World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:8, No:2, 2014

Decode and Forward Cooperative Protocol Enhancement Using Interference Cancellation

Siddeeq Y. Ameen, Mohammed K. Yousif

***Abstract*—**Cooperative communication systems are considered to be a promising technology to improve the system capacity, reliability and performances over fading wireless channels. Cooperative relaying system with a single antenna will be able to reach the advantages of multiple antenna communication systems. It is ideally suitable for the distributed communication systems; the relays can cooperate and form virtual MIMO systems. Thus the paper will aim to investigate the possible enhancement of cooperated system using decode and forward protocol. On the decode and forward an attempt to cancel or at least reduce the interference instead of increasing the SNR values is achieved. The latter can be achieved via the use group of relays depending on the channel status from source to relay and relay to destination respectively.

In the proposed system, the transmission time has been divided into two phases to be used by the decode and forward protocol. The first phase has been allocated for the source to transmit its data whereas the relays and destination nodes are in receiving mode. On the other hand, the second phase is allocated for the first and second groups of relay nodes to relay the data to the destination node. Simulations results have shown an improvement in performance is achieved compared to the conventional decode and forward in terms of BER and transmission rate.

***Keywords*—**Cooperative systems, decode and forward, interference cancellation, virtual MIMO.

I. INTRODUCTION

EXTENSIVE research have witnessed recently in Ad-hoc and wireless sensor networks towards replacing the diversity in multiple antenna communication systems to single antenna nodes. This research development has achieved with multi hop cooperative systems or cooperative diversity [1], [2]. The main disadvantage of using multiple antenna might be unfeasible in mobile terminals due to the size, power consideration for mobile phones and the separation between adjusted antennas should be longer than a half wavelength to keep all the channels uncorrelated.

The main idea of cooperative diversity is to use nearby idle nodes to assist transmitting and receiving data, it is also imperative to adapt the routing scheme to incorporate the requirement for multiple paths between nodes [3]. Cooperative communication system has emerged as a noteworthy concept to enhance the reliability and throughput in wireless communication systems. In cooperative communication, the resources of distributed nodes are efficiently pooled for the mutual advantage of all nodes [4].

The main idea of cooperative systems was the conception of relaying presented by Meulen [5] and the work of Cover and others on the information features of the relaying [6]. In [6] authors are studied the capacity of the three nodes model. The authors also research many methods, in which the relay tries to support the source node. The authors in [6] also analyzed the capacity in an additive white Gaussian noise channel and the main task from the relay is to offer the help to the direct channel. Whereas in cooperative communication, the concept of diversity in fading wireless channels is the major motivation doing as information source as well as relays with fixed system resources [7]. In [8], Sendonaris et al. first presented the idea of cooperative diversity .Later; cooperative communication has been regarded as an encouraging technique to form spatial diversity over user cooperation. The spatial diversity achieved from relaying schemes that well developed to give the advantages of cooperative communication [9].

The cooperative communications was initially developed from the concept relay channel. The concept of relay channel has a major effect on capacity of the three nodes system containing of source, relay and destination. Many methods can be used to achieve the relay to support the source. However, the cooperative communication is diverse from the relay channel because the main purpose from the relay is only to offer the help to the main channel. On the other hand, with cooperative communication, the idea of diversity in fading wireless channels is the first motivation act as information source as well as relays with fixed system resources [7].

The relaying systems used in cooperative communication adopt two well-known models; decode and forward model and amplify and forward model. In the first model, decode and forward, the relay node decodes the received information signal transmitted from the source node prior to retransmission it. On the other hand, in the amplify and forward model, the relay node just amplifies the received information signal prior to retransmission it to the destination node. Even with these differences, and some signal processing at relay is concerned, they are nearly similar. So they are interchangeably known as cooperative communication and relaying communication as well. Extra study shows that, the source node may not involve in cooperation. This assumes that there is no direct link between the source and the destination. With this development extra advantages can be extracted in terms of diversity and error performance when the source node is keenly involved in cooperation.

