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Performance Analysis of MIMO Based Multi-User Cooperation Diversity Over Various Fading Channels

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***Abstract*—In this paper, hybrid FDMA-TDMA access technique in a cooperative distributive fashion introducing and implementing a modified protocol introduced in [1] is analyzed termed as Power and Cooperation Diversity Gain Protocol (PCDGP). A wireless network consists of two users terminal , two relays and a destination terminal equipped with two antennas. The relays are operating in amplify-and-forward (AF) mode with a fixed gain. Two operating modes: cooperation-gain mode and power-gain mode are exploited from source terminals to relays, as it is working in a best channel selection scheme. Vertical BLAST (Bell Laboratories Layered Space Time) or V-BLAST with minimum mean square error (MMSE) nulling is used at the relays to perfectly detect the joint signals from multiple source terminals. The performance is analyzed using binary phase shift keying (BPSK) modulation scheme and investigated over independent and identical ($i.i.d$) Rayleigh, Ricean-K and Nakagami-m fading environments. Subsequently, simulation results show that the proposed scheme can provide better signal quality of uplink users in a cooperative communication system using hybrid FDMA-TDMA technique.**

Index terms - **Cooperation Diversity, Best Channel Selection scheme, MIMO relay networks, V-BLAST, QR decomposition, and MMSE.**

I. Introduction

To achieve very high data rates is the main goal for the next fourth generation (4-G) broadband mobile communication systems. In this perspective, multiple antennas at the input and multiple antennas at the output are used to exploit the technology called as Multiple-input Multiple-output (MIMO) [2]-[4]. To improve the signal quality and achieves higher data rates, MIMO is the best technology to cope with, in the spite of the fact that MIMO possesses complex structure and lot of difficulties in implementing it. IEEE 802.16 have explained about MIMO systems and defined MIMO to be of utmost interest because using MIMO technology in the system exploits the spatial diversity and great spectral gain [5]. Reliability improvements for the fixed bandwidth, the power transmitted from source and high channel capacity gains are the key advantages of MIMO systems [6].

A powerful technique to improve the throughput and channel reliability between different users of wireless networks is Cooperative communication. Cooperative communication systems allow different multiple users to collaborate their resources and spatial diversity can be exploited by utilizing this cooperation which in the literature termed as cooperative diversity [7], [8]. IEEE802.16j standard is defined for the multi hop relay system due to the importance of the cooperative networks [15].

Many researchers are proposing new form of diversity schemes, authors are introducing new techniques to achieve spatial diversity, whereby diversity gains are achieved via the cooperation of in-cell users. In the spite of using traditional trend of diversity schemes, additional spatial diversity can be achieved by using the cooperation between in-cell users. In-cell users can assist each other messages as a relay terminal and can give rise to spatial diversity [9]. The three-terminal relay channel was first introduced by van der Meulen [10], and then was widely studied by many researchers.

In [1, 7], different transmission schemes are established in the form of transmission protocols. At relay, different modes are used for transmission. The basic two modes used are Amplify-and-Forward (AF) and Decode-and-Forward (DF) modes. AF-mode exploit diversity scheme achieve full diversity and its performance is better than direct transmission and decode-and forward transmission scheme. AF-mode achieves the capacity when number of relays tends to infinity. DF-mode is simple and adaptable to channel condition, more used as a power allocation. In this mode, receiver needs CSI between source and relay for optimum decoding. In [1], author has presented three protocols which have different degrees of broadcasting and receive collision. In the first time slot, a message has been transmitted from source S to relay R whereas, in the second time slot, source S and relay R then forward the amplified version of the received signal to the destination using two types of modes i.e. AF- mode or DF-mode.

