RELAY SELECTION SCHEME FOR COOPERATIVE MIMO COMMUNICATIONS

Thossaporn Chanpuek

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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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การพัฒนาระบบการสื่อสารมีมาตรฐานใหม่มาอย่างต่อเนื่อง เพื่อรองรับความต้องการใช้งานที่มากขึ้นอย่างรวดเร็วและแก้ปัญหาการมีบริเวณที่เป็นจุดอับของสัญญาณ แนวคิดหนึ่งที่สามารถเพิ่มความสามารถในการส่งสัญญาณคือการสื่อสารร่วมมือ ซึ่งเป็นระบบการสื่อสารรูปแบบใหม่ ที่เป็นการเพิ่มประสิทธิภาพของระบบการสื่อสารโดยการใช้รีเลย์ แต่การใช้งานรีเลย์เพียงอย่างเดียวยังไม่สามารถทำให้ระบบการสื่อสารร่วมมือทำงานได้อย่างเต็มประสิทธิภาพ ดังนั้นจึงได้มีการประยุกต์ระบบการสื่อสารแบบไมโมเข้ามาใช้งานร่วมกับระบบการสื่อสารร่วมมือ ซึ่งทำให้การใช้รีเลย์มีประสิทธิภาพมากขึ้น อย่างไรก็ตามในระบบการสื่อสารร่วมมือแบบไมโมเป็นการใช้ประโยชน์จากรีเลย์ในการช่วยถ่ายทอดสัญญาณ แต่โดยทั่วไปในทางปฏิบัตินั้นรีเลย์มีตำแหน่งที่กระจายอยู่แตกต่างกันไป ซึ่งแต่ละตำแหน่งจะส่งผลต่อความสามารถในการรับส่งข้อมูลที่ต่างกัน จึงทำให้ปัญหาการเลือกตำแหน่งรีเลย์มีความสำคัญอย่างมากต่อระบบการสื่อสารร่วมมือแบบไมโม จากการจำลองประสิทธิภาพของระบบการสื่อสารร่วมมือที่พัฒนาขึ้น พบว่าแบบแผนการเลือกรีเลย์ที่นำเสนอให้ผลที่ดีกว่าแบบแผนในการเลือกรีเลย์แบบอื่นๆที่นำมาเปรียบเทียบ ยิ่งไปกว่านั้นผลการวัดจากชุดทดสอบที่สร้างขึ้นยืนยันว่าแบบแผนการเลือกรีเลย์ที่นำเสนอมีประสิทธิภาพดีกว่าแบบแผนการเลือกรีเลย์แบบอื่น โดยงานวิจัยนี้เป็นการเสนอแบบแผนการเลือกใช้งานรีเลย์ที่มีเป้าหมายในการพิจารณาความจุช่องสัญญาณและในการพิจารณากำลังส่งสัญญาณเป็นสำคัญ ผลลัพธ์ที่ได้จากวิทยานิพนธ์นี้เป็นประโยชน์อย่างมากสำหรับการสร้างระบบการสื่อสารร่วมมือแบบไมโมในทางปฏิบัติ

สาขาวิชาวิศวกรรมโทรคมนาคม	ลายมือชื่อนักศึกษา ________________
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THOSSAPORN CHANPUEK : RELAY SELECTION SCHEME FOR COOPERATIVE MIMO COMMUNICATIONS. THESIS ADVISOR : ASSOC. PROF. PEERAPONG UTHANSAKUL, Ph.D., 157 PP.

RELAY SELECTION SCHEME / OUTAGE PROBABILITY / COOPERATIVE MIMO COMMUNICATION / DECODE AND FORWARD

The developmentof communication systemsconsistently creates communication technology standards in order to meet the requirements of increasing data transmission and solving the non-service location. One concept that has the ability to increase data transmission is the cooperative communication systems. The cooperative communication systems are a new form of communication which increases efficiency of communication systems by using relay nodes. However, using only the relay node method alone cannot make the cooperative communication systems fully efficient. Thus, the cooperative communication systems have been applied with MIMO technology. The cooperative MIMO communication systems repeat the transmission signal through the relay node. In general, the relay node is randomly located in the communication area. The different position of relay node affects the ability to send and receive data differently. As a result, the problem of relay node selection is very important for cooperative MIMO communications. The simulations revealed that the proposed relay selection scheme offered a better result in comparing with the other relay selection schemes. Moreover, the measurement results collected from the real communications can confirm that the proposed relay selection scheme outperforms the other relay selection schemes in practice. This thesis presents the relay selection scheme by considering either the channel capacity or transmission

power as the main objective. The outcome of this thesis is useful for implementing the cooperative MIMO systems in practice.

School of Telecommunication Engineering Student's Signature_______________

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SYMBOLS AND ABBREVIATIONS

AF	=	Amplify and forward
AWGN	=	Additive white gaussian noise
BER	=	Bit error rate
BPSK	=	Binary phase shift keying
CF	=	Compress and forward
CPU	=	Computer processing unit
CSI	=	Channel state information
DDC	=	Digital downconverters
DF	=	Decode and forward
DUCs	=	Digital upconverters
FPGA	=	Field programmable gate array
GRC	=	GNU radio companion
MISO	=	Multiple input single output
MIMO	=	Multiple input multiple output
MMSE	=	Minimum mean square error
MRC	=	Maximal ratio combiner
PER =	=	Packet error rate
SDR	=	Software defined radio
SIMO	=	Single input multiple output

SYMBOLS AND ABBREVIATIONS (Continued)

SISO	=	Single input multiple output
SM	=	Spatial multiplexing
SNR	=	Signal to noise ratio
STC	=	Spatial Time Coding
STBC	=	Spatial time block code
TDD	=	Time Division Duplex
USRP	=	Universal software radio peripheral
ZF	=	Zero forcing

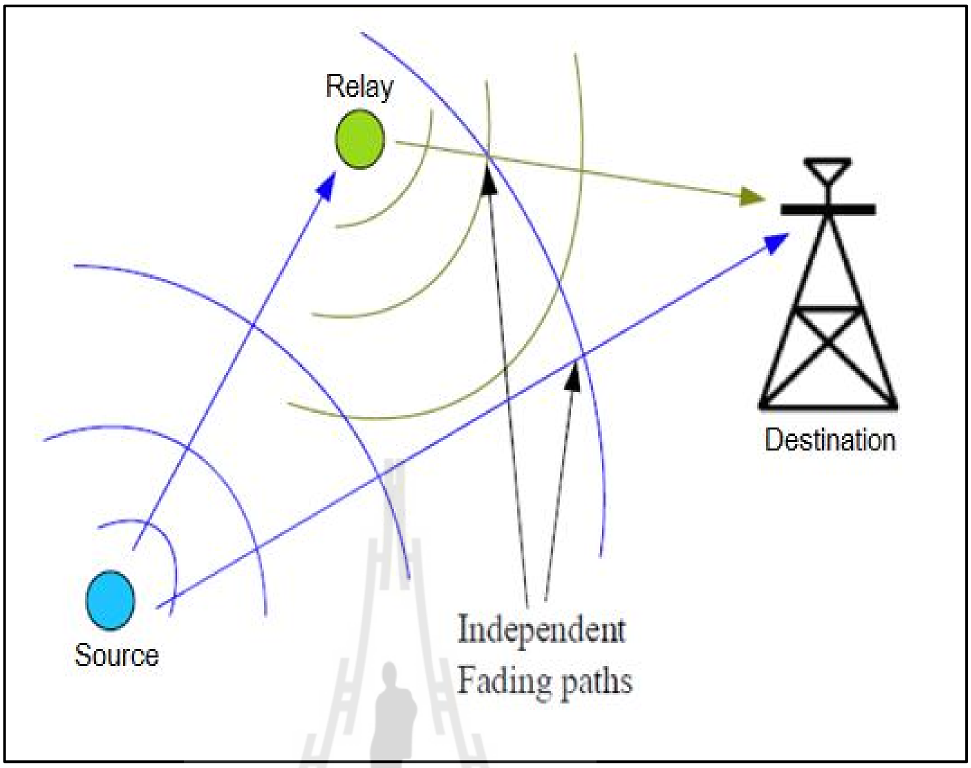
CHAPTER I

INTRODUCTION

1.1 Rationale and Background

Currently, the communication technology has a huge role in everyday life. Wireless communications systems are another form of communications. It is widely used because the systems are convenient to operate. The systems will meet the needs of users, for example, high speed data transmission, coverage area extension and quality of service to all users. It needs to be further developed for efficiency of data transmission and communication quality.

It is well known that MIMO wireless communication systems (Paulraj, A. J., Gore, D. A., Nabar, R. U. and Bolcskei, H. (2004)) can support needs for high data transmission of multimedia communication in the future. Since the MIMO systems make the system better because the systems can increase performance of a communication channel in data transmission. However, one type of wireless communication systems will meet the needs of data transmission and increase performance of a communication channel in data transmission. Without the need to increase the number of antenna at transmitter or receiver. This is the communication system so called cooperative communication systems. A preliminary explanation of the ideas behind cooperative communications is referred in Figure 1.1. This figure shows two node agents communicating with the same destination.


Relay
Destination
Independent
Fading paths
Source

information technique by whereby users help forward the data information to the receiver. This creates a virtual MIMO communication system. This technique can increase channel diversity and can reduce the Bit Error Rate (BER) of the systems. However, the problem of channel fading due to signal noise, signal delay and multipath signal can result in signal distortion. Based on these problems, cooperative communication systems can increase the performance in order to respond to user's usability in communication systems.

From these problems, the candidate sees the need of higher efficient communication to respond the higher need of users. Therefore, communication systems have to reduce BER and eliminate the interference signal in the systems. The system development was focused on transmission signals in cooperative communication systems in order to optimize the received and transmitted signals of the wireless communication systems. The system advantages of Spatial Time Encoding (STC) are based on an increase in diversity, channel coding and utilization of multiple antennas. Thus, STC can effectively reduce the effects of channel fading, increase high speed data transmission, reduce BER in the systems and the system desig is not complicated.

The proposed cooperative MIMO technique is introduced to improve the system performance of wireless communication networks. A Spatial Time Block Encoding (STBC) is selected to implement the virtual MIMO transmitter. By using the neighboring antennas, the overall system can be operated as MIMO communications. It is interesting to see the improvement of using the proposed concept in wireless communication networks. In the case of relay selection, the process of relay cooperation is done by considering channel information and Signal-to-Noise Ratio (SNR) throughout the path from the transmitter to the receiver. This thesis presents relay power selection scheme and relay capacity selection scheme for using in each situation in order to improve transmission rate in the cooperative MIMO communication system. The systems consider a selection of channel capacity scheme in which the systems can support the higher transmission rate than the power scheme. On the other hand, if the cooperative MIMO communication systems requires low energy consumption for signal transmission, the systems consider selection power scheme in which the systems can save energy over the selection channel capacity scheme.

1.2 Research Objectives

To develop a relay selection scheme for cooperative MIMO communication systems by considering the energy and channel capacity.

1.3 Thesis Hypotheses

1.3.1 The relay selection scheme can select the higher channel capacity for cooperative MIMO communication systems.

1.3.2 The relay selection scheme can select lower energy for cooperative MIMO communication systems.

1.3.2 The relay selection scheme can be optimized for cooperative MIMO communication systems.

1.4 Scope and limitation of the study

1.4.1 This research focuses on development of relay selection schemes for cooperative MIMO communication systems.

1.4.2 The Decode-and-Forward (DF) protocol is employed for transmitted signal.

1.4.3 A testbed is designed as cooperative MIMO communication systems. The systems install one antenna at source node, one antenna at relay node and two antennas at destination node.

1.4.4 Only one relay will be considered for system performance testing.

1.4.5 The relay selection on testbed considers a relay that can choose between energy consumption or channel capacity.

1.4.6 Testbed is designed to investigate performance of the proposed technique.

1.5 Contributions

This thesis proposes a relay selection technique for cooperative MIMO communication systems in which the outcome can be categorized into two major contributions.

1.5.1 The proposed relay selection technique can be practically implemented because it offers a low outage probability that can reduce energy and increase channel capacity for the systems.

1.5.2 This thesis shows the construction of relay selection scheme measurement for cooperative MIMO communication systems.

1.6 Methods

1.6.1 Methodology

1) Literature reviews will be carried out to study the related works.

2) Computer programing is used to simulate the performance of cooperative MIMO communication systems and relay selection.

3) Mathematical analysis is used to verify the accuracy of simulation.

1.6.2 Research Location

Wireless Communications Laboratory, School of Telecommunication Engineering, F4 building, Suranaree University of Technology, 111 University Avenue, Suranaree Sub-District, Muang Nakhon Ratchasima District, Nakhon Ratchasima 30000, Thailand.

1.6.3 Instruments for Hardware Implementation

1) Computer notebook

2) Matlab program

3) Power amplifier

4) Network analyser

5) Oscilloscope

6) Power supply

7) Universal Software Radio Peripheral (USRP)

8) GNU Radio Companion (GRC) Program

1.7 Thesis Contents

This thesis is divided into seven chapters. The first chapter includes problem and rationale, research objective, hypotheses, scope and limitation of the study, contributions and methods. Chapter II presents literature review and the related works. The principle and theory of cooperative communication systems are discussed in Chapter III. Chapter IV describes the principle of the proposed cooperative MIMO communication technique and derivation of the probability of outage used for relay selection. Chapter V presents the simulation results compared with analytical results. The implementations of cooperative MIMO communication systems for relay selection scheme testbed are illustrated in Chapter VI. Chapter VII provides discussion and conclusion.

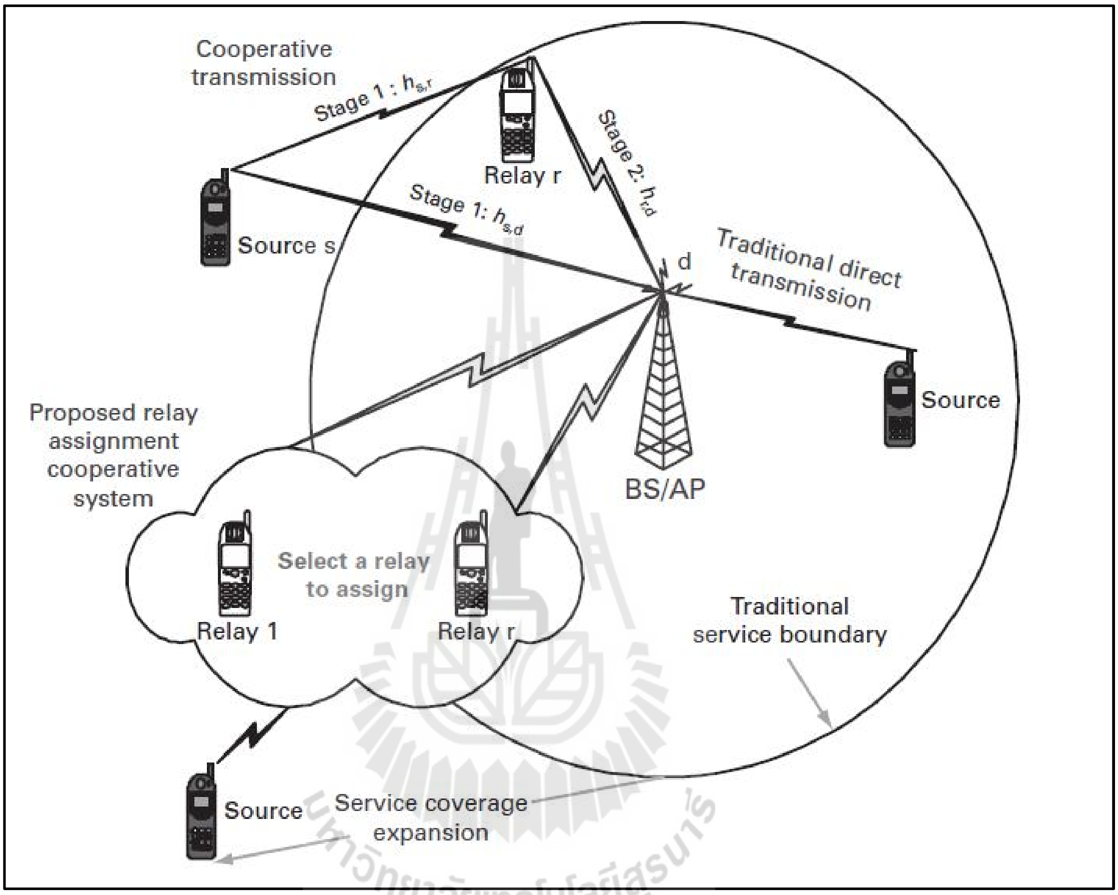
CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Wireless communication systems are a form of communication systems, which a transmitter sends information to a receiver through wireless communication channel. However, the characteristics of the wireless channel have various factors such as physical environment, mobility of receiver or transmitter and temperature. Those factors affect the characteristics of the received signal deviatly it from the original signal. Therefore, the systems have been developed and various methods to solve such problems.

Cooperative communication systems have been attractive for researchers because they enhance the performance of communication systems (Wang, C.-X., Hong, X., Ge, X., Cheng, X., Zhang, G. and Thompson, J. S. (2010)). The cooperative communication systems are shown in Figure 2.1. The cooperative communication systems are one form of wireless communication systems. The relays in the cooperative communication systems receive signals from the transmitter and received signals are forwarded to the destination. This receive a diversity of wireless channels when each signal is sent to the destination. Currently, the cooperative communication systems have been developed in many fields. For example, model of the signal transmission in the cooperative communication systems is widely developed. This operation will make the



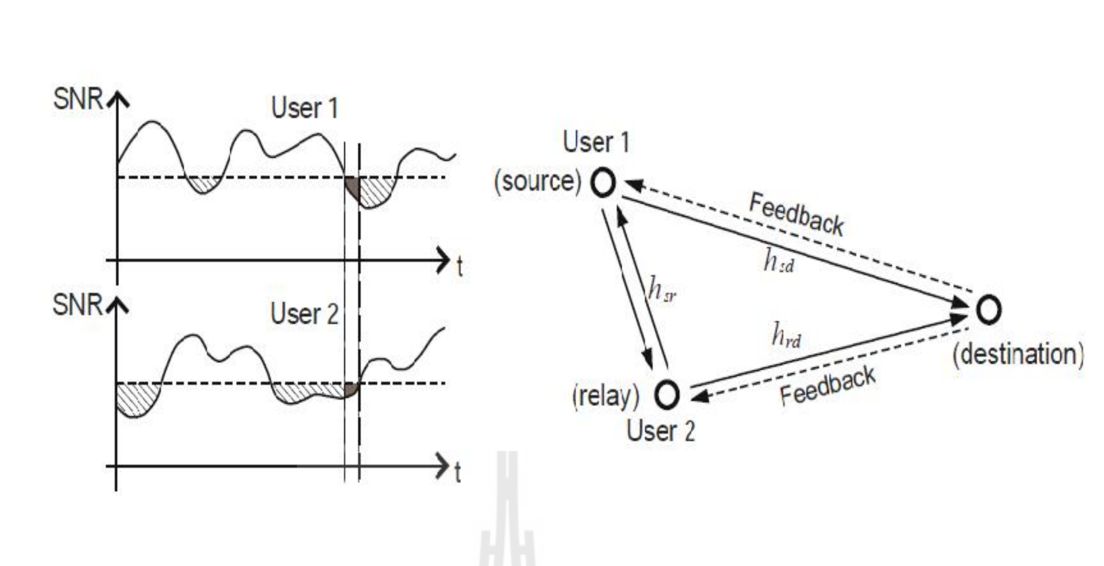
Cooperative transmission
Stage 1 : $h_{s,r}$
Relay r
Stage 2: $h_{r,d}$
Stage 1: $h_{s,d}$
Source s
d
Traditional direct transmission
Source
Proposed relay assignment cooperative system
BS/AP
Select a relay to assign
Relay 1
Relay r
Traditional service boundary
Source
Service coverage expansion

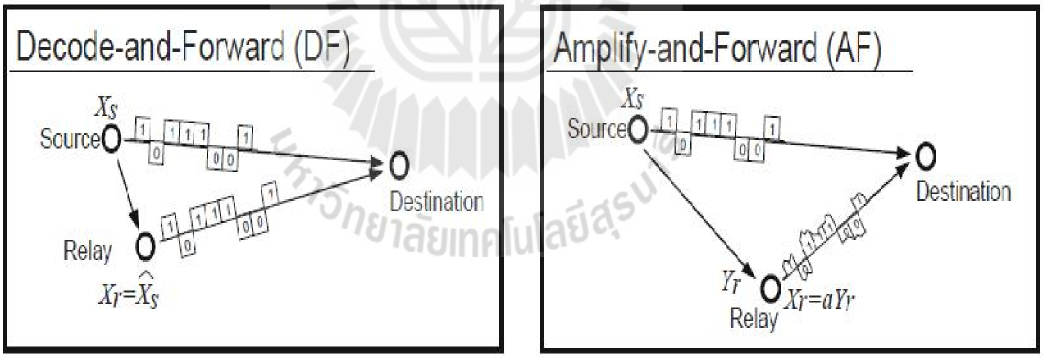
Therefore, it is necessary to conduct literature reviews in the related research regarding the process operating on the cooperative communication systems.

The objective of in this chapter is to discuss an overview on cooperative communications with a brief detail on MIMO communications. This content discusses a principle decoding and detection of the conventional MIMO systems, cooperative MIMO concepts, relay selection techniques, literature review and related work.

2.2 An Overview on Cooperative Communications

Cooperative communications, as popularized by the works (Laneman, J.N., Tse, D.N.C., Wornell, G.W.(2004); Laneman, J.N., Wornell, G.W.(2003); Scaglione, A., Hong, Y.-W.(2003); Sendonaris, A., Erkip, E., Aazhang, B.(2003)), allow users in the systems to cooperate by relaying each other's messages to the destination. By doing so, users can effectively form a distributed antenna array that emulates the spatial diversity gains achievable by centralized MIMO systems. An example of a pair-wise cooperative communication systems is shown in Figure 2.2, where the users are assumed to experience independent fading channels to the destination. Due to multipath fading, the signal-to-noise ratios (SNRs) at the destination may vary rapidly over time, causing communication outage whenever one of the users' SNRs falls below the required level (as illustrated by the shaded regions in Figure. 2.2). However, if the two users can cooperate by relaying each other's messages to the destination, communication outage will occur only when both users simultaneously experience poor channels, thereby improving the transmission reliability.





(a) Decode-and-Forward

(b) Amplify-and-Forward

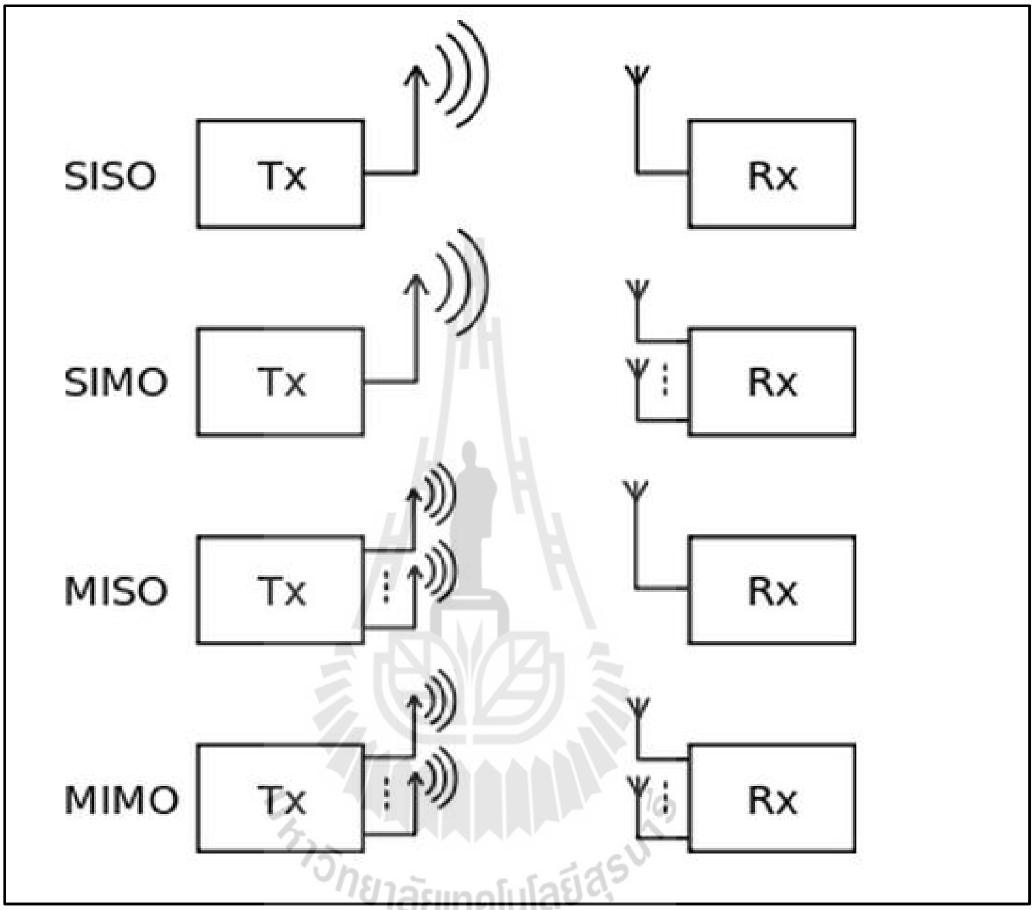
Many cooperation strategies have been proposed in the literature based on different relaying techniques, such as amplify-and forward (AF) (Laneman, J.N., Tse, D.N.C., Wornell, G.W.(2004)), decode-and-forward (DF) (Laneman, J.N., Tse, D.N.C., Wornell, G.W.(2004); Sendonaris, A., Erkip, E., Aazhang, B.(2003)), selective relaying (SR) (Laneman, J.N., Tse, D.N.C., Wornell, G.W.(2004)), coded cooperation (Janani, M., Hedayat, A., Hunter, T.E., Nosratinia, A.(2004)), compress-and-forward (CF) (Kramer, G., Gastpar, M., Gupta, P.(2003)) and etc. When these schemes are employed in a pair-wise cooperating system as shown in Figure 2.2, the candidate can assume that, at each instant time, only one user acts as the source while the other user serves as the relay that forwards the source's message to the destination. The role between the source and the relay can be interchanged at any instant time. An illustration of the DF and AF schemes are given in Figure 2.3. In these schemes, cooperative transmissions are commonly initiated by first having the source (e.g., user 1) broadcast its message to both the relay and the destination. If the DF scheme is employed, the relay will decode and regenerate a new message to the destination in the subsequent time slot. At the destination, signals from both the source and the relay are combined to provide better detection performance. As an extension to the DF scheme, the message generated by the relay can be re-encoded to provide additional error protection, and such a scheme can also be referred to as coded cooperation. If the AF scheme is employed, the relay simply amplifies the received signal and forwards it directly to the destination without explicitly decoding the message. This scheme can be applied on top of both DF and AF schemes to improve cooperation efficiency. Among the many cooperation schemes proposed in the literature, DF and AF schemes are the most basic and widely adopted.

2.3 An Overview on MIMO Communications

2.3.1 MIMO Systems

MIMO systems employ multiple antennas at both transmitters and receivers to improve communication performance. The terms of input and output refer to the radio channel carrying the signal. MIMO systems have attracted attention in wireless communication because it offers significant increases in data throughput. It achieves an array gain that improves the spectral efficiency (bits per second per hertz of bandwidth). MIMO technology has been developed and implemented in some standards, e.g. 802.11n products. In Single Input Single Output (SISO), both the transmitter and receiver have one antenna. In Single Input Multiple Output (SIMO), there is one antenna at the transmitter and multiple antennas at the receiver. In Multiple Input Single Output (MISO), there are multiple antennas at the transmitter and one antenna at the receiver. Illustrations of SISO, MISO, SIMO and MIMO can be shown in Figure 2.4.

MIMO communication is the advanced technology for recent and future platform. Both the transmitting and receiving side are equipped with multiple antennas to expand the opportunity of receiving higher received signal. Both diversity gain and channel capacity can be increased corresponding to the number of antennas. The Spatial Multiplexing (SM) MIMO (Foschini, G. J. (1996)) applies multiple antennas at transmitter and receiver to increase capacity gain as well as the Space-Time Block Coding (STBC) MIMO (Alamouti, S. M. (1998) and Tarokh, V., Jafarkhani, H. and Calderbank, A. R. (1999)) applies two time slots and two antennas to transmit block coding message to the receiver. The combination signal and


SISO
Tx
Rx
SIMO
Tx
Rx
MISO
Tx
Rx
MIMO
Tx
Rx

2.3.2 MIMO Detection

MIMO transmitter and receiver are equipped with multiple antennas. The transmitted signal is sent through MIMO channel to the receiver at the same time. The received signal at the receiver can be written as

$$\boldsymbol{y} = \mathbf{H}\boldsymbol{x} + \boldsymbol{w} \tag{2-1}$$

$$\begin{bmatrix} y_1 \\ \vdots \\ y_{N_r} \end{bmatrix} = \begin{bmatrix} h_{11} & \cdots & h_{1N_t} \\ \vdots & \ddots & \vdots \\ h_{N_r1} & \cdots & h_{N_rN_t} \end{bmatrix} \begin{bmatrix} \boldsymbol{x}_1 \\ \vdots \\ \boldsymbol{x}_{N_t} \end{bmatrix} + \begin{bmatrix} w_1 \\ \vdots \\ w_{N_r} \end{bmatrix} , \tag{2-2}$$

where **y** denotes the received signal vector, H denotes the channel matrix, $\boldsymbol{x}$ denotes the transmitted symbol vector and w denotes the white Gaussian noise vector with zero mean and variance $\pm_z^2$, N_r and N_t represent the number of receiving antenna and the number of transmitting antenna, respectively.

