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Relay Beamforming to Mitigate Inter-Relay Interference In Multi-Cell Scenario

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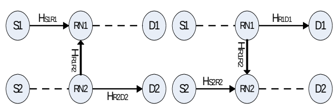
Graphical abstract



Abstract

In relay assisted Long Term Evolution-Advanced (LTE-A) network, enhanced Node B (eNB) autonomously selects different backhaul sub-frame configurations to adopt traffic variations, which might cause inter-relay interference (IRI) between relay nodes (RNs) in adjacent cells. IRI can happen due to asynchronous transmission between adjacent cells, which results in IRI from the access link to the backhaul link of adjacent relay in the downlink direction and vice versa. This causes severe loss in system capacity and introduces high outage probability. In this article, we consider the IRI problem in a multi-cell relaying system. Previous studies consider the beamforming design for cooperative relay network as a single-cell problem, without taking into account the occurrence of IRI. However, the performance of the RN assisted network is limited by the IRI from adjacent RN. A hybrid zero-forcing and singular value decomposition (ZF-SVD) beamforming technique is proposed to eliminate the IRI. Simulation results show that the proposed scheme out-performs the comparable scheme in both the ergodic capacity and outage probability.

Keywords: Beamforming; inter-relay interference; singular value decomposition; zero-forcing, sub-frame misalignment; ergodic capacity, outage probability; LTE-A

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1.0 INTRODUCTION

Long Term Evolution-Advanced (LTE-A) targeted peak data rates of 500 Mbps in uplink and 1 Gbps in downlink, up to 100 MHz bandwidth scalability, increased spectral efficiency up to 30 bps/Hz in downlink and 15 bps/Hz in uplink. To meet those requirements, relay node (RN) has shed new light on improving cell edge capacity, reducing backhaul costs, lowering capital and operating expenditure (CAPEX and OPEX) and enhancing network topology. LTE-A deploys RNs between eNB and user equipment (UE), as a core ingredient to extend the coverage, tolower the infrastructure cost and to forward high data rates to cell edge UEs [1] ,[2].

Type 1 in-band relay node utilizes the same channel on the backhaul and access links. The links are separated by time division multiplexing, to prevent self-interference (due to half-duplex operation). This separation practically is done on the downlink at the RN by configuring the Multicast Broadcast over Single Frequency Network (MBSFN) sub-frames on the access link. The eNB schedules the RNs for relay link transmission using the access link [3].

Ideally, the MBSFN sub-frame should be aligned among all eNBs in a multi-cell environment. However, due to eNB specific traffic and load requirements, the eNB employs different asynchronous sub-frame scheduling. This results in MBSFN sub-frame misalignment, which causes different interferences such as RN to UE, eNB to RN and RN to RN [4].

In a multi-cell scenario, inter-relay interference (IRI) can happen due to the interference between misaligned uplink and downlink transmission sub-frames from adjacent cells. In the downlink direction, the IRI is generated from the access link of RN1 of cell 1 to the backhaul link of RN2 of cell 2 [5-7]. IRI can cause severe loss in system capacity and introduced high outage probability [8-10]. MugenPeng et al. proposed the IRI mitigation in a cooperative amplify-and-forward (AF) relay transmission, where the eNB decodes the UE desired messages from adjacent RNs. Since the RN1 and RN2 receive two messages from UE1 and UE2 respectively, it may also receive interference from other adjacent relays [11]. [12] discusses different scheduling strategies for enhanced Inter-Cell Interference Coordination (eICIC). The scheduling techniques are proposed for orthogonal resource allocation between macro cell and Pico cell, which does not look into the case with relays. In wireless systems, where the relay performs AF operation, co-channel interference remains the main impairment [13], [14].

With the recent advancements in multi-antenna technologies, beamforming is widely used as an interference reduction technique to direct the transmission in the presence of noise and interference. Beamforming not only allows co-channel frequency allocation but also enables spatial removal or filtering of interfering signals. Beamforming is generally proposed to enhance the SINR performance in the uplink and downlink at the UE [15-17]. Reference [18] considers multiple pairs of single-antenna users and multiple distributed single-antenna relays in a two-way relay network. The self-interference and inter-pair interferences are removed using ZF. However, the multi-cell scenario and IRI are not considered.