In cooperative networks, transparent or regenerative methods are used at relays. The retransmission of the data of a signal stream received in one frequency band is done in another frequency band in transparent relaying, whereas, in regenerative method of relaying, the signal first get decoded, re-encoded and then retransmitted. Hybrid FDMA-TDMA allocation technique with transparent relaying scheme is used to determine the end-to-end performance in terms of bit error rate (BER) and symbol error rate (SER) over Ricean and Nakagami-m fading channels. [11, 13].

In this research paper, a new scheme called best channel selection scheme [14] is examined that utilizes the better resource management where the uplink radio channels are shared

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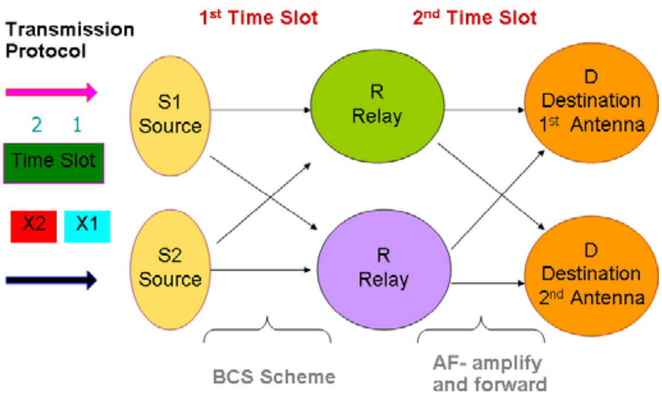

Fig. 1. Illustration of MIMO wireless network in Power and Cooperation Diversity gain mode with two source terminals S, two relays and the destination terminal D with two antennas

among multiple uplink different users, implemented on the protocol-III defined by [1], modified by using the advantage of cooperative diversity in hybrid FDMA-TDMA access technique. The signal quality of the uplink gets improved using the defined technique due to the advantage of cooperative diversity and a channel selection among different uplink multiple users in an uplink transmission. The proposed scheme composed of two types of transmission modes: cooperation gain mode and power gain mode. Vertical BLAST (Bell Laboratories Layered Space Time) or V-BLAST with the help of QR-decomposition [12] is analyzed at the relays to approach towards the required signal to noise ratio (SNR) expressions for multiple users. In the literature, there is an idea proposed for the better channel reliability termed as BCS scheme. None of them have implemented BCS system with cooperative diversity.

The remainder of this paper is systematized in a following fashion. Section II describes the complete structure of system model. End-to-end analytical expressions of SNR for users and expression of V-BLAST with MMSE nulling at the relays is derived in section III. Simulation results are shown in section IV. Finally, conclusion is stated with some remarks in the last section V.

II. System Model

This section describes an implementation of a modified protocol exploiting channel utilization scheme, the best channel scheme considering [1], channel model and fading channel. The system is furnished with two users at the transmitting end, two relays and two receiving antennas at the destination node. The performance have been analyzed in the term of end-to-end signal to noise ratio for both users over Rayleigh fading channel. BPSK modulation is assumed for the simplicity of system.

A. Transmission Protocol

For the design example, using this protocol, two symbols from two different users can be sent in the two time slots using hybrid FDMA-TDMA access technique exploiting the cooperative diversity. A schematic diagram explain the whole scenario of the system, as shown in the Fig.1. The transmission protocol is summarized in Table 1. The protocol is introduced by Nabar et al. [1].

TABLE I
Transmission Protocol

Time Slot	1	2
Protocol	$S \rightarrow R$	$R \rightarrow D$, S is silent

The transmission protocol defines that there are two users with single antenna at the transmitting node, relays and two antennas at the destination node. In the first time slot, the transmission of a signal from source S_i to relays R_i $(i\varepsilon 1, 2)$ takes place by applying best channel selection scheme. Relays R_i transmit their corresponding signals by amplifying the corresponding signals and then forward to the destination in the second time slot. Source S remains silent in the second time slot and can be utilized in any other mode of communication. At the destination, signals can be summed up using maximal ratio combining (MRC) technique. The defined mode can be explained in the form of modified proposed protocol termed as Power and Cooperation Diversity Gain Protocol (PCDGP) as shown in the Table 1.