2.3.3 Linear Signal Detection

When the transmitted signals arrive at the receiver, the received signal will be detected by applying a weight matrix $\mathbf{U}$ by

$$\boldsymbol{x} = [\tilde{x}_1 \; \tilde{x}_2 \; \tilde{x}_3 \ldots \tilde{x}_{N_t}]^T = \mathbf{U}\boldsymbol{y} \quad , \tag{2-3}$$

where (2-3) represents the detected symbol. The linear signal detection can be generally divided into two methods. One is Zero-Forcing (ZF) technique and another one is Minimum Mean Square Error (MMSE).

1) Zero-Forcing (ZF)

The interference of other streams can be cancelled by weight matrix as follows,

$$\mathbf{U}_{ZF} = (\mathbf{H}^H \mathbf{H})^{-1} \mathbf{H}^H \quad , \tag{2-4}$$

where $(\cdot)^H$ represents conjugate transpose operation and the dimension of $\mathbf{H}$ is $N_r \times N_t$. The detected symbols can be detected by

$$\tilde{\boldsymbol{x}}_{ZF} = \mathbf{U}_{ZF}\boldsymbol{y} = \boldsymbol{x} + \left(\mathbf{H}^H \mathbf{H}\right)^{-1} \mathbf{H}^H \boldsymbol{w} = \boldsymbol{x} + \boldsymbol{w}_a \tag{2-5}$$

where $\boldsymbol{w}_a = [\, w_{a1} \;\, w_{a2} \;\, w_{a3} \ldots w_{a\mathrm{Nr}} \,]^{\mathrm{T}}$ denotes the noise vector due to the ZF process.

2) Minimum Mean Square Error (MMSE)

The interference of other streams can be cancelled by weight matrix as follows.

$$\mathbf{U}_{MMSE} = \left(\mathbf{H}^H \mathbf{H} + \sigma_z^2 \mathbf{I}\right)^{-1} \mathbf{H}^H \tag{2-6}$$

where $\mathbf{I}$ denotes the identity matrix with dimension $N_r \times N_t$. The detected symbols can be detected by

$$\tilde{\boldsymbol{x}}_{MMSE} = \mathbf{U}_{MMSE}\boldsymbol{y} = (\mathbf{H}^H \mathbf{H} + \sigma_z^2 \mathbf{I})^{-1} \mathbf{H}^H \boldsymbol{y} = \tilde{\boldsymbol{x}} + (\mathbf{H}^H \mathbf{H} + \sigma_z^2 \mathbf{I})^{-1} \mathbf{H}^H \boldsymbol{w} \tag{2-7}$$

2.3.4 Maximum Likelihood Detection

For detection, the minimum Euclidean distance is used to choose the optimum signal. This distance can be calculated from the difference between the received signal, the product of channel matrix and all possible symbols in constellation. The detected symbols can be obtained by

$$\boldsymbol{x}_{ML} = \underset{\boldsymbol{x} \in C^{N_t}}{\arg\min} \left\| \boldsymbol{y} - \mathbf{H}\boldsymbol{x} \right\|_F^2 \quad , \tag{2-8}$$

where C^{N_t} denotes all possible symbols in constellation and $\|\cdot\|_{\mathrm{F}}^2$ represents Frobenius norm operation whereby $\|\boldsymbol{A}\|_F = \sqrt{\sum_{i=1}^{a}\sum_{j=1}^{b}|A_{ij}|^2}$, alignment a and b denote the number of row and the number of column of matrix $\boldsymbol{A}$, respectively

2.3.5 Channel Capacity of MIMO Systems

The channel capacities of MIMO signals depend on the information power to noise power ratio, the number of transmit and receive antennas, and channel gain. Thus, the channel capacity can be increased by increasing transmitted power or the number of antennas. This relation can be expressed as

$$C_{MIMO} = E\left\{ \log_2 \det(\mathbf{I}_{N_r} + \frac{\overline{\gamma}}{N_t}\mathbf{H}^H\mathbf{H}) \right\} \quad , \tag{2-9}$$

where $E\{\cdot\}$ represents expectation operation and $\overline{\gamma}$ denotes the signal-to-noise ratio.

2.4 Cooperative MIMO Concepts

The MIMO term originally describes the use of the multiple antennas concept or exploitation of spatial diversity techniques. In early research works, the MIMO concept was proposed to fulfill the demand for providing reliable high-speed wireless communication links in harsh environments. Subsequently, MIMO technology has been proposed for use in wireless local area networks and cellular networks (Proakis, J.G. (2001); Singh, M. and Prasanna, V.K. (2003)), particularly at the base station and access point to improve transmission rates and reliability in system with no constraints on energy efficiency. In contrast, cooperative communication systems have energy constraints due to the fact that each relay node depends on its battery for its operation. Apart from battery constraints, relay nodes located in harsh environments require reliable communication links rather than high transmission rates.

Therefore, to provide reliable communication links, the concept of cooperative MIMO was introduced in cooperative communication systems. The MIMO concept uses the collaborative nature of dense relay nodes with the broadcast wireless in order to improve reliability and reduce the total energy consumption for each relay node. Therefore, instead of using multiple antennas attached to one node or device such in the traditional MIMO concept, cooperative MIMO presents the concept of multiple relay nodes physically grouped together to cooperatively transmit and/or receive signals. Within a group, relay nodes can communicate with relatively low power compared to inter-group communication (Singh, M. and Prasanna, V.K. (2003); Gupta, G. and Younis, M. (2003); Yuksel and Erkip, (2004)). Furthermore, by using this cooperative MIMO concept, the advantages of traditional MIMO in cooperative communication systems can be achieved particularly in terms of energy efficient operation.

2.5 Relay Selection Techniques

In cooperative communications, the relay selection is a challenging task. The proper selection of the relay can effectively improve the overall performance of the networks in terms of higher data rate, higher throughput, lower power consumption and lower bit error rate. The relay selection is based on the performance indices like Channel State Information (CSI), Signal-to-Noise Ratio (SNR), Packet Error Rate (PER), etc. The relay should not be selected by only considering the source to destination performance, but it must be done by maintaining the overall system performance. The relay selection can be classified as follows.

Group selection

In this method, relay selection occurs before transmission. The purpose of selection is to achieve certain pre-defined performance level.

Proactive selection

In this method, relay selection is performed by the source, the destination, or the relay itself during the transmission time.

On-demand selection

Here, the relay selection is performed when needed, i.e., when direct channel conditions decrease below a pre-defined threshold.

Depending on the relation between the network entities, relay selection mechanisms can be divided into two categories:

1) Opportunistic Relay Selection

2) Cooperative Relay Selection

The basic opportunistic relay selection scheme is based on local measurements. They can be further classified as

1) Measurement-based relay selection

2) Performance-based relay selection

3) Threshold-based relay selection

All these three approaches are opportunistic and follow a proactive selection approach. The on-demand selection category (e.g. adaptive relay selection) follows a different approach, in which the relay selection procedure is only triggered if needed. Contrary to opportunistic relay selection, cooperative relay selection procedures require the exchange of information among the involved communication nodes. In this case, there are two categories:

1) Table-based relay selection that leads to the selection of a controlled number of relays (one or two) based on information kept by the source

2) Contention-based relay selection that leads to the selection of a set of a variable number of relays.

These approaches depend on the considerations the used network.

2.6 Literature Review and Related Work

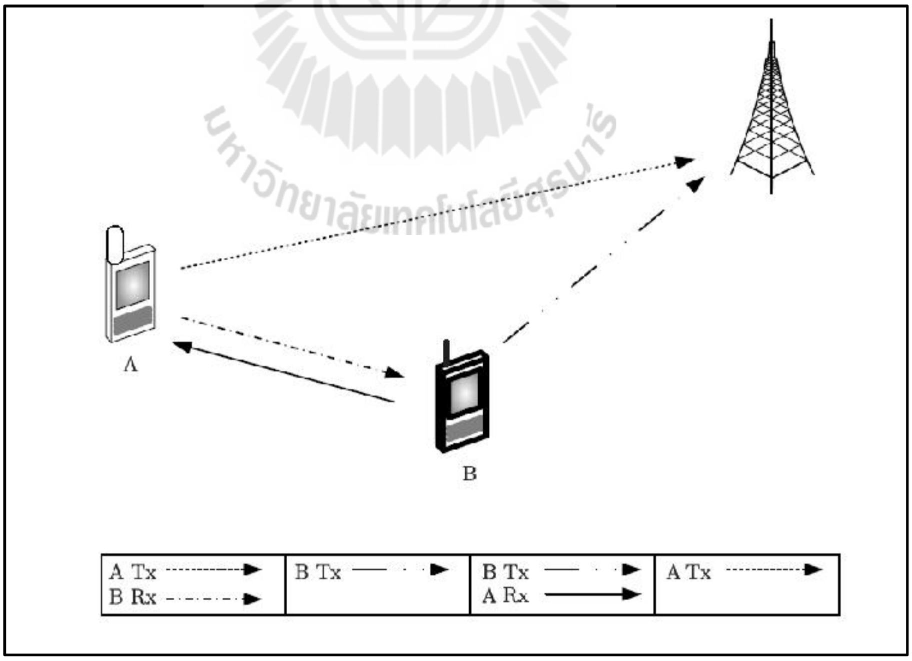
In the past few years, cooperative communication has been a very active research field. Extensive researches have focused on the physical layer aspects of cooperative communications (Zheng, S., Ding, Z. and Leung, K. (2011); Kramer, G., Gastpar, M. and Gupta, P. (2005)). Therefore, there are many developments of research in cooperative wireless communication systems in the literature. In general, the cooperative transmission protocols used in the relay node are classified into amplify-and-forward (AF) protocol and decode-and-forward (DF) protocol (Laneman, J. N., Tse, D. N. C. and Wornell, G. W. (2004)). Recently, a group of researchers (Sendonaris, A., Erkip, E., Aazhang, B. (2003); Himsoon, T., Su, W. and Liu, K. J. R. (2005); Abdaoui, A., Ikki, S. S., Ahmed, M. H. and Chatelet, E. (2010)) have proposed a transmission technique in type of forwarding data information by using cooperative communications. The group of researchers developed a transmission technique in the amplify-and-forward protocol. The work in (Ganwani, V., Dey, B. K., Sharma, G. V. V., Merchant, S. N. and Desai, U. B. (2009)) has proposed to use data transmission in distributed data forwarding to the relay which the destination receiver obtained MIMO channels for data transmission. However, the positions of the relay in cooperative communication systems are distributed. So, the relay selection is very important in the cooperative MIMO communications system. In (Ikki, S. S. and Ahmed, M. H. (2008)), the authors focus on the relay selection in cooperative communication. They have proposed a method to select a relay using the estimated channel by the coefficients of the signal in each path (Seyfi, M., Muhaidat, S. and Liang, J. (2012)) and the authors have shown the method of the relay selection by considering SNR from the transmitter to the receiver. All methods in the reviewed literature, they proposed the methods which select a relay using the effects of channel. The results may not meet the needs of users.

However, in literatures the process of relay cooperation is done by forwarding and repeating the signal symbols on the allocated time slot. In contrast, this thesis proposes the utility of relay by creating the process of sending symbols based on

STBC mode. By changing the symbols sent from source to relay ($S_1 \rightarrow S_1^*$ and $S_2^* \rightarrow S_2$), the destination can be easily detected as a typical STBC mode. The proposed cooperative MIMO technique is introduced to improve the system performance of wireless communication networks. The STBC is selected to implement the virtual MIMO transmitter. By using the neighboring antennas, the overall systems can be operated as a MIMO communication system. It is interesting to see the improvement of using the proposed concept in wireless communication networks. This thesis proposes power scheme and capacity scheme for relay selections of the cooperative MIMO communication systems. The proposed system selects the capacity scheme when the systems need high transmission rate rather than the power scheme. However, in some cases which the cooperative MIMO communication systems need to save energy for the transmitted signal. The power scheme is than due to less energy consumption.

2.7 Summary

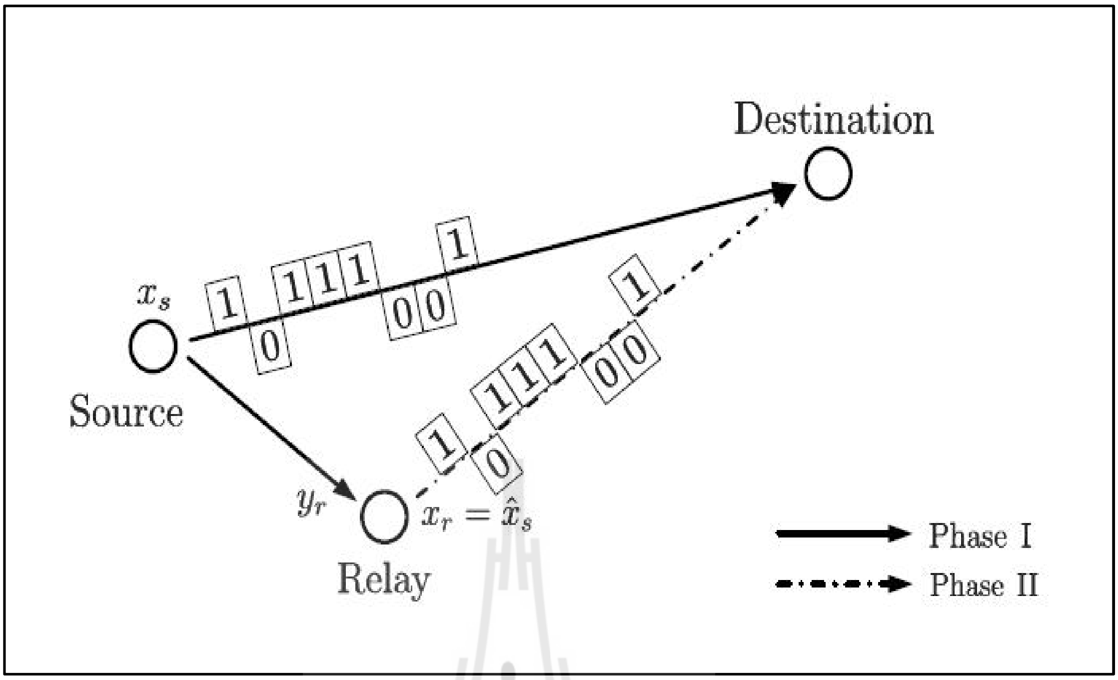
This chapter provides an overview on cooperative communications and MIMO communications. It also introduces the principle of decoding and detection of the conventional MIMO systems, cooperative MIMO concepts, relay selection techniques, literature review and related work.


A
B
A Tx
B Rx
B Tx
B Tx
A Rx
A Tx

Cooperative communications refer to systems or techniques that allow users to transmit message to the destination. Most cooperative transmission schemes involve two phases of transmission. The users exchange their own source data and control messages with each other to destination and the users cooperatively retransmit their messages to the destination. A basic cooperation system consists of two users that transmit data to a common destination, as illustrated in Figure 3.1. At any instant in time, one user acts as the source while the other user serves as the relay. In Phase I, the source user broadcasts its data to both the relay and the destination. In Phase II, the relay forwards the source's data (either by itself or by cooperating with the source) to enhance reception at the destination. Two users may interchange their roles as source and relay at different instants in time. To enable such cooperation among users, the different relay technology can be employed depending on the relative user location, channel conditions, and transceiver complexity.

3.2 Decode-and-Forward Relaying Scheme

Decode-and-Forward (DF) relaying scheme refers to the cases that the relay explicitly decodes the message transmitted by the source and then forwards a newly generated signal to the destination, as illustrated in Figure. 3.2. This scheme is also known as regenerative relaying scheme, which has been widely adopted in the literature, including those employed in conventional multihop networks. In this section, DF relaying scheme is introduced. The basic DF relaying scheme can be divided into two types, ie, with and without diversity combined at the destination. In Basic DF, the relay is assigned to forward the source message in Phase II, given that has successfully decoded in Phase I. This scheme is described as follows.



$\mathbf{x}_s = \left[x_s[0], x_s[1], \ldots, x_s[M-1] \right]$ M

$\mathbf{E}\left[\left| x_s[m] \right|^2 \right] = 1$ m $\mathbf{E}[\cdot]$

$x_s[m]$ m

$$y_r[m] = h_{s,r}\sqrt{P_s}\,x_s[m] + w_r[m], \tag{3-1}$$

$$y_d^{(1)}[m] = h_{s,d}\sqrt{P_s}\,x_s[m] + w_d^{(1)}[m], \tag{3-2}$$

when $m = 0,1,\ldots,M-1$. Here, P_s is the source transmission power, $h_{s,r}$ and $h_{s,d}$ are the channel coefficients of the source-to-relay (s,r) and the source-to-destination (s,d) links, respectively, and $w_r[m] \sim \mathcal{CN}\left(0,\sigma_r^2\right)$ and $w_d^{(1)}[m] \sim \mathcal{CN}\left(0,\sigma_d^2\right)$ are the Additive White Gaussian Noise (AWGN) at the relay and the destination for first time in mean 0, variance σ_r^2 and σ_d^2 respectively. The complex normal distribution $\mathcal{CN}\left(mean, variance\right)$ is the most widely used probability model for a complex random variable. The channel is assumed to remain constant over the transmission of a codeword but varies independently and identically from block-to-block. With sufficiently long codewords, one can invoke the channel coding theorem and assume that decoding at the relay is successful only if the transmission rate is no greater than the capacity of the s,r link, which is given by

$$C_{s,r}\left(\gamma_{s,r}\right) = \log_2\left(1+\gamma_{s,r}\right) , \tag{3-3}$$

where $\gamma_{s,r} = P_s\left|h_{s,r}\right|^2 / \sigma_r^2$ and the unit of $C_{s,r}\left(\gamma_{s,r}\right)$ is in bits per channel use. If the desired average end-to-end rate is R, the codeword $\mathbf{x}_s$ must be encoded with rate $2R$ since it will be transmitted twice (i.e, once by the source and once by the relay)

s,r

$2R > C_{s,r}\left(\gamma_{s,r}\right)$

$2R \le C_{s,r}\left(\gamma_{s,r}\right)$ $\mathbf{x}_r$

$\mathbf{x}_r = \mathbf{x}_s$

$$y_d^{(2)}\left[m\right] = h_{r,d}\sqrt{P_r}\,x_s\left[m\right] + w_d^{(2)}\left[m\right] \qquad m = 0,1,\ldots,M-1$$

P_r $h_{r,d}$

$\left(r,d\right)$ $w_d^{(2)}\left[m\right] \sim \mathcal{CN}\left(0,\pm_d^2\right)$

m

s,d

Case I: Without Diversity Combined

In the case without diversity combined, the destination performs detection based only on the signal received from the relay in Phase II. The scheme is identical to conventional multi-hop (or, in this case, dual-hop) transmissions. In order to successfully transmit a codeword over both s,r and r,d links, in this case, the rate of the codeword must be bounded by the capacity of both links, i.e.,

$$2R \le \min\left\{\log_2\left(1+\gamma_{s,r}\right), \log_2\left(1+\gamma_{r,d}\right)\right\}, \tag{3-5}$$

where $\gamma_{s,r} = P_s\left|h_{s,r}\right|^2 / \sigma_r^2$ and $\gamma_{s,d} = P_s\left|h_{s,d}\right|^2 / \sigma_d^2$. Hence, the average end-to-end achievable rate in Case I (without diversity combined) is given by

$$C_{\text{BasicDF,I}}\left(\gamma_{s,r}, \gamma_{r,d}\right) = \frac{1}{2}\min\left\{\log_2\left(1+\gamma_{s,r}\right), \log_2\left(1+\gamma_{r,d}\right)\right\}. \tag{3-6}$$

Hence, an outage occurs when $R > C_{\text{BasicDF,I}}$.

Let us consider the Rayleigh fading scenario, where $h_{s,r}$, $h_{r,d}$ and $h_{s,d}$ are independent circularly symmetric complex Gaussian random variables with zero mean and variances $\sigma_{s,r}^2, \sigma_{r,d}^2$ and $\sigma_{s,d}^2$ respectively. The outage probability can be computed as follows:

$$p_{out} = \Pr\left(\min\left\{\log_2\left(1+\gamma_{s,r}\right),\log_2\left(1+\gamma_{r,d}\right)\right\} < 2R\right)$$

$$= 1 - \Pr\left(\min\left\{\log_2\left(1+\gamma_{s,r}\right),\log_2\left(1+\gamma_{r,d}\right)\right\} \geq 2R\right)$$

$$= 1 - \Pr\left(\log_2\left(1+\gamma_{s,r}\right) \geq 2R, \log_2\left(1+\gamma_{r,d}\right) \geq 2R\right). \quad (3\text{-}7)$$

Assume thet $\log_2\left(1+\gamma_{s,r}\right) \geq 2R$ and $\log_2\left(1+\gamma_{r,d}\right) \geq 2R$ are independent from each other.Since $h_{s,r}$ and $h_{r,d}$ are assumed to be independent with distributions $h_{s,r} \sim \mathcal{CN}\left(0, ¦^{2}_{s,r}\right)$ and $h_{r,d} \sim \mathcal{CN}\left(0, ¦^{2}_{r,d}\right)$, respectively, it follows that $\gamma_{s,r}$ and $\gamma_{r,d}$ are exponentially distributed with mean $\bar{\gamma}_{s,r} \square \frac{P_s ¦^{2}_{s,r}}{±^{2}_{r}}$ and $\bar{\gamma}_{r,d} \square \frac{P_r ¦^{2}_{r,d}}{±^{2}_{d}}$ respectively. Thus, the outage probability can be further evaluated as

$$p_{out} = 1 - \Pr\left(\gamma_{s,r} \geq 2^{2R} - 1\right)\Pr\left(\gamma_{r,d} \geq 2^{2R} - 1\right)$$

$$= 1 - \exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{s,r}}\right)\exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{r,d}}\right). \quad (3\text{-}8)$$

Given the total power constraint $P_s + P_r \leq 2P$, let $P_s = 2\ \ P$ and $P_r = 2\left(1-\ \ \right)P$, for some weight $\ \ \in (0,1)$, and let $±^{2}_{r} = ±^{2}_{d} = ±^{2}_{w}$. For example, if $\ \ = 1/2$, then candidate have $P_s = P_r = P$. Then, at high SNR (i.e., when $\mathrm{SNR} \square P/±^{2}_{w}\ \square 0$), the outage probability can be approximated as

$$p_{out} \approx \frac{2^{2R}-1}{\bar{\gamma}_{s,r}} + \frac{2^{2R}-1}{\bar{\gamma}_{r,d}} = \frac{2^{2R}-1}{\mathrm{SNR}}\left(\frac{1}{2\ \ \sigma_{s,r}^{2}} + \frac{1}{2\left(1-\ \ \right)\sigma_{r,d}^{2}}\right). \tag{3-9}$$

This shows that the diversity order in Basic DF without diversity combined is equal to 1. It is worthwhile to remark that, in the case of direct transmission, the outage probability is given by

$$\begin{aligned} p_{out}^{\text{direct}} &= \Pr\left(\log_2\left(1+\gamma_{s,d}\right) < R\right) = \Pr\left(\gamma_{s,d} < 2^{R}-1\right) \\ &= 1-\exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{s,d}}\right) \approx \frac{2^{2R}-1}{\mathrm{SNR}}\frac{1}{\sigma_{s,d}^{2}} \end{aligned} \tag{3-10}$$

where $\gamma_{s,d} = P\left|h_{s,d}\right|^{2} \big/ \sigma_{w}^{2}$ and $\bar{\gamma}_{s,d} = \mathbf{E}\left[\gamma_{s,d}\right] = P\sigma_{s,d}^{2} \big/ \sigma_{w}^{2}$. By comparing (3-9) with (3-10), one can see that no diversity gain is obtained over direct transmission by employing multi-hop transmission (i.e., Basic DF without diversity combined). Even though this may be the case, multi-hop transmissions may still be useful in practice where the minimum adaptable transmission rate and the maximum transmission power are limited.

Although diversity gains cannot be obtained in this case, one can still perform power allocation to improve the coding gains. Specifically, given the total power constraint $P_s + P_r \leq 2P$, the optimal power allocation between P_s and P_r can be found by minimizing the outage probability in (3-8). Due to monotonicity of the exponential function, the optimization problem can be formulated as follows:

$$\min_{P_s,P_r} \quad \frac{1}{P_s \Omega_{s,r}^2 / \sigma_r^2} + \frac{1}{P_r \Omega_{r,d}^2 / \sigma_d^2} \tag{3-11}$$

$$\text{subject to } P_s + P_r \leq 2P \text{ and } P_s, P_r \geq 0. \tag{3-12}$$

By introducing Lagrange multipliers, the optimal power allocation can be derived as

$$P_s = 2P\frac{\Omega_{r,d}^2/\sigma_d^2}{\Omega_{s,r}^2/\sigma_r^2 + \Omega_{r,d}^2/\sigma_d^2} \text{ and } P_r = 2P\frac{\Omega_{s,r}^2/\sigma_r^2}{\Omega_{s,r}^2/\sigma_r^2 + \Omega_{r,d}^2/\sigma_d^2}. \tag{3-13}$$

Thus, by substituting (3-13) into (3-8) and by assuming that $\sigma_r^2 = \sigma_d^2 = \sigma_w^2$ the minimum outage probability can be expressed as

$$p_{out} = 1 - \exp\left(-\frac{2^{2R}-1}{P}\left(\frac{1}{\Omega_{s,r}^2/\sigma_r^2} + \frac{1}{\Omega_{r,d}^2/\sigma_d^2}\right)\right) \tag{3-14}$$

$$= 1 - \exp\left(-\frac{2^{2R}-1}{\text{SNR}}\left(\frac{1}{\Omega_{s,r}^2} + \frac{1}{\Omega_{r,d}^2}\right)\right). \tag{3-15}$$

Notice that, when the optimal power allocation is found by minimizing the outage probability, only the statistics of the channel must be known. However, when instantaneous CSI is available at the source and the relay, one can further derive the optimal power allocation to maximize the dualhop capacity $C_{\text{BasicDF,I}}\left(\gamma_{s,r}, \gamma_{r,d}\right)$. In this case, the optimal power allocation is determined by solving the following

$$\max_{P_s,P_r} \ \frac{1}{2}\min\left\{\log_2\left(1+\frac{P_s\left|h_{s,r}\right|^2}{\pm_r^2}\right),\log_2\left(1+\frac{P_r\left|h_{r,d}\right|^2}{\pm_d^2}\right)\right\} \tag{3-16}$$

$$\text{subject to } P_s+P_r\le 2P \text{ and } P_s,P_r\ge 0\,. \tag{3-17}$$

One can observe that, to maximize the dual-hop capacity given in (3-16), the power constraint $P_s+P_r\le 2P$ must be satisfied with equality. Thus, as P_s increases, the first term of (3-16) will increase while the second term decreases, and vice versa as P_s decreases. Since either term inside the minimum of (3-16) cannot be increased without decreasing the other, the objective is maximized when both terms are equal, i.e., when

$\frac{P_s\left|h_{s,r}\right|^2}{\pm_r^2}=\frac{P_r\left|h_{r,d}\right|^2}{\pm_d^2}$. The optimal power allocation under instantaneous CSI is given by

$$P_s=2P\frac{\left|h_{r,d}\right|^2/\pm_d^2}{\left|h_{s,r}\right|^2/\pm_r^2+\left|h_{r,d}\right|^2/\pm_d^2} \tag{3-18}$$

and

$$P_r=2P.\frac{\left|h_{s,r}\right|^2/\pm_r^2}{\left|h_{s,r}\right|^2/\pm_r^2+\left|h_{r,d}\right|^2/\pm_d^2}\,. \tag{3-19}$$

Furthermore, by assuming that $\sigma_r^2 = \sigma_d^2 = \sigma_w^2$, the resulting dual-hop capacity is instead given by

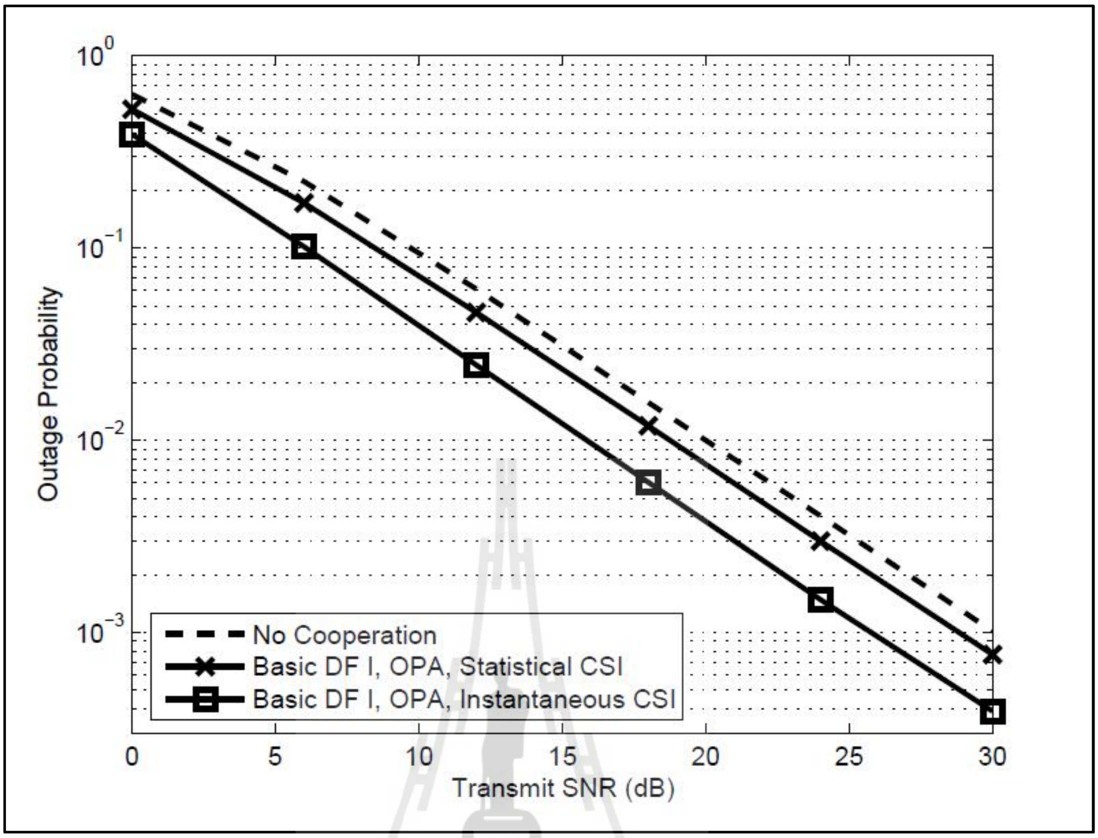
$$C = \frac{1}{2}\log_2\left(1 + \frac{2\mathrm{SNR}}{1/\left|h_{s,r}\right|^2 + 1/\left|h_{r,d}\right|^2}\right). \tag{3-20}$$

Notice that, in the case of direct transmission, the capacity is given by

$$C = \log_2\left(1 + \mathrm{SNR}.\left|h_{s,d}\right|^2\right). \tag{3-21}$$

Let us consider, for example, the case where $\left|h_{s,d}\right|^2 \propto 1/d^{\alpha}$ and $\left|h_{s,r}\right|^2, \left|h_{r,d}\right|^2 \propto 1/\left(\frac{d}{2}\right)^{\alpha}$ (i.e., the case where the relay is located in the middle of the source and the destination). By utilizing the approximation $\log(1+x) \approx x$, for $x \ll 1$, one can show that a gain of $2^{\alpha-1}$ can be obtained at low SNR when taking the ratio between the capacity of basic DF (without diversity combined) and that of direct transmission.