Reference [19] studies the performance of MIMO-relaying scheme for the TDD downlink scenario in heterogeneous network, by applying proportional fair based zero-forcing (PF-ZF) beamforming with greedy algorithm for picking UE served by eNB or RN. However, the sub-frames misalignment issue is not considered. Therefore, the interference of the heterogeneity network would affect system capacity. A comprehensive literature on different interference management schemes such as fractional frequency reuse can be found in [20].

In this paper, we study the sub-frame misaligned multi-cell scenario with the problem of IRI. A hybrid zero-forcing and singular value decomposition (ZF-SVD) beamforming is proposed to remove IRI and at the same time increase the system capacity.

The article is organized as follows. Sub-Section 1.1 reviews the IRI interference Scenario. In Section 2, the system model is introduced. The beamforming matrices design is discussed in Section 3. Numerical simulations are given in Section 4 and conclusion is drawn in Section 5.

1.1 Inter-Relay Interference Scenario

The misaligned downlink sub-frame configurations of cell 1 and cell 2 with frequency reuse factor 1 (co-channel) are depicted in Figure 1. The IRI (from RN2 to RN1) occurs in sub-frame 1 and 3 when RN2 is serving UE2 on its access link and RN1 is receiving data from eNB1 on its backhaul link. Similarly, the IRI (from RN1 to RN2) occurs in sub-frame 7 and 8 when RN1 isserving its UE1 on its access link and RN2 is receiving data from eNB2 on its backhaul link. Figure 2 shows the scenario where RN1 interferes the reception at RN2.

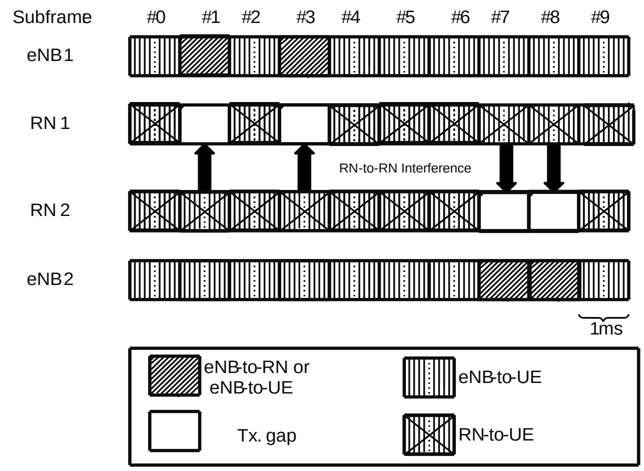

Figure 1 FDD Downlink LTE-Advanced frame structure for Type1 RNs Misalignment of backhaul sub frames is depicted

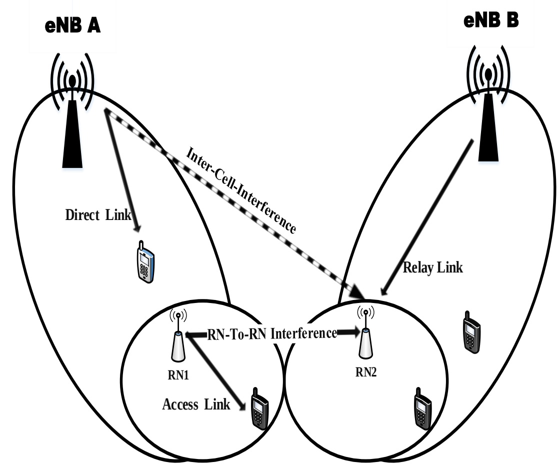

Figure 2 Downlink IRI due to backhaul subframe misalignment

2.0 SYSTEM MODEL

Figure 3 considers the adjacent two cells scenario where sources S1, S2, decode-and-forward (DF) relays RN1, RN2, and destination D1, D2 nodes are equipped with MIMO antennas M, R and N antennas respectively. In the downlink, the source is eNB and the destination is UE while in the uplink, the source is the UE and the destination is eNB. We assume that the direct link between S and D is negligible due to extreme path loss. The channels are assumed to have i.i.d. slow varying Rayleigh fading distribution. The noise **n** is an additive white Gaussian noise (AWGN) with complex normal distribution with zero mean and unit covariance matrix.

