Multi-Hop Virtual MIMO Communication using STBC and Relay Selection

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***Abstract*— Emerging wireless communication systems requires high data rates coupled with better QoS (Quality of Service). Multiple Input Multiple Output (MIMO) technology uses multiple transmit and receive antennas to achieve higher data throughput and link range. The implementation of conventional MIMO in small devices has certain limitations like, power, size, and cost. Alternatively, MIMO system can be implemented by exploiting the cooperation between multiple antenna elements of nearby users to realize a Cooperative MIMO or Virtual MIMO system. The cooperative transmission is assisted by a relay and the relay can include single node or multiple nodes. The relay selection is an important problem in virtual MIMO communication. By incorporating multi-hop scenario, the reliability of communication between the source and the destination node can be increased. In this paper a reliable data communication between the source and the destination node will be established with the help of the concept of Virtual MIMO extended to multi-hop scenario.**

Keywords*— Cooperative communication; Virtual MIMO; Multihop communication; Space Time Block Codes (STBC); Relay node selection.

I. INTRODUCTION

The next generation wireless communication systems (3G and beyond) demands advanced algorithms and techniques that not only increase the data rate, but also enable the system to guarantee the desired quality of service (QoS). Recently, Multiple Input Multiple Output (MIMO) systems has emerged as the technology to provide high data rates and link range. MIMO technology uses multiple antennas at transmitters and receivers for the transmission of data. Both spatial diversity and spatial multiplexing can be achieved with MIMO systems depending on the data carried by the multiple antennas.

The transmission of signals through the wireless channel introduces channel impairments like pathloss and fading. Pathloss is the reduction in received power of the signal as a function of distance and Fading is the deviation in attenuation affecting a signal over certain propagation media. By effectively transmitting or processing (semi)independently fading copies of the signal, diversity is a method for directly combating the effects of fading. Spatial diversity techniques like transmit diversity, receive diversity are more suited for MIMO systems. Another form of diversity technique based on the concept of cooperative communication is the cooperative diversity technique. The cooperative diversity is based on the concept of user cooperation. A three-terminal network consisting of source, relay and destination is the fundamental unit in user cooperative communication. It can be achieved with the help of Relay node, which assists in the transmission of data from source node to destination nodes. The Repetition based cooperative diversity techniques like Amplify and Forward (AF), Decode and Forward (DF) and Coded cooperation are studied in [1]. In the amplify and forward protocol, the relay nodes amplifies and retransmits the received signal, whereas in decode and forward protocol, the relay nodes decodes and re-encodes the data before retransmission. Cooperative diversity can be achieved with the use of space time codes, where the data is encoded and distributed among multiple antennas and time slots to improve the reliability of transmission. In Space time coded cooperative diversity, the terminals share their antennas and other resources to create a virtual array[2]. In this paper comparative study of repetition based cooperative diversity and space time coded based cooperative diversity based on outage probability is done.

Implementing MIMO systems using physical antenna arrays in a single transmitter has the disadvantages of power, cost and size constraints. Subsequently Virtual MIMO or Cooperative MIMO systems has been developed where multiple single user antennas share their antennas to create virtual antenna arrays [3]. A clustered multi-hop virtual MIMO communication is studied in this paper. The cooperation between multiple users can be achieved with the help of Distributed Space Time Block Codes (DSTBCs) [3][4][5]. Application of Distributed STBCs in cooperative MIMO reduces the probability of correlated channel coefficients as in[4]. In [4] Quasi orthogonal STBC (Q-OSTBC) with constellation rotation is considered. Depending on the no. of relay stations and no. of transmit antennas, five different cases are studied in this paper. Relay assisted Cooperative MIMO using STBCs is studied in [5]. STBC is done after pre-transmission of the data symbols to the relay node. The channel capacity and error performance of the system has been studied for different relay positions and no. of relays. In [6], a novel distributed Virtual MIMO scheme for wireless sensor networks is considered. Cross layer design approach which involves MIMO techniques on the physical layer and a directed diffusion protocol on the network layer is included in this paper.

The selection of relay nodes plays an important role in virtual MIMO communication. In [7] different relay positions of relay node used in cooperative communication is analyzed. Symmetric and asymmetric scenarios are studied and the best results are obtained when the relay is equidistant from sender and receiver, but slightly closer to sender. An autonomic cooperative communication system using virtual MIMO is considered in [8]. Cross layer design has been included and various protocols assure the reliability of cooperative communications. The relay selection can be done in better way using network layer protocols [8][9]. The aspects of cross layer design are needed for this purpose.