B. Channel

: The received signal at the destination node is operating under Rayleigh fading distribution so the envelope structure of the signal will follow Rayleigh probability density function (PDF), which possess uniform phases distributed over (0,2π]. The probability distribution function (p.d.f.) of Rayleigh distribution is given by

$$f(\alpha) = \begin{cases} \frac{\alpha}{\sigma^2} e^{-\frac{\alpha^2}{2\sigma^2}} & \text{if } \alpha \geq 0 \\ 0 & \alpha < 0 \end{cases} \quad (1)$$

where σ^2 is the variance value of in-phase and quadrature factors of the complex fading environment coefficient parameter (**h**) and α is the amplitude value of **h**.

It is assumed that perfect channel state information (CSI) is known at the respective receivers. It is also assumed that the energy is normalized and at the source terminal, the average signal power is normalized to unity with $E(x_i^2) = 1$.

III. SNR Analysis

In this section, the equivalent end-to-end expressions of SNR for both users have been derived. The input-output relationship is discussed. Later, the channel matrix is defined. According to the scheme, channel co-efficient gains will be compared. At relays, V-BLAST with MMSE nulling operation have performed to jointly detect the signals with the help of QR-decomposition. The Input-output equations are summarized as follow:

A. Input-output Relationship

As described earlier about the transmission protocol that is, the signal quality of $user1$ is better than $user2$, so $user1$ will use both of the two frequencies whereas $user2$ will use only one frequency that is, F_1 and send the complete signal. On the frequency F_1, both users will send their data, so the signals received at the both receivers can be expressed as:

The signals received at the R_1 on F_1 can be expressed as:

$$r_1^{(1)} = h_{11}^{(1)} \frac{s_1}{\sqrt{2}} + h_{12}^{(1)} s_2 + n_1^{(1)} \tag{2}$$

The signals received at the R_2 on F_1 can be expressed as:

$$r_2^{(1)} = h_{21}^{(1)} \frac{s_1}{\sqrt{2}} + h_{22}^{(1)} s_2 + n_2^{(1)} \tag{3}$$

The received signal at the R_1 on F_2 can be expressed as:

$$r_1^{(2)} = h_{11}^{(2)} \frac{s_1}{\sqrt{2}} + n_1^{(2)} \tag{4}$$

The received signal at the R_2 on F_2 can be expressed as:

$$r_2^{(2)} = h_{21}^{(2)} \frac{s_1}{\sqrt{2}} + n_2^{(2)} \tag{5}$$

where $r_1^{(1)}$ and $r_2^{(1)}$ are the received signals on frequency F_1 at the relays, and $r_1^{(2)}$ and $r_2^{(2)}$ are the received signals on frequency F_2, at relays, R_1 and R_2 respectively. R_1 and R_2 are the respective two relays in a system.

The channel matrix $\mathbf{H}_c$ from the system can be extracted as:

$$\mathbf{H}_c = \begin{bmatrix} h_{11}^{(1)} & h_{12}^{(1)} \\ h_{21}^{(1)} & h_{22}^{(1)} \\ h_{11}^{(2)} & h_{12}^{(2)} \\ h_{21}^{(2)} & h_{22}^{(2)} \end{bmatrix}$$

According to the proposed scheme, the scheme compares the channel gains of second columns in $\mathbf{H}_c$, $i.e.$: $|h_{12}^{(1)}|^2 + |h_{22}^{(1)}|^2$ to $|h_{12}^{(2)}|^2 + |h_{22}^{(2)}|^2$ and selects one channel with best gain.