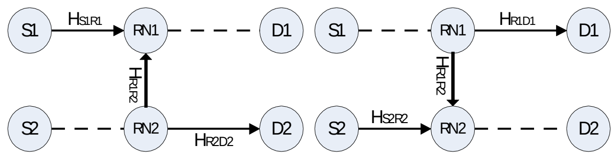

Figure 3 System model

At time slot (t), the source S2 transmits the message $\mathbf{x}_{S2}$ to RN2, as in (1), while RN1 transmits the decoded received signal at previous time slot (t − 1) to D1 in the same frequency channel. Therefore, RN1 will cause interference to RN2 through the inter-relay interference (IRI) $\mathbf{H}_{R1R2}$ channel. The received signal at RN2 is

$$\mathbf{y}_{R2}(t) = \mathbf{H}_{S2R2}\mathbf{F}_{S2}\mathbf{x}_{S2} + \mathbf{H}_{R1R2}\mathbf{W}_{R1}\mathbf{x}_{R1} + \mathbf{n}_{R2}, \quad (1)$$

The following equation shows the received signal at RN2, after the received beamforming is performed

$$\mathbf{G}_2\mathbf{y}_{R2}(t) = \mathbf{G}_2\mathbf{H}_{S2R2}\mathbf{F}_{S2}\mathbf{x}_{S2} + \mathbf{G}_2\mathbf{H}_{R1R2}\mathbf{W}_{R1}\mathbf{x}_{R1} + \mathbf{G}_2\mathbf{n}_{R2}, \quad (2)$$

Where $\mathbf{x}_{S2} \in \mathbb{C}^{M\times 1}$ is the transmitted signal vector from S2 which has a normalised power $\mathrm{E}(\mathbf{x}_{S2}\mathbf{x}_{S2}^{\mathbf{H}}) = 1$. The superscript $(.)^{\mathbf{H}}$ and $\mathrm{E}(.)$ indicate the Hermitian transpose and expectation respectively. $\mathbf{F}_{S2} \in \mathbb{C}^{M\times R}$ is the transmit beamforming matrix of S2. $\mathbf{H}_{S2R2} \in \mathbb{C}^{R\times M}$ is the channel matrix between S2 and RN2. $\mathbf{H}_{R1R2} \in \mathbb{C}^{R1\times R2}$ is the inter-relay channel between RN2 and RN1. $\mathbf{G}_2 \in \mathbb{C}^{R\times M}$ is the receive beamforming matrix of RN2. $\mathbf{W}_1 \in \mathbb{C}^{R1\times R2}$ is the transmit beamforming matrix of RN1. $\mathbf{x}_{R1} \in \mathbb{C}^{M\times 1}$ is the transmitted signal from RN1. Vector $\mathbf{n}_{R2}$ is the additive white Gaussian noise (AWGN) at RN with $\mathrm{E}(\mathbf{n}_2\mathbf{n}_2^{\mathbf{H}}) = \sigma^2 I$ and it is uncorrelated to $\mathbf{x}_{S2}$. At the same time, the received signal at D1 can be expressed as

$$\mathbf{Q}_1\mathbf{y}_{D1}(t) = \mathbf{Q}_1\mathbf{H}_{R1D1}\mathbf{W}_{R1}\mathbf{x}_{R1} + \mathbf{Q}_1\mathbf{n}_{D1}. \quad (3)$$

Where $\mathbf{Q}_1 \in \mathbb{C}^{N\times R}$ is the receive beamforming matrix at the destination and $\mathbf{H}_{R1D1} \in \mathbb{C}^{M\times R}$ is the channel matrix between D1 and RN1. The noise vector at D1 has zero mean and covariance $\mathrm{E}(\mathbf{n}_D\mathbf{n}_D^{\mathbf{H}}) = \sigma^2 I$.