Siddeeq Y. Ameen is with the Computers and Information Technology Department, Mosul University, Iraq (e-mail: prof-siddeeq@ieee.org).

Mohammed K. Yousif is with the Communication Engineering Department, Mosul University, Iraq (corresponding author to e-mail: mo7ammedkhalid@gmail.com).

In this paper, the cooperative communication system has been introduced together with outlines for basic protocols of cooperative communication. The main aim of this paper is to test the performance of the multi relays communication system using decode and forward cooperative protocol using interference cancellation to improve the performance and compared it with conventional decode and forward and the direct transmission system in terms of bit error rate and average transmission rate.

II. COOPERATIVE COMMUNICATION SYSTEMS

The main components of the cooperative communication system are source, relays and destination nodes as shown in Fig. 1. It is clear from Fig. 1 that a virtual MIMO system can be used to provide diversity gains without implementing multiple antennas at wireless nodes.

Cooperative diversity (spatial diversity) can be realized by using the antennas of other nearby users (relays) in the network to help the transmission of messages from the source to the destination [10].

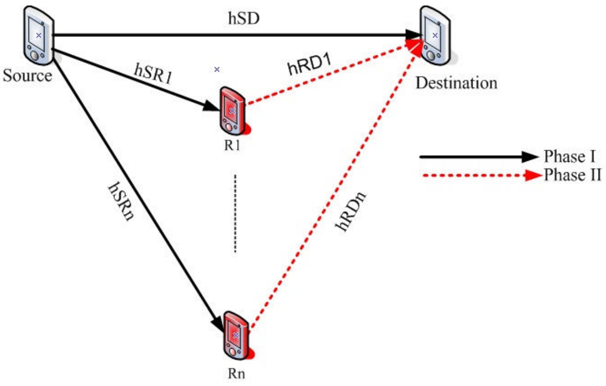

Fig. 1 Cooperative communication system

Furthermore, the performance of cooperative communication system can be further enhanced by using different cooperative protocols amplify and forward and decode and forward protocols. These protocols have been widely studied in the design of relaying protocols for cooperative systems.

A. Amplify and Forward Protocol

Amplify and forward is simple cooperative protocol. In this protocol, the received signal at the relay will be amplified and then forwarded to the destination [4]. The destination will receive multi version of the same information from the relay and the from source or from another relay when there is direct transmission between the source and destination as shown in Fig. 2.

With amplify and forward relay channel model, the transmitted signal from the source node x is received at both the relay and destination nodes as;

$$y_{S,R} = h_{S,R}x + n_{S,R} \tag{1}$$

$$y_{S,D} = h_{S,D}x + n_{S,D} \tag{2}$$

where$h_{S,R}$and $h_{S,D}$ are the channel coefficients between the source and the relay and destination, respectively.$n_{S,R}$and$n_{S,D}$ are additive white Gaussian noise with zero-mean and varianceN_o. In this model the channel is modeled as a Rayleigh flat fading channel. With amplify and forward protocol, the relay receives the signal from the source, amplified it and forwarded it to intended destination node. The relay also equalizes the influence of the fading channel between the source and the relay. This will be accomplished by scaling the received signal by a factor A_G. The scaling factor is inversely relative to the received power and given as:

$$A_G = \sqrt{\frac{p_S}{|h_{SR}|^2 p_S + N_o}} \tag{3}$$

where$p_s$andN_o are denote the average transmit power at the source and variance, respectively.

