to a weighted sum MSE problem with additional optimization MSE weights for each symbol in. However, still this work is not able to solve this problem optimally (i.e., its solution is suboptimal). On the other hand, duality approach also considered in and to get sub-optimal solution for weighted sum rate optimization. Note

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that the optimal linear precoding can be computed using monotonic optimization algorithms, but the computational complexity scales exponentially fast with the number of users. These algorithms are therefore only useful for benchmarking in small systems.

### C. Linear Precoding With Limited Channel State Information

In practice, the channel state information is limited at the transmitter due to estimation errors and quantization. Inaccurate channel knowledge may result in significant loss of system throughput, as the interference between the multiplexed streams cannot be completely controlled. In closed-loop systems, the feedback capabilities decide which precoding strategies that is feasible. Each receiver can either feedback a quantized version of its complete channel knowledge or focus on certain critical performance indicators (e.g., the channel gain) If the complete channel knowledge is fed back with good accuracy, then one can use strategies designed for having full channel knowledge with minor performance degradation.

Zero-forcing precoding may even achieve the full multiplexing gain, but only provided that the accuracy of the channel feedback increases linearly with signal-to-noise ratio (in dB). Quantization and feedback of channel state information is based on vector quantization, and codebooks based on Grassmannian line packing have shown good performance. Other precoding strategies have been developed for the case with very low channel feedback rates. Random beamforming (or opportunistic beamforming) was proposed as a simple way of achieving good performance that scales like the sum capacity when the number of receivers is large. In this suboptimal strategy, a set of beamforming directions are selected randomly and users feed back a few bits to tell the transmitter which beam gives the best performance and what rate they can support using it. When the number of users is large, it is likely that each random beamforming weight will provide good performance for some user. In spatially correlated environments, the long-term channel statistics can be combined with low-rate feedback to perform multi-user precoding. As spatially correlated statistics contain much directional information, it is only necessary for users to feed back their current channel gain to achieve reasonable channel knowledge. As the beamforming weights are selected from the statistics, and not randomly, this approach outperforms random beamforming under strong spatial correlation.

- It is a method of beamforming for narrowband signals where we want to have a simple way of compensating delays of receiving signals from a specific source at different elements of the antenna array.
- If the transmitter knows the downlink channel state information (CSI) perfectly, ZF-precoding can achieve almost the system capacity when the number of users is large

### D. Zero Forcing Precoder

Zero-forcing (or Null-Steering) precoding is a method of spatial signal processing by which the multiple antenna transmitters can null multiuser interference signals in wireless communications. Regularized zero-forcing precoding is enhanced processing to consider the impact on a background noise and unknown user interference,<sup>[1]</sup> where the background noise and the unknown user interference can be emphasized in the result of (known) interference signal nulling. In particular, Null-Steering is a method of beamforming for narrowband signals where we want to have a simple way of compensating delays of receiving signals from a specific source at different elements of the antenna array. Otherwise we first need to compensate the delays and then to sum them up. To reach this goal, we may only add the weighted version of the signals with appropriate weight values. We do this in such a way that the frequency domain output of this weighted sum produces a zero result. This method is called null steering. The generated weights are of course related to each other and this relation is a function of delay and central working frequency of the source.

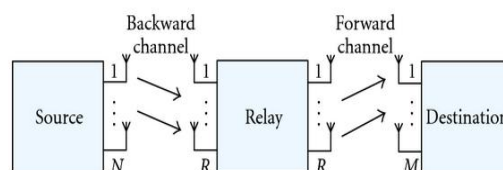


Fig 4.1 system model of three channel MIMO channel

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Figure 4.2 shows the transmission technique between the sender and receiver. Here both sender and receiver having multiple antennas.

A joint beam forming algorithm for a multiuser wireless information and power transfer (MU-WIPT) system that is compatible with the conventional multiuser multiple input multiple output (MU-MIMO) system. The proposed joint beam forming vectors are initialized using the well established MU-MIMO zero-forcing beam forming (ZFBBF) and are further updated to maximize the total harvested energy of energy harvesting (EH) users and guarantee the signal to interference plus noise ratio (SINR) constraints of the co-scheduled information decoding (ID) users. When ID and EH users are simultaneously served by joint beam forming vectors, the harvested energy can be increased at the cost of an SINR loss for ID users. To characterize the SINR loss, the target SINR ratio, is introduced as the target SINR (i.e., SINR constraint) normalized by the received SINR achievable with ZFBBF. Based on that ratio, the sum rate and harvested energy obtained from the proposed algorithm are analyzed under perfect/imperfect channel state information at the transmitter (CSIT).