At time slot (t + 1), S1 transmit data to RN1. RN2 which is serving D2 causes co-channel interference to RN1 through the IRI channel $\mathbf{H}_{R1R2}$. The received signals at RN1 and D2 are as follow

$$\mathbf{y}_{R1}(t+1) = \mathbf{H}_{S1R1}\mathbf{F}_{S1}\mathbf{x}_{S1} + \mathbf{H}_{R1R2}\mathbf{W}_{R2}\mathbf{x}_{R2} + \mathbf{n}_{R1}, \quad (4)$$

$$\mathbf{G}_1\mathbf{y}_{R1}(t+1) = \mathbf{G}_1\mathbf{H}_{S1R1}\mathbf{F}_{S1}\mathbf{x}_{S1} + \mathbf{G}_1\mathbf{H}_{R1R2}\mathbf{W}_{R2}\mathbf{x}_{R2} + \mathbf{G}_1\mathbf{n}_{R1}, \quad (5)$$

$$\mathbf{Q}_2\mathbf{y}_{D2}(t) = \mathbf{Q}_2\mathbf{H}_{R2D2}\mathbf{W}_{R2}\mathbf{x}_{R2} + \mathbf{Q}_2\mathbf{n}_{D2}. \quad (6)$$

Where $\mathbf{F}_{S1}$ is the transmit beamforming matrix of S1. The individual transmit power at the source S1, S2 and relay RN1 and RN2 are $Tr\{\mathbf{F}_{S1}\mathbf{F}_{S1}^H\} = 1$, $Tr\{\mathbf{F}_{S2}\mathbf{F}_{S2}^H\} = 1$, $Tr\{\mathbf{W}_{R1}\mathbf{W}_{R1}^H\} = 1$, $Tr\{\mathbf{W}_{R2}\mathbf{W}_{R2}^H\} = 1$, respectively.

3.0 PROPOSED BEAMFORMING MATRICES DESIGN

In the section, the proposed beamforming matrices at the relay and destination are presented. The default source transmit beamforming matrix is $\mathbf{F}_S = \mathbf{I}$. In this paper, the hybrid ZF and SVD beamforming scheme is proposed. In particular, the RNs apply ZF beamforming to cancel the interferences from the other transmitting relay (interferer). The RN–D link then applies SVD beamforming to maximise the capacity performance. The details of the proposed ZF-SVD beamforming scheme and baseline scheme are discussed in the following subsections.

3.1 Proposed Receive Beamforming at Relay: ZF Beamforming

The capacity of the system can be maximised by designing the relay receive matrix that suppresses the interference from the other transmitting relay. At the relay, the weighting matrix **G** has been designed to eliminate the IRI. To cancel the IRI, the main idea is to project the effective IRI channel to a lower dimensional subspace, known as the null-space, such that

$$\mathbf{G}_2 = \mathrm{null}(\mathbf{H}_{R1R2}\mathbf{W}_{R1}), \quad (7)$$

$$\mathbf{G}_1 = \mathrm{null}(\mathbf{H}_{R1R2}\mathbf{W}_{R2}). \quad (8)$$

With these criteria, (2) and (5) reduces to

$$\mathbf{G}_2\mathbf{y}_{R2}(t) = \mathbf{G}_2\mathbf{H}_{S2R2}\mathbf{F}_{S2}\mathbf{x}_{S2} + \mathbf{G}_2\mathbf{n}_{R2}, \quad (9)$$

$$\mathbf{G}_1\mathbf{y}_{R1}(t+1) = \mathbf{G}_1\mathbf{H}_{S1R1}\mathbf{F}_{S1}\mathbf{x}_{S1} + \mathbf{G}_1\mathbf{n}_{R1}, \quad (10)$$

Equations (9) and (10) implies the dimension of the null-space of $\mathbf{H}_{R1R2}$ must be R ≥ 2M which means that the number of relay antennas R must be at least two times greater than the total number of transmit antennas M.