In this paper, a multi-hop virtual MIMO system is implemented. The first step is the selection of relay nodes for the virtual MIMO system. The Relay selection algorithm is based on distance. The selected nodes form the virtual MIMO relays between the source and destination. STBC coupled with DF protocol is used at each of the virtual MIMO stages. The number of virtual MIMO stages is varied adaptively to improve the performance of the system.

II. SYSTEM MODEL

The system model in this paper is shown in Fig. 1. All the nodes, i.e. source, destination and intermediate nodes considered are single antenna nodes. For simplicity, three hop system is shown here which includes two virtual MIMO stages. Each of the VMIMO stages consists of two nodes. The source node transmits the data to the first virtual MIMO system (VMIMO-1). The VMIMO-1 performs Distributed STBC (DSTBC) and relays the data to the second VMIMO system. The VMIMO-2 again performs DSTBC and transmits data to the destination node.

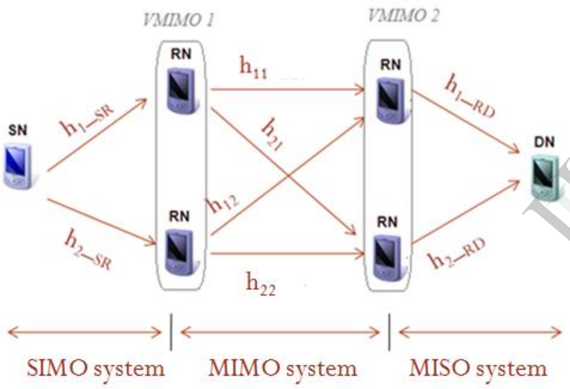

Fig. 1: Block diagram of 3-hop virtual MIMO System

At the first stage a 1×2 SIMO channel is considered. This is followed by a 2×2 virtual MIMO channel at the intermediate stage. The additional intermediate stage if any also uses 2×2 virtual MIMO channel. At the final stage a 2×1 MISO channel is considered. The channel is assumed to be Rayleigh flat fading with AWGN noise. The effect of pathloss is also incorporated into the channel effects. Pathloss modeling is done based on models such as Simplified Pathloss model [11], Two Ray model [5] and Winner model [10].

The virtual MIMO channel between the receive node *i* and transmit node *j* is given by the channel matrix

$$H_{M\times M} = \begin{bmatrix} h_{11} & \cdots & h_{1M} \\ \vdots & \ddots & \vdots \\ h_{M1} & \cdots & h_{MM} \end{bmatrix} \qquad (1)$$

where h_{ij} denotes the virtual MIMO channel coefficients.

III. RELAY SELECTION

The selection of relay plays an important role in the performance of the virtual MIMO system. The position of the relay is an important criterion in selecting the relay. In the case of single relay node relaying data between the source and the destination, the best performance is obtained when the relay is equidistant from source and destination, but slightly closer to the source. Based on this concept a simple relay selection algorithm has been developed. This algorithm considers a 3-hop virtual MIMO system. The performance of the system can be further improved by introducing an intermediate virtual MIMO stage as in the Adaptive Relay Selection.

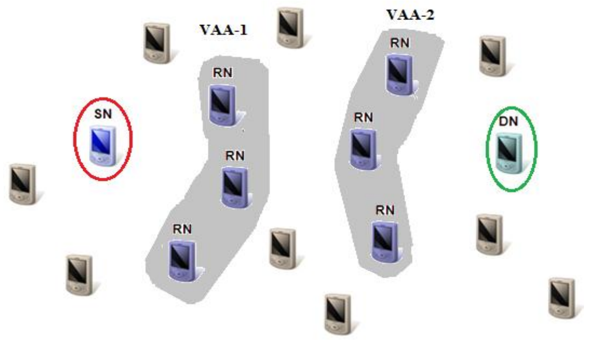

Fig. 2: Relay Selection

A. *Simple Relay Selection Algorithm*

In simple relay selection algorithm, the nodes are assigned to the virtual MIMO system based on Euclidean distance between them. Positions are assigned randomly to the set of nodes involved in relay selection. The source and the destination nodes are assigned fixed positions. The algorithm is as follows:

i. For each node N, calculate the distance D_{NS} and D_{ND} where D_{NS} is the distance between node N and source(S) and D_{ND} is the distance between node N and destination(D).
ii. Sort the nodes in ascending order based on D_{NS} and D_{ND} to form VAA-1 and VAA-2.
iii. The first two nodes from VAA-1 and VAA-2 are chosen to form VMIMO-1 and VMIMO-2.