Through simulations and numerical results, we validate the derived analyses and demonstrate the EH and ID performance compared to both state of the art and conventional schemes. Three types of cooperative MIMO schemes in cellular systems:

*i) Co-MP (Co-Ordinate Multi-Point Transmission)*

Co-MP is an emerging technique to combat inters cell interference and improves cell edge performance. The system architecture is illustrated in Fig. The idea is to share data and channel state information (CSI) among neighbouring base stations (BSs) to coordinate their transmissions in the downlink and jointly process the received signals in the uplink. Co-MP techniques can effectively turn otherwise harmful inter cell interference into useful signals, allowing significant power gain, channel rank advantage, and/or diversity gains to be exploited. The promised advantages of Co-MP rely on a high-speed backbone enabling the exchange of information (e.g., data, control information, and CSI) between the BSs. Co-MP has been studied intensively in both academia and industry over recent years, and is a very strong candidate technology for 4G standards. Co-MP systems are only concerned with the BS to mobile station (MS) channels, which are fixed-to-mobile (F2M) channels.

*ii) Fixed Relay*

Fixed relays are low-cost and fixed radio infrastructures without wired backhaul connections. They store data received from the BS and forward to the MSs, and vice versa. Fixed relay stations (RSs) typically have smaller transmission powers and coverage areas than a BS. They can be deployed strategically and cost effectively in cellular networks to extend coverage, reduce total transmission power, enhance the capacity of a specific region with high traffic demands, and/or improve signal reception. By combining the signals from the relays and possibly the source signal from the BS, the MS is able to exploit the inherent diversity of the relay channel. The disadvantages of fixed relays are first the additional delays introduced in the relaying process, and second the potentially increased levels of interference due to frequency reuse at the RSs. As the most mature cooperative MIMO technology, fixed relay has attracted significant support in major cellular communication standards.

The IEEE 802.16j specification has incorporated fixed relays to enhance Wi-MAX performance. Fixed relay is also a very strong candidate technology for 4G, with possible mesh extensions in a later standard release. As shown in Fig, fixed relay systems involve different types of links, including BS-MS, BS-RS, RS-RS, and RSMS links. The BS-RS and RS-RS channels are fixed-to-fixed (F2F) channels, while the BS-MS and RS-MS channels are F2M channels.

*iii) Mobile Relay*

Mobile relays differ from fixed relays in the sense that the RSs are mobile and are not deployed as the infrastructure of a network. Mobile relays are therefore more flexible in accommodating varying traffic patterns and adapting to different propagation environments. For example, when a target MS temporarily suffers from bad channel conditions or requires relatively high-rate service, its neighboring MSs can help to provide multi-hop coverage or increase the data rate by relaying information to the target MS. Moreover, mobile relays enable faster and lower-cost

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network rollout. Similar to fixed relays, mobile relays can enlarge the coverage area, reduce the overall transmit power, and/or increase the capacity at cell edges.

All key MIMO and MU-MIMO schemes (except diversity-oriented) can be interpreted from previous drawing:

- ❖ A N-antenna beam former can amplify one source (no interference) by a factor N in the average SNR: Beam forming
- ❖ A N-antenna beam former can extract one source and cancel out N – 1 interferers simultaneously: Interference cancelling
- ❖ Transmit beam forming realizes the same benefits/gains at receive beam forming if CSIT is given: Transmit beam forming and interference nulling
- ❖ All N sources can be simultaneously extracted (assuming the other N – 1 are viewed as interferers) by beam former superposition: Spatial multiplexing
- ❖ N sources can be assigned to N distinct users: MU-MIMO, SDMA
- ❖ Some of the N sources may belong to different cells: cooperative multi cell MIMO

In the source phase, the information symbol is first multiplied with a beam forming

Vector  $\mathbf{W}_s = (\omega_{s,1}, \omega_{s,2}, \dots, \omega_{s,N_s})^T$  Before being transmitted from the antenna of source S. We assume that symbol  $x_s$  is gaussianly coded with average power  $P_s$  and  $w_s$  is a unit-norm vector, where

$$\|\mathbf{W}_s\|^2 = |\omega_{s,1}|^2 + |\omega_{s,2}|^2 + \dots + |\omega_{s,N_s}|^2 = \mathbf{1}. \quad (1)$$

Thus, the complex baseband received symbol at D in the source phase is mathematically given by

$$\gamma_{D,S} = \mathbf{h}_{D,S}^T \mathbf{w}_s x_s + n_{D,S} \quad (2)$$

Where  $\mathbf{h}_{D,S}$  denotes the channel gain vector from S to D and  $n_{D,S}$  is scalar additive Gaussian noise with unit variance. It follows that the received signal to noise ratio (SVD) at D during the source phase is given by,

$$\gamma_{D,S} = |\mathbf{h}_{D,S}^T \mathbf{w}_s|^2 P_s \quad (3)$$

Meanwhile, the complex baseband signal vector received at N antennas of node R can be mathematically given by

$$\mathbf{\gamma}_{R,S} = \mathbf{H}_{R,S} \mathbf{w}_s x_s + \mathbf{n}_{D,R} \quad (4)$$