3.2 Proposed SVD Beamforming at RN-D Link

The relay to destination channel can be decomposed by SVD method into the following

$$\mathbf{H}_{R1D1} = \mathbf{U}_{R1}\mathbf{\Lambda}_{R1}\mathbf{V}_{R1}^{\mathbf{H}}, \quad (11)$$

$$\mathbf{H}_{R2D2} = \mathbf{U}_{R2}\mathbf{\Lambda}_{R2}\mathbf{V}_{R2}^{H}, \quad (12)$$

Where $\mathbf{\Lambda}_{R1}$, $\mathbf{\Lambda}_{R2}$ are the diagonal matrices with singular values of $\mathbf{H}_{R1D1}$ and $\mathbf{H}_{R2D2}$ with a dimension equals to the rank of $\mathbf{H}_{R1D1}$ and $\mathbf{H}_{R2D2}$ respectively. The matrix denoted by $\mathbf{V}_{R1}$ where $\mathbf{V}_{R1} = \{\mathbf{v}_{R1,1}, \mathbf{v}_{R1,2}, ..., \mathbf{v}_{R1,R}\}$ is the right singular matrix of $\mathbf{H}_{R1D1}$, which represents $\mathbf{W}_{R1}$ i.e. $\mathbf{W}_{R1} = [\mathbf{v}_{R1,1} \quad \mathbf{v}_{R1,2}]$. $\mathbf{U}_{R1}$ is the left singular matrix of $\mathbf{H}_{R1D1}$ represented by $\mathbf{Q}_1$ i.e. $\mathbf{Q}_1 = \mathbf{U}_{R1}^{H}$. Similarly the right and left singular matrices of $\mathbf{H}_{R2D2}$ represented by $\mathbf{V}_{R2}$ and $\mathbf{U}_{R2}$ respectively i.e. $\mathbf{W}_{R2} = [\mathbf{v}_{R2,1} \quad \mathbf{v}_{R2,2}]$, and $\mathbf{Q}_2 = \mathbf{U}_{R2}^{H}$.

3.3 Proposed Capacity Calculation

The total channel capacity is the minimum between the source-relay capacity C_{SR} and relay-destination capacity C_{RD}, such that

$$C = \frac{1}{2}\min(C_{SR}, C_{RD}). \quad (13)$$

Due to the ZF beamforming operation which removes the IRI, the capacity of source-relay link is only affected by the noise. Omitting the subscript of the channels of S1, S2, RN1 and RN2, the capacity of S to RN link can be generalised as

$$C_{SR} = \log_2 \det\left(\mathbf{I}_R + \frac{SNR}{M}(\mathbf{G}\mathbf{H}_{SR}\mathbf{F}_S\mathbf{F}_S^H\mathbf{H}_{SR}^H\mathbf{G}^H)(\mathbf{G}^H\boldsymbol{\sigma}^2\mathbf{G}^H)^{-1}\right), \quad (14)$$

The relay-destination channel is decomposed by SVD into non-interfering parallel streams, which is only affected by the noise. Omitting the subscript of the channels of S1, S2, RN1 and RN2, the capacity of RN to D link can be generalised as

$$C_{RD} = \log_2 \det\left(\mathbf{I}_N + \frac{SNR}{R}(\mathbf{\Lambda}_{R2}^2)(\boldsymbol{\sigma}^2)^{-1}\right). \quad (15)$$

3.4 Baseline Scheme

We consider the scheme in [21] with unit power constraint as a baseline scheme. The weighting matrices $\mathbf{F}_{S2}$ and $\mathbf{G}_2$ are designed according to the channels $\mathbf{H}_{S2R2}$ and $\mathbf{H}_{R2D2}$ respectively. The SVD of $\mathbf{H}_{S2R2}$ given as

$$\mathbf{H}_{S2R2} = \mathbf{U}_{R2}\mathbf{\Lambda}_{R2}\mathbf{V}_{R2}^{H}, \quad (16)$$