Now, if$|h_{12}^{(1)}|^2 + |h_{22}^{(1)}|^2 \geq |h_{12}^{(2)}|^2 + |h_{22}^{(2)}|^2$, the received signal at the relays can be expressed as:

$$\begin{bmatrix} r_1^{(1)} \\ r_2^{(1)} \\ r_1^{(2)} \\ r_2^{(2)} \end{bmatrix} = \begin{bmatrix} h_{11}^{(1)} & h_{12}^{(1)} \\ h_{21}^{(1)} & h_{22}^{(1)} \\ h_{11}^{(2)} & 0 \\ h_{21}^{(2)} & 0 \end{bmatrix} \begin{bmatrix} \frac{s_1}{\sqrt{2}} \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1^{(1)} \\ n_2^{(1)} \\ n_1^{(2)} \\ n_2^{(2)} \end{bmatrix} \tag{6}$$

Similarly, if$|h_{12}^{(1)}|^2 + |h_{22}^{(1)}|^2 < |h_{12}^{(2)}|^2 + |h_{22}^{(2)}|^2$, the received signal at the relays can be expressed as:

$$\begin{bmatrix} r_1^{(1)} \\ r_2^{(1)} \\ r_1^{(2)} \\ r_2^{(2)} \end{bmatrix} = \begin{bmatrix} h_{11}^{(1)} & 0 \\ h_{21}^{(1)} & 0 \\ h_{11}^{(2)} & h_{12}^{(2)} \\ h_{21}^{(2)} & h_{22}^{(2)} \end{bmatrix} \begin{bmatrix} \frac{s_1}{\sqrt{2}} \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1^{(1)} \\ n_2^{(1)} \\ n_1^{(2)} \\ n_2^{(2)} \end{bmatrix} \tag{7}$$

The input-output relationship with the scenario can be presented as:

$$\mathbf{Y} = \mathbf{HX} + \mathbf{N} \tag{8}$$

Now using QR-decomposition, let $\overline{\mathbf{H}} = \overline{\mathbf{Q}}\ \overline{\mathbf{R}}$ where $\overline{\mathbf{Q}}$ is a unitary matrix and $\overline{\mathbf{R}}$ is an upper triangular matrix. For detection purpose, a signal vector can be re-arranged as:

$$\bar{\mathbf{z}} = \overline{\mathbf{Q}}^H \mathbf{y} = \overline{\mathbf{Q}}^H (\overline{\mathbf{H}}\bar{\mathbf{x}} + \mathbf{n}) = \overline{\mathbf{R}}\bar{\mathbf{x}} + \bar{\mathbf{g}} \tag{9}$$

where $\bar{\mathbf{g}} = \overline{\mathbf{Q}}^H \mathbf{u}$ is the vector, we get after the multiplication of a matrix for noise. By expanding this given equation, we can compute vector $\bar{\mathbf{z}}$ as:

$$\begin{aligned} \bar{z}_1 &= < c_1.u_1 > x_1 + < c_2.u_1 > x_2 + \bar{g}_1 \\ \bar{z}_2 &= < c_2.u_2 > x_2 + \bar{g}_2 \end{aligned} \tag{10}$$

where $< c_{j,i}.u_{j,i} >$ is the $(j,i)^{th}$ element of $\overline{\mathbf{R}}$, $\bar{z}_j$ and $\bar{g}_j$ are the j^{th} element of $\bar{\mathbf{z}}$ and $\bar{\mathbf{g}}$, respectively [12].

Now V-BLAST will detect the signal in the two steps using the process called as "Slicing". At the first stage, signal x_1 can be detected, later, interference from $\bar{z}_2$ will be subtracted and the another signal will be detected too using slicing process. Slicing represents the operation to map the exact point in the constellation to the nearest neighbor symbol. At each step, slicing will take place can be expressed as:

$$\begin{aligned} \tilde{x}_1 &= slice(x_1), \\ \tilde{x}_2 &= slice(x_2) \end{aligned} \tag{11}$$