In the relay phase, R forwards its decoded symbol to D using beam forming transmission over its antennas. Similar to the source phase, symbol is also Gaussianly coded, but with average power. Specifically, the symbol is multiplied with a unit-norm beam forming vector

$$\mathbf{w}_r = (\omega_{r,1}, \omega_{r,2}, \dots, \omega_{r,N_r})^T \quad (5)$$

Satisfying,

$$\|\mathbf{W}_r\|^2 = |\omega_{r,1}|^2 + |\omega_{r,2}|^2 + \dots + |\omega_{r,N_r}|^2 = \mathbf{1}, \quad (6)$$

And then transmitted via  $N_r$  antennas. Hence, the complex symbol received at D in the relay phase can be mathematically given by,

$$\mathbf{y}_{D,R} = \mathbf{h}_{D,R}^T \mathbf{w}_r x_r + n_{D,R} \quad (7)$$

Where  $\mathbf{n}_{D,R} \sim \mathcal{CN}(\mathbf{0}, \mathbf{1})$  is scalar additive Gaussian noise with unit variance and denotes the channel gain vector from R to D. It therefore follows that the received SNR at D in the relay phase is given by,

$$\gamma_{D,R} = |\mathbf{h}_{D,R}^T \mathbf{w}_r|^2 P_r. \quad (8)$$

After that, D combines the signal received over the S-D link in the source phase and the signal received from R in the relay phase using the MRC method. Thus the achievable information transmission rate at D in the relay phase is,

$$\mathbf{C}_D = \log_2(\mathbf{1} + \gamma_{D,S} + \gamma_{D,R}). \quad (9)$$

Since it has been well established that the maximum information rate from source S to destination D over the half-duplex DF relay channel is bounded by and, the total achievable information transmission rate at D from S over the MIMO relay Channel can be given by,

$$\mathbf{C}_{DF} = \frac{1}{2} \min\{\mathbf{C}_R, \mathbf{C}_D\} \quad (10)$$

Where the pre-log parameter  $\frac{1}{2}$ , actually captures the time-division feature of the half-duplex relay system.

In the previous Section, we transform the original optimization problem in into an equivalent optimization problem of. However, the optimization problem in (26) is a max-min problem, which is, in general, non-convex and difficult to solve. To derive an effective method for solving this problem, we first discuss several features of the optimal solution in this section. It is obvious that both and are related to the real vector, which motivates the following

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method. Firstly, we formulate a preparatory optimization problem with fixed. We can derive the explicit optimal solution off or a given. The resulting optimal solution, denoted by, can actually be considered as a conditional optimal result. The corresponding maximum of, denoted by, can also be derived. Further, we explore the mapping relation from to and derive some key features of the optimal solution of our original optimization. Finally, we arrive at an efficient algorithm to calculate the optimal beam forming vector.

## IV. RESULT AND DISCUSSION

We show the effectiveness of our proposed optimal design for MIMO DF relay channels through numerical examples.

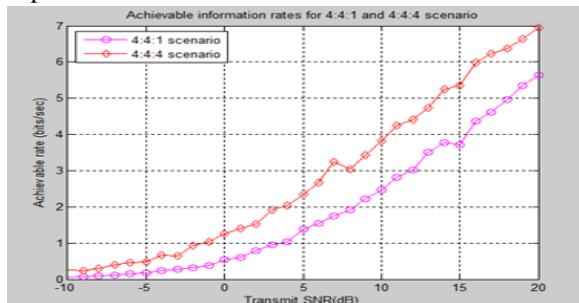


Fig.2. Achivable information rates for 4:4:4 scenario scenario

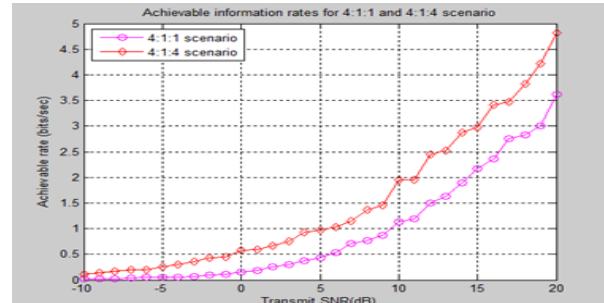


Fig.3. Achivable information rates for 4:1:4 scenario

Figure 2 and 3 shows that by using the optimal beamforming design for 4:4:4 scenario the maximum achievable information rates attained are upto 7(bits/sec) compared to 4:4:1 scenario.

## V. CONCLUSION

The beamforming design for MIMO DF relay channels, where both the source node and relay node are equipped with multiple antennas. We developed an efficient scheme to solve the optimization problem and determine the optimal beamforming vector for MIMO DF relay networks. In existing method source and relay having multiple antennas and destination having single antenna. It achieves the maximum data rate up to 5.8bits/sec. The proposed method achieves maximum data rate up to 7bits/sec. It eliminates the interference value and improving the SNR value.

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