Such that $\mathbf{F}_{S2} = \mathbf{V}_{R2}$, $\mathbf{G}_2 = \mathbf{G}\mathbf{U}_{R2}^{H}$ where

$$\mathbf{G} = \mathbf{H}_{R2D2}^{H}(\mathbf{H}_{R2D2}\mathbf{H}_{R2D2}^{H})^{-1}. \quad (17)$$

The achievable capacity of S-RN link can be denoted as

$$C_{Base-SR} = \log_2 \det\left(\mathbf{I}_R + \frac{SNR}{M}(\mathbf{G}\mathbf{H}_{SR}\mathbf{H}_{SR}^H\mathbf{G}^H)(\mathbf{H}_{R1R2}\mathbf{H}_{R1R2}^H)^{-1}\right), \quad (18)$$

And the achievable capacity of RN − D link

$$C_{Base-RD} = \log_2 \det\left(\mathbf{I}_N + \frac{SNR}{R}(\mathbf{H}_{RD}\mathbf{G}\mathbf{G}^H\mathbf{H}_{RD}^H)(\boldsymbol{\sigma}^2)^{-1}\right), \quad (19)$$

Where $SNR = P_t/\sigma_r^2$, P_t is the total power. The total channel capacity of the base line scheme is

$$C_{Base} = \frac{1}{2}\min(C_{Base-SR}, C_{Base-RD}). \quad (20)$$

4.0 NUMERICAL RESULTS

This section discusses the numerical simulations of the proposed scheme compared to the baseline scheme. We assume the source and RNs have unit transmit power. The curves are generated by the Monte Carlo simulation technique which averages over 10,000 channel realizations, corresponding to M × R × N number of antennas at the source, relay and destination.

Figure 4 shows the outage probability versus SNR of the proposed ZF-SVD scheme, equal gain beamforming without interference cancellation and the baseline scheme in [21]. We can observe the detrimental effect of IRI in Figure 4. The proposed ZF-SVD beamforming achieves the lowest outage probability than both the equal gain beamforming and baseline scheme due to the effective mitigation of the IRI in the back-haul link. This justifies the need to manage the IRI by ensuring that the system performance is not severely degraded. As predicted, the performance of the hybrid ZF-SVD beamforming scheme outperforms the comparable schemes.

Figure 5 elucidates the outage probability versus SNR of the proposed ZF-SVD scheme at various target data rates. As the target data rate increases. The result shows that the proposed scheme is effective at all data rates, as evident by the parallel slope of the curves. The slope of the curve denotes the diversity gain, which indicates how robust the system is. It is also clear that the lower target data rates naturally produces lower outages.

To put things in perspective, we elucidates in Figure 6 the ergodic capacity versus SNR of the proposed ZF-SVD beamforming compared with the baseline scheme in [21], equal gain beamforming and matched filter without interference cancellation. The proposed ZF-SVD scheme delivers the highest ergodic capacity.

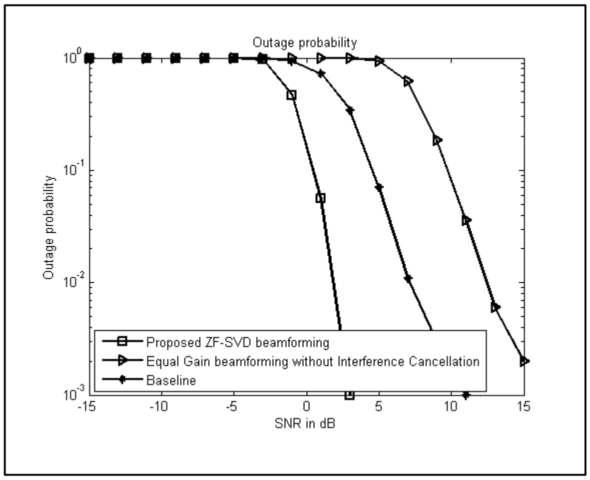

Figure 4 Outage Probability versus SNR with M = 2,N = 4,R = 2 and Rate=3 bits/s/Hz