B. SNR Relationship

At the receiver, the jointly signals get detected using V-BLAST algorithm. For $user1$ the signal to noise ratio can be computed as:

$$\gamma_1 = \frac{\{< c_1.u_1 >\}^2 \mid x_1 \mid^2}{{\sigma_g}^2} \tag{12}$$

Similarly, for $user2$ the expression can be computed in the same manner as:

$$\gamma_2 = \frac{\{< c_2.u_2 >\}^2 \mid x_2 \mid^2}{{\sigma_g}^2} \tag{13}$$

where $\{< c_1.u_1 >\} = {h_{11}^{(1)}}^2 + {h_{21}^{(1)}}^2 + {h_{11}^{(2)}}^2 + {h_{21}^{(2)}}^2$ =A, $\{< c_2.u_2 >\} = \text{A}{h_{12}^{(1)}}^2 + \text{A}{h_{22}^{(1)}}^2 - 2h_{11}^{(1)}h_{22}^{(1)}h_{21}^{(1)}h_{12}^{(1)} - {h_{12}^{(1)}}^2{h_{11}^{(1)}}^2 - {h_{22}^{(1)}}^2{h_{21}^{(1)}}^2$ and σ_g is the variance of noise.

Now relays are operating in AF- amplify and forward mode. The message data received on the relays is simply amplified and forward in the next time slot.

After the detection of joint signals at the relays, R_i, the signal to be forwarded using AF by R_1 can be expressed as:

$$Y_1 = G_1 \tilde{x}_1 \tag{14}$$

where, G_1 is the amplifying factor and it's value is as follows:

$$G_1 = \frac{1}{\sqrt{E + \sigma_g}} \tag{15}$$

where E is the energy of a signal which is normalized and assumed to be one for the simulation purpose and σ_g is the variance of Additive White and Gaussian Noise (AWGN) for the specified channel.

Similarly, the message data from $user2$ received at the relay can be amplified and send in the second time slot. The amplified signal can be shown as:

$$Y_2 = G_1\tilde{x}_2 \tag{16}$$

In the second time slot, the relay will communicate with the destination and transmit the amplified version of messages received in first time slot at corresponding relays. Now, the received signals at the both antennas at the destination can be computed as:

$$Z_{R_1-D_1} = Y_1 h_{r_1 d_1} + n_{r_1 d_1} \tag{17}$$

$$Z_{R_1-D_2} = Y_2 h_{r_1 d_2} + n_{r_1 d_2} \tag{18}$$

$$Z_{R_2-D_1} = Y_1 h_{r_2 d_1} + n_{r_2 d_1} \tag{19}$$

$$Z_{R_2-D_2} = Y_2 h_{r_2 d_2} + n_{r_2 d_2} \tag{20}$$

The effective signal to noise ratio is the summed up SNR from source to relay and then relay to destination. The SNR for relay to destination can be expressed as:

$$\gamma_{Z_{RD}} = \frac{\mid V \mid^2}{\sigma_g} \tag{21}$$

where $\mid V \mid^2$ is the signal's energy and can be presented as:

$$\mid V \mid^2 = \sqrt{E_{RD}} h_{rd} \tag{22}$$

The effective SNR for $user1$ and $user2$ will be the summed up SNR at the destination from source to relay and relay to destination respectively.

IV. Simulation Results and Analysis

To discover the effectiveness of the proposed scheme, the computer simulations have been performed to demonstrate the performance of a PCDGP system. 10^7 independent channel realizations are used to obtain the BER performance at each SNR value. Different channel environments are assumed to analyze the effectiveness of PCDGP system. The simulation is carried out for Rayleigh and Nakagami-m fading environments. The simulation is also performed over Ricean-K fading channel for different values of K, i.e. K = 5, 10. For the sake of simplicity, BPSK modulation scheme is performed for PCDGP system over all fading environments. Equi- probable symbols are randomly generated.

The comparison between the two time slot cooperative system have been performed by investigating the performance of a proposed system with the implementation of BCS system and the system without BCS.