This algorithm assigns the nodes for a 3-hop system. The performance of this system will be poor if the distances between the two virtual MIMO relays are more. The adaptive relay selection method addresses this problem.

B. *Adaptive Relay Selection Algorithm*

In adaptive relay selection algorithm, an intermediate VMIMO relay is introduced if the distances between the two relays are more. A choice between 3-hop system and 4-hop system is made adaptively depending upon on the distances between the virtual MIMO systems. Initially, as detailed in simple relay selection algorithm, nodes for VMIMO-1 and VMIMO-2 are selected. The adaptive algorithm is as follows:

i. Calculate the distance between the two VMIMO nodes
ii. If distance > threshold
   » Intermediate virtual MIMO relay needs to be considered. The intermediate nodes are chosen based on distance to form the 4-hop system.

- » Calculate the distance between the VMIMO nodes of 4-hop system.
- » If the intermediate relay is too far, then that relay is avoided and 3-hop system is chosen.

iii. Else
- » Continue with the 3-hop system.

IV. STBC ENCODING AND DECODING

Distributed Space Time Block Codes are implemented in virtual MIMO systems to achieve spatial diversity. The data to be transmitted is encoded in the form of Block codes for STBCs and in the form of Trellis codes for STTCs (Space Time Trellis Codes). This encoded data is distributed among multiple transmit antennas and multiple time slots. Orthogonality property of the STBCs helps to achieve full diversity. Alamouti's 2×2 STBC has the advantages of unity transmission rate and is chosen for the proposed system.

During the first time slot t_1,the nodes 1 and 2 of VMIMO-1 transmits the symbols s_1 and s_2. During the second time slot t_2, the nodes 1 and 2 transmits the symbols $-s_2^*$ and s_1^*. These are received at node 1 and 2 of VMIMO-2. The coding matrix is

$$\begin{bmatrix} s_1 & -s_2^* \\ \tilde{s}_2 & \tilde{s}_1^* \end{bmatrix} \quad (2)$$

where the rows correspond to the multiple antennas or nodes and columns denote the timeslots. For the transmission of the symbols s1 and s2 at time slots t1 and t2, the channel is assumed to be constant. The received signals after transmission of STBC signals through the MIMO channel is given by

$$\begin{bmatrix} y_{1(t1)} & y_{2(t1)} \\ y_{1(t2)} & y_{2(t2)} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} s_1 & -s_2^* \\ \tilde{s}_2 & \tilde{s}_1^* \end{bmatrix} + \begin{bmatrix} n_{11} & n_{12} \\ n_{21} & n_{22} \end{bmatrix}$$
(3)

Assuming perfect channel knowledge at the receiver, STBC decoding is done at each of the receive nodes of VMIMO system. The signal estimate at node 1 is given by

$$\begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \end{bmatrix} = \begin{bmatrix} h_{11}^* & h_{12} \\ h_{12}^* & -h_{11} \end{bmatrix} \begin{bmatrix} y_{1(t1)} \\ y_{1(t2)}^* \end{bmatrix} \quad (4)$$

Similarly the signal estimate is obtained at node 2

At the final stage, for the MISO system, the 2×1 Alamouti STBC encoding and decoding is given by

$$\begin{bmatrix} y(t_1) \\ y(t_2) \end{bmatrix} = \begin{bmatrix} s_1 & -s_2^* \\ \tilde{s}_2 & \tilde{s}_1^* \end{bmatrix}^T \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (5)$$

The signal estimates after STBC decoding is given by

$$\begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \end{bmatrix} = \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} y(t_1) \\ y^*(t_2) \end{bmatrix} \quad (6)$$

The signal received at each of the virtual MIMO nodes follows DF protocol, i.e. signals are decoded and re-encoded before transmission to the next stage.

V. SIMULATION RESULTS

The system model is implemented and the propagation channel is modeled by pathloss including flat fading with noise. Three different pathloss models, ie., Simplified Pathloss model , Two Ray model and Winner model are considered for the study. The fading channel is modeled with coefficients following Rayleigh distribution with complex additive white Gaussian noise (AWGN). Randomly generated data symbols are modulated by BPSK and transmitted. The channel state information is assumed to be known at each of the receiving stages. Perfect timing synchronization is also assumed for data transmission. The error performance of the system is analyzed at each stage. Experiments were done for the system without and with relay selection.