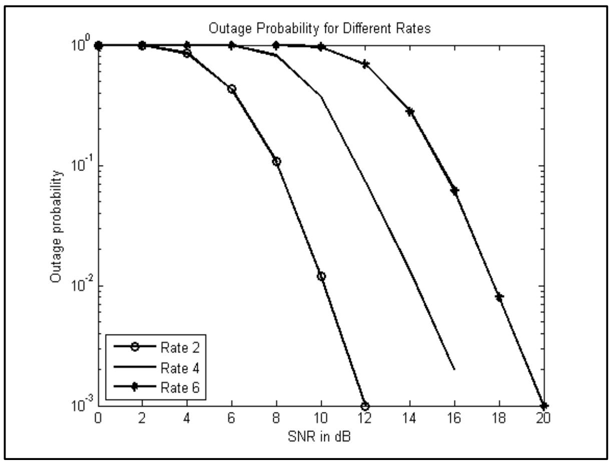

Figure 5 Outage probability of the proposed ZF-SVD at differentrates

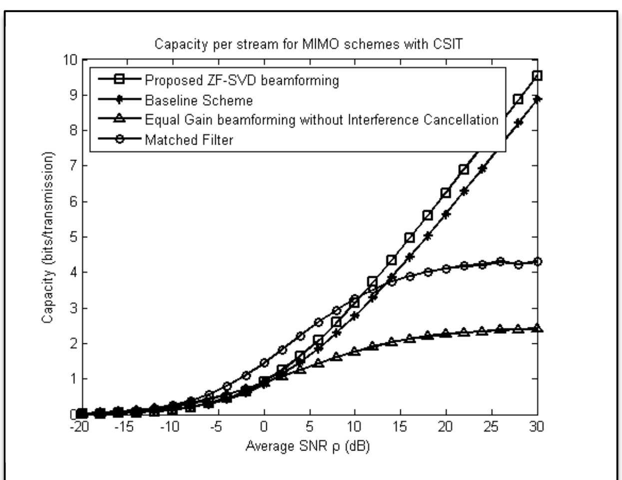

Figure 6 Capacity versus SNR for M=2, R=4, N=2 antennas

The ZF beamforming cancels the IRI while the SVD decomposes the access channel into non-interfering parallel data streams. In comparison, the matched filter focusing the energy to the intended relay and destination, but fails to remove the IRI. This results in poor capacity performance at high SNR region (interference limited region), similar to the equal gain beamforming without interference cancellation.

5.0 CONCLUSION

In this article, beamforming design for a multi-cell scenario assisted by DF MIMO relays operating in co-channel is investigated. The problem mainly lies in the interference caused by one relay to the other adjacent relay node operating in co-channel. To mitigate the inter-relay interference (IRI) and to maximize the capacity, the hybrid ZF-SVD beamforming is proposed. The ZF beamforming cancels the IRI while the SVD decomposes the access channel into non-interfering parallel data streams. Numerical results justify that the proposed scheme delivers lower outage probability and higher ergodic capacity compared to existing schemes.

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References

[1] Asmaa, A., D., Serhal, and K., Fakih. 2015. Relaying Techniques for LTE-Advanced.*European Wireless 2015.*

[2] Ramon F., and O., Sallent. 2014. Extending the LTE/LTE-A Business Case: Mission-and Business-Critical Mobile Broadband Communications. *IEEE Vehicular Technology Magazine*. 9(3): 47-55.

[3] Saleh, A., O., Bulakci, S., Redana, B., Raaf, and J., Hamalainen. 2011. A Divide-And-Conquer Approach To Mitigate Relay-To-Relay Interference. *IEEE International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC)*. 1889—1893.

[4] Sangmi M., S., Malik, B., Kim, H., Choi. 2014. Cell Range Expansion and Time Partitioning for Enhanced Inter-cell Interference Coordination in Heterogeneous Network. *Hawaii 47th International Conference on System Sciences (HICSS)*,2014. 5109-5113.

[5] Hanzo, L., J., Blogh, and S. Ni, Song. 2008. *3G, HSPA and FDD versus TDD Networking: Smart Antennas And Adaptive Modulation*. John Wiley & Sons.