BCS system is implemented on PCDGP system. The simulation results show that proposed scheme can significantly improve the signal quality of a weak user, exploiting the cooperative diversity, over Rayleigh fading channel as shown in the Fig. 2.

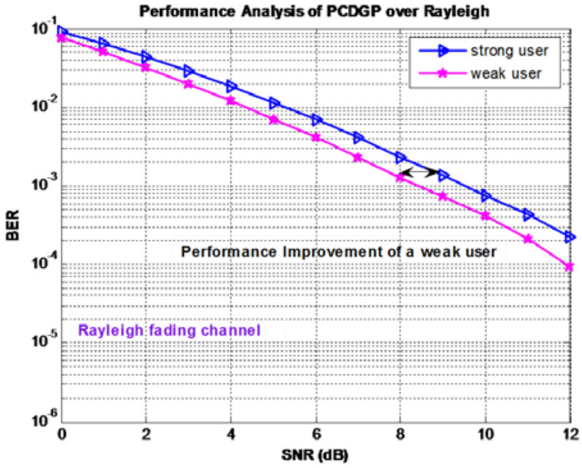

Fig. 2. Simulation results for the PCDGP system for both users over Rayleigh fading channel

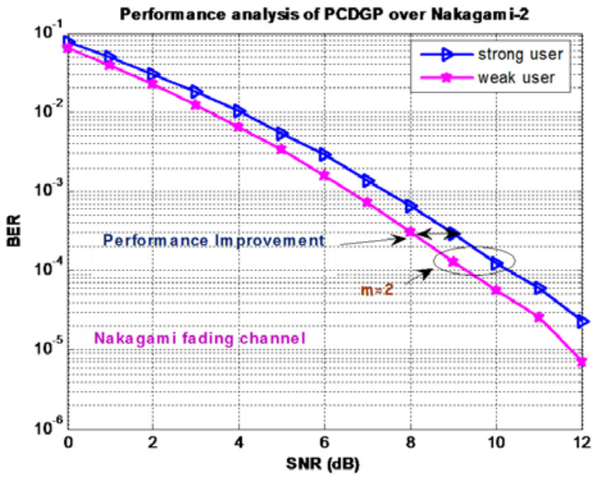

Fig. 3. Simulation results for the PCDGP system for both users over Nakagami-2 fading channel

In Fig. 3 and 4, the simulation is performed for the Nakagami distribution for the values of m=2,3. It is analyzed that, for the value of m=1, the graph trend follows the same pattern as Rayleigh fading channel. The results shows that the performance of a weak user is getting better as compared to a strong user and by increasing the value of m the performance is getting better.

The system is analyzed on the other fading channel distribution, that is, Ricean fading channel. Simulation is performed on different values of K as shown in the Fig. 5 and 6, respectively. The results depict that for the value of K=0, the graph follows the same trend as Rayleigh fading channel. By increasing the value of K, the performance of a weak user dramatically getting better at the higher value of SNR.

The simulation results are obtained for the comparison of cooperative system with and without BCS scheme as shown

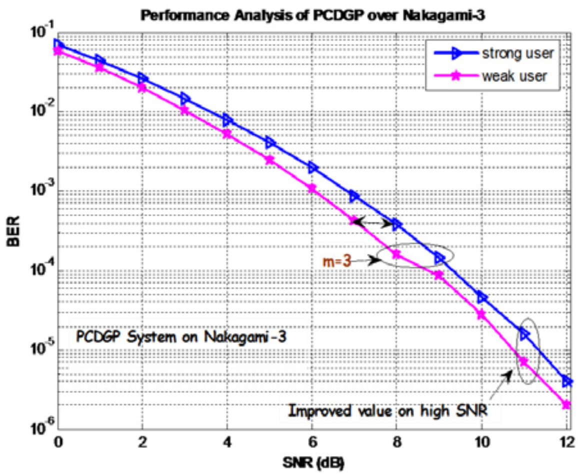

Fig. 4. Improved simulation results for the PCDGP system for both users over Nakagami-3 fading channel