A. Without Relay Selection

The performance of the system without considering the relay selection problem was studied first. The relays were assumed to be preselected. The channel model considered in for this case included on the fading effect combined with additive noise. The Bit Error Rate performance of the basic 3-hop system at stages VMIMO-1, VMIMO-2 and Destination is shown in Fig 3.

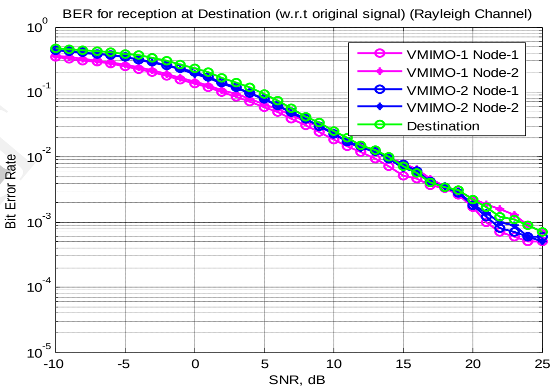

Fig. 3 : BER for reception at each stages of 3-hop system

The error performance of the system at Destination for different data modulation techniques such as BPSK, QAM and QPSK are studied and compared in Fig 4. The BPSK modulation technique has the least error performance.

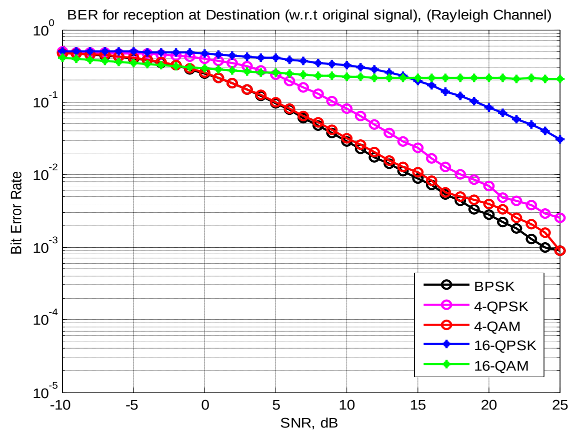

Fig. 4 : BER for reception at destination for different modulation techniques

Further, study was done on the system for multiple number of hops. The performance of the system is almost same for more number of hops. This is because the effect of pathloss based on distance was not considered.

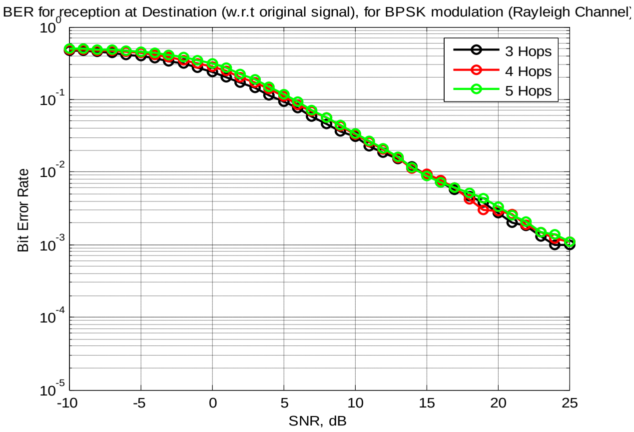

Fig. 5 : BER for reception at destination for multiple hops

B. *With Relay Selection*

The relay selection problem is considered in the system model. The effect of pathloss is included in the channel. Including pathloss in the channel has the effect of reducing the received power of the signal as a function of the distance. The reduction in received power affects the error performance of the system.

The simple relay selection algorithm is considered and the relay nodes for virtual MIMO system are selected from a set of nodes. The positions of Source Destination were assigned, and a set of nodes were considered and random positions are assigned for each of them. The BER graphs of simple relay selection scheme is shown in Fig 6.