[6] Bulakci, O., S., Redana,B., Raaf and J., Hamalainen. 2011. Impact Of Power Control Optimization On The System Performance Of Relay Based LsTE-Advanced Heterogeneous Networks. *IEEE Journal of Communications and Networks.* 13(4): 345—359.

[7] Mattia M., M., Ma, M., Coupechoux, and J., Kelif. 2014. Optimal Relay Placement In Cellular Networks. *IEEE Transactions on Wireless Communications.* 13(2): 998-1009.

[8] O., Bulakci, A., Saleh, S., Redana, B., Raaf and J., Hamalainen. 2011. Flexible Backhaul Resource Sharing And Uplink Power Control Optimization In LTE-Advanced Relay Networks. *IEEE Vehicular Technology Conference (VTC Fall)*, 2011. 1—6.

[9] Sadek, M., and S., Aissa. 2011. Leakage Based Precoding For Multi-User MIMO-OFDM Systems. *IEEE Transactions on Wireless Communications.* 10(8): 2428—2433.

[10] Moon, A., S., Malik, B., Kim, H., Choi, S., Park, C., Kim and I., Hwang. 2014. Cell Range Expansion and Time Partitioning for Enhanced Inter-cell Interference Coordination in Heterogeneous Network. *Hawaii 47th International Conference on System Sciences (HICSS)* 2014. 5109-5113.

[11] M., Peng, Z., Zhao, X., Xie and W., Wang. 2012. A Network Coded Interference Coordination Scheme In Cellular Relay Systems. *IEEE Communications Letters*. 16(5): 688-690.

[12] A., Weber and O., Stanze. 2012. Scheduling strategies for HetNets using eICIC. *IEEE International Conference on Communications (ICC),* 2012. 6787- 6791.

[13] Lin, M., H., Wei, J., Ouyang, K., An, Kang and Yuan, Can. 2013. Performance Analysis of a Dual-Hop Cooperative Relay Network with Co-Channel Interference. Radio Engineering. 23(4): 1-5.

[14] Yang, M., O., Shin,Y., Shin, H., Kim. 2013. Inter-cell interference management using multi-cell Shared Relay Nodes in 3GPP LTE-Advanced networks*. IEEE Wireless Communications and Networking Conference (WCNC),* 2013. 3579-3584.

[15] Baik, J., E., Lee and H., Song. 2013. *Adaptive Cooperative Communications With Multiple Antennas.* Taylor & Francis. 27(13): 1632—1639.

[16] E., Yilmaz, R., Zakhour, D., Gesbert and R., Knopp. 2010. Multi-Pair Two-Way Relay Channel With Multiple Antenna Relay Station. *IEEE International Conference on Communications (ICC),* 2010. 1-5.

[17] G., Bartoli, R., Fantacci, K., Letaief, D., Marabissi, N., Privitera, M., Pucci and J. Zhang. 2014. Beamforming For Small Cell Deployment in LTE-Advanced And Beyond. *IEEE Wireless Communications*. 21(2): 50-56.

[18] J., Zhang, F., Roemer and M., Haardt. 2011. Beamforming Design For Multi-User Two-Way Relaying With MIMO Amplify And Forward Relays. *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 2011. 2824—2827.

[19] W.,Byun, C. Ho An and D., Kim. 2009. A study on performance of MIMO-relaying scheme in heterogeneous networks. *Fourth International Conference on Computer Sciences and Convergence Information Technology, ICCIT'09*, 2009. 788—793.

[20] U., Rahat, N., Fisal, H., Safdar, Z., Khalid, W., Maqbool, and H., Ullah. 2014. Stochastic Geometry Based Dynamic Fractional Frequency Reuse for OFDMA Systems*. Jurnal Teknologi*. 67(1): 61-67.

[21] Jie Xu and Ling Qiu. 2010. The Effect of Channel Estimation Error in Multiuser Downlink MIMORelay Channels. *IEEE Wireless Communications and Networking Conference (WCNC) Proceedings*, Sydney, Australia, 18-21 April 2010
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