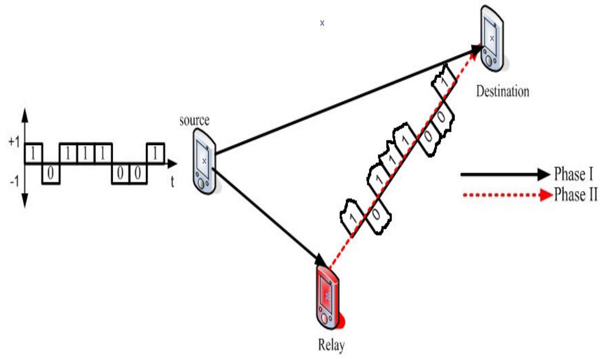

Fig. 2 Amplify and Forward model

$$y_{R,D} = A_G h_{R,D} y_{S,R} + n_{R,D} \tag{4}$$

where $h_{R,D}$ *is* the channel coefficient from the relay to the destination and $n_{R,D}$ is an additive noise. In the amplify and forward mode, the two copies of signal x is received by the destination node from the source and relay links. These two signals can be combined in many different techniques. One of the optimum techniques that maximize the overall signal to noise ratio is called the maximal ratio combiner [11].

The major advantages of this method are the good diversity gain, better performance than direct transmission and decode-and-forward and high capacity when number of relays tends to infinity can be achieved [12]. However, the drawback of this protocol is that the noise is also be amplified at the relay node. This can be excluded by keeping a high threshold level at the receiver [13].

The maximum feasible end-to-end transmission rate for the basic amplify and forward relaying protocol scheme with diversity combining is thus as given by [14]:

$$C = \frac{1}{2}log_2\left(1 + \gamma_{s,d} + \frac{\gamma_{s,r}\gamma_{r,d}}{\gamma_{s,r}+\gamma_{r,d}+1}\right) \tag{5}$$

where

$$\gamma_{s,d} = \frac{|h_{S,D}|^2}{N_o}, \gamma_{s,r} = \frac{|h_{S,R}|^2}{N_o} \text{ and } \gamma_{r,d} = \frac{|h_{R,D}|^2}{N_o}$$

B. Decode and Forward Protocol

With the decode and forward protocol, the relay node decodes the received signal to get the original information. Next, the decoded information encoded and retransmitted to the destination as shown in Fig. 3. It is clear from this protocol that the noise will not be amplified because it is excluded by the decoding process. However, when a decoding error occurred at the relay node due to the deep fading in the channel between the source and the relay, this can be considered as the major problem with decode and forward protocol. The problem will be worsen if detection at the relay node unsuccessful too and will give bad performance [1].

Due to the broadcast nature of the wireless medium, the relay and the destination nodes will receive a noisy copy of the signal as mentioned in (1) and (2). Thus, the received signal at the destination in Phase II from the relay as shown below [14]:

$$y_{R,D} = h_{R,D}\hat{x} + n_{R,D} \tag{6}$$

where$\hat{x}$ is the hypothesis symbol detected by the relay.

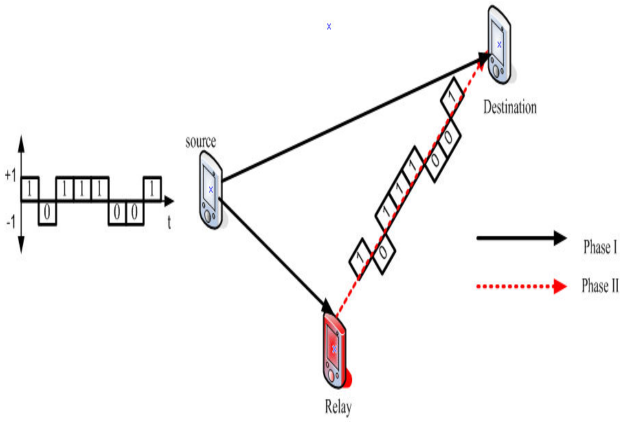

Fig. 3 Decode and forward protocol

The transmission rate is bounded by the capacity of the two links from the source to relay and relay to destination respectively, to make the relay successfully detect the information sent by source in phase I, the transmitted rate should be less than the capacity of source-relay link, Hence, the maximum end to-end achievable rate in phase II is given by [14]:

$$C = \tfrac{1}{2}\min\{log_2(1+\gamma_{s,r}), log2(1+\gamma_{s,d}+\gamma_{s,d}+\gamma_{r,d})\} \tag{7}$$

III. System Modeling

For system modeling, it is assumed that the system is a multi-hope system with a single source, few transmitting users as (relays) and a single destination. Furthermore, all the nodes in the system are supposed to have single antenna. The system model can be relied to any wireless system such as wireless LAN, Ad hoc or wireless sensor networks modeling. Therefore, the channels are modeled as flat fading channels with additive white Gaussian noise (AWGN). The channels also are assumed to be independent because when two or more wireless channels are separated in space, then the fading on these channels will be uncorrelated [15].