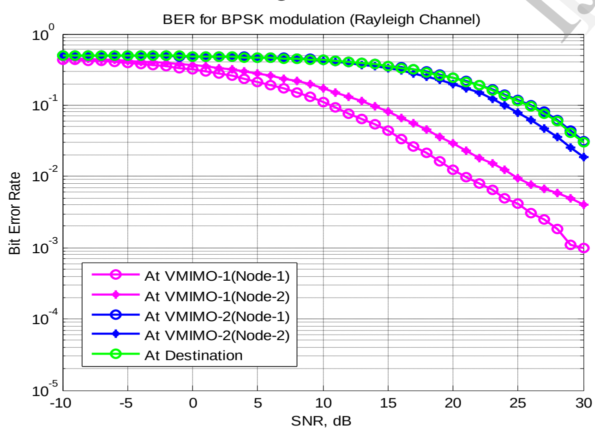

Fig. 6 : BER for 3-hop virtual MIMO system with Simple Relay Selection

Further the Adaptive relay selection scheme was considered. This technique adaptively switches between a 3-hop and a 4-hop system based on the distance between the nodes forming the virtual MIMO stages. Similar to the simple relay selection technique the positions for all the nodes are initialized and the nodes are selected to form a 3-hop system. In this scenario the distance between the two virtual MIMO relays are more and there is a need of another VMIMO relay. The node selection for intermediate virtual MIMO stage is done based on distance and the 4-hop system model formed. The switching between 3-hop to 4-hop system is done based on the algorithm. The final system model is shown in Fig 7. The BER graph of the corresponding system is shown in Fig 8.

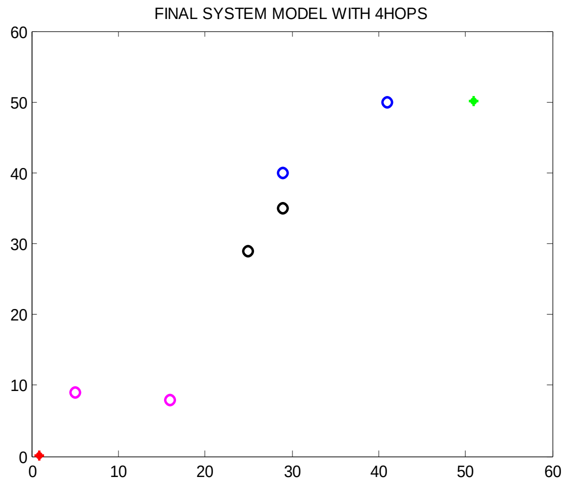

Fig. 7 : Final System model of 4-hop virtual MIMO system using Adaptive relay selection

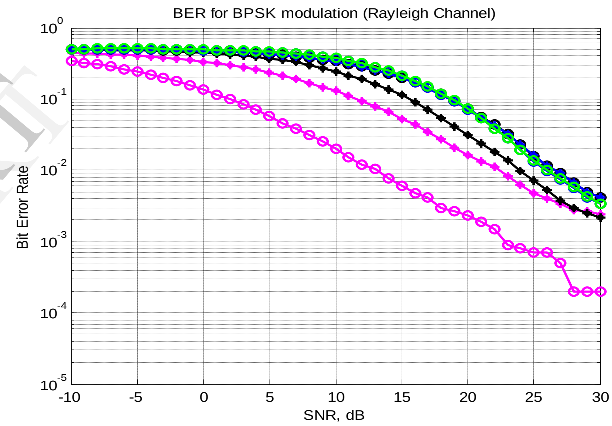

Fig 8 : BER for 4-hop virtual MIMO system using Adaptive Relay Selection

Further, experiments were done considering the different pathloss models such as Two ray model, Simplified model and Winner models. All these models relates the distance and the power of the received signal. The graph showing the comparison of BER performance of these models is shown in Fig 9. From the graph the simplified pathloss model is having the best performance compared to the other two models.

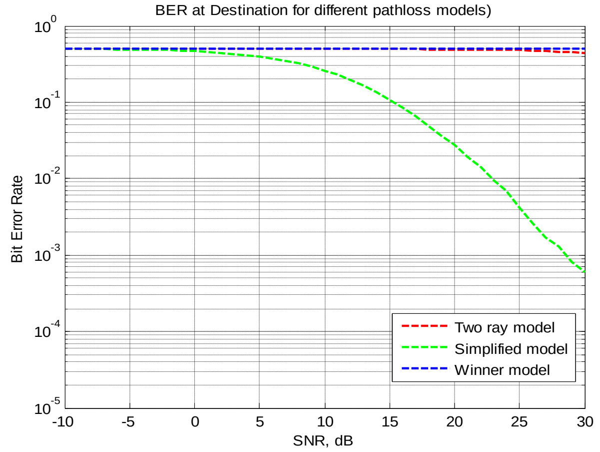

Fig 9 : BER for virtual MIMO system with Adaptive relay selection for different pathloss models

The virtual MIMO system with Adaptive Relay Selection technique is studied and analyzed based on comparison with Adaptive and Simple relay selection schemes. The Bit error rate and channel capacity are analysed and these are shown in figures Fig 10 and Fig 11.