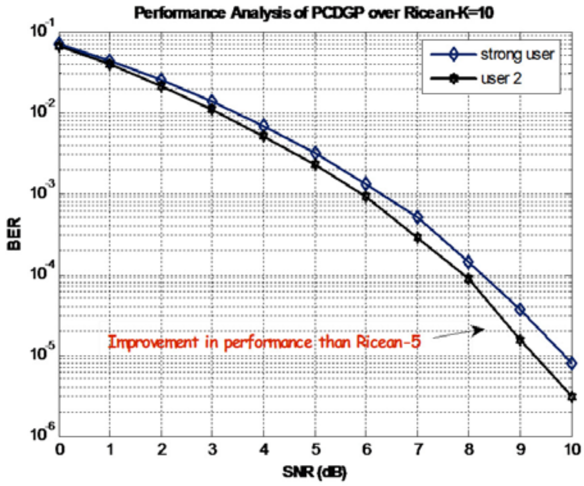

Fig. 6. Improved simulation results for the PCDGP system for both users over Ricean-10 fading channel

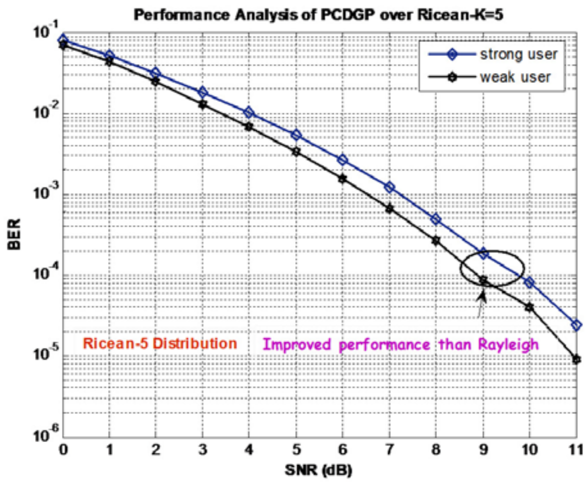

Fig. 5. Simulation results for the PCDGP system for both users over Ricean-5 fading channel

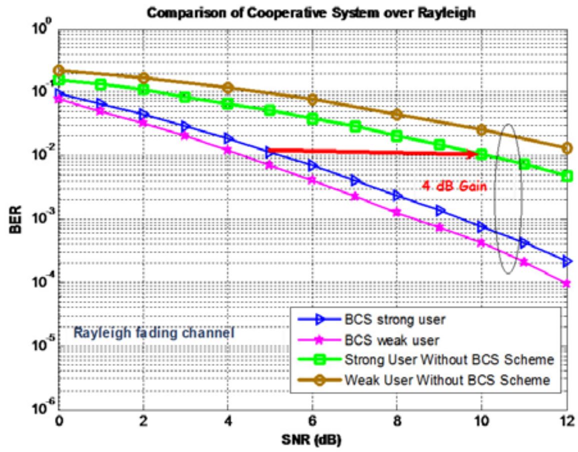

Fig. 7. The comparison of two-hop cooperative system between with and without BCS scheme

in Fig. 7. The results conclude that using BCS scheme implemented on two hop cooperative networks can dramatically increase the performance of a weak user up to more than 4 dB gain.

V. Conclusions

A compact investigation on the performance is analyzed for a best channel selection (BCS) system in terms of end-to-end SNR expressions. The best channel selection system exploiting the cooperative diversity have been investigated and termed as power and cooperation diversity gain protocol (PCDGP). The relays are fixed and working in amplify-and-forward mode. The performance is analytically computed for the V-BLAST with the help of QR-decomposition at the destination over Rayleigh fading channel. Simulation is performed in detail for different fading environments to investigate the effectiveness of the proposed system. By implementing channel selection technique on cooperative networks exploit the increase in the efficiency of a weak user. According to the simulation results, we show that using BCS technique with cooperation increase the performance for a weak user in cooperative networks.