The system model is as shown in Fig. 4. The system adopts a timesharing scheme in which, the communication between source and destination is shared into two phases with synchronous transmission between transmitting nodes per phase.

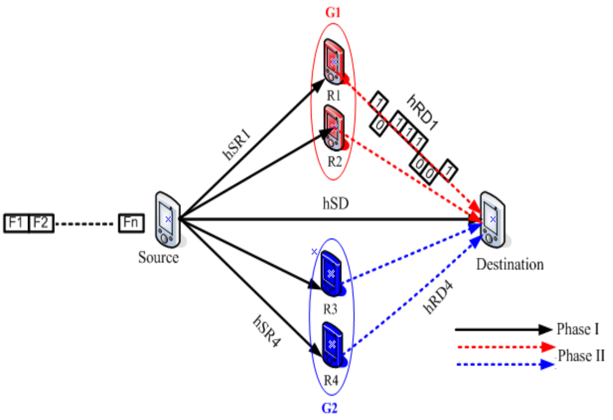

Fig. 4 Proposed cooperative communication system model

The first phase is named the broadcast phase whereas the second and third phase is known as multiple access phase of the transmission. With the first phase, the source node broadcasts $\boldsymbol{x}$ information symbols to the destination node and to the relays as well in the first phase. In the second phase, the relays in G1 and G2 will detect the received signal, mapping it prior to re-transmission it to the destination node. Let $\boldsymbol{x} = [x_1, \ldots, x_N]$denotes the symbol vector to be transmitted from the source node in phase I. Then the received signal vector at the relays with CSI is defined as:

$$\boldsymbol{y}_{rn} = \boldsymbol{h}_{SRn}\boldsymbol{s} + \boldsymbol{n}_n \tag{8}$$

where$\boldsymbol{n}_n$ is the additive white Gaussian noise at the relay nodes. The relays will decodes and provides $\hat{x} = [\hat{x}_1, \ldots, \hat{x}_N]$ before retransmitting it to the destination. Thus, the received vector signal by the destination with CSI is:

$$\boldsymbol{y}_{dn} = \boldsymbol{h}_{RDn}\hat{\boldsymbol{x}} + \boldsymbol{n}_{Dn} \tag{9}$$

where n_{Dn} is the additive white Gaussian noise.

In phase II, it will be assumed that there is only the deterministic set of relays in G1 and G2 to be involved in cooperation. Thus, the final received signal vector at the destination at phase II will be given by:

$$\boldsymbol{y}_{eq} = [\boldsymbol{y}_{S,D}, \boldsymbol{y}_{dn}] \tag{10}$$

In phase I, the $\boldsymbol{y}_{sd}$ signal vector is to be sent to the maximum likelihood detector. Assuming the CSI is available at the maximum likelihood detector, the set of all possible transmitted vector is $\bar{\mathrm{x}} = [\,\bar{\mathrm{x}}_1, \ldots, \bar{\mathrm{x}}_\mathrm{N}\,]$ also known. The maximum likelihood detector attempts to minimize the Euclidean distance (J) from the signal constellation with equal probabilities. *Thus:*

$$J = \left|y_{S,D} - h_{S,D}\bar{x}\right|^2 \tag{11}$$

The minimum Euclidean distance (J) can be obtained when $\bar{x} = \tilde{x}$, where $\tilde{x}$, is the hypothesis transmitted symbol vector by the sources. This information can be used in the second phase to cancel the interference in G1 and G2 relays. The cancellation relies strongly on the link status between the source, relay and destination nodes respectively in each group. The received signal vector from each group can be computed as:

$$\boldsymbol{y}_{R,DG1} = \boldsymbol{h}_{R1,D}\widehat{\boldsymbol{x}} + \boldsymbol{h}_{R2,D}\widehat{\boldsymbol{x}} + \boldsymbol{n}_{R,DG1} \tag{12}$$

$$\boldsymbol{y}_{R,DG2} = \boldsymbol{h}_{R3,D}\widehat{\boldsymbol{x}} + \boldsymbol{h}_{R4,D}\bar{\boldsymbol{x}} + \boldsymbol{n}_{R,DG2} \tag{13}$$

where$\boldsymbol{n}_{R,DG1}$ and $\boldsymbol{n}_{R,DG2}$ are the additive white Gaussian noise added at the destination node.

The hypothesis symbol extracted from source to the destination link will be used to cancel the interference in G1 and G2 relays, i.e. the destination node will discard one link from each group after elimination the received signal vectors that will be send to the maximum ratio combiner to combine the three signal copies described below:

$$\boldsymbol{y}_{R,DG1} = \boldsymbol{h}_{Ri,D}\widehat{\boldsymbol{x}} + \boldsymbol{n}_{R,DG1} \tag{14}$$

$$\boldsymbol{y}_{R,DG2} = \boldsymbol{h}_{Rj,D}\widehat{\boldsymbol{x}} + \boldsymbol{n}_{R,DG2} \tag{15}$$

where$i$= 1 or 2 andj = 3 or 4.

For this method of combining, the received signals are weighted with c_0, c_1, and c_2 and summed to give;

$$\boldsymbol{y} = \boldsymbol{c_o y}_{SD} + \boldsymbol{c_1 y}_{R,DG1} + \boldsymbol{c_2 y}_{R,DG2} \tag{16}$$

The weighting factors c_0, c_1, and $c_2$are related to direct, first group weighting and second group weighting. These values weighting factors are designed to enhance the performance of the system. The combination rule can be considered as an optimization problem that requires optimum solution to find the values of these weighting factors. Thus;

$$c_o = h^*_{S,D}, c_1 = h^*_{Ri,D} \text{ and } c_2 = h^*_{Rj,D}$$
$$\boldsymbol{y} = \boldsymbol{h}^*_{S,D}\boldsymbol{y}_{SD} + \boldsymbol{h}^*_{Ri,D}\boldsymbol{y}_{R,DG1} + \boldsymbol{h}^*_{Rj,D}\boldsymbol{y}_{R,DG2} \tag{17}$$

The optimum solution adopted in (17), is to maximize the SNR at the output of the MRC as shown below:

$$SNR = SNR1 + SNR2 + SNR3 \tag{18}$$

where

$$SNR1 = \frac{|h_{S,D}|^2}{No}, SNR2 = \frac{|h_{Ri,D}|^2}{No} \text{ and } SNR3 = \frac{|h_{Rj,D}|^2}{No}$$

Finally, the vectorγ will be send to the maximum likelihood detector to recover the transmitted x from the source. From the above, it can be seen that information can be detected with low difficulty decoding. Furthermore, by swapping the destination to detecting mode in phase I, the model exhibits good improvement.

The average rate achievable in Phase II of this model with diversity combining will be as given by:

$$C = \tfrac{1}{2}\min\{\, log_2(1 + \gamma_{s,ri})\,, log2(1 + \gamma_{s,rj}), log2(1 + \gamma_{s,d} + \gamma_{r,dG1} + \gamma_{r,dG2}) \tag{19}$$

where

$$\gamma_{s,ri} = \frac{\left|h_{S,Ri}\right|^2}{No}$$
$$\gamma_{s,rj} = \frac{\left|h_{S,Rj}\right|^2}{No}$$
$$\gamma_{r,dG1} = \frac{\left|h_{Ri,D}\right|^2}{No}$$
$$\gamma_{r,dG2} = \frac{\left|h_{Rj,D}\right|^2}{No}$$

IV. SYSTEM SIMULATION AND EVALUATION

In this section, the BER performance of the proposed system is evaluated and compares it with the conventional decode and forward. It is assumed that all the relays nodes and destination node provided with channel state information. In the simulation, the following parameters were setup as shown in Table I.