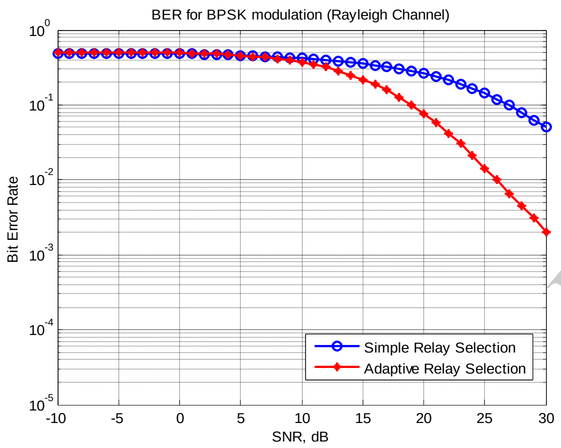

Fig 10 : Comparison of BER for Adaptive relay selection and Simple Relay Selection

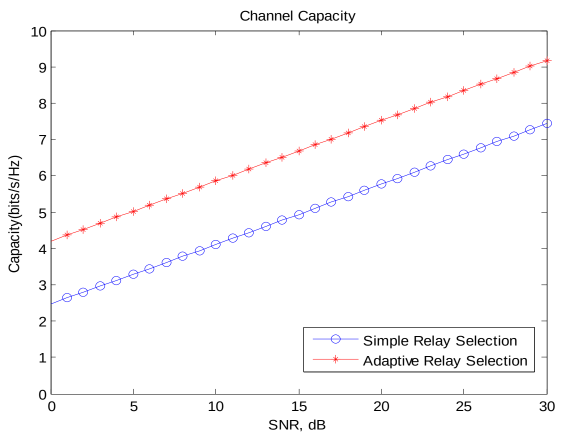

Fig 11 : Comparison of Channel capacity for Adaptive relay selection and Simple Relay Selection

Based on the results obtained, the error performance of the system using adaptive relay selection technique is better compared to that of simple relay selection technique as obtained in the Fig 10. In addition, the channel capacity (Fig 11) is higher for the proposed Adaptive relay selection algorithm.

VI. CONCLUSION

Reliable data communication between source and destination nodes having single antennas is a major issue in wireless communication. The cooperative MIMO technique enables a source with single antenna to realize MIMO communication by using the antennas of neighboring users. The concept of virtual MIMO system is incorporated in a multi-hop communication scenario. The virtual MIMO system is implemented using Distributed Space Time Block Codes. A relay selection technique for selecting the cooperative nodes for each stage is also considered. Simple and Adaptive Relay Selection Techniques are implemented and its performance is studied and the Adaptive Technique has a better performance.

REFERENCES

[1] Aria Nosratinia, Todd E.Hunter, Ahmadreza Hedayat, "Cooperative Communication in Wireless Networks",IEEE Communications Magazine, October 2004.

[2] J. Nicholas Laneman, Gregory W. Wornell, "Distributed Space–Time-Coded Protocols for Exploiting Cooperative Diversity in Wireless Networks" , IEEE Transactions on Information Theory, Vol.49, No.10, October 2003.

[3] Mischa Dohler, "Virtual Antenna Arrays" – November 2003.

[4] Timo Unger, Anja Klein, "Cooperative MIMO relaying with Distributed Space Time Block Codes" ,The 17th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'06).

[5] Thossaporn Chanpuek, Peerapong Uthansakul, Monthippa Uthansakul, "Performance Enhancement of Mobile Networks using Cooperative MIMO Technique", 2012

[6] Quanquan Liang, Dongfeng Yuan, Yong Wang, Ruihua Zhang ,"A Distributed Virtual MIMO Scheme Using Cross Layer Design For Wireless Sensor Networks", 2007

[7] Andrej Stefanov and Elza Erkip, "Cooperative Space Time Coding for wireless networks", ITW2003, Paris, France, March 31 – April 4, 2003.

[8] Michal Wodczak, "Autonomic Cooperative Communications for Emergency Networks", The 4th IEEE International Workshop on Management of Emerging Networks and Services, 2012

[9] M. Wodczak, "Aspects of Cross-Layer Design in Autonomic Cooperative Networking," *IEEE Third International Workshop on Cross Layer Design, Rennes, France*, 30 November - 1 December 2011.

[10] Michal Wodczak, *Autonomic Cooperative Networking*. Springer-Verlag New York, 2012.

[11] A. Goldsmith, *Wireless Communications*. Cambridge University Press, 2005.