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References

[1] R. U. Nabar, H. Bolcskei, and F. W. Kneubuhler, "Fading relay channels: performance limits and space-time signal design", *IEEE Journal on Selected Areas in Communications*, 22(6), 1099-1109.

[2] IEEE 802.16e-2005 "IEEE standard for local and metropolitan area networks-Part 16: Air interface for fixed broadband wireless access systems", *Feb. 28, 2006.*
[3] V. Tarokh, A. Naguib, and N. Seshadri, " Combined array processing and spacetime coding", *IEEE Trans. Inform. Theory*, vol. 45, 1121-1128, May 1999.
[4] G. G. Raleigh and J. M. Cioffi, "Spatio-temporal coding for wireless communication", *IEEE Trans. Commun.*, vol. 46, pp. 357366, Mar. 1998.
[5] V. Erceg et al, "Channel models for fixed wireless applications", *IEEE, Tech.Rep*, IEEE 802.16-3c-01/29r4 Work Group, (2001).
[6] G. Foschini and M. Gans, "On the Limits of Wireless Comunications in a Fading Environment when Using Multiple Antennas", *Wireless Personal Communication*, vol.6, pp.311-335, 1998.
[7] J. N. Laneman, D. N. C. Tse and G. W. Wornell, "Cooperative diversity in wireless networks: efficient protocols and outage behavior", *IEEE Trans. Inform. Theory*, vol. 50, pp. 3062 3080, Dec. 2004.
[8] A. Sendonaris, E. Erkip, and B. Aazhang, "User cooperative diversity -Part I:system description", *IEEE Trans. Commun.*, vol. 51, pp. 1927 1938, Nov. 2003.
[9] M. Yuksel, and E. Erkip, "Diversity in relaying protocols with amplify and forward", *IEEE GLOBECOM*, 2003, 4 , 2025-2029.
[10] E. C. van der Meulen, "Three-terminal communication channels", *Adv. Appl. Probab.*, vol. 3, pp. 120-154, 1971
[11] J. Adeane, M. R. D. Rodrigues and I. J. Wassell, "Optimum power allocation in cooperative networks, Proceedings of the Postgraduate Research Conference in Electronics, Photonics", *Communications and Networks, and Computing Science, Lancaster*, U.K., pp. 23-24, March-April 2005.
[12] W. Peng, S. Ma, T. Ng, J. Wang, and F. Adachi, "An Analytical Approach to V-BLAST Detection with Optimal Ordering for Two Input Multiple Output Systems", *IEEE 68th, Vehicular Technology Conference*, 2008, VTC 2008-Fall (December). 21-24 Sept. 2008. 1-5.
[13] I. Khan, S. A. K. Tanoli, and N. Rajatheva, "SER analysis of hybrid FDMA-TDMA based user cooperation diversity over Nakagami fading channels", *the 12th International Symposium on Wireless Personal Multimedia Communications (WPMC09)* ¡http://www.wpmcsymposium.org/index.html¿, Sendai Japan, Sep 7-10 2009.
[14] K. T. Kim, S. K. Oh, and S. H. Kim, "A Best Channel Selection Scheme for Better User Multiplexing in an Uplink Environment", *in Proc. Asia Pacific Wireless Communications Symposium*, 5th IEEE VTS, APWCS 2008, Sendai, Japan, Aug. 21-22, 2008.
[15] V. Genc, S. Murphy, Y. Yu, and J. Murphy, "IEEE 802.16j relay-based wireless access networks: an overview [recent advances and evolution of WLAN and WMAN standards]", *IEEE Wireless Comm. Mag.*, vol. 15, no. 5, pp. 5663, 2008.