TABLE I
SIMULATION PARAMETERS OF DECODE AND FORWARD MULTI RELAY

Relay Mode	Decode and Forward
No. of Bits / Frame	100
No. of Frames	10000
No: Relays	4
Input Sample Period	10e-6
Combining Technique	MRC

The performance of the proposed system have been evaluated for two form of modulation BPSK and QPSK modulation schemes as shown in Figs. 5 and 6, respectively. The results show that the BPSK modulation scheme gives an enhanced diversity gain performance of 2 dB compared with conventional decode and forward at BER=10^{-3}. A same enhancement can be witnessed in Fig. 6 for the BER performance with QPSK modulation scheme.

Furthermore, it can be noted that more information can be achieved by changing the receiver to reception mode at phase I, this advances the BER performance of the system with small decoding difficulty drawback by canceling the interference in each group of relays. The average transmission rate is also improved as shown in Fig. 7 using the proposed model with respect to the conventional decode and forward model, for example at 2 bps/Hz there is about 5.5 dB enhancement, this will give the system to increase the upper data-rate bound in terms of bits / s.

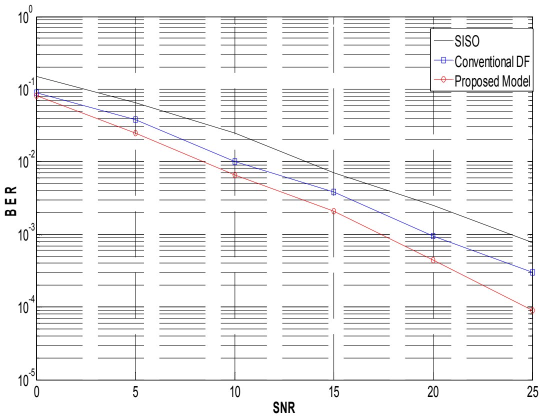

Fig. 5 Performance comparison of the proposed model with conventional decode and forward in multi-relay cooperative and non-cooperative networks for BPSK modulation scheme

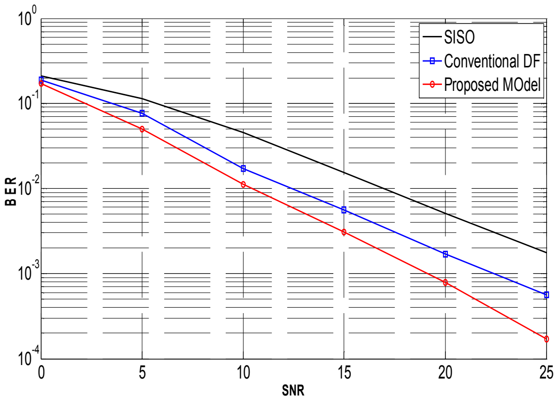

Fig. 6 Performance comparison of the proposed model with conventional decode and forward in multi-relay cooperative and non-cooperative networks for QPSK modulation scheme

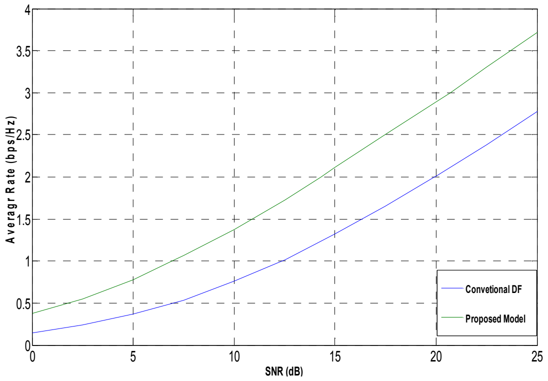

Fig. 7 Average transmission rate for the conventional DF and proposed mode

V. CONCLUSION

The paper categorize that most works on cooperative system adopt there is no direct link between the source and the destination and this give good enhancement to the propose system when switching the destination node to receive mode in phase I to cancel the interference in each group of relays because the relays on each group transmit on the same frequency, this will save the frequencies of transmission and increase the performance of the system and data rate as well. Measured results show that cooperative schemes can bring diversity advantages to single antenna terminals, these scheme have the power to outperform conventional MIMO systems in terms of BER and upper data-rate bound.