In Figure 3.3, the outage probabilities versus transmit SNR are shown (i.e., $\mathrm{SNR}{=}P/\sigma_w^2$) for the basic DF relaying scheme without diversity combining. Here, the rate is set as $R = 1$ bits/sec/Hertz. Let $d_{s,r}$, $d_{r,d}$ and $d_{s,d}$ be the distances between s,r, r,d and s,d respectively. The channel coefficients are assumed independently with distribution $h_{s,r} = \mathcal{CN}\left(0, d_{s,r}^{-\alpha}\right)$, $h_{r,d} = \mathcal{CN}\left(0, d_{r,d}^{-\alpha}\right)$ and $h_{s,d} = \mathcal{CN}\left(0, d_{s,d}^{-\alpha}\right)$, where the path loss exponent α is set as 3. In the study of wireless communications (Okumbor N. A., Okonkwo Obikwelu, R. (2014)), path loss can be represented by the path loss exponent, of which its value is normally in the range of 2 to 4 where 2 are for propagation in free space and 4 is for relatively lossy environments based on two-ray model. So, the path loss exponent α is set as 3 because it is simulation environment in the urban area. In this experiment, it is assumed that the relay is located in the middle between source and destination, so that $d_{s,d} = 1$ and $d_{s,r} = d_{r,d} = 1/2$. Setting $d_{s,d} = 1$ means that the results are normalized by the performance of the s,d link. Assuming the given transmission power of the source node is $P_{s,d}$, the maximum communication distance between the source and destination node is $d_{s,d} = \left(P_{s,d}/d\right)^{1/\sim}$. The relay node assume the transmission power of the source plus that of the relay node is the same as the transmission power of the source without using relay $P_{s,r} + P_{r.d} = P_{s,d}$. Then, the communication distance between source and destination node is maximized when the relay is located in the middle of two ends. However, the distance of the relay node is not located in the middle between source and



Outage Probability
Transmit SNR (dB)
No Cooperation
Basic DF I, OPA, Statistical CSI
Basic DF I, OPA, Instantaneous CSI

SNR

However, significant power gains can be observed when optimal power allocation is derived under instantaneous CSI.

Case II: With Diversity Combined

In the previous case, only the signal transmitted by the relay is utilized for detection at the destination. However, due to the broadcast nature of the wireless medium, the signal transmitted by the source in Phase I will also be received at the destination thus, can be combined with the signal received from the relay to increase diversity. This is especially useful when the quality of the s,d link is comparable to that of the r,d link. Firstly, in the basic DF scheme, the relay is allowed to forward the source's message in Phase II only if it is able to successfully decode the message in Phase I. If this is the case, the destination will receive two copies of the signal, as given in (3-2) and (3-4), which can be collected into the vector below

$$\mathrm{y}_d\left[m\right]=\begin{bmatrix} y_d^{(1)}\left[m\right] \\ y_d^{(2)}\left[m\right] \end{bmatrix}=\begin{bmatrix} \sqrt{P_s}h_{s,d} \\ \sqrt{P_r}h_{r,d} \end{bmatrix}x_s\left[m\right]+\begin{bmatrix} w_d^{(1)}\left[m\right] \\ w_d^{(2)}\left[m\right] \end{bmatrix}, \quad \text{for } m=0,...,M-1. \qquad (3\text{-}22)$$

The signal model is similar to conventional SIMO systems and the MRC can be employed to maximize the received SNR at the destination. In particular, the signals received in Phase I and Phase II are multiplied by the weight coefficients $\sqrt{P_s}h_{s,d}^*$ and $\sqrt{P_r}h_{r,d}^*$ respectively, to obtain

$$\tilde{y}_d[m] = \left[\sqrt{P_s}h_{s,d}^* \quad \sqrt{P_r}h_{r,d}^*\right] \mathrm{y}_d[m]$$

$$= \left(P_s\left|h_{s,d}\right|^2 + P_r\left|h_{r,d}\right|^2\right) x_s[m] + \tilde{w}_d[m]$$

$$\tilde{w}_d[m] = \sqrt{P_s}h_{s,d}^* w_d^{(1)}[m] + \sqrt{P_r}h_{r,d}^* w_d^{(2)}[m] \sim \mathcal{CN}\left(0, \pm_d^2\left(P_s\left|h_{s,d}\right|^2 + P_r\left|h_{r,d}\right|^2\right)\right)$$

SNR

$$\gamma_{\text{BasicDF,II}} = \frac{P_s\left|h_{s,d}\right|^2}{\pm_d^2} + \frac{P_r\left|h_{r,d}\right|^2}{\pm_d^2} = \gamma_{s,d} + \gamma_{r,d}$$

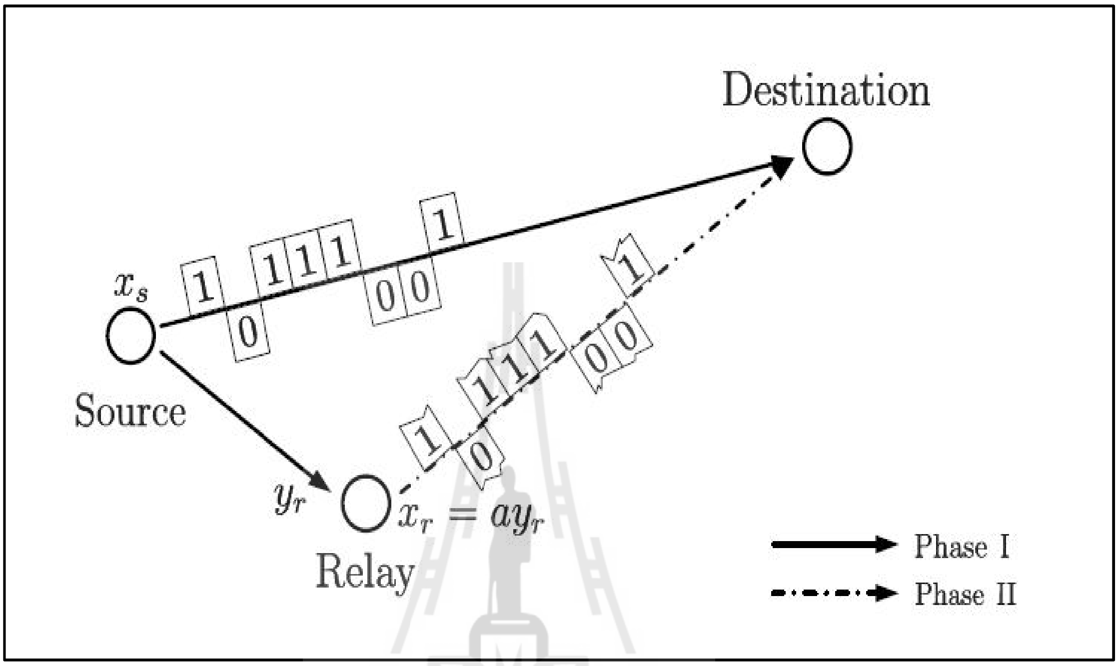
$\gamma_{s,d} = P_s\left|h_{s,d}\right|^2 \big/ \pm_d^2$ $\gamma_{r,d} = P_r\left|h_{r,d}\right|^2 \big/ \pm_d^2$

$$C_{\text{BasisDF,Phase II}} = \log_2\left(1 + \gamma_{s,d} + \gamma_{r,d}\right)$$

s, r

$\log_2\left(1 + \gamma_{s,r}\right)$ $\gamma_{s,r} = P_s\left|h_{s,r}\right|^2 \big/ \pm_r^2$

$$C_{\mathrm{BasicDF,II}}\left(\gamma_{s,r},\gamma_{s,d},\gamma_{r,d}\right)=\frac{1}{2}\min\left\{\log_2\left(1+\gamma_{s,r}\right),\log_2\left(1+\gamma_{s,d}+\gamma_{r,d}\right)\right\}$$



s,r

this case, amplifying the analog signal preserves soft information that can be further exploited at the destination. In this section, the basic AF relaying scheme can be divided into two types (with and without diversity combined at the destination).

3.3.1 Basic AF Relaying Scheme

In the basic AF relaying scheme, the relay forwards a scaled version of the received signal to the destination, regardless of the s,r link quality. Specially, in Phase I, the source transmits the symbol block $\mathbf{x}_s = \left[x_s[0],...,x_s[M-1]\right]$ to both the relay and the destination, where the received signals are given by

$$y_r[m] = h_{s,r}\sqrt{P_s}x_s[m] + w_r[m] \tag{3-27}$$

$$y_d^{(1)}[m] = h_{s,d}\sqrt{P_s}x_s[m] + w_d^{(1)}[m], \tag{3-28}$$

for $m = 0,...,M-1$, similar to that in (3-1) and (3-2).

In Phase II, the relay first scales the received signal in (3-27) to yield a normalized transmit vector $\mathbf{x}_r$ with $\mathbf{E}\left[|x_r[m]|^2\right] = 1$, for all m. If the instantaneous channel gain $|h_{s,r}|^2$ is known at the relay, the relay can multiply the received signal $y_r[m]$ by the gain G_3 below

$$G_3 = \frac{1}{\sqrt{\mathbf{E}\left[|y_r[m]|^2\right]}} = \frac{1}{\sqrt{P_s|h_{s,r}|^2 + \sigma_r^2}} \tag{3-29}$$

$$x_r[m] = G_3\, y_r[m]$$

$$= \sqrt{\frac{P_s}{P_s\left|h_{s,r}\right|^2 + \pm_r^2}}\, h_{s,r} x_s[m] + \frac{1}{\sqrt{P_s\left|h_{s,r}\right|^2 + \pm_r^2}}\, w_r[m]$$

G_3 s,r $h_{s,r}$

P_r $\mathbf{x}_r$

$$y_d^{(2)}[m] = h_{r,d}\sqrt{P_r}\, x_r[m] + w_d^{(2)}[m]$$

$$= \sqrt{\frac{P_s P_r}{P_s\left|h_{s,r}\right|^2 + \pm_r^2}}\, h_{s,r} h_{r,d} x_s[m] + \sqrt{\frac{P_r}{P_s\left|h_{s,r}\right|^2 + \pm_r^2}}\, h_{r,d} w_r[m] + w_d^{(2)}[m]$$

$m = 0, \ldots, M-1$

$y_d^{(2)}$

SNR

$$\gamma_{\text{BasicAF,I}} = \frac{\dfrac{P_s P_r}{P_s \left|h_{s,r}\right|^2 + \pm_r^2} \left|h_{s,r}\right|^2 \left|h_{r,d}\right|^2}{\dfrac{P_r \pm_r^2}{P_s \left|h_{s,r}\right|^2 + \pm_r^2} \left|h_{r,d}\right|^2 + \pm_d^2} = \frac{\gamma_{s,r}\gamma_{r,d}}{\gamma_{s,r} + \gamma_{r,d} + 1} \;, \tag{3-32}$$

where $\gamma_{s,r} = P_s \left|h_{s,r}\right|^2 \big/ \pm_r^2$ and $\gamma_{r,d} = P_s \left|h_{r,d}\right|^2 \big/ \pm_d^2$. Thus, the maximum achievable end-to-end rate is given by

$$C_{\text{BasicAF,I}}\left(\gamma_{s,r}, \gamma_{r,d}\right) = \frac{1}{2}\log\left(1 + \frac{\gamma_{s,r}\gamma_{r,d}}{\gamma_{s,r} + \gamma_{r,d} + 1}\right). \tag{3-33}$$

Given that the end-to-end transmission rate is R, the outage probability is given by

$$p_{out} = \Pr\left(\gamma_{\text{BasicAF.I}} < 2^{2R} - 1\right). \tag{3-34}$$

This probability depends on the distribution of the effective SNR, i.e., $\gamma_{\text{BasicAF,I}}$, which is difficult to evaluate in closed-form. However, at high SNR, the constant in the denominator in (3-33) can be omitted and the effective SNR can be approximated as

$$\gamma_{\text{BasicAF,I}} \approx \frac{\gamma_{s,r}\gamma_{r,d}}{\gamma_{s,r} + \gamma_{r,d}} = \left(\frac{1}{\gamma_{s,r}} + \frac{1}{\gamma_{r,d}}\right)^{-1}. \tag{3-35}$$

That is, at high SNR, the effective SNR (i.e., $\gamma_{\text{BasicAF,I}}$) can be approximated by the harmonic mean of the SNRs on each hop. In Rayleigh fading scenarios, where $h_{s,r} = \mathcal{CN}\left(0, \Omega_{s,r}^2\right)$, $h_{r,d} = \mathcal{CN}\left(0, \Omega_{r,d}^2\right)$ and $h_{s,d} = \mathcal{CN}\left(0, \Omega_{s,d}^2\right)$, the SNRs $\gamma_{s,r}$ and $\gamma_{r,d}$ are exponentially distributed with mean $\bar{\gamma}_{s,r} = P_s \Omega_{s,r}^2 / \sigma_r^2$ and $\bar{\gamma}_{r,d} = P_r \Omega_{r,d}^2 / \sigma_d^2$, respectively.

Case II: With Diversity Combined

In the case with diversity combined, the signals received in Phases I and II, i.e., (3-28) and (3-31), can be optimally combined at the destination using MRC to obtain the output signal

$$\tilde{y}_d = \frac{\sqrt{P_s} h_{s,d}^*}{\sigma_d^2} y_d^{(1)} + \frac{\sqrt{\frac{P_s P_r}{P_s \left|h_{s,r}\right|^2 + \sigma_r^2}} h_{s,r}^* h_{r,d}^*}{\frac{P_r}{P_s \left|h_{s,r}\right|^2 + \sigma_r^2} \left|h_{r,d}\right|^2 \sigma_d^2 + \sigma_d^2} y_d^{(2)} . \tag{3-36}$$

The effective SNR at the output of the MRC is given by

$$\begin{aligned} \gamma_{\text{BasicAF,II}} &= \frac{P_s \left|h_{s,d}\right|^2}{\sigma_d^2} + \frac{P_s \left|h_{s,r}\right|^2 / \sigma_r^2 \, P_s \left|h_{s,d}\right|^2 / \sigma_d^2}{P_s \left|h_{s,r}\right|^2 / \sigma_r^2 + P_s \left|h_{s,d}\right|^2 / \sigma_d^2 + 1} \\ &= \gamma_{s,d} + \frac{\gamma_{s,r} \gamma_{r,d}}{\gamma_{s,r} + \gamma_{r,d} + 1} . \end{aligned} \tag{3-37}$$

The maximum achievable end-to-end transmission rate for the basic AF relaying scheme with diversity combining is thus given by

$$C_{\text{BasicAF,II}}\left(\gamma_{s,r},\gamma_{r,d},\gamma_{s,d}\right)=\frac{1}{2}\log\left(1+\gamma_{s,d}+\frac{\gamma_{s,r}\gamma_{r,d}}{\gamma_{s,r}+\gamma_{r,d}+1}\right). \tag{3-38}$$

3.4 Summary

This chapter explained principle of the decode and forward relaying schemes and the amplify and forward relaying scheme in cooperative communications. The principle of the cooperative communication systems and the performance analysis of each scheme were also described.

CHAPTER IV

COOPERATIVE MIMO COMMUNICATION SYSTEMS

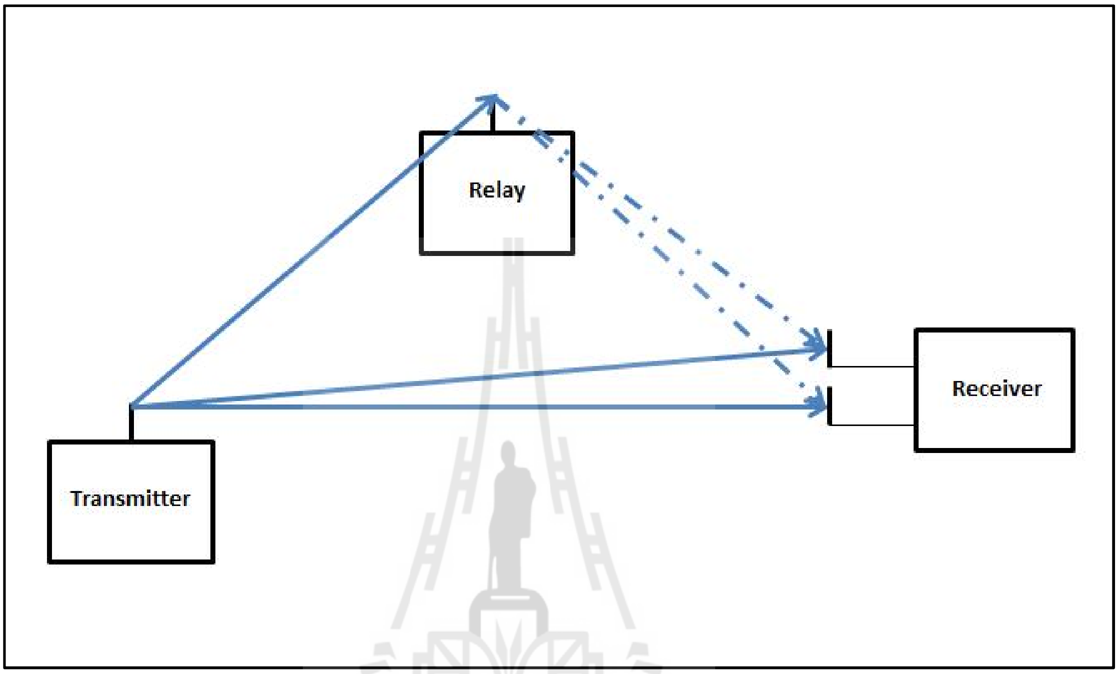
4.1 Introduction

This thesis improves performance of the conventional cooperative communication described in Chapter III by using MIMO technique and STBC coding technique. The improved cooperative communication systems with MIMO system, namely, the cooperative MIMO communication systems is applied to cooperative systems because this technique offers a simple structure and more flexibility for power limitation in cooperative systems. Moreover, the proposed relay selections are compatible with the cooperative MIMO communication systems.

4.2 Structure and Process of Cooperative MIMO Communication Systems

4.2.1 Structure of cooperative MIMO communication systems

The cooperative MIMO communication systems presented in this thesis consists of transmitter, relay and receiver. The transmitter sends data signals to the relay and receiver. The relay receives signal from the transmitter and then forwards that signal to the receiver. The receiver receives the same signal from both the transmitter and relay. The receiver will then decode both signals in order to put to further use. The process of transmission signals employs in the cooperative MIMO



S

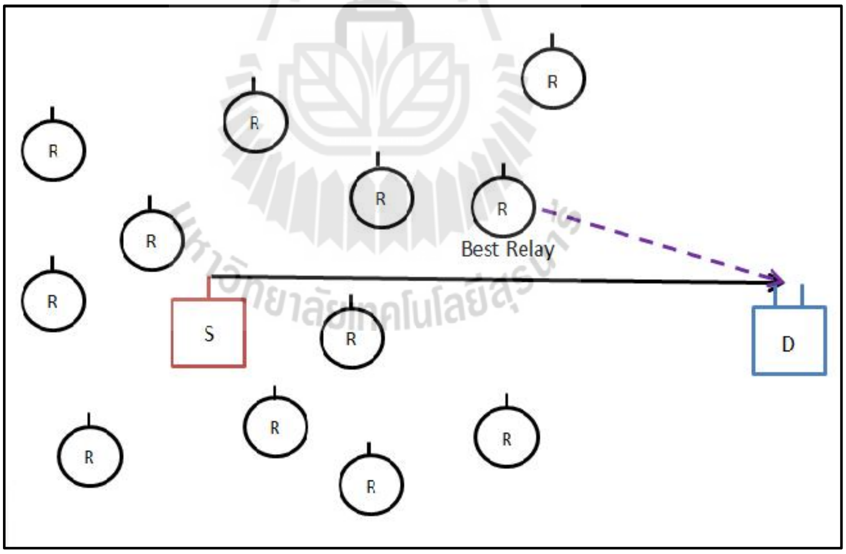
D R_i

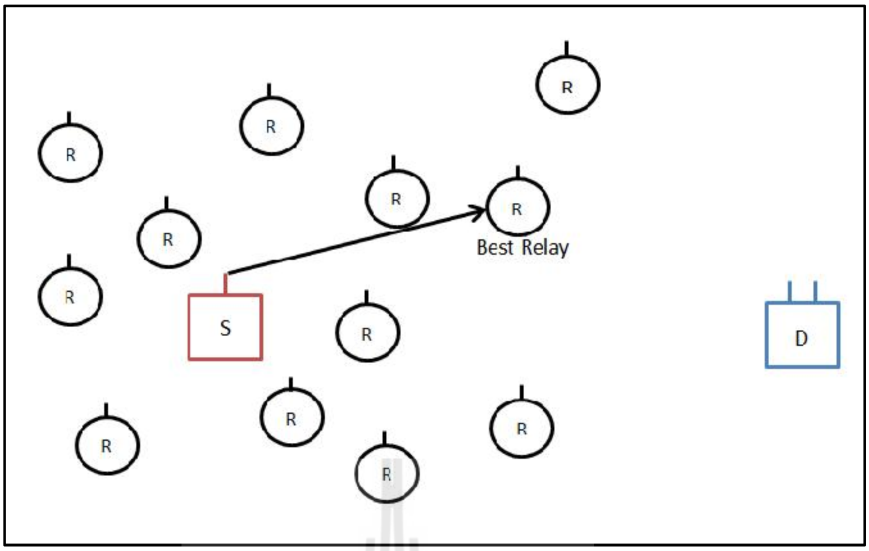
multipath, and slow fading. Source and relay nodes must know the Channel State Information (CSI) between the source and relay as well as between the relay and destination, respectively.

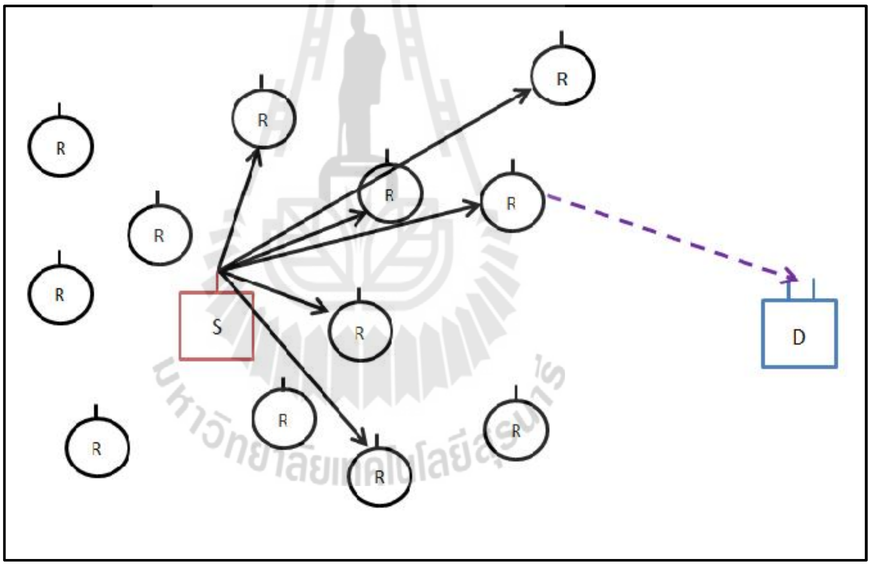
In general, wireless devices must have two transmitting antennas in order to apply 2×2 Alamouti STBC MIMO systems. The work in literature (Ho-Jung An, Jee-Hoon Kim, and Hyoung-Kyu Song, (2007)) applied precoding scheme with the STBC symbols to employ STBC with a single antenna. However, it suffers a significant delay from AF protocol. In this thesis, a technique is proposed to transmit virtual STBC symbols in order to apply with a single antenna system. The source node and relay nodes virtually offer the multiple antennas for the cooperation of transmitted symbols at the same STBC schemes to the destination. The proposed system works according to the following steps.

The first step is shown in Figure. 4.2 (a). The source node makes an agreement with the destination node to transmit and receive by using the cooperative MIMO technique. The source node then finds relay nodes by sending an invitation message to all potential relay nodes. The available relay nodes will send a confirmation message to cooperate with source node and destination node. At this point, the source node, relay node and destination node are now ready to operate the system with cooperative MIMO technique.

The second step is the pre-transmitting process shown in Figure. 4.2 (b). The source node transmits symbols to relay node. When the relay node obtains symbols form source node, then the relay node will adjust or reformat symbols in the form of STBC coding schemes. In the proposed scheme, the relay node does not necessarily modify anything with the received data. By using the conventional method for relay


R
R
R
R
R
R
Best Relay
R
S
R
D
R
R
R
R
R


R
R
R
R
R
R
Best Relay
R
S
R
D
R
R
R
R


R
R
R
R
R
R
R
S
R
D
R
R
R
R

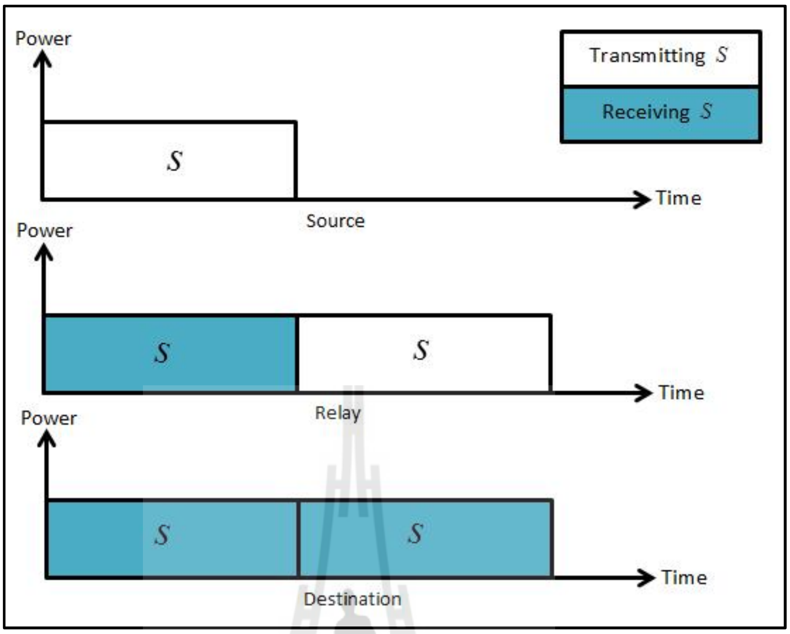
(a) First step (b) Second step (c) Third step

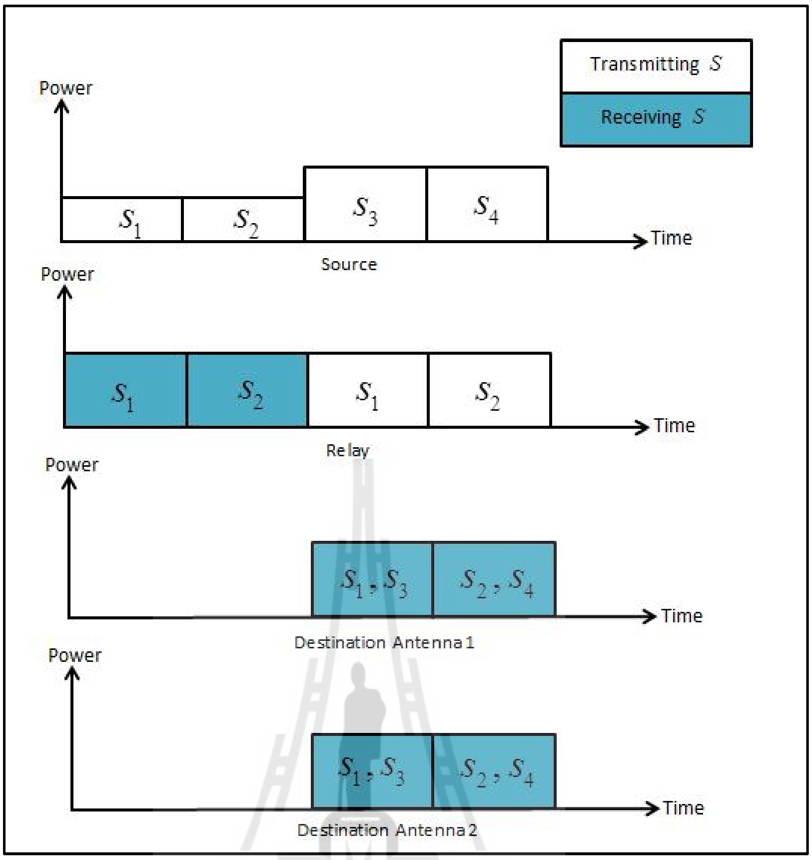
4.2.2 Modified STBC Scheme for Cooperative MIMO Technique

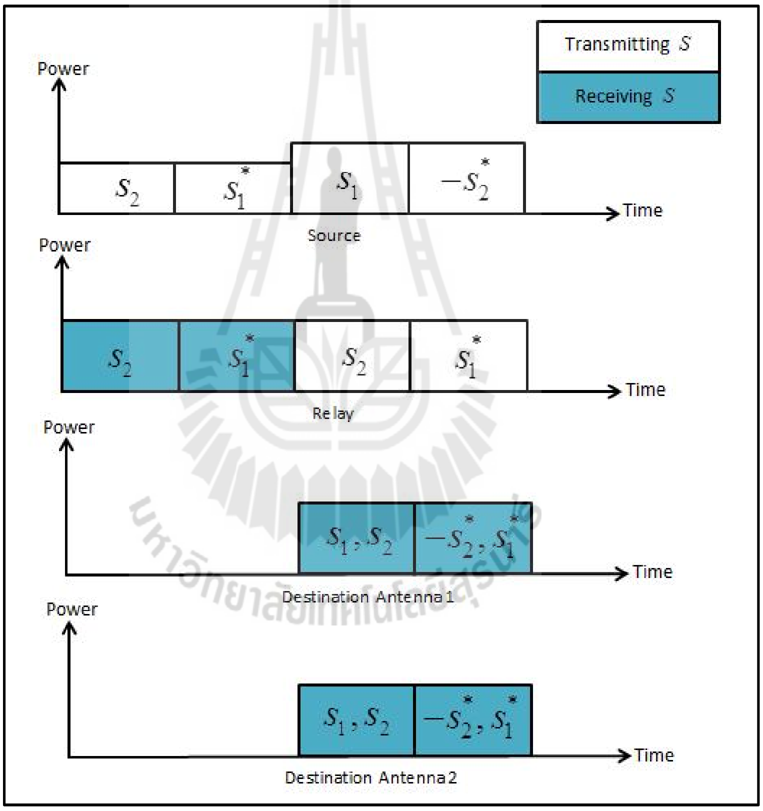
Transmission models in the cooperative MIMO communication systems are presented in this thesis. The system consists of source, relay and destination nodes. Source node transmits data signals to relay node and destination node. The relay node transmits the signal received from the source node to the destination node. The destination node receives signals information from the relay node and source node. The destination node will decode information signals based on the CSI of both relay and source nodes. By using transmission models in the cooperative MIMO communications, the system will forward the information signal from the relay node to the destination node using DF protocol through Rayleigh fading channels. The total transmitted power from all transmitting antenna is considered. The sum of output power of the source node and the relay node is obtained from $P_T = P_s + P_r$ where P_T is the total power in the system.

In general, the cooperative MIMO communications have many transmission models. However, in this thesis the candidate considers the STBC MIMO scheme in comparing the conventional (diversity) MIMO scheme. According to the channel using TDD (Time Division Duplex), the form of transmission models in a cooperative communication system is shown in Figure 4.3.

In Figure 4.3, the source node sends information to the relay node which will forward this information to the destination to be decoded later. This method uses diversity techniques to attain the higher performance of the cooperative communication system.


Transmitting S
Receiving S
Power
S
Time
Source
Power
S
S
Time
Relay
Power
S
S
Time
Destination


Transmitting S
Receiving S
Power
S_1
S_2
S_3
S_4
Time
Source
Power
S_1
S_2
S_1
S_2
Time
Relay
Power
S_1, S_3
S_2, S_4
Time
Destination Antenna 1
Power
S_1, S_3
S_2, S_4
Time
Destination Antenna 2


Transmitting S
Receiving S
Power
s_2
s_1^*
s_1
$-s_2^*$
Time
Source
Power
s_2
s_1^*
s_2
s_1^*
Time
Relay
Power
s_1, s_2
$-s_2^*, s_1^*$
Time
Destination Antenna 1
Power
s_1, s_2
$-s_2^*, s_1^*$
Time
Destination Antenna 2

The time periods of the first symbol and the second symbol shown in Figure 4.5 are the time that source node sends signals to the relay node. The received signal at relay node is expressed by

$$y_r = \sqrt{P_s} h_{s,r} s + w_r \qquad , s = s_2, s_1^*. \tag{4-1}$$

By assuming that both periods experience the same fading, then

$$y_r^{(1)} = \sqrt{P_s} h_{s,r} s_2 + w_r \tag{4-2}$$

$$y_r^{(2)} = \sqrt{P_s} h_{s,r} s_1^* + w_r \tag{4-3}$$

where $h_{s,r}$ is the wireless channel from source node to relay node, $w_r \sim \mathcal{CN}\left(0, \sigma_r^2\right)$ is complex AWGN including the effect of interference signal, P_s and s are the source node transmission power and transmission of symbols, respectively.

The signals at relay node have to go through the process that the relay node can receive signals for forwarding symbols. The two estimated symbols, $\tilde{s}_1$ and $\tilde{s}_2$, can be calculated by

$$\tilde{s}_1 = h_{s,r} y_r^* \tag{4-4}$$

$$\tilde{s}_2 = h_{s,r}^* y_r \tag{4-5}$$

The time periods of the third symbol and the fourth symbol are the STBC MIMO transmission. This thesis considers one source node, one relay node and one destination node. Then, the received signals of both antennas at the destination node can be expressed by

$$y_{d1}^{(1)} = \sqrt{P_s} h_{s,d1} s_1 + \sqrt{P_r} h_{r,d1} s_{2r} + w_{d1}^{(1)} \tag{4-6}$$

$$y_{d1}^{(2)} = -\sqrt{P_s} h_{s,d1} s_2^* + \sqrt{P_r} h_{r,d1} s_{1r}^* + w_{d1}^{(2)} \tag{4-7}$$

where $h_{s,d1}$ and $h_{r,d1}$ are the wireless channel from source node to destination node at the first antenna and the wireless channel from relay node to destination node at the first antenna, $w_{d1}^{(1)} \sim \mathcal{CN}\left(0, \pm_{d1}^{2}\right)$ and $w_{d1}^{(2)} \sim \mathcal{CN}\left(0, \pm_{d1}^{2}\right)$ are complex AWGN including the effect of interference signals at the first antenna, P_s and P_r is the transmission power of source node and relay node, respectively.

Considering the second antenna at destination node, the received signals are expressed by

$$y_{d2}^{(1)} = \sqrt{P_s} h_{s,d2} s_1 + \sqrt{P_r} h_{r,d2} s_{2r} + w_{d2}^{(1)} \ , \tag{4-8}$$

$$y_{d2}^{(2)} = -\sqrt{P_s} h_{s,d2} s_2^* + \sqrt{P_r} h_{r,d2} s_{1r}^* + w_{d2}^{(2)} \ , \tag{4-9}$$

where $h_{s,d2}$ and $h_{r,d2}$ are the wireless channel from source node to destination node at the second antenna and the wireless channel from relay node to destination node at the second antenna, $w_{d2}^{(1)} \sim \mathcal{CN}\left(0, \sigma_{d2}^2\right)$ and $w_{d2}^{(2)} \sim \mathcal{CN}\left(0, \sigma_{d2}^2\right)$ are complex AWGN including the effect of interference signals at the second antenna.

Note that $s_1 = s_{1r}$ and $s_2 = s_{2r}$ because the link between relay node and source node in the second step mentioned earlier has the effects of fading channel as well. This might cause symbol realization uncertainty at the relay node. However, most of the works in this area assume that relay node can perfectly retrieve all received symbols.

Then, at the destination, the process of extracting the data symbols from incoming signals is the same as described by the normal STBC scheme. The two estimated symbols, $\tilde{s}_1$ and $\tilde{s}_2$, from the first antenna are calculated by

$$\tilde{s}_1 = h_{s,d1}^{*} y_{d1}^{(1)} + h_{r,d1} y_{d1}^{(2)*} + h_{s,d2}^{*} y_{d2}^{(1)} + h_{r,d2} y_{d2}^{(2)*} \tag{4-10}$$

$$\tilde{s}_2 = h_{r,d1}^{*} y_{d1}^{(1)} - h_{s,d1} y_{d1}^{(2)*} + h_{r,d2}^{*} y_{d2}^{(1)} - h_{s,d2} y_{d2}^{(2)*} \tag{4-11}$$

Hence, we can consider signal to noise ratio at destination node by (4-12)

$$\boldsymbol{y} = \sqrt{P_T}\,\mathbf{H}\boldsymbol{s} + \boldsymbol{w} \tag{4-12}$$

So, we can decode symbol as

$$
\begin{aligned}
\tilde{s} &= \mathbf{H}^{H}\boldsymbol{y} \\
&= \mathbf{H}^{H}\mathbf{H}\boldsymbol{s}+\mathbf{H}^{H}\boldsymbol{w} \\
&= \left\|\mathbf{H}\right\|_{\mathrm{F}}^{2}\boldsymbol{s}+\mathbf{H}^{H}\boldsymbol{w}
\end{aligned}
\tag{4-13}
$$

where $\left\|\mathbf{H}\right\|_{\mathrm{F}}^{2}$ represents the squared Frobenius norm of the matrix $\mathbf{H}$. The signal-to-noise ratio is defined as P_{signal}/P_{noise}. By considering the signal-to-noise ratio at destination node, the received signal-to-noise ratio can be expressed by

$$
\begin{aligned}
\mathrm{SNR}_{\mathrm{d}} &= \mathrm{E}\left\{\left|\frac{\left\|\mathbf{H}\right\|_{\mathrm{F}}^{2}\boldsymbol{s}}{\mathbf{H}^{H}\boldsymbol{w}}\right|^{2}\right\} = \frac{\mathrm{E}\left\{\left(\left\|\mathbf{H}\right\|_{\mathrm{F}}^{2}\boldsymbol{s}\right)^{H}\left(\left\|\mathbf{H}\right\|_{\mathrm{F}}^{2}\boldsymbol{s}\right)\right\}}{\mathrm{E}\left\{\left(\mathbf{H}^{H}\boldsymbol{w}\right)^{H}\left(\mathbf{H}^{H}\boldsymbol{w}\right)\right\}} \\
&= \frac{\mathrm{E}\left\{\left\|\mathbf{H}\right\|_{\mathrm{F}}^{2H}\left\|\mathbf{H}\right\|_{\mathrm{F}}^{2}\right\}\mathrm{E}\left\{\boldsymbol{s}^{H}\boldsymbol{s}\right\}}{\mathrm{E}\left\{\boldsymbol{w}^{H}\boldsymbol{w}\right\}\mathrm{E}\left\{\mathbf{H}^{H}\mathbf{H}\right\}} = \frac{\left\|\mathbf{H}\right\|_{\mathrm{F}}^{4}\dfrac{P_T}{n_T}}{\left\|\mathbf{H}\right\|_{\mathrm{F}}^{2}\pm_{n}^{2}} \\
&= \frac{P_T\left\|\mathbf{H}\right\|_{\mathrm{F}}^{2}}{\pm_{n}^{2}n_T}
\end{aligned}
\tag{4-14}
$$

when $\boldsymbol{s}^{H}\boldsymbol{s} = P_T/n_T$ and $\boldsymbol{w}^{H}\boldsymbol{w} = \pm_{n}^{2}$. Let $P_T = P_s + P_r$, where P_T, n_T and $\pm_{n}^{2}$ denote the total power in the system, the number of receive antennas at the destination and the noise of receive antennas at destination, respectively.

4.3 Performance of Cooperative MIMO Communication Systems.

In communication systems especially in telecommunications, the parameter SNR is important. This parameter indicates the effectiveness of communication. The parameter calculated from probability and statistics. Signal noise is difficult to predict because random magnitude and phase in time. This chapter proposes the derivation the outage probability and outage capacity which will be discussed in the following section.

4.3.1 Analysis of Outage Probability

In this section, the outage probability of the proposed system is derived. The outage capacity is another popular performance index for communication techniques in fading channels. This outage is the situation that the message cannot be reliably decoded at the destination node. From an information theoretic standpoint, given the transmission rate R and the channel realization h, it can be said that the outage occurs if the channel capacity is less than the transmission rate, i.e., $\log_2(1+\mathrm{SNR}|h|^2) < R$. Hence, the outage probability under the channel realization can be expressed as a function of the transmission rate as given below (Peter Hong, Y.-W., Huang, Wan-Jen. and Jay Kuo, C.-C. (2009))

$$p_{out} \triangleq \Pr\left(\log_2\left(1+\mathrm{SNR}|h|^2\right) < R\right)$$

$$= \Pr\left(\mathrm{SNR}|h|^2 < 2^R - 1\right). \tag{4-15}$$

The £ -outage capacity is then defined as the maximum transmission rate that can be achieved over the fading channel such that the outage probability is smaller than £ , i.e.,

$$C_{£} = \underset{\{R:R\geq 0, P_{out}\leq £\}}{\arg\max}\; p_{out} \,, \tag{4-16}$$

where £ ∈ [0, 1] is a constant threshold.

The outage probability can be calculated by using the probability density function of the channel coefficient or the received SNR . For example, in a Rayleigh channel where the envelope of channel coefficient is Rayleigh distribution and the received SNR , $\text{SNR}\left|h\right|^2$ is exponentially distributed with mean $\text{SNR}\pm_h^2$, the outage probability of a Rayleigh channel given the transmission rate R is expressed by

$$\begin{aligned} p_{out} &= \Pr\left(\text{SNR}\left|h\right|^2 < 2^R - 1\right) \\ &= 1 - \exp\left(-\frac{2^R - 1}{\text{SNR}\pm_h^2}\right) \;, \end{aligned} \tag{4-17}$$

where p_{out} denotes the outage probability of the system that the destination performs detection based only on the received signals from the relay node. This scheme is identical to the conventional transmissions. In order to successfully transmit a codeword over both s, r and r, d links in this case, the rate of the codeword must be bounded by the capacity of both links by

$$2R \le \min\left\{\log_2\left(1+\mathrm{SNR}_{s,r}\left|h_{s,r}\right|^2\right), \log_2\left(1+\mathrm{SNR}_d\left\|\mathbf{H}\right\|_{\mathrm{F}}^2\right)\right\} \tag{4-18}$$

Hence, the channel capacity is given by

$$C = \frac{1}{2}\min\left\{\log_2\left(1+\mathrm{SNR}_{s,r}\left|h_{s,r}\right|^2\right), \log_2\left(1+\mathrm{SNR}_d\left\|\mathbf{H}\right\|_{\mathrm{F}}^2\right)\right\} . \tag{4-19}$$

Following (4-17)

$$p_{out} = \Pr\left(\frac{1}{2}\min\left\{\log_2\left(1+\gamma_{s,r}\right), \log_2\left(1+\gamma_d\right)\right\} < R\right) \tag{4-20}$$

where C is the channel capacity and $\left\|\mathbf{H}\right\|_{\mathrm{F}}^2$ represents the squared Frobenius norm of the matrix $\mathbf{H}$. The above formula can be further rewritten as,

$$p_{out} = \Pr\left(\frac{1}{2}\log_2\left(1+\gamma_{s,r}\right) < R\right) + \Pr\left(\frac{1}{2}\log_2\left(1+\gamma_{s,r}\right) \ge R\right) \times \Pr\left(\frac{1}{2}\log_2\left(1+\gamma_d\right) < R\right)$$

$$= \Pr\left(\gamma_{s,r} < 2^{2R}-1\right) + \Pr\left(\gamma_{s,r} \ge 2^{2R}-1\right) \times \Pr\left(\gamma_d < 2^{2R}-1\right) \tag{4-21}$$

In a Rayleigh fading scenario, $\gamma_{s,r}$ and γ_d are exponentially distributed with mean $\overline{\gamma}_{s,r} = \mathrm{SNR}_{s,r}\left|h_{s,r}\right|^2$ and $\overline{\gamma}_d = \mathrm{SNR}_d\left\|\mathbf{H}\right\|_{\mathrm{F}}^2$. Hence, the outage probability can be rewritten as

$$p_{out} = 1 - \exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{s,r}}\right) + \exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{s,r}}\right) \times \left(1 - \exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{d}}\right)\right)$$

$$= 1 - \exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{s,r}}\right) + \left[\exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{s,r}}\right) - \exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{s,r}} - \frac{2^{2R}-1}{\bar{\gamma}_{d}}\right)\right]. \quad (4\text{-}22)$$

By letting, $e^{-x} \approx 1 - x$, we have that

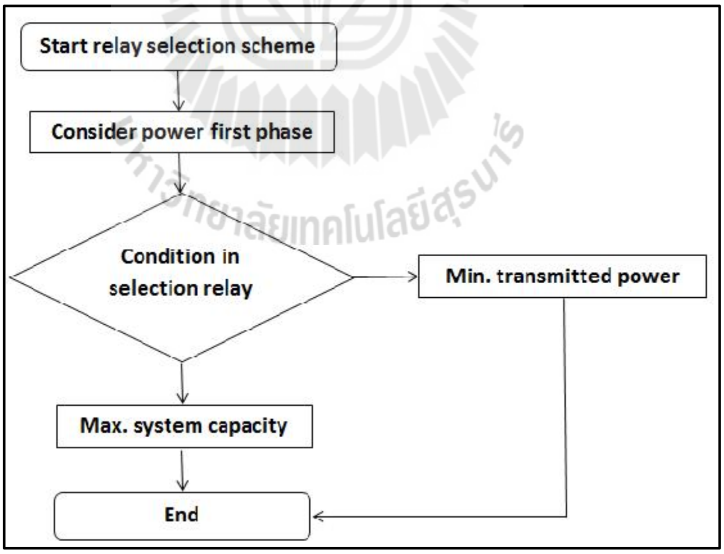
$$p_{out} = 1 - \left(1 - \frac{2^{2R}-1}{\bar{\gamma}_{s,r}}\right) + \left(1 - \frac{2^{2R}-1}{\bar{\gamma}_{s,r}}\right) - \left(1 - \frac{2^{2R}-1}{\bar{\gamma}_{s,r}} - \frac{2^{2R}-1}{\bar{\gamma}_{d}}\right)$$

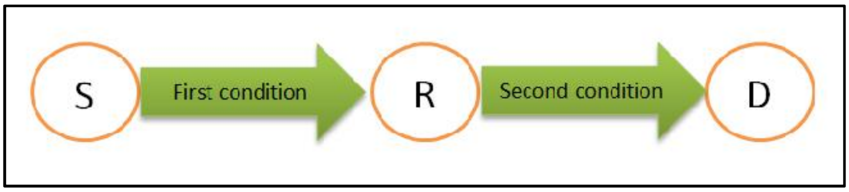
$$= \frac{2^{2R}-1}{\bar{\gamma}_{s,r}} + \frac{2^{2R}-1}{\bar{\gamma}_{d}}. \quad (4\text{-}23)$$

By considering the total power constraint $P_s + P_r = P_T$, and setting $P_s = \alpha P_T$ and $P_r = (1-\alpha)P_T$, for some $0 \le \alpha \le 1$, and $\sigma_r^2 = \sigma_d^2 = \sigma_w^2$, the outage probability can be approximated as

$$p_{out} = \frac{2^{2R}-1}{\mathrm{SNR}}\left(\frac{1}{\|\mathbf{H}\|_F^2}\right) + \frac{2^{2R}-1}{\mathrm{SNR}}\left(\frac{1}{(1-\alpha)\,\mathrm{¦}_{s,r}^2}\right)$$

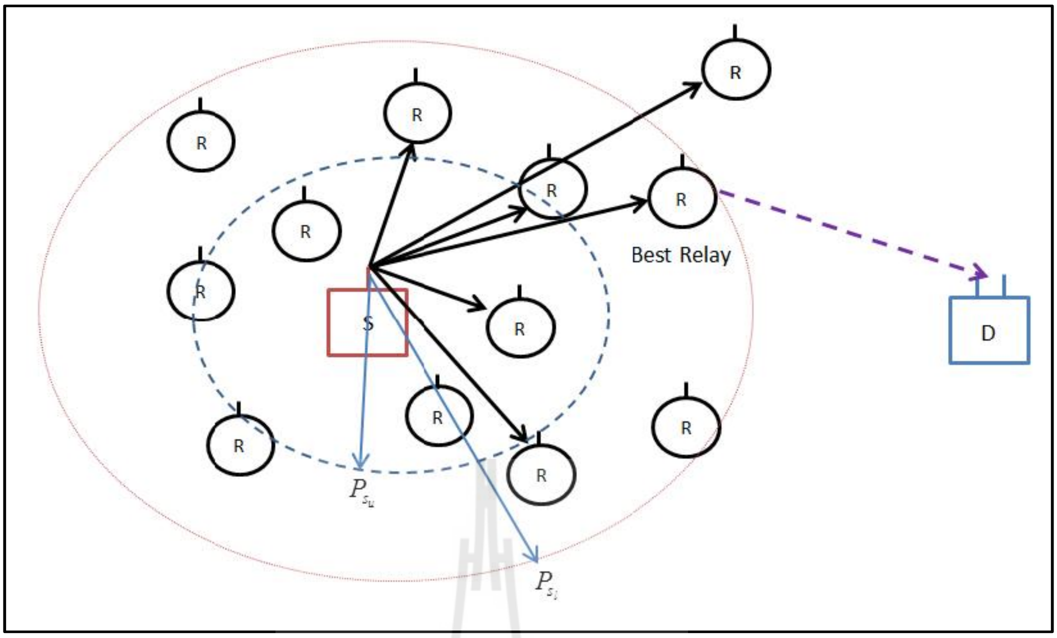
$$= \frac{2^{2R}-1}{\mathrm{SNR}}\left(\frac{1}{\|\mathbf{H}\|_F^2} + \frac{1}{(1-\alpha)\,\mathrm{¦}_{s,r}^2}\right). \quad (4\text{-}24)$$


Start relay selection scheme
Consider power first phase
Condition in selection relay
Min. transmitted power
Max. system capacity
End



P_{s_l}

P_{s_u}



P_{s_l}

P_{s_u}

$$p_{out}^{first\_condition} = \frac{1}{2}\sum_{i=1}^{N} f\left(i\right) P_{R_i} \left(\frac{1}{\sum_{i=1}^{N} P_{R_i}} \right) \qquad \text{for} \qquad P_{s_u} \le P_{R_i} \le P_{s_l}$$

$$= \frac{1}{2}\sum_{i=1}^{N} f\left(i\right) P_{R_i} \left(\frac{1}{\sum_{i=1}^{N} \frac{\left|h_{s,R_i}\right|^2}{d_{s,R_i}^{\sim} \pm_{s,R_i}^{2}}} \right) \qquad \text{for} \qquad P_{s_u} \le P_{R_i} \le P_{s_l}, \qquad (4\text{-}25)$$

when, P_{s_u} and P_{s_l} are the upper bound power of source node and the lower bound power of source node, $f\left(i\right)$ is probability mass function of uniform random variable, h_{s,R_i} is the wireless channel from the source node to relay node i, $w_{s,R_i}^{2} \sim \mathcal{CN}\left(0, \pm_{s,R_i}^{2}\right)$ is complex AWGN including the effect of interference signal at the relay node, d_{s,R_i} is the distance between from source node to relay node i, $\sim$ is path loss exponent and i is the index of relay node.

Next, various relay selection methods were considered, such as selection the channel coefficient of relay node or selection the channel capacity of relay node. The relay receiver is selected such that it is able to receive most power from the relay node. In this thesis, the relay selection by considering the energy can be obtained. In the second phase, the minimum system power and maximum system capacity is considered. The best relay is selected such that,

$$\mathrm{SNR}_{R_i,d} = \left|h_{R_i,d}\right|^2 \left(1-\quad\right)\mathrm{SNR}\,. \qquad (4\text{-}26)$$

Therefore, the outage probability of the relay selection in the second phase is given as,

$$\begin{aligned} p_{out}^{second\_condition} &= \Pr\left\{\frac{1}{2}\log_2\left(1+\left(1-\quad\right)\mathrm{SNR}\right)\left|h_{R_i,d}\right|^2 < R\right\} \\ &= 1-\exp\left(-\frac{2^{2R}-1}{\left(1-\quad\right)\mathrm{SNR}\text{¦}_{R_i,d}^{2}}\right) \end{aligned} \qquad (4\text{-}27)$$

when, $h_{R_i,d}$ is the wireless channel from relay node to destination node, R is desired average end-to-end data transmissions and is the allocation of power between source power and relay power in transmitted signal.

Therefore, the outage probability of the relay selection is written as

$$\begin{aligned} p_{out} = &\left(1-\frac{1}{2}\sum_{i=1}^{N} f\left(i\right)P_{R_i}\left(\frac{1}{\sum_{i=1}^{N}\frac{\left|h_{s,R_i}\right|^2}{d_{s,R_i}^{\sim}\pm{}_{s,R_i}^{2}}}\right)\right) \\ &+\left(\frac{1}{2}\sum_{i=1}^{N} f\left(i\right)P_{R_i}\right)\left(\frac{1}{\sum_{i=1}^{N}\frac{\left|h_{s,R_i}\right|^2}{d_{s,R_i}^{\sim}\pm{}_{s,R_i}^{2}}}\right)\left(1-\exp\left(-\frac{2^{2R}-1}{\left(1-\quad\right)\mathrm{SNR}\text{¦}_{R_i,d}^{2}}\right)\right)\left(1-\exp\left(-\frac{2^{2R}-1}{\mathrm{SNR}_d\left\|\mathbf{H}\right\|_{\mathrm{F}}^{2}}\right)\right) \end{aligned}$$

(4-28)

4.5.1 Power Relay Selection Scheme

In this scheme, the relay selection power scheme which considers energy in the form of cooperative MIMO communication systems is presented. In this process, the relay node in the second phase is aware of the required power in transmitting data because the destination node receives different power from each relay node. When the relay node considers the power of the signal, the relay selection is determined by considering the power the relay node. This means that the chosen relay node transmits the signal from the relay node to the destination by consuming a minimum power transmission,

$$\tilde{\mathrm{R}}_{opt} = \arg\min\left\{P_{R_i}\right\}, \begin{cases} P_{s_u} \le P_{R_i} \le P_{s_l} \\ p_{out} \le 10^{-4} \end{cases} . \tag{4-29}$$

4.5.2 Capacity Relay Selection Scheme

In this scheme, the relay selection capacity scheme for the cooperative MIMO communication systems is based on the efficiency of data transmission rate. Communication systems may not require energy efficiency, but rather high data transmission rate. The relay selection capacity scheme saves time to receive or transmit data which allows the cooperative MIMO communication systems use the relay node cost-effectively. Similar to the power scheme, the relay selection capacity scheme talks place in the second phase. However, this scheme enables the relay node to maximize the channel capacity,

$$\tilde{R}_{opt} = arg\max\left\{C_{R_i}\right\}, \begin{cases} P_{s_u} \le P_{R_i} \le P_{s_l} \\ p_{out} \le 10^{-4} \end{cases} . \tag{4-30}$$

4.5.3 Minimum Channel Relay Selection Scheme

In this scheme (Bai, Z., Xu, Y., Yuan, D. and Kwak, K. (2010)), the minimum channel relay selection scheme considers the effect of channel. The scheme considers the channels with minimal attenuation regardless of the direction from the relay node. This scheme may result in poor system performance when the relay is positioned too close or too far away from the destination node. In this scheme, the relay node is selected according to

$$\tilde{R}_{opt} = \arg\min\left\{\left|h_{R_i}\right|^2\right\}, \left\{\min\left(\left|h_{s,R_i}\right|^2, \left|h_{R_i,d}\right|^2\right) .\right. \tag{4-31}$$

4.5.4 Harmonic Mean Relay Selection Scheme

In this scheme (Bletsas, A., Khisti, A., Reed, D. P. and Lippman, A. (2006)), the harmonic mean relay selection scheme balances the relay channel with source node and destination node. This approach may require excessive system power because the relay maybe in the middle position between the source node and destination node which is inappropriate node. In this scheme, the relay node is selected according to

$$\tilde{R}_{opt} = \arg\max\left\{\left|h_{s,R_i,d}\right|^2\right\}, \left\{\frac{2}{\frac{1}{\left|h_{s,R_i}\right|^2}+\frac{1}{\left|h_{R_i,d}\right|^2}}\right.$$

$$= \arg\min\left\{\left|h_{s,R_i,d}\right|^2\right\}, \left\{\frac{2\left|h_{s,R_i}\right|^2\left|h_{R_i,d}\right|^2}{\left|h_{s,R_i}\right|^2+\left|h_{R_i,d}\right|^2}\right. . \qquad (4\text{-}32)$$

4.5.5 Effective SNR Relay Selection Scheme

In this scheme (Kaiser, M. S., Khan, I., Adachi, F. and Ahmed, K. M. (2009)), the effective SNR relay selection scheme considers the signal-to-noise ratio of the direct path and average signal-to-noise ratio of the multihop path. The power is balanced from selecting the relay according to

$$\tilde{R}_{opt} = \arg\max\left\{SNR\right\}, \left\{SNR_{direct} + \frac{SNR_{s,R_i}SNR_{R_i,d}}{1+SNR_{s,R_i}+SNR_{R_i,d}}\right. \qquad (4\text{-}33)$$

4.6 Summary

This chapter discusses the principle structure and derivation of cooperative MIMO communication systems. This chapter proposed the relay selection based on power and capacity scheme. Moreover, comparisons of several existing relay selection schemes are presented. The relationship between the relay selection schemes and the efficiency of wireless networks were discussed.

CHAPTER V

PERFORMANCE OF COOPERATIVE MIMO COMMUNICATION SYSTEMS AND RELAY SELECTION SCHEMES

5.1 Introduction

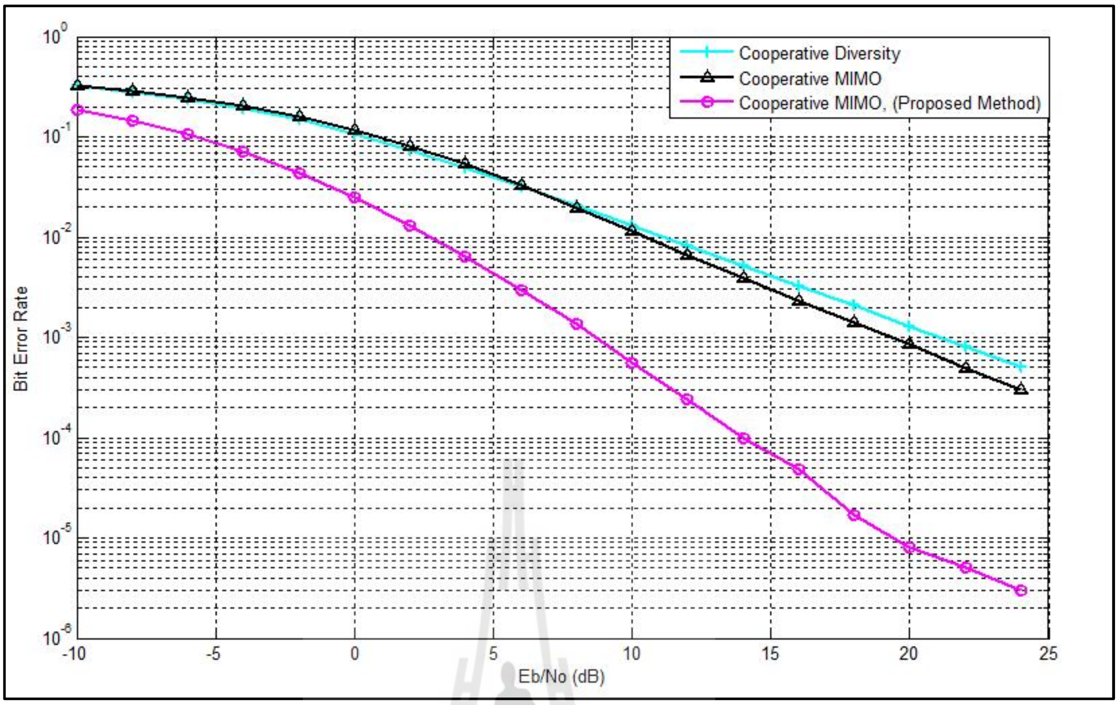
The previous chapters have discussed the principle of several existing cooperative communication systems, MIMO systems, relay selection schemes, proposed cooperative MIMO communication systems and proposed relay selection scheme for cooperative MIMO communication systems. Each scheme applies a different technique to lower power transmission and higher channel capacity. From these differences, each scheme also offers the different performance. Therefore, this chapter demonstrates the performance of proposed cooperative MIMO communication systems compared with other systems and relay selection scheme compared with other schemes. The simulation results and analytical results are jointly demonstrated for verifying the validity of this work. In this chapter, the performances can be demonstrated and divided into four parts. The first part presents the performances of cooperative MIMO communication systems. The second part presents the performances of channel capacity. The third part presents the performances of outage probability and the final part presents the performances of proposed relay selection schemes.

5.2 The Performance of Cooperative MIMO Communication Systems

This thesis has compared the performance of cooperative MIMO communication systems with the computer simulation. In this section, the fading channels are generated by Rayleigh distribution including the complex additive white Gaussian noise (AWGN). The data symbols are randomly generated and modulated by BPSK modulation. The estimated channels are assumed to be perfect which means that the destination is also assumed with the full knowledge of channel information. The cooperative MIMO technique in wireless communication networks is assumed with the perfect synchronization of timing symbols. This assumption is possible for wireless communication networks because in fact the wireless devices always adjust the time slot to base station from time to time. The ML decision is also assumed to be employed at the destination. The performances of cooperative MIMO Communication systems are using to measure the efficiency of this system consist of the following.

5.2.1 BER Performances

In this section, the BER performance of cooperative MIMO communication systems consider the bit errors of signal transmitted from source node and relay node to destination node. The system model in simulation is consisted of one source with one antenna, one relay with one antenna and one destination with two antennas. Three transmission schemes are compared here including cooperative diversity, cooperative MIMO and proposed method as shown in Figure 5.1.

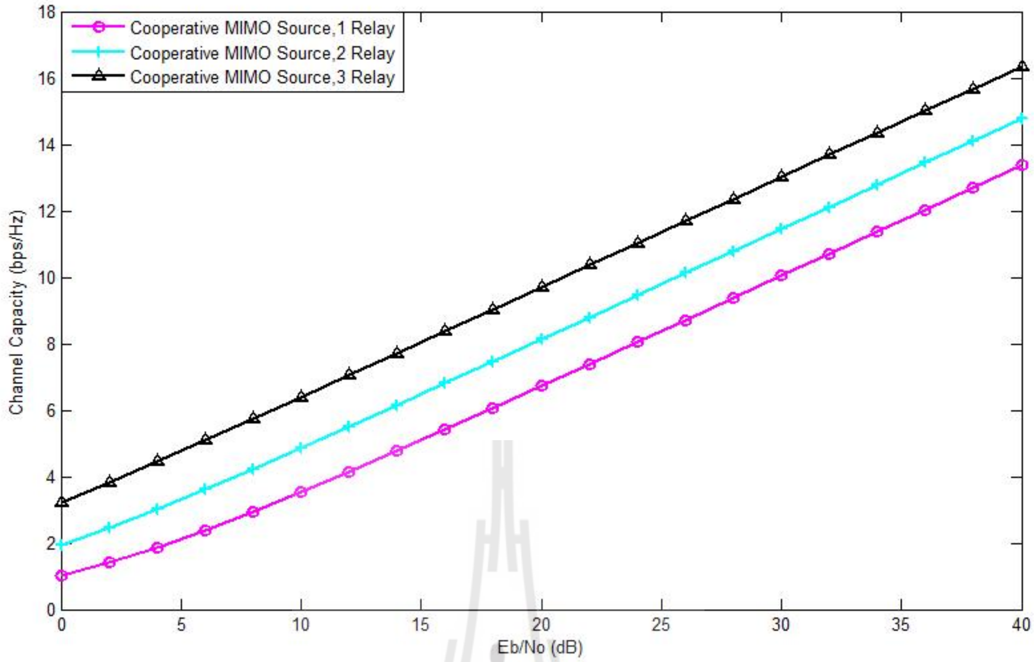


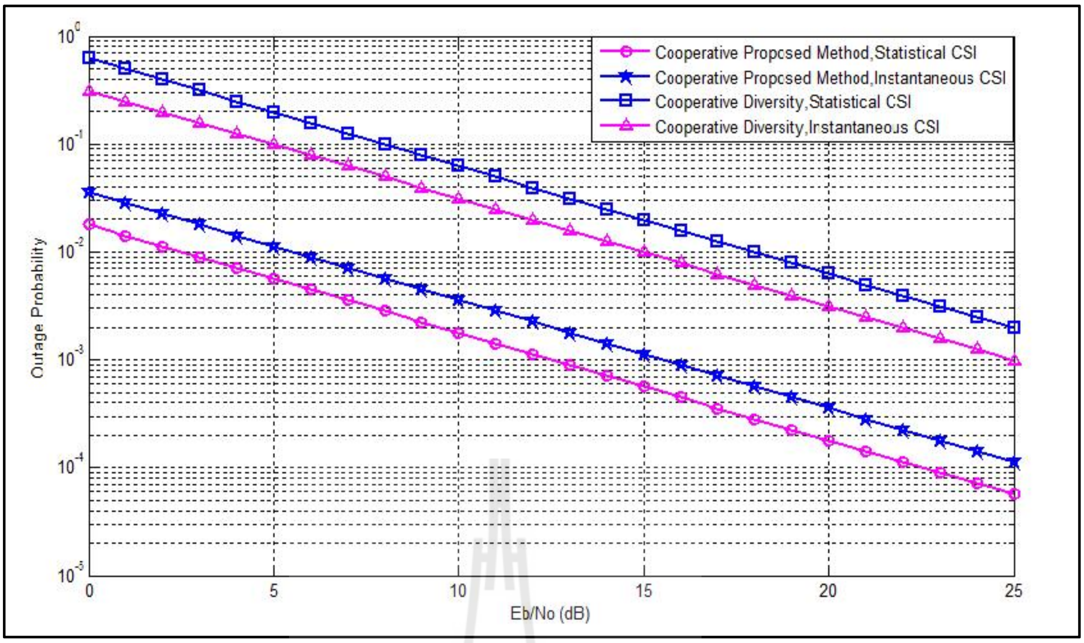
10^{-3}

E_b/N_0 dB

dB dB

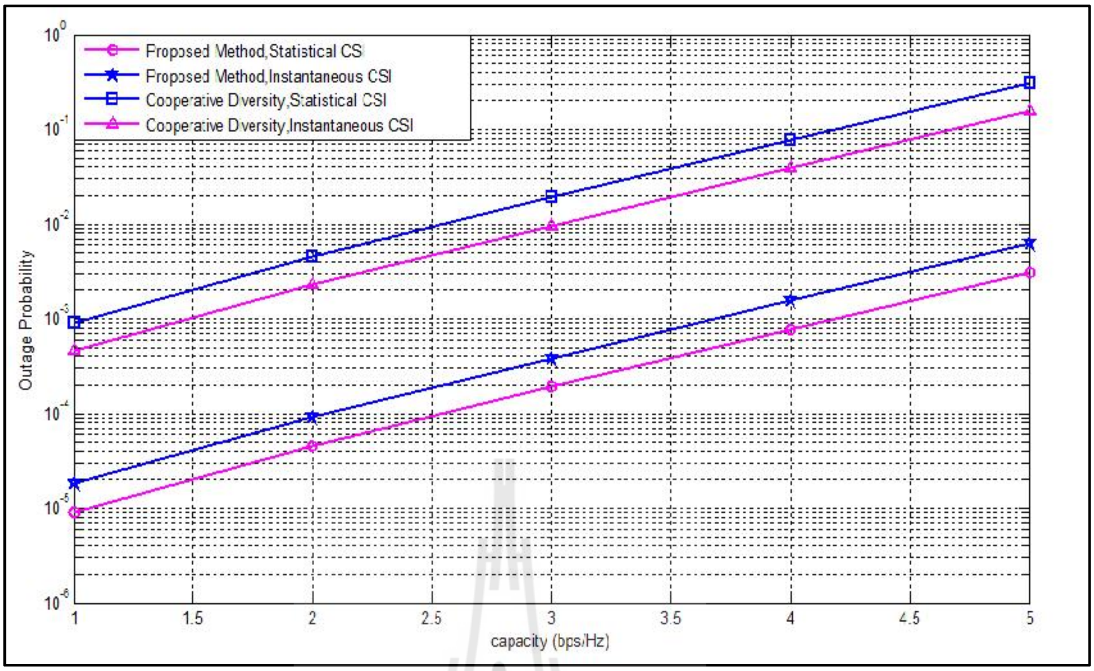
E_b/N_0


Cooperative MIMO Source,1 Relay
Cooperative MIMO Source,2 Relay
Cooperative MIMO Source,3 Relay
Channel Capacity (bps/Hz)
Eb/No (dB)
0
2
4
6
8
10
12
14
16
18
0
5
10
15
20
25
30
35
40

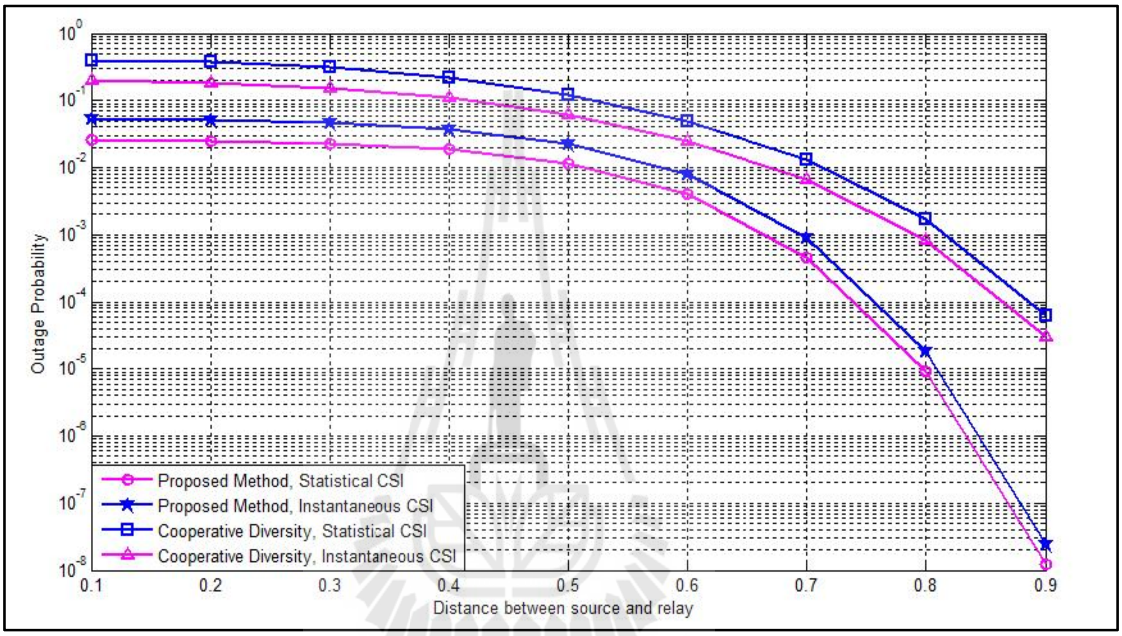


Cooperative Propcsed Method,Statistical CSI
Cooperative Propcsed Method,Instantaneous CSI
Cooperative Diversity,Statistical CSI
Cooperative Diversity,Irstantaneous CSI
Outage Probability
Eb/No (dB)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
5
10
15
20
25

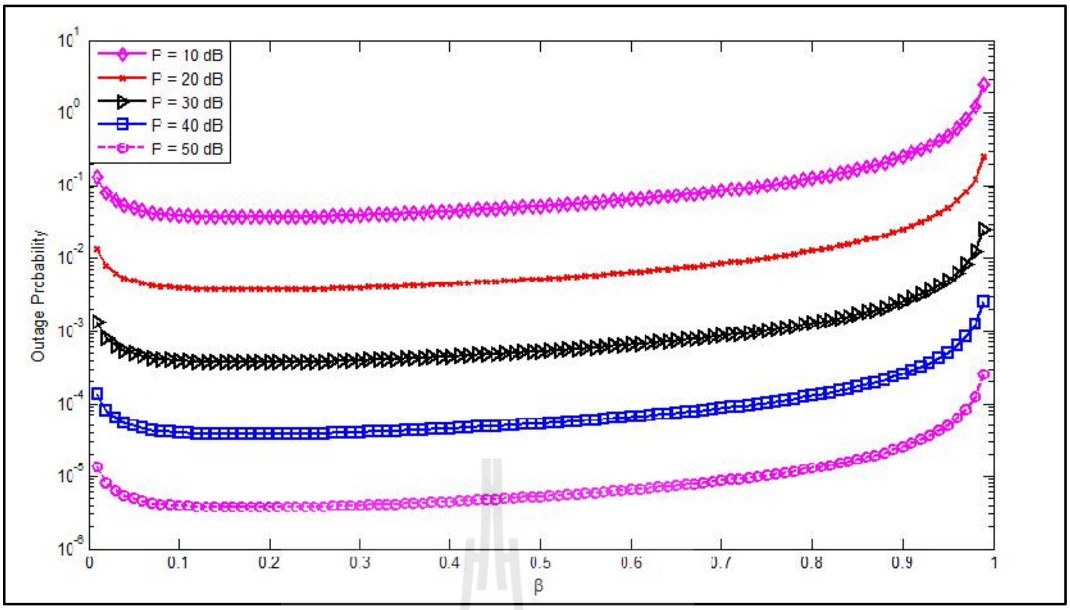
In Figure 5.3, the results indicate that the system performance in terms of outage probability of the proposed method provides the lowest outage probability. Because the proposed method use STBC technique. The STBC technique is the technique of sending information repeatedly. As a result, the system can reduce outage probability in data transmission. Also seen in Figure 5.3, for p_{out} of 10^{-3}, the E_b/N_0 at 12 dB in statistical CSI and the p_{out} of 10^{-3}, the E_b/N_0 at 15 dB in instantaneous CSI can be achieved by using the proposed method while it must be attained at 25 dB in statistical CSI and more than 25 dB in instantaneous CSI by using cooperative diversity method. In Figure 5.4, the results indicate that the systems performance of outage probability versus spectral efficiency of the proposed method provides the lowest outage probability. This is beause the propose method is using STBC technique. The STBC technique is the technique at caused phenomenon time diversity. As a result, the system can reduce outage capacity in data transmission when system channels capacity is increased. Also seen in Figure 5.4, for p_{out} of 10^{-3}, at 1 bps/Hz in statistical CSI and p_{out} of 10^{-3}, at 1.5 bps/Hz in instantaneous CSI. The proposed system can be achieved by using the proposed method while it must be attained at 3.8 bps/Hz in statistical CSI and more than 4.3 bps/Hz in instantaneous CSI by using cooperative diversity method.



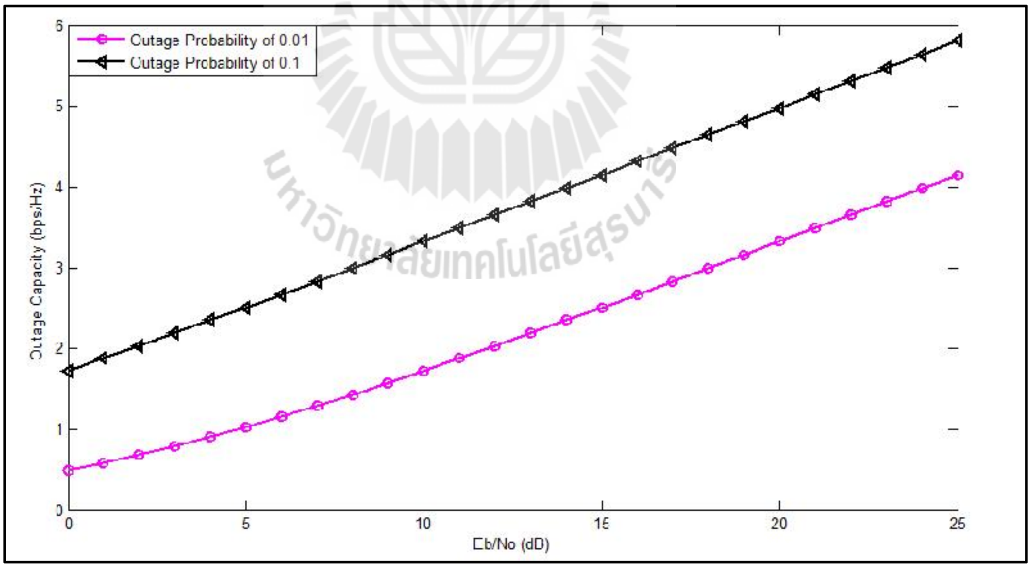
Proposed Method,Statistical CSI
Proposed Method,Instantaneous CSI
Cooperative Diversity,Statistical CSI
Cooperative Diversity,Instantaneous CSI
Outage Probability
capacity (bps/Hz)



Outage Probability
Distance between source and relay
Proposed Method, Statistical CSI
Proposed Method, Instantaneous CSI
Cooperative Diversity, Statistical CSI
Cooperative Diversity, Instantaneous CSI



P = 10 dB
P = 20 dB
P = 30 dB
P = 40 dB
P = 50 dB
Outage Probability
β



Outage Probability of 0.01
Outage Probability of 0.1
Outage Capacity (bps/Hz)
Eb/No (dB)

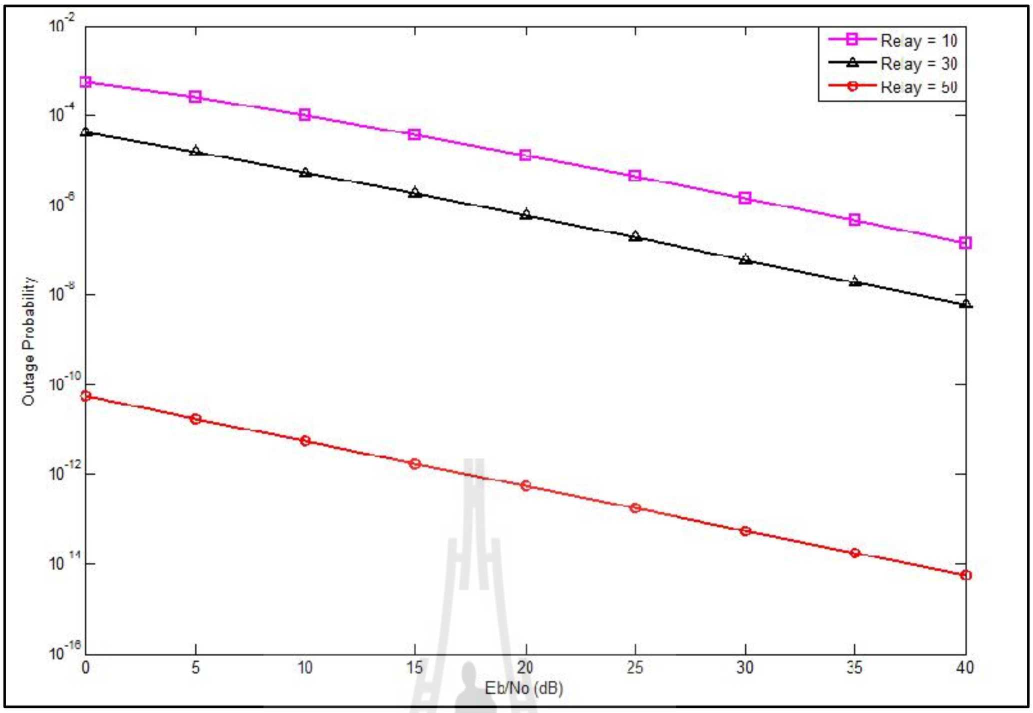
5.2.4 Outage Capacity Performance

The outage capacity performance is another well-known performance measurement for communication systems in fading channels. Outage is the event that the message cannot be reliably decoded at the receiver. From an information theoretic standpoint, the transmission rate is defined as R and the channel realization is defined as h. In this section, the outage capacity performance according to equation (4-24) is shown in Figure 5.7.

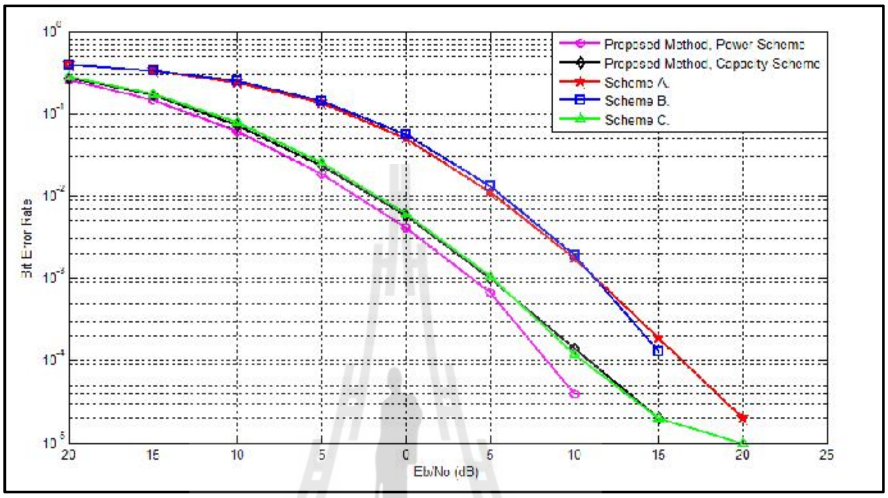
5.3 The Performance of Relay Selection

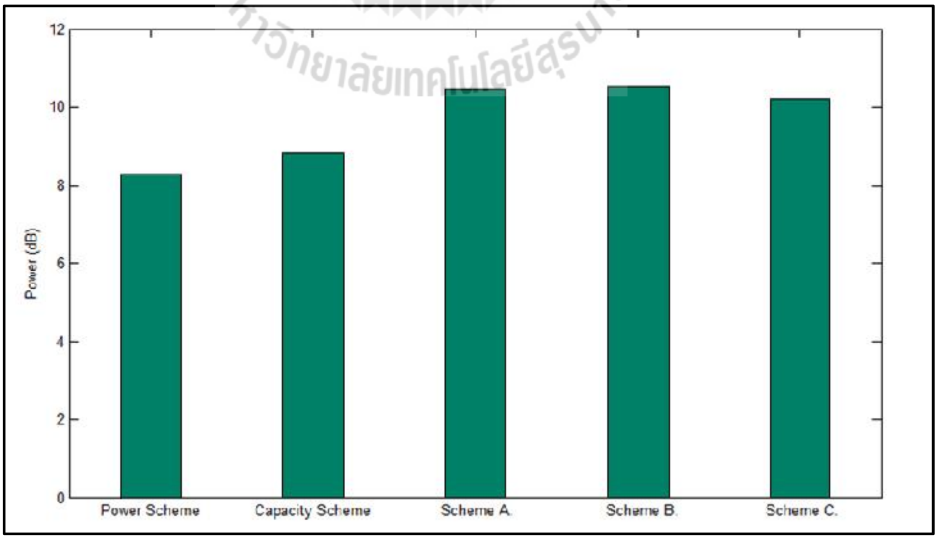
From Chapter 4 regarding efficiency of the relay selection, this chapter proposes a relay selection based on either the power or capacity. The relay selection process was presented in the previous chapter. Figure 5.8 shows the performance of cooperative communications systems with the various numbers of relays through the selection of energy which can be analyzed mathematically by equation (4-28). In order to show how the number of relay nodes affect the cooperative MIMO communication systems, the number of relay nodes is varied from 10 to 50 nodes. Results show that the more number of relay node provides more opportunity to choose a good relay node. As a result, the systems have more efficient signal transmission.

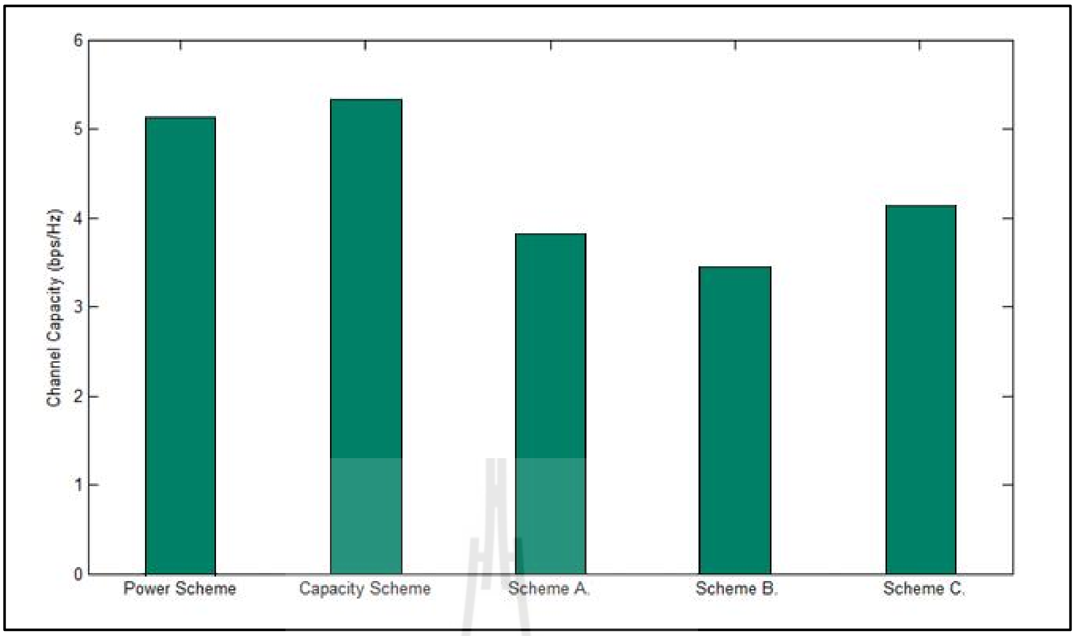
Next, the results in Figure 5.9 to Figure 5.12 are presented in order to investigate the system performance of using relay selection schemes for cooperative MIMO communications. In this case, BER in the systems, the power transmission, systems capacity and outage probability are the main parameters to be compared. The system for


Relay = 10
Relay = 30
Relay = 50
Outage Probability
Eb/No (dB)
10^-2
10^-4
10^-6
10^-8
10^-10
10^-12
10^-14
10^-16
0
5
10
15
20
25
30
35
40

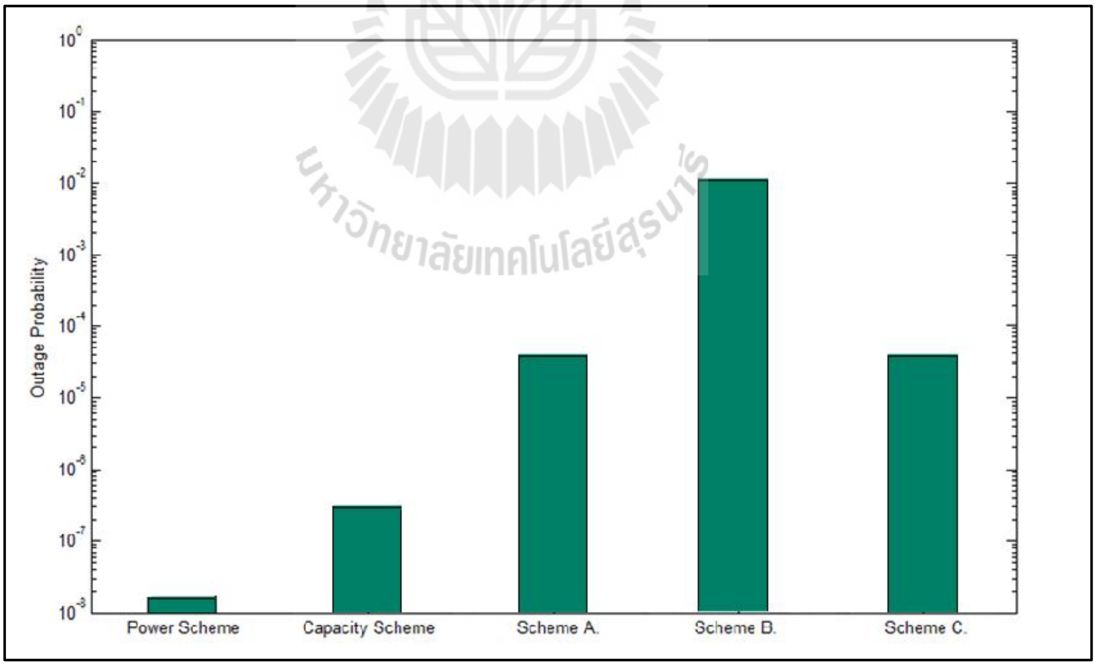
technique sends the information repeatedly. So the system works with the proposed relay selection power scheme. As a result, the system can reduce BER in data transmission. Figure 5.10 to Figure 5.12 show the system performance using various relay selection schemes in terms of power transmission, systems capacity and outage probability. In the simulation, the system channel capacity is set to 3 bps/Hz and power transmission is 10 dB for simulation the systems. Figure 5.10 compares the power transmission among the relay selection schemes. From the simulation, it can be seen that the proposed method power scheme can use the lowest power in signal transmission. The use of power in descending order is : the proposed method capacity scheme, schemes C, B and A. This is because the relay node is aware of the required power in transmitting data. The destination node receives a different power in each relay node. Relay selection is determined by considering the power of the relay node while the relay node receives the most power. This means the power of the relay node transmits the signal from the relay node to the destination node by consuming a minimum power transmission. Figure 5.11 indicates the system capacity among the relay selection schemes. From the simulation, it can be seen that the proposed method capacity scheme provides the highest system capacity. The capacity in descending order is : the proposed method power scheme, schemes C, A and B. This is because the relay selection scheme which considers a relay node with the most channel capacity used in cooperative MIMO communications systems. Such reasons, the selection relay node can choose the relay node that has the most channel capacity. Figure 5.12 indicates the outage probability in the relay selection schemes. From the simulation, it can be seen that the proposed method power scheme offers the lowest outage probability. The outage probability in descending order is : the proposed


Proposed Method, Power Scheme
Proposed Method, Capacity Scheme
Scheme A.
Schema B.
Schema C.
Bit Error Rate
Eb/No (dB)

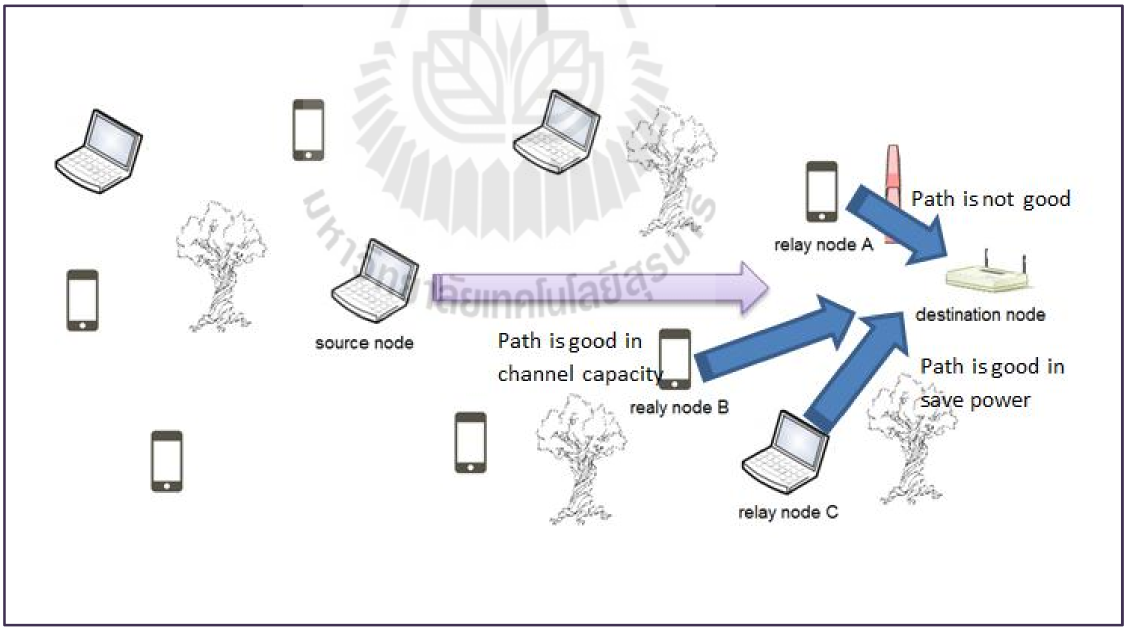

Power (dB)
Power Scheme
Capacity Scheme
Scheme A.
Scheme B.
Scheme C.



Channel Capacity (bps/Hz)
0
1
2
3
4
5
6
Power Scheme
Capacity Scheme
Scheme A.
Scheme B.
Scheme C.



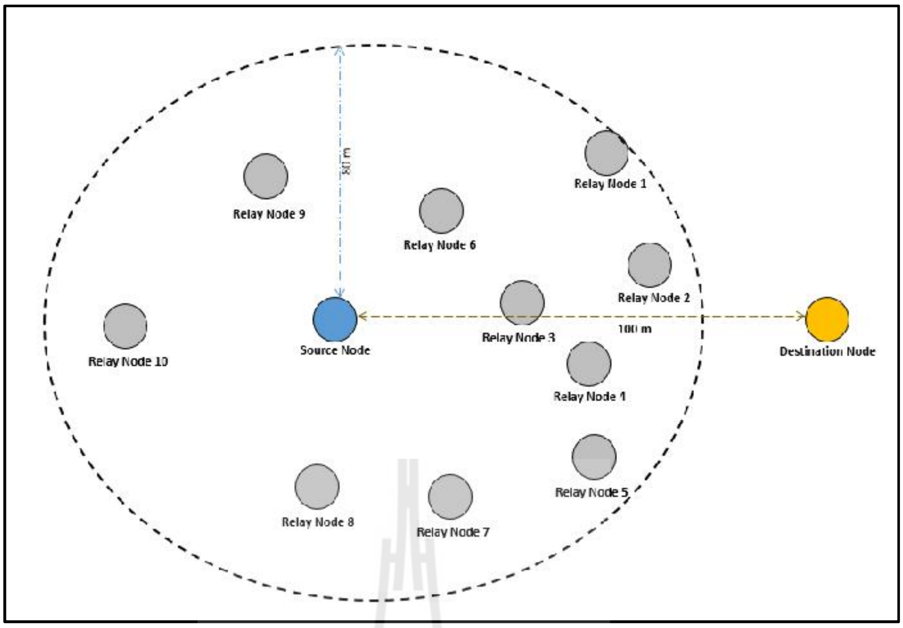
Outage Probability
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
Power Scheme
Capacity Scheme
Scheme A.
Scheme B.
Scheme C.


Path is not good
relay node A
destination node
source node
Path is good in
channel capacity
realy node B
Path is good in
save power
relay node C

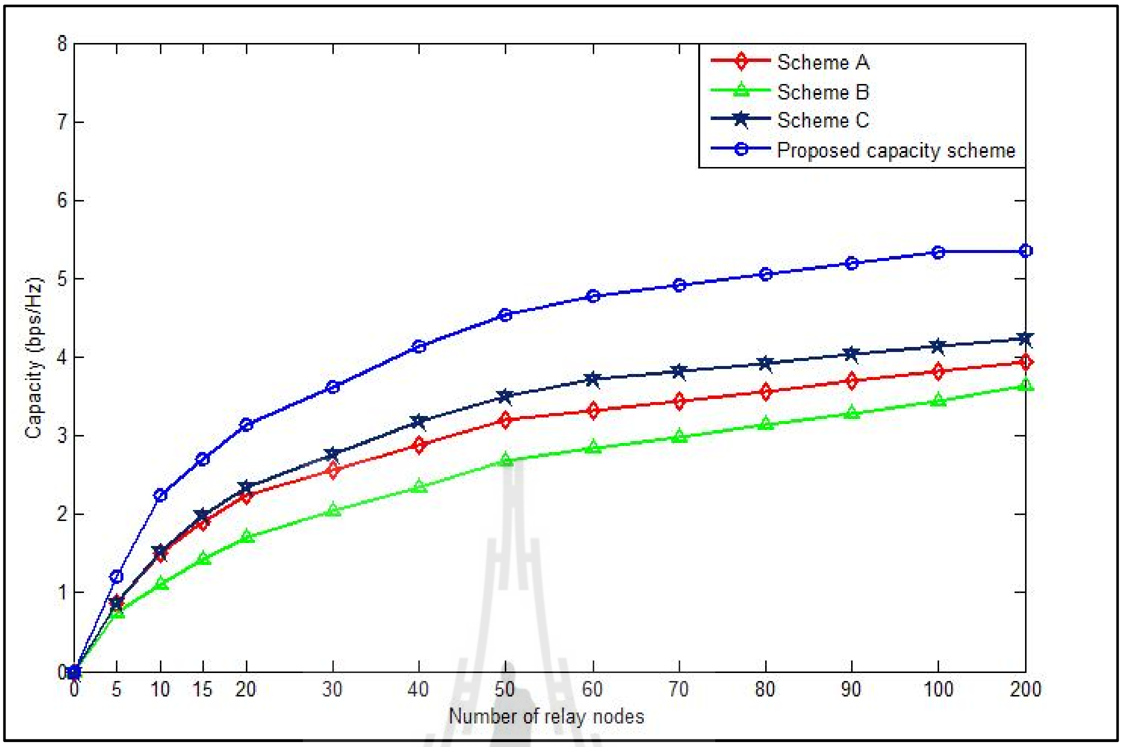
offer a minimum power instead. Hence, the proposed relay selection scheme can help the system to select the relay node and to save more power.

To further study the capacity, the distance from the source node to destination node is set to 50 meters. The distances of relay nodes A, B and C to the destination node are 10 meters, 20 meters and 15 meters, respectively.From Figure 5.13, relay node A is located behind a wall the relay resulting in a reduction of the transmitting signal power by $P_r/2$. So the equation of channel capacity is $C = \log_2\left(1 + P_T \|\mathbf{H}\|_{\mathrm{F}}^2\right)$ where $P_T = P_s/d_{s,d}^{\sim} + P_r/d_{r,d}^{\sim}$, $\|\mathbf{H}\|_{\mathrm{F}}^2$ represents the squared Frobenius norm of the matrix $\mathbf{H}$. P_T, P_s and P_r are the total power in the system, the transmission power of source node and the transmission power of relay node, respectively. $d_{s,d}$ is the distance between from source node to destination node, $d_{r,d}$ is the distance between from relay node to destination node and $\sim$ is path loss exponent. Suppose that the relay channels are similar to one another, i.e., $\left\|\mathbf{H}_{\mathrm{s,relayA}}\right\|_F^2 \approx \left\|\mathbf{H}_{\mathrm{s,relayB}}\right\|_F^2 \approx \left\|\mathbf{H}_{\mathrm{s,relayC}}\right\|_F^2$ and the transmitting power of source node, relay node, destination node are equal. In this case, relay node B may provide the maximum capacity. The system can select the relay node by using the proposed scheme.

Figure 5.14 shows an example of a distribution of the relay node selection. The positions of all relay nodes were randomized by simulation. Then a relay node was selected according to the relay schemes. The resulting relay node selection is presented in Table 5.1.



Selection scheme	**Selected relay node**	**Capacity (bps/Hz)**
Scheme A	Relay node 4	1.92
Scheme B	Relay node 3	1.10
Scheme C	Relay node 4	1.92
Proposed capacity scheme	Relay node 2	2.64



Scheme A
Scheme B
Scheme C
Proposed capacity scheme
Capacity (bps/Hz)
Number of relay nodes
0
1
2
3
4
5
6
7
8
0
5
10
15
20
30
40
50
60
70
80
90
100
200

source node in practice. Hence, the proposed scheme enables more practical implementation of cooperative MIMO systems over other schemes in the literature.

5.5 Summary

This chapter presents the advantage of cooperative MIMO communication systems by comparing to other systems in simulations. The results show that the BER performances of the proposed cooperative MIMO communication systems outperform other cooperative MIMO communication systems. From the analytical performance study, the proposed system can reduce power consumption in data transmission or the BER in system. Moreover, this chapter presents the advantage of the proposed cooperative MIMO communication systems. The proposed relay selection schemes in practice have confirmed the validity of principle cooperative communication.

CHAPTER VI

EXPERIMENTS OF RELAY SELECTION SCHEMES

6.1 Introduction

This chapter presents the experiment of cooperative MIMO communication systems with relay selection schemes in order to validate the concept of this thesis. The methods to setup cooperative MIMO communication systems with relay selection schemes including hardware and program software for signal processing are explained. The method to import data from hardware into computer are explained. The limitations of experiment and devices are described. Moreover, the experimental scenario is also discussed.

6.2 Experimental Devices

This part presents the details and specification of the important devices used in relay section scheme for cooperative MIMO communication. The function of each device is also explained to understand the overall concept of cooperative MIMO communication.

6.2.1. Software Defined Radio

Software Defined Radio (SDR) is a term used to describe a radio communication system where a range of different hardware components (e.g., filters, amplifiers, modulators/demodulators, detectors, etc.) are implemented in software.

When components are built as application-specific hardware, there is difficulty in modifying existing systems or prototyping new systems. This is due to the time and costs of hardware.

The functionality of radio components is implemented on a software environment which provides more flexibility. For a radio communication system, flexibility means the ability to transmit and receive different radio protocols. Another benefit from using software is that the data processing may be performed by any computer, eliminating the need to buy expensive specialized hardware. Furthermore, software even allows a component to be reused.

In summary, SDR minimizes hardware to provide faster modifications, easier prototyping, lower costs, greater flexibility and reusability. In educational institutions, the majority of learning and research in digital communications involves developing software using computers. Thus, SDR is very beneficial for educational institutions where computers are sufficient, but the budget for supplementary hardware is limited.

6.2.2. GNU Radio

GNU is a free operating system developed by GNU Project which was intended to be compatible with UNIX. It was first initiated by Richard Stallman in 1983. Several versions of GNU have been released but there is no stable version till date. It is abbreviated as GNU. Although GNU is UNIX, it is free software and containing no UNIX code.

GNU Radio is an open source software development tool kit that helps to process the signal through software defined radio. User can write applications to transmit and receive data streams through hardware.

It has various elements in the tool blocks for example, filters, modulators, demodulators, encoders, and decoders etc. Various elements are typically found in an equipment radio. Primarily the tool has a method of connecting these blocks and managing the data step by step. Since GNU Radio is software and handles only digital signals, the output of the transmitters and input of the receivers are always complex baseband samples. The shifting of the signal to the desired center frequency is done by the analog hardware. Any data type can be passed from one block to other by dint of bytes, float or other complex data types. There are also other user friendly features which makes this software suitable to model real world radio systems and wireless communication systems for academic and research purposes.

GNU Radio's applications are primarily written in the Python programming language while the signal processing path is written in C++. So, GNU Radio supports a rapid application development environment.

6.2.3. GRC (GNU Radio Companion)

Although GNU Radio's process is completely written in Python, there is a tool called GNU Radio Companion (GRC) which allows user to construct blocks on the application when the user wants to build. So, it is not necessary for the users to know the Python language to construct an application. Of course one needs to know Python if wanting to understand the frontend functionality of the application/flow graphs that is made.

The functionality of cooperative relays using GNU Radio and USRP is implemented by GRC according to GNU Radio standard.

6.2.4. USRP (Universal Software Radio Peripheral)

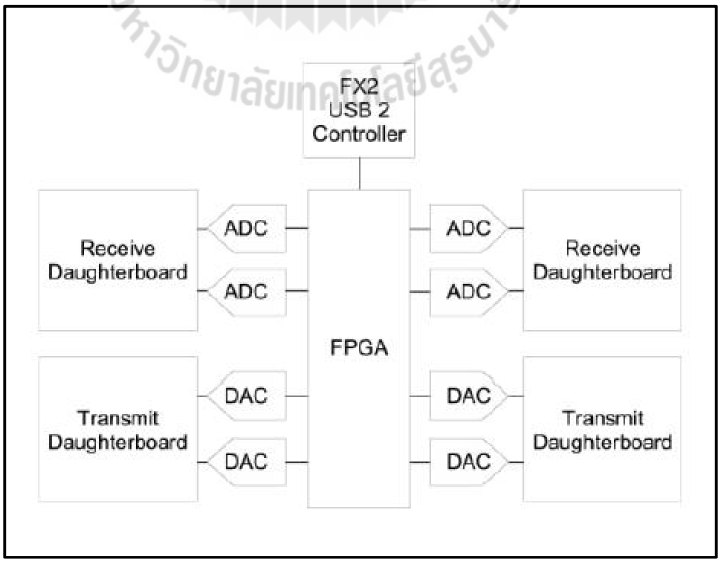
USRP is an open source computer hosted SDR designed by Ettus Research, LLC and National Instruments. The USRP product family is intended to be a comparatively inexpensive hardware platform for software radio and is used widely in research labs, universities, etc. USRPs connect to a host computer through a high speed USB where the software controls this radio to transmit and receive information.

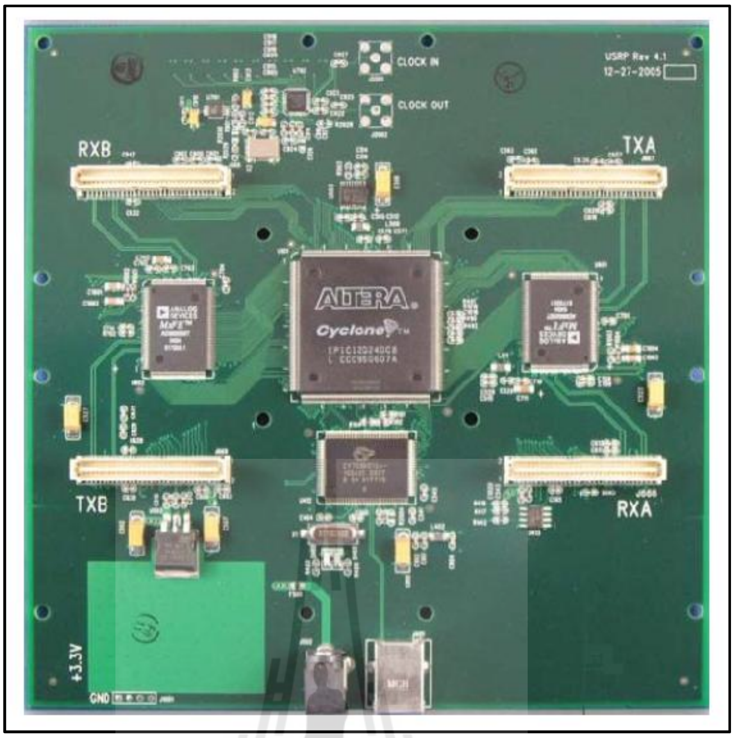
A typical USRP can accommodate one motherboard and two daughter boards, one for receiving and the other for transmitting. A USRP can simultaneously transmit and receive on two antennas.

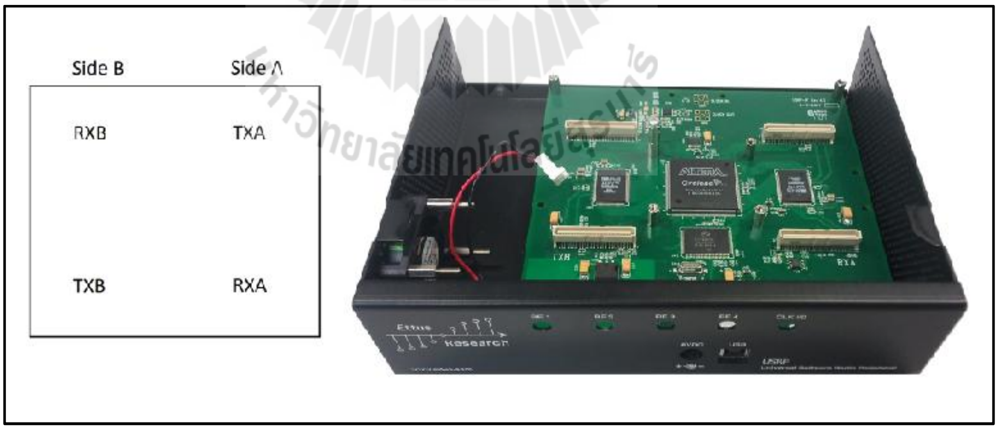
The motherboard in a USRP has clock generation, FPGA, DAC, ADC, power regulation and host processor interface subsystems which are the basic components required for processing of baseband signals. A modular front end called daughterboard is used for analog operations such as DAC, ADC etc. According to USRP manual, the following are the components:

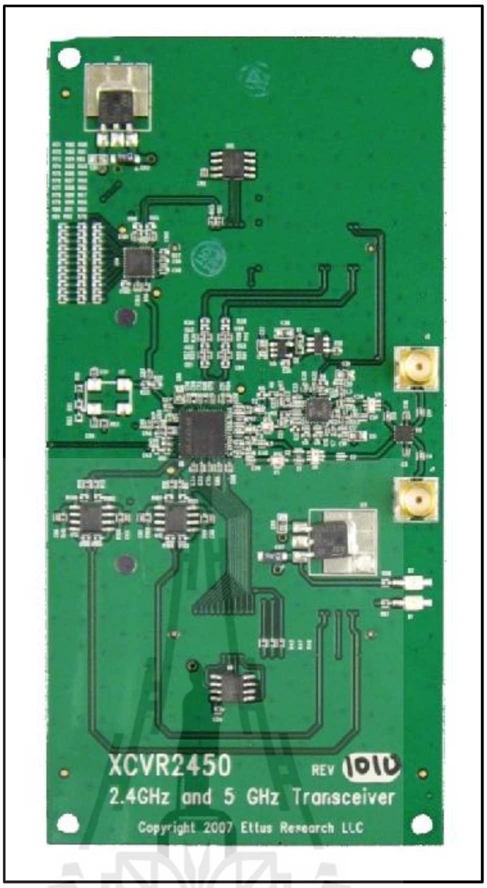
1) USRP Motherboard

The main components of the USRP motherboard include four high-speed 64 MS/s (64M samples/second) 12-bit ADCs, four high-speed 128 MS/s (128M samples/second) 14-bit DACs, a million gate Altera Cyclone EP1C12 field programmable gate array (FPGA), and a Cypress FX2 chip; a programmable USB 2.0 controller. Since the USB 2.0 interface has a theoretical data throughput of 480 Mb/s, the FPGA has four digital downconverters (DDC) with programmable decimation rates (for RX side) and two digital upconverters (DUCs) with programmable interpolation rates (for TX side). The USRP performance is limited by the speeds of USB 2.0 and the computer processing unit (CPU). Figure 6.1 shows a block diagram


FX2
USB 2
Controller
Receive
Daughterboard
ADC
ADC
FPGA
ADC
ADC
Receive
Daughterboard
Transmit
Daughterboard
DAC
DAC
DAC
DAC
Transmit
Daughterboard


USRP Rev 4.1
12-27-2005
CLOCK IN
CLOCK OUT
RXB
TXA
ALTERA
Cyclone
TXB
RXA
+3.3V
GND


Side B
Side A
RXB
TXA
TXB
RXA


XCVR2450
REV
2.4GHz and 5 GHz Transceiver
Copyright 2007 Ettus Research LLC

performance transceiver intended for operating in 2.4 GHz and 5.9 GHz range. Filtering on the XCVR2450 provides exceptional selectivity and dynamic range in the intended bands of operation. The typical power output of the XCVR2450 is 100 mW.

3) Antenna

Omni-directional antenna is used to transmit and receive RF signal at both transmitter and receiver in the 2.4GHz band. This experiment used VERT2450 Dual Band 2.4 to 2.48 GHz and 4.9 to 5.9 GHz omni-directional vertical antenna, at 3dBi Gain shown in Figure 6.5.

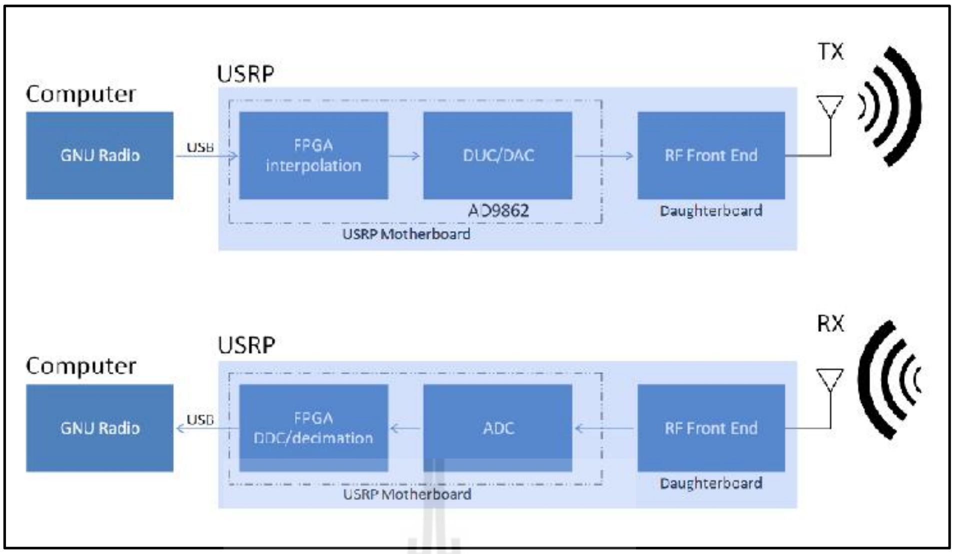
4) Power

The USRP is powered by a 6V 4A AC/DC power converter. This converter is capable of 90-260VAC, 50/60 Hz operations. The USRP itself needs 5V of supply and 6V of supply is required for the daughter boards. It draws a 1.6 A with 2 daughterboards fixed on it.

6.3 Interfacing between Hardware and Software

This thesis implements cooperative MIMO communication on USRP that can be interfaced with GNU Radio. The interfacing between hardware and software can be fully demonstrated in Figure 6.6.

Daughterboard	Daughterboard Type	Frequency Band
Basic RX	Receiver	0.1-300 MHz
Basic TX	Transmitter	0.1-200 MHz
LFRX	Receiver	DC-30 MHz
LFTX	Transmitter	DC-30 MHz
TVRX	Receiver	50-860 MHz
DBSRX	Receiver	800-2400 MHz
WBX	Transmitter	50-2200 MHz
RFX400	Transmitter	400-500 MHz
RFX900	Transmitter	750-1050 MHz
RFX1200	Transmitter	1150-1450 MHz
RFX1800	Transmitter	1500-2100 MHz
RFX2400	Transmitter	2250-2900 MHz
XCVR2450	Dual-Band Transceiver	2400-5000 MHz



TX
USRP
Computer
GNU Radio
USB
FPGA
interpolation
DUC/DAC
RF Front End
AD9862
Daughterboard
USRP Motherboard
RX
USRP
Computer
GNU Radio
USB
FPGA
DDC/decimation
ADC
RF Front End
Daughterboard
USRP Motherboard

6.3.3 ADC/DAC and RF Front End

The function of ADC/DAC can be divided into two sections. The first section is the digital to analog (DA) conversion. DA section sends the analog signal to RF part (TX) for up-converter, amplifier and RF signals propagation. The second section is analog to digital (AD) conversion. AD section receives the IF received signals from RF part (RX) to convert the analog signals to be digital signals. SMA connector can be used to connect all carrier frequency between ADC/DAC section and RF front end part.

6.4 Limitations of experiment

In this part, the limitations of experiment are described by considering the physical characteristic of devices and the link budget in experiment. These limitations can be divided into four portions as follows.

6.4.1 Number of Relay Experiment

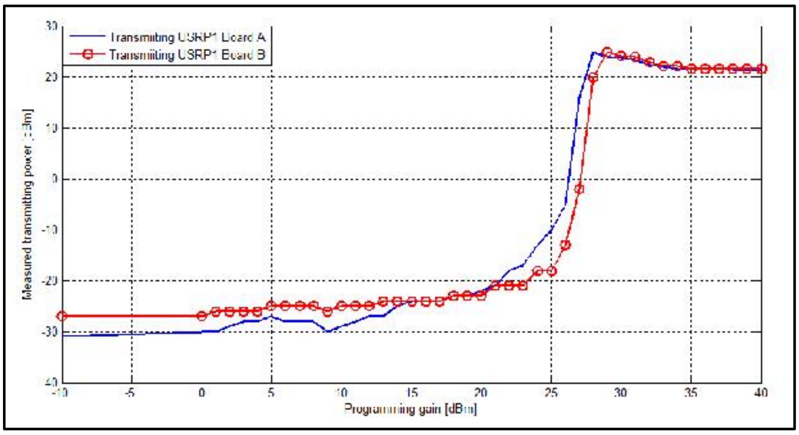
This experiment is to test the effectiveness of the relay selection scheme. The experiments were conducted using USRP 2 sets of experiments. The experiment assumes a consistent phase of source to destination, a consistent phase of source to relay and a consistent phase of relay to destination.

6.4.2 Link Distance

In the experiment, the link distance between source and destination is about 10 meters and the link distance between relay and destination is about 1 to 4 meters. This is because the RF power in the experiment is limited by the transmitted power, gain and loss of RF devices, loss in radio channels and the interference from

$2D^2/$a a

Source	Limitation
Transmitted power	<=29dBm
Cable loss at transmission line	0.8dB
Cable loss at receiver	3.86dB
Antenna gain	3dBi
Free space path loss (FSPL)	54.22dB



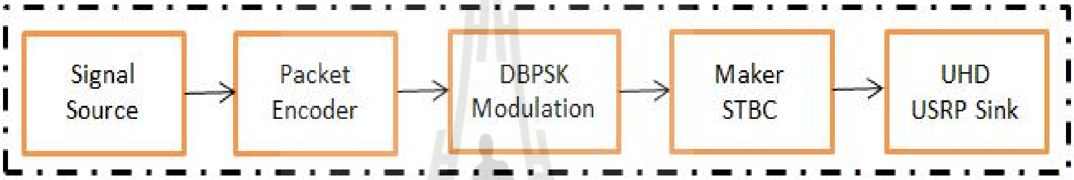
respectively. Thus, the started point of far-field region for this work is 0.334 meters that is shorter than the link distance of 10 meters in the experiment. This means that the experimental results can be correctly applied to validate an advantage of the proposed system although the link distant is quite short.

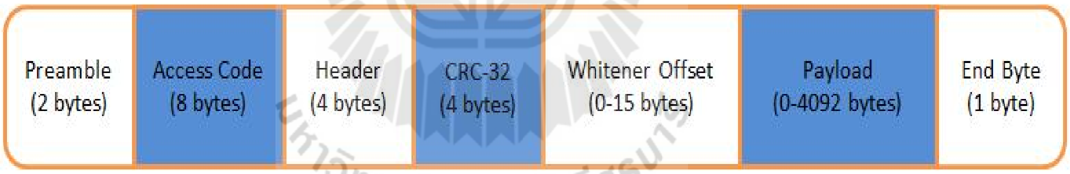
6.4.3 Determination of power unit

In simulations and analysis, E_b/N_0 unit is defined as the horizontal axis for BER performances. The transmitted power P_T unit can be converted to be E_b/N_0 unit by scaling with channel gain, bit rate and signal bandwidth. The theoretical channel gain can be generated by using a random coefficient function that has specific pattern in statistic. In contrast, the practical channel gain can be rapidly varied in the different locations and durations. Therefore, the P_T unit at the horizontal axis of BER performances is not converted to be E_b/N_0 unit. However, to check the validity of the experimental results, the transmitting power of USRP was calibrated using the network analyser as shown in Figure 6.7.

6.5 The Developed Systems on GRC

For designing and creating cooperative MIMO communication systems on USRP, all sub-function blocks of the cooperative MIMO communication systems can be developed by GRC program that support GNU Radio from USRP products designed by Ettus Research, LLC and National Instruments. This thesis divides the cooperative MIMO communication systems into three parts. The first part is a transmitter called as source node the next part is a relay called as relay node and the


Signal Source
Packet Encoder
DBPSK Modulation
Maker STBC
UHD USRP Sink


Preamble (2 bytes)
Access Code (8 bytes)
Header (4 bytes)
CRC-32 (4 bytes)
Whitener Offset (0-15 bytes)
Payload (0-4092 bytes)
End Byte (1 byte)

2) Packet Encoder

The data will be generated in the digital format. In order for the signal to be transmitted over the air, the signal has to be made into packets. The packet encoder is created to prevent the information from various errors during transmission. The packet structure consists of various parts shown in Figure 6.9.

Preamble – 2 bytes in length and used for maintaining synchronization (in frequency and time) in between the transmitter and the receiver.

Access Code – 8 bytes in length and positioned at the start of the packet. Both preamble and access code are correlated with the receiver for better synchronization.

Header – 4 bytes in length and has the information about the length of the payload. When a stream of sampled data comes to the receiver, all the data are discarded until the beginning of the packet is signaled either by the stream tag or a trigger signal from the coming inputs. Once the start of the packet is detected, the preamble and header are copied to the output by the de-multiplexer. The header is then demodulated with any of the GRC blocks.

CRC-32 – 4 bytes in length and is used for error detection for the payload.

Whitener Offset – Ranges from 0 to 15 bytes in length. The payload is 'whitened' which means an XOR operation is done with a PN code generated by the Linear Feedback Shift Register (LFSR) in order to avoid phase error during the transmission. This offset determines where to begin the whitening.

Payload – The length of the payload ranges from 1 to 4092 bytes.

End Byte – 1 byte in length which tells the receiver that the transmission is complete.

3) DBPSK Modulation

The differential phase shift keying is a non-coherent form of phase shift keying which avoids the need for a coherent reference signal at the receiver. Non-coherent receivers are relatively easy and cheap to build, and hence are widely used in wireless communications. Differential binary phase shift keying (BPSK) modulations were adopted to represent data by changes in phase of subsequent symbols. The DPSK Mod block uses gray coding to modulate the encoded bits. Although BPSK has enabled the simple implementation of the receiver because channel estimation is unnecessary in differential modulation schemes.

4) STBC Maker

In this block, the signals from modulation block are modified in terms of phase or amplitude and position of the symbol. This allows the relay signals to be combined with the source signals at destination node in STBC format.

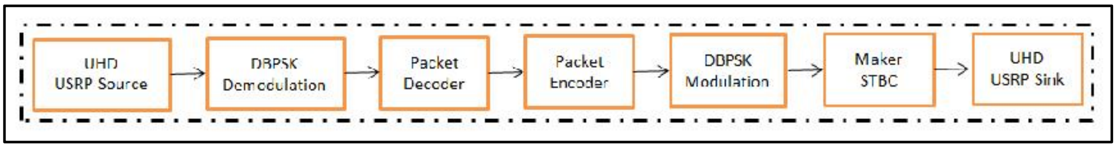
5) USRP Sink

The analog signal generated by the blocks above is sent over the USRP sink for the transmission over air on the prescribed center frequency. The signal was transmitted at 2.45GHz since the daughterboards XCVR2450 works best in the range of 2.4-2.5 GHz.

6.5.2 Relay Node of Cooperative MIMO Communication Systems

At the relay node, the ready-made blocks and the developed block are connected to generate the GRC program for cooperative MIMO communication systems. The transmitter and receiver can be divided into six parts as follows.

1) DBPSK Demodulation


UHD
USRP Source
DBPSK
Demodulation
Packet
Decoder
Packet
Encoder
DDPSK
Modulation
Maker
STBC
UHD
USRP Sink

5) USRP Sink

Analog signals generated by the blocks above are sent to the USRP sink for the transmission using the prescribed center frequency. The signal is transmitted at 2.45GHz since the daughterboard XCVR2450 works to comply with transmission signals from the source node.

6.5.3 Destination Node of Cooperative MIMO Communication Systems

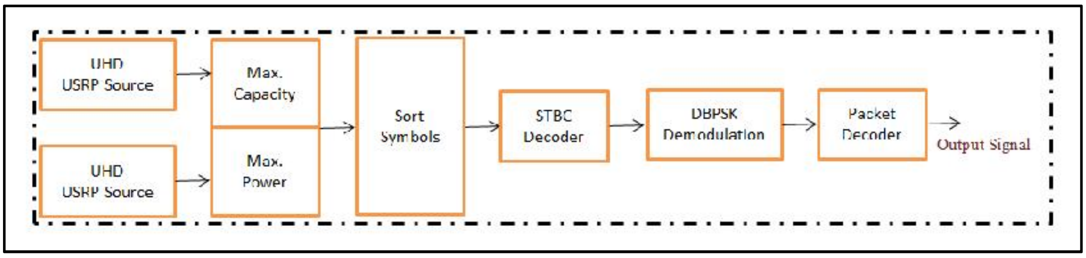
At the destination node, the ready-made block and the developed block are connected to generate the GRC program for cooperative MIMO communication systems. The transmitter and receiver can be divided into six parts as follows.

1) Capacity and power maximum consideration

The relay selection scheme is implemented in the capacity and power maximum consideration blocks based on the value of the channel capacity and transmit power. This part is the most important consideration in selecting the relay of cooperative MIMO communication systems.

2) Sort symbols

This part sorts the data symbol transmitted from the source node and relay node symbol to each antenna at destination node. This information can be decoded by STBC descrbed in the next section.


UHD
USRP Source
UHD
USRP Source
Max.
Capacity
Max.
Power
Sort
Symbols
STBC
Decoder
DBPSK
Demodulation
Packet
Decoder
Output Signal

6.6.1 Power Selection Scheme

The power selection scheme is of main importance in cooperative MIMO communication systems. In this process, each relay node knows when the systems require different transmission power to the destination node. The systems consider the power of relay node receiver. In the experiments, the experimental results in the second phase are recorded for the lowest power.

6.6.2 Capacity Selection Scheme

The relay selection based on the capacity scheme enables high data rate transmission in cooperative MIMO communication systems. Some communication systems may not require power efficiency but rather the shortest time for information transmission. The relay selection based on capacity scheme exploits the advantage that a chosen relay node can maximize the channel capacity of the system. From experiments, the experimental results are recorded in the second phase for the channel capacity.

6.6.3 The Outage Probability

The outage probability performance is an important performance measurement of communication systems operating over fading channels. In the experiments, the outage probability is the likelihood of signal loss in the experiments such that the transmission signals can receive normally or the transmission signals cannot be obtained from the receiver. In the experiments, the candidate records the experimental results are recorded in the receiver for the outage probability performance.

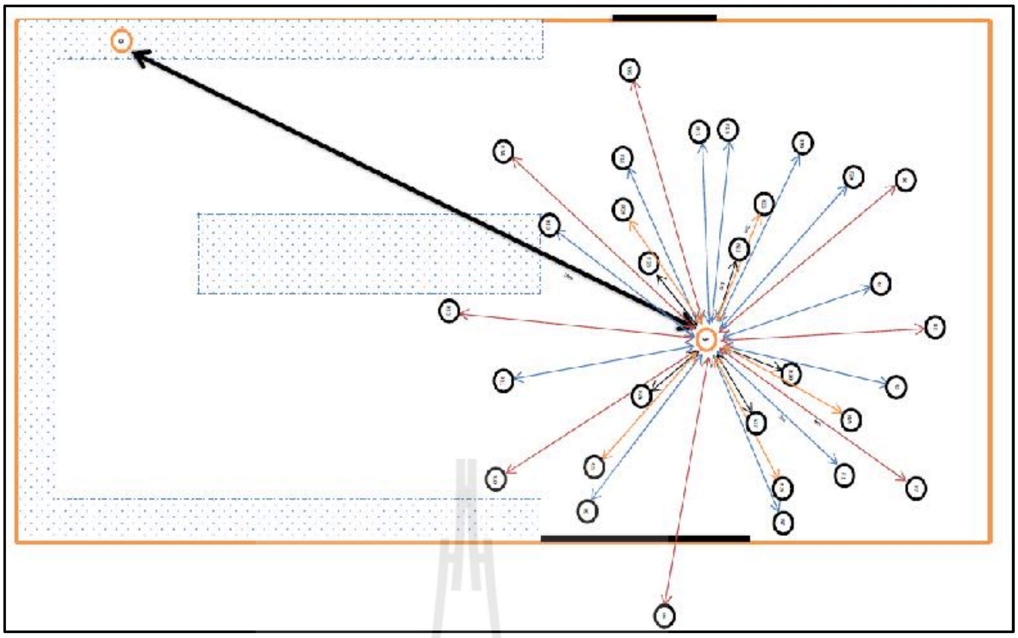
6.7 Experimental Scenarios

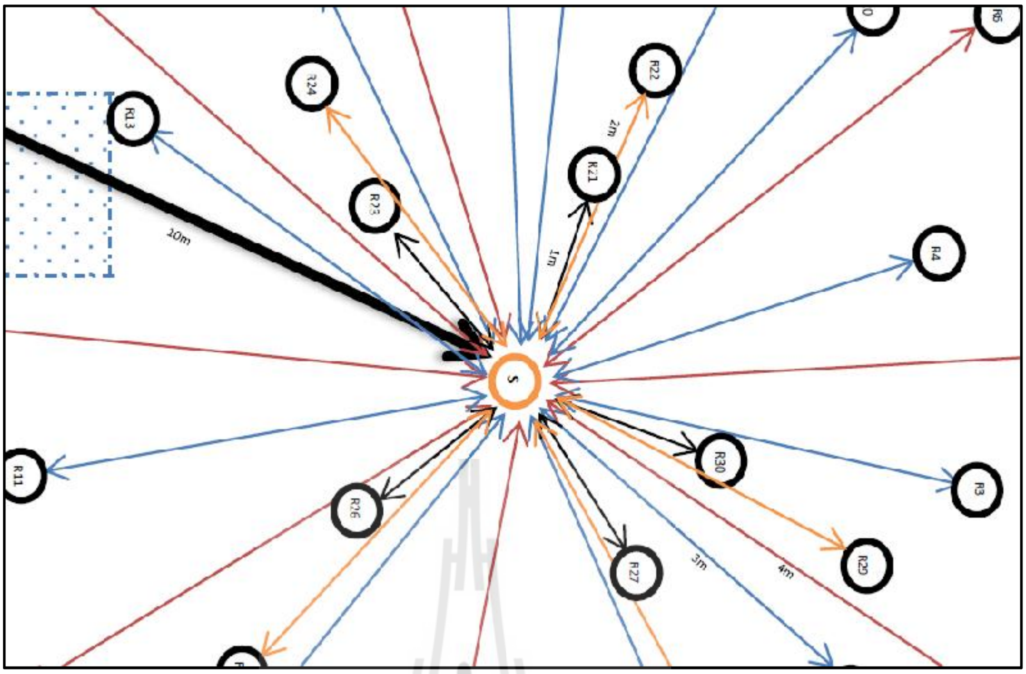
The experiments are undertaken in a rich scattering environment at F4 building in Suranaree University of Technology. The performances of proposed cooperative MIMO communication systems with relay selection scheme are measured in the telecommunication laboratory in order to evaluate practical performances of the relay selection schemes. All parameters in the experiments are similarly specified for locations in Table 6.3 to validate the relay selection performances under the different position scenarios.

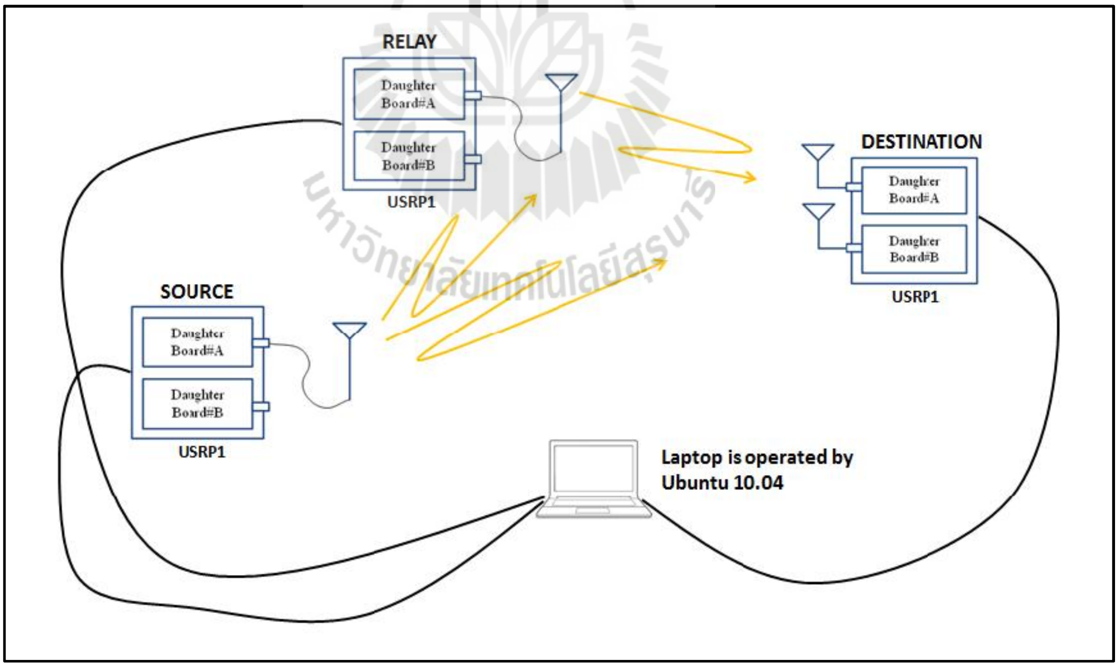
The signal stream from source node with one antenna is transmitted with the effect of scattering as shown in Figure 6.12 and Figure 6.13. This work applies 2.45 GHz carrier signal and the other parameters in experiments are assigned as in Table 6.3. The experiments are shown in Figure 6.14 to Figure 6.17.

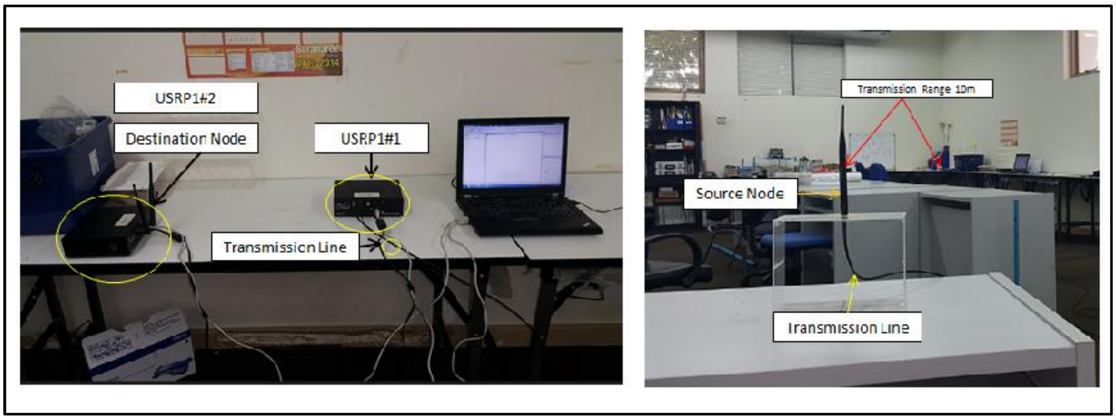
6.8 Experimental Results

In experiments, the transmission signals in the cooperative MIMO communication systems show different efficiency in each relay selection scheme. This experiment was conducted repeatedly for 40 times in various positions defined by the random relay positions. The number of relays in each time is 20 nodes.




S
R13
R24
R23
R21
R22
R4
R6
R11
R26
R30
R3
R27
20m
1m
2m
3m
4m


RELAY
Daughter Board#A
Daughter Board#B
USRP1
DESTINATION
Daughrer Board#A
Daughrer Board#B
USRP1
SOURCE
Daughter Board#A
Daughter Board#B
USRP1
Laptop is operated by Ubuntu 10.04

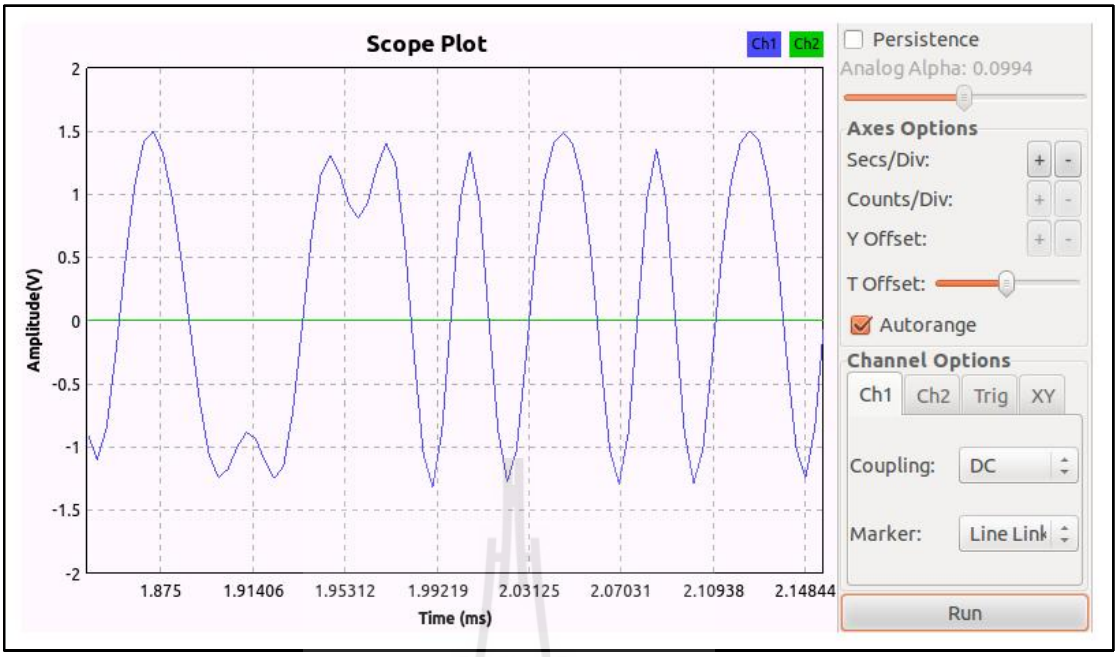

USRP1#2
Destination Node
USRP1#1
Transmission Line
Transmission Range 10m
Source Node
Transmission Line


USRP1#2
Destination Node
USRP1#1
Transmission Line
Transmission Range 7m
Relay Node
Transmission Line

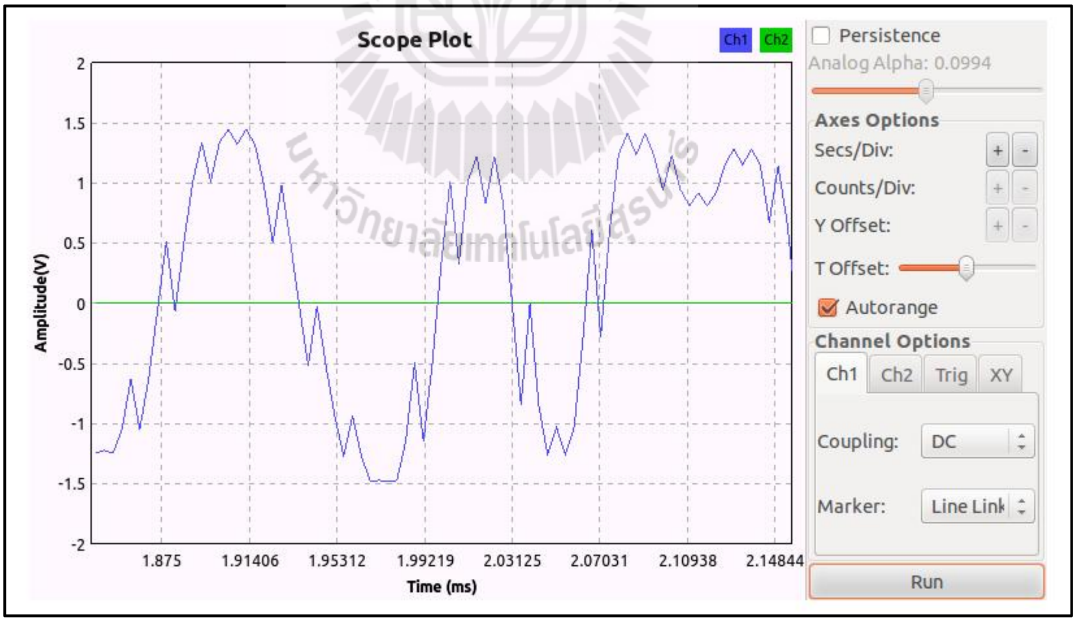

Relay Node
USRP1#2
Transmission Range 2m
Source Node
USRP1#1
Relay Node
USRP1#2
Transmission Range 4m
Source Node
USRP1#1

Table 6.3 The experimental parameters.

Item	Detail
Hardware	USRP1
USRP Motherboard (FPGA)	Altera Cyclone EP1C12
Daughterboard	XCVR2450 operation 2.4 GHz and 5.9 GHz range
Antenna	VERT2450 Dual Band 2.4 to 2.48 GHz and 4.9 to 5.9 GHz
Number of transmit bits	1Mbit
Sample rate	256kHz
Carrier frequency	2.45GHz
Channels	Rich scattering environment
Modulation	DBPSK
Link distance of source node to destination node	10 meters
Link distance of source node to relay node	1 meter, 2 meters, 3 meters and 4 meters
Number of transmit antenna at source node	1
Number of transmit antenna at relay node	1
Number of receive antenna at destination node	2

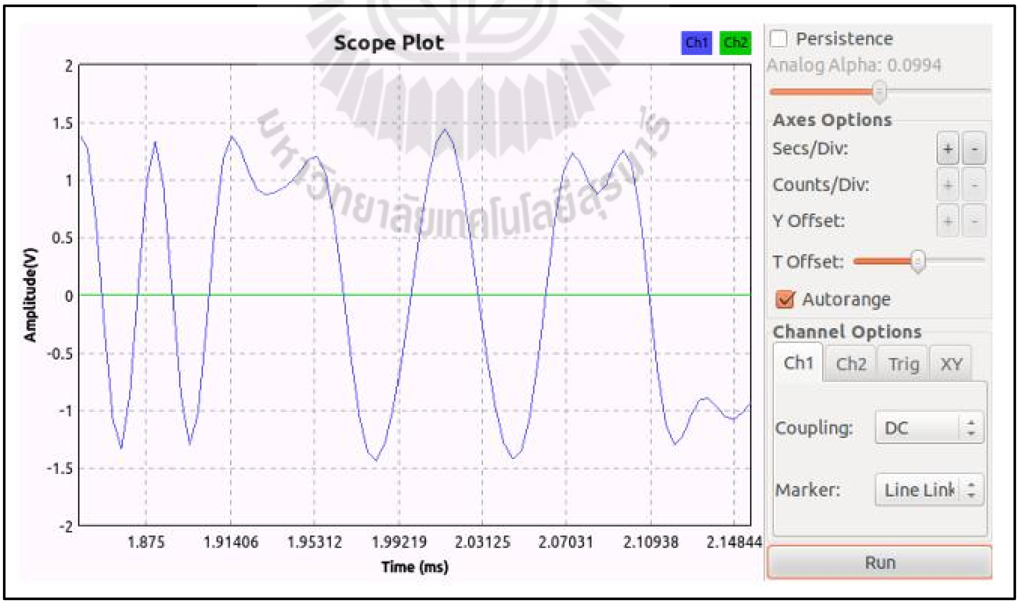


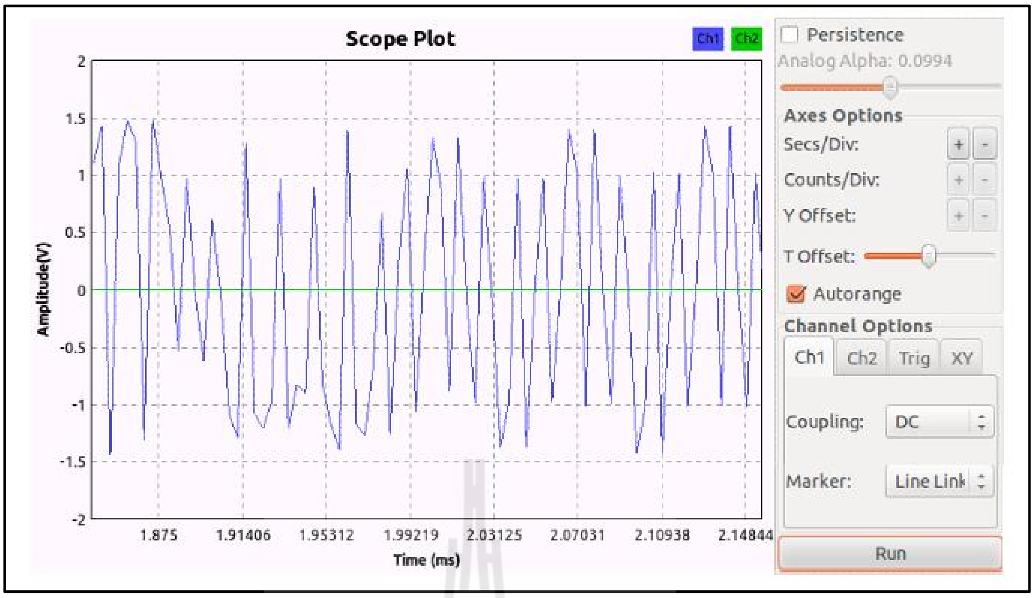
Scope Plot
Ch1
Ch2
Amplitude(V)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1.875
1.91406
1.95312
1.99219
2.03125
2.07031
2.10938
2.14844
Time (ms)
Persistence
Analog Alpha: 0.0994
Axes Options
Secs/Div:
Counts/Div:
Y Offset:
T Offset:
Autorange
Channel Options
Ch1
Ch2
Trig
XY
Coupling:
DC
Marker:
Line Link
Run

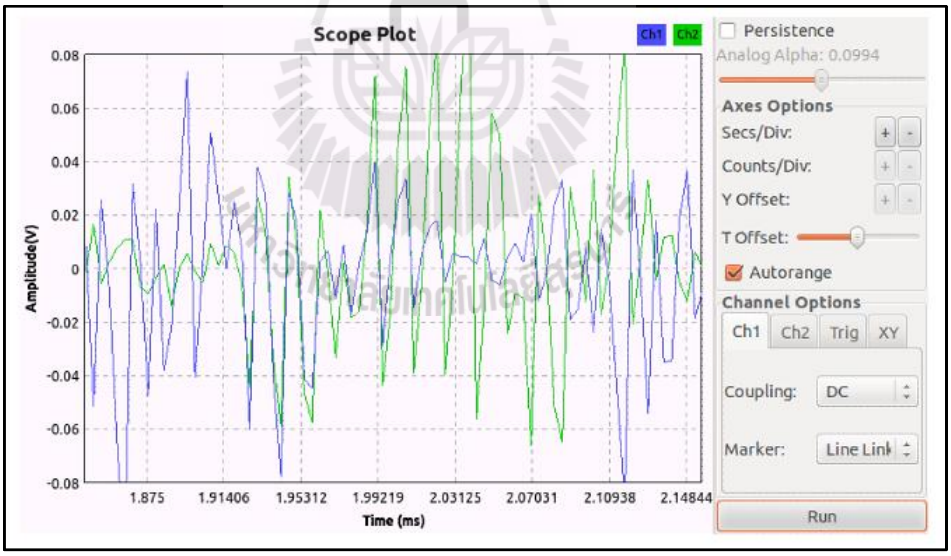


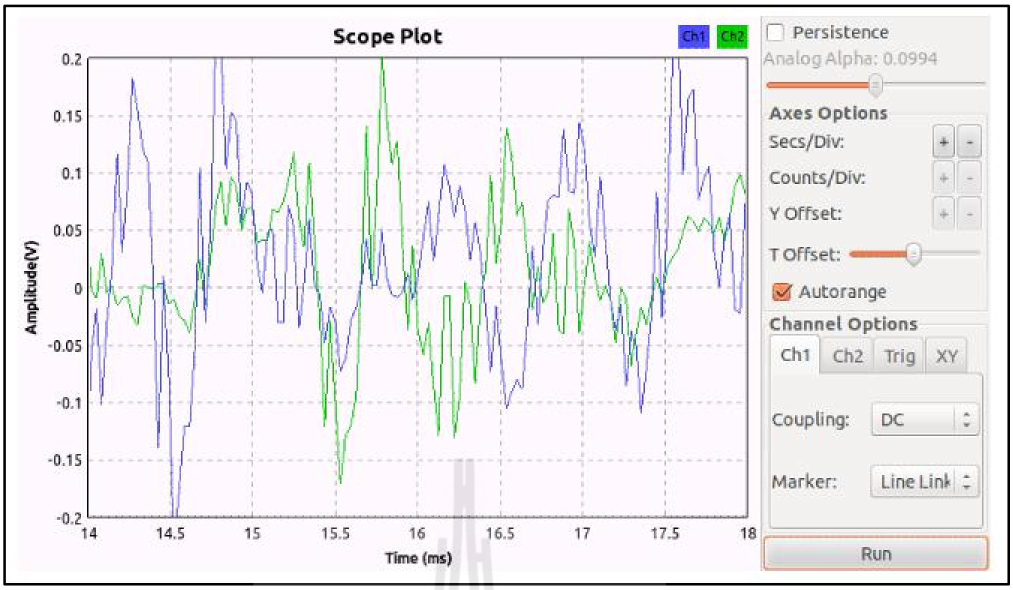
Scope Plot
Ch1
Ch2
Amplitude(V)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1.875
1.91406
1.95312
1.99219
2.03125
2.07031
2.10938
2.14844
Time (ms)
Persistence
Analog Alpha: 0.0994
Axes Options
Secs/Div:
Counts/Div:
Y Offset:
T Offset:
Autorange
Channel Options
Ch1
Ch2
Trig
XY
Coupling:
DC
Marker:
Line Link
Run

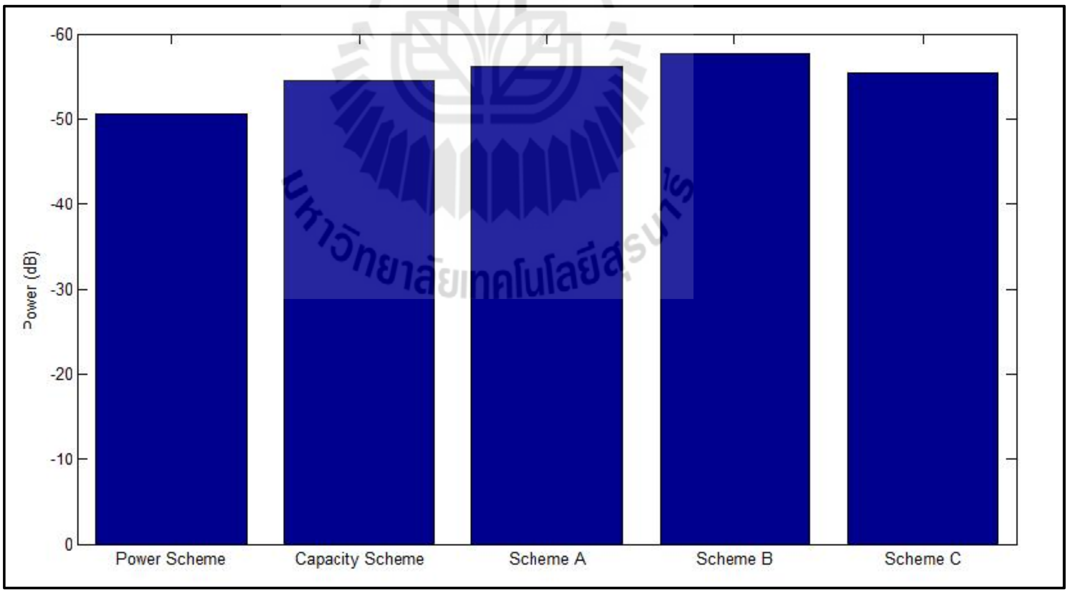

Scope Plot
Ch1
Ch2
Amplitude(V)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
1.875
1.91406
1.95312
1.99219
2.03125
2.07031
2.10938
2.14844
Time (ms)
Persistence
Analog Alpha: 0.0994
Axes Options
Secs/Div:
Counts/Div:
Y Offset:
T Offset:
Autorange
Channel Options
Ch1
Ch2
Trig
XY
Coupling:
DC
Marker:
Line Link
Run

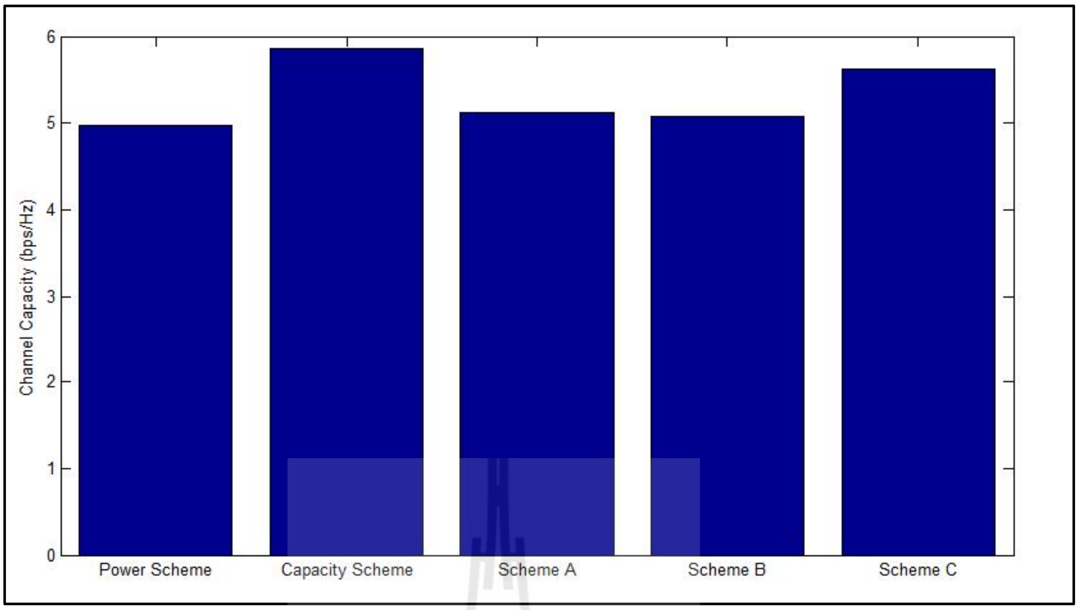

Scope Plot
Ch1
Ch2
Amplitude(V)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1.875
1.91406
1.95312
1.99219
2.03125
2.07031
2.10938
2.14844
Time (ms)
Persistence
Analog Alpha: 0.0994
Axes Options
Secs/Div:
Counts/Div:
Y Offset:
T Offset:
Autorange
Channel Options
Ch1
Ch2
Trig
XY
Coupling:
DC
Marker:
Line Link
Run

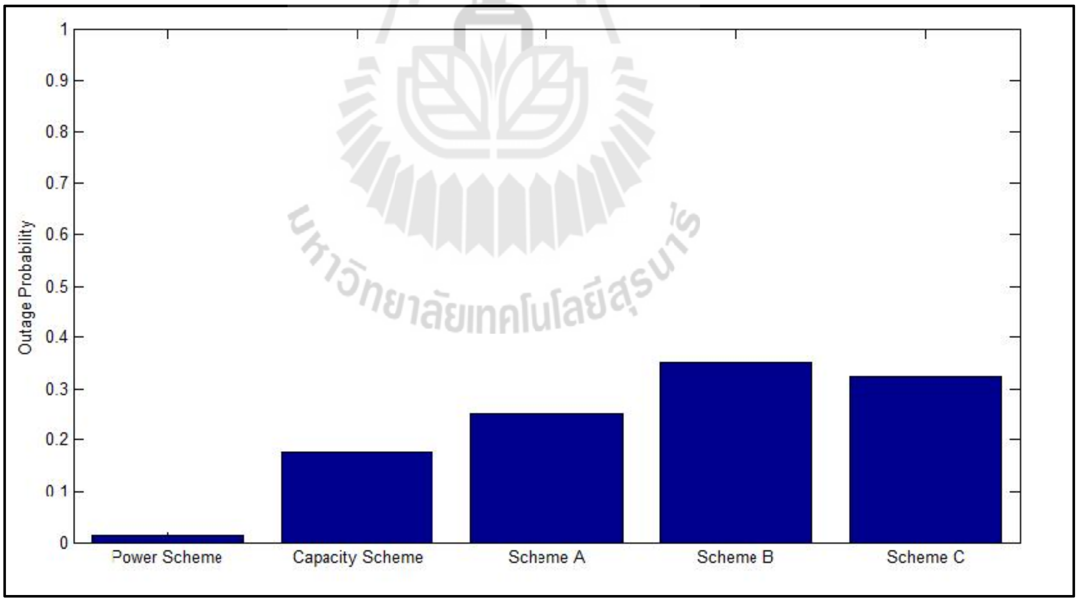

Scope Plot
Ch1
Ch2
Amplitude(V)
Time (ms)
1.875
1.91406
1.95312
1.99219
2.03125
2.07031
2.10938
2.14844
Persistence
Analog Alpha: 0.0994
Axes Options
Secs/Div:
Counts/Div:
Y Offset:
T Offset:
Autorange
Channel Options
Ch1
Ch2
Trig
XY
Coupling:
DC
Marker:
Line Link
Run


Scope Plot
Ch1
Ch2
Amplitude(V)
Time (ms)
1.875
1.91406
1.95312
1.99219
2.03125
2.07031
2.10938
2.14844
Persistence
Analog Alpha: 0.0994
Axes Options
Secs/Div:
Counts/Div:
Y Offset:
T Offset:
Autorange
Channel Options
Ch1
Ch2
Trig
XY
Coupling:
DC
Marker:
Line Link
Run


Scope Plot
Ch1
Ch2
Amplitude(V)
Time (ms)
Persistence
Analog Alpha: 0.0994
Axes Options
Secs/Div:
Counts/Div:
Y Offset:
T Offset:
Autorange
Channel Options
Ch1
Ch2
Trig
XY
Coupling:
DC
Marker:
Line Link
Run


Power (dB)
Power Scheme
Capacity Scheme
Scheme A
Scheme B
Scheme C


Channel Capacity (bps/Hz)
0
1
2
3
4
5
6
Power Scheme
Capacity Scheme
Scheme A
Scheme B
Scheme C


Outage Probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Power Scheme
Capacity Scheme
Scheme A
Scheme B
Scheme C

The source node is randomly generated by a mathematical function in GRC program. DBPSK modulation is shown in Figure 6.18-a and each bit stream encoding by STBC code transmitted signal at the antenna is shown in Figure 6.18-b. The transmitted signal at the antenna of relay node is depicted in Figure 6.18-c.

The relay node receives bit streams form the source node. Each bit stream is demodulated by DBPSK demodulation because each bit stream must check the accuracy of information. Next, each bit stream is modulated by DBPSK modulation shown in Figure 6.19-a and each bit stream encoded by STBC code as shown in Figure 6.19-b. The transmitted signal of destination node can be demonstrated in Figure 6.19-c.

The destination node receives bit streams from the source node and relay node as shown in Figure 6.20. Each bit stream is decoded by STBC decode block and each bit stream is demodulated by DBPSK demodulation. Figure 6.20 shows that the transmitted signal generated by the same pattern in every period.

The proposed schemes are selected according to the methods in Section 6.6.1 to Section 6.6.2. The relay selection schemes in the experiment record the received signals at each relay node to the destination node as shown in Figure 6.20. To prove the benefit of relay selection schemes, the experimental relay selection performances and the analytical relay selection performance are compared to verify the advantage of cooperative MIMO communication systems. Figure 6.21 to Figure 6.23 present the experimental relay selection schemes when varying the selection schemes. Performance of the relay selection schemes will differ between analytical results and practical results. This is because experimental and simulation experiments are different. The practical experimental results were affected by signal reflection, scattering and interference, whereas simulation experimental results were affected by mathematical model.

Figure 6.21, Figure 6.22 and Figure 6.23 present the experiments in order to investigate the system performance of using relay selection scheme in terms of power transmission, system capacity and outage probability**.** In Figure 6.21, the experimental results indicate that the power transmission in relay selection scheme with proposed method can attain the lowest power in signal transmission. The use of power in descending order is: the proposed capacity scheme, scheme C, scheme A and scheme B. In Figure 6.22, the experimental results indicate that the system capacity in relay selection scheme with the proposed capacity scheme provides the highest system capacity. The capacity in descending order is: scheme C, the proposed method power scheme, scheme A and scheme B. In Figure 6.23, the experimental results indicate that the outage probability in relay selection scheme with the proposed power scheme offers the lowest outage probability. The outage probability in descending order is: the proposed power scheme, scheme C, scheme A and scheme B.

A comparison was made with the schemes Section 5.3. The trends of experimental results are shown in Figure 6.21 to Figure 6.23 and the trends of simulation experiment are shown in Figure 5.10 to Figure 5.12. From the comparison, the trends of all graphs are similar which confirms the advantage of relay selection schemes in practice.

6.9 Summary

This chapter presents the experiments of the relay selection schemes in the cooperative MIMO communication systems. The performance of the proposed relay selection schemes are measured in the experiments. From the experiments, the proposed scheme can reduce power consumption in data transmission as well as increase the channel capacity in system. Moreover, this chapter presents the advantage of the proposed relay selection schemes in cooperative MIMO communication system which is confirmed in practical implementation.

CHAPTER VII

CONCLUSIONS

This thesis has proposed the improved cooperative MIMO communication systems with relay selection schemes. The cooperative MIMO communication systems are in wireless communication systems. This technique applied STBC code with cooperative communication systems in order to increase system performance. The relay selection schemes are based on considering the transmitted power and the system capacity. The proposed relay selection schemes will choose the relay node to suit each situation that the systems make existing resources effectively.

The simulation results from Monte Carlo simulation demonstrated the advantage of cooperative MIMO communication systems with relay selection schemes. Besides, the analytical performances with relay selection schemes have verified the validity of simulation results with the benefits of the proposed technique in the practical scenarios

The simulation results show the performance analysis of cooperative MIMO technique by using modified STBC scheme. It is based on the modification of STBC scheme for DF protocol. The outage probability and BER performances are investigated. The results conclude the proposed system that it has a better BER and a lower outage probability than other methods.

This thesis also implements cooperative MIMO communication systems to confirm the advantage of the proposed technique. The transmitted symbols are generated by USRP. The transmitted streams are sent over the rich scattering MIMO channels while the received signals from USRP can be decoded by transferring data into GRC program to determine the system performances. The results show that the trends of all performances between analysis and the experimental results are well matched.

Based on the knowledge learned in this research. The future works of research the aims on developments of the relay selection for applying on existing standards. The relay selection can adapt selection more than one relay node. In order to the systems can choose the best route for saving energy in transmitted signal or increasing high speed data transmission.

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APPENDIX A

PUBLICATIONS

List of Publications

International Journal Paper

Chanpuek, T., Uthansakul, P. and Uthansakul, M. (2014). Performance Analysis of Modied STBC Scheme for Cooperative MIMO Communications. **ECTI Transactions on Electrical Engineering, Electronics, and Communication (ECTI-EEC Trans)**. 12(2): 19-27. (Scopus Indexing)

International Conference Paper

Chanpuek, T., Uthansakul, P. and Uthansakul, M. (2012). Performance enhancement of mobile networks using cooperative MIMO technique. **Digital Information and Communication Technology and it's Applications (DICTAP)**.

Chanpuek, T., Uthansakul, P. and Uthansakul, M. (2013). Performance analysis of modified STBC scheme for cooperative MIMO communications. **International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)**.

National Conference Paper

ทศพร จันทร์เผือก พีระพงษ์ อุฑารสกุล และ มนต์ทิพย์ภา อุฑารสกุล (2013). การวิเคราะห์ประสิทธิภาพระบบการสื่อสารร่วมมือแบบไมโม. **Conference on Application Research and Development (ECTI-CARD)**.

Performance Analysis of Modified STBC Scheme for Cooperative MIMO Communications

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ABSTRACT

The cooperative MIMO communications is a new challenge to provide more reliable transmissions from the collaboration between users. Mostly, the MIMO employment is performed by using a simple diversity scheme. However, there are many MIMO schemes that can be implemented in practice. This paper proposes the modified STBC scheme for cooperative MIMO communications. Also the performance analysis of the proposed system in term of the data error rate and the outage probability is originally presented. The simulation results indicate that the proposed system can offer a better bit error rate and improve the outage probability than the diversity scheme.

Keywords: Decode and Forward, Outage Probability, Cooperative MIMO Communications

1. INTRODUCTION

Currently, the communication technology has a huge impact in everyday life. Among those technologies, wireless communication system is the most influent form of communications. They are commonly used due to the ease of installation but they need to be developed effectively to get a higher data transmission, a freedom of movement and a quality of communication that is reliable in providing a good service. In order to support the requirements of multimedia data communication in the future, the MIMO (Multiple Input Multiple Output) technique has been introduced for wireless communication system [1-5]. This technqiue can support the need of high transmission data of multimedia communication in the future since the system can increase the channels of communication and send data in the parallel channels. However, the MIMO operation requires multiple antennas at both transmitter and receiver which are not practical for mobile devices. In this light, the new challenge to increase the channels of communication as well as MIMO wireless communication system but no need to increase the number of antennas at the transmitter and the receiver is presented and called as cooperative MIMO communications [6-10]. This technique depends on the conditionally transmitted data by allowing users in system to help each other to send their data like MIMO technique. This operation is performed as a virtual MIMO system. This technique can increase more channel diversity and can reduce the bit error rate (BER) of the system. However, the problem of fading in the channel due to noise of the signal sent by the delay and reflected in multipath of the channel resulted in signal distortion. From these problems the authors have aware of the needs for communications to respond the demands of users increasing for the improved performance of communication system.

In the past few years, a cooperative communication has been a very active research field. Extensive researches have focused on the physical layer aspects of cooperative communications [11-15]. Therefore, there are many developments of research in cooperative wireless communication systems in literature. The cooperative communications have categorized into two main protocols used in the relay node consisting of Amplify-and-Forward (AF) and Decode-and-Forward (DF) [6,16]. Recently, the researches in [17-19] proposed the transmission technique in type of forwarding data information for cooperative communications. The researchers in [20-21] have developed the system to propose the amplify-and-forward protocol using the transmission of data in distributed and forwarding data information to obtain in MIMO channels for data transmission. However, the positions of the relay in cooperative communication system are varied in practice so the relay selection is very important issue for the cooperative MIMO communication. In [22], the authors point out that relay selection in cooperative communication depends on power transmission, distance and condition of channel. The solution of methods to choose relay is proposed by using the estimated channel and the coefficients of the signal in each path. In [23], it shows the method to select relay from consideration of signal-to-noise ratio throughout the path from the transmitter to the receiver.

However, in literatures the process of relay cooperation is done by forwarding and repeating the signal symbols on the allocated time slot. In this paper, the authors propose the utility of relay by cre-

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ating the process of sending symbols based on STBC mode so called as modified STBC mode. By changing the symbols sent from source to relay ($S_1 \rightarrow \widetilde{S}_1^*$ and $S_2^* \rightarrow \widetilde{S}_2$) the destination can be easily detected as a typical STBC mode. The proposed cooperative MIMO technique is introduced to improve the system performance of wireless communication networks. The modified STBC scheme is selected to implement the virtual MIMO transmitter. By using the neighbouring antennas, the overall system can be operated as MIMO communication. It is interesting to see the improvement of using the proposed concept in wireless communication networks. In case of relay selection in literatures the process of relay cooperation is done by considering channel information [24] and signal-to-noise ratio throughout the path from the transmitter to the receiver [25].This paper also proposes the performance analysis of modified STBC scheme for cooperative MIMO communications in term of the data error rate and the outage probability. The remainder of the paper is as follows. Section II describes the details of the cooperative MIMO communications. In Section III explains the technique of modified STBC code scheme with cooperative MIMO communications. The outage probability analysis of the cooperative MIMO communications is presented in Section IV. Simulation results are presented in Section V and the paper is concluded in Section VI.

2. COOPERATIVE MIMO COMMUNICATIONS

Since the mobile communications is considered in this paper, hence all wireless devices are assumed with only single antenna. They are connected to a base station which is assumed to be located at the center of a cell. The authors consider a system model as depicted in Fig. 1, where source node and relay nodes have only single antenna and destination node (base station) has two antennas. The cooperative system is in the manner that source node S transmits information to a destination node D with the help of the best-selected relay node R_i. The channels considered in this system model are assumed to undergo AWGN, multipath, and slow fading. Source and relay nodes must know Channel State Information (CSI) between source and relay as well as between relay and destination, respectively.

In general, wireless devices must have two transmitting antennas in order to apply 2×2 Alamouti STBC MIMO systems. Although Ho-Jung An et. al. [26] applied precoding scheme with the STBC symbols to employ STBC with single antenna, but it costs a significant delay and suffers from AF protocol. In this paper, the authors propose a technique to transmit virtual STBC symbols in order to apply with a single antenna system. The source node and relay node virtually offer the multiple antennas for the cooperation of transmitted symbols at the same STBC schemes to the destination. The proposed system works as given in the following steps.

The first step is shown in Fig. 1 (a). The source node makes agreement with the destination node to transmit and receive by using the cooperative MIMO technique. The source node then finds relay nodes by sending the invitation message to all potential relay nodes. The available relay nodes will send the confirmation message to cooperate with source node and destination node. At this point, source node, relay node and destination node are now ready to operate the system with cooperative MIMO technique.

The second step is the pre-transmitting process shown in Fig. 1 (b). The source node transmits symbols to relay node. When the relay node obtains symbols form source node, then the relay node will adjust or reformat symbols in the form of STBC coding schemes. In the proposed scheme, the relay node is not necessary to modify anything with the received data. By using the conventional method for relay node, then it can retransmit any received data to destination. This step is based on the perfect synchronization between source node and relay node and also including with the perfect knowledge of coding sequences. In addition, the transmission in this step requires a less power than the other steps because only the enough power in transmission range between source and relay is required.

For the third step, it can be shown in Fig. 1(c). The source node and relay node transmit simultaneously the coding symbols to the destination node. The destination node receives all signals from both source node and relay node by multiple receiving antennas. This process is as same as the normal MIMO system because the destination node can virtually see the received signals coming from multiple-antennas source.

3. MODIFIED STBC SCHEME FOR COOPERATIVE MIMO TECHNIQUE

Transmission models in the cooperative MIMO communication systems are presented in this paper. The system consists of source, relay and destination nodes. Source node transmits data signals to relay node and destination node. The relay node transmits the signal received from the source node to the destination node. Destination node receives signals information from relay node and source node. The destination node will decode information signals based on CSI of both relay and source nodes. By using transmission models in the cooperative MIMO communications, the system will forward the information signal from the relay node to the destination node using DF protocol through Rayleigh fading channels. The authors consider the total transmitted power from all transmitting antenna. The sum of output power of the source node and the relay node is obtained with $P_T = P_s + P_r$ where P_T is the total power in the

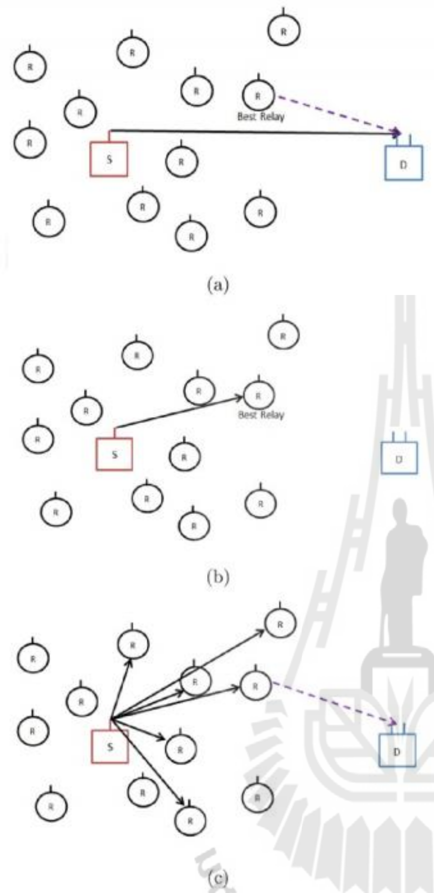

Fig.1: (a): The First Step of Cooperative MIMO Communications. (b): The Second Step of Cooperative MIMO Communications. (c): The Third Step of Cooperative MIMO Communications.

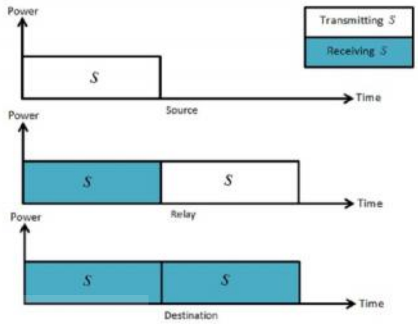

Fig.2: Transmitting/Receiving Symbols of Source Node Relay Node and Destination Node for Cooperative Communication.

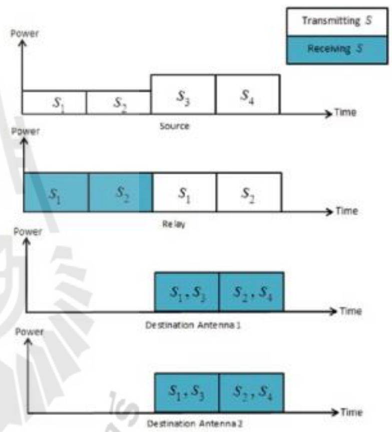

Fig.3: Transmitting/Receiving Symbols of Source Node Relay Node and Destination Node for Cooperative MIMO Communication (Diversity Scheme).

system.

In general, the cooperative MIMO communications have many transmission models. However, in this paper the