REFERENCES

[1] M. Abrar, X. Gui1, A. Punchihewa, S. Khan and M. Iqbal “Cooperative Diversity versus Antenna Diversity in Wireless Communication Systems,” in *Proc. 4th International Conference on New Trends in Information Science and Service Science*, 2010, pp. 260–263.

[2] J. George, M. Abdelgadir, M. Yousif and I. Hussein “The Performance of Cooperative Distributed Space Time Block Codes (CDSTBC) in Wireless System,” in *Proc. 7th International Conference on Wireless Communications, Networking and Mobile Computing , 2011 pp. 1-3* .

[3] B. Zafar, D. Schulz, S. Gherekhloo, and M. Haardt “Cooperative MIMO Multihop Networks,” *IEEE Vehicular Technology Magazine, March 2011, pp 31-36.*

[4] P. Murphy, A. Sabharwal and B. Aazhang “On Building a Cooperative Communication System: Testbed Implementation and First Results,” EURASIP Journal on Wireless Communications and Networking, 2009 (in press)..

[5] E.C.V.D. Meulen, “Three-Terminal Communication Channels,” *Advances in Applied Probability, vol. 3, Spring. 1971, pp. 120-154.*

[6] T. Cover and A. Gamal, “Capacity theorems for the relay channel,”IEEE Transactions on Information Theory, vol. 25, 1979, pp. 572-584.

[7] A. Nosratinia, T. Hunter, and A. Hedayat, “Cooperative communication in wireless networks,” IEEE Communications Magazine, vol. 42, 2004, pp. 74-80.

[8] A. Sendonaris, E. Erkip, and B. Aazhang, “User cooperation diversity. Part II. Implementation aspects and performance analysis,” *IEEE Transactions on Communications,* vol. 51, 2003, pp. 1939-1948.

[9] A. Aziz and Y. Iwanami "Maximum Likelihood Detection for Detect-and-Forward Relay Channels," Int. Journal Communications, Network and System Sciences, 2011, 4, pp.88-97.

[10] L. P. Natarajan and B. S. Rajan, “ Distributed STBCs with Full-diversity Partial Interference Cancellation Decoding,” in *Proc.* IEEE Int. Symposium on Inf. Theory, 2011, pp. 2025-2029.

[11] K. J. Ray liu, A. K. Sadek, W. SU and A. Kwasinski, “Cooperative Communications and Networking,” Cambridge University Press, 2009, pp. 120-124.

[12] Y. Chin, D. Jayalath and B. Senadji, “Distributed Orthogonal Space-Time Block codes with Adaptive Diversity Gain,”in*Proc.*4th International Conference on Signal Processing and Communication Systems, 2010, pp. 1-6.G.

[13] P. Liu, Z. Tao, Z. Lin, E. Erkip and S. Panwar, "Cooperative Wireless Communications: A Cross-Layer Approach", IEEE Wireless Communications, vol.13, no.4, 2006, pp.84-92.

[14] Y. -W. Peter Hong, Wan-Jen Huangand C. -C. JayKuo, “Cooperative Communications and Networking,” Springer Science, 2010,pp. 67-79.

[15] S. Viqar, S. Ahmed, Z. ul Mustafap and W. Ejaz, "Performance Analysis of Cooperative Communication System with a SISO system in Flat Fading Rayleigh channel", IACSIT, Vol.42, no.4, 2012, pp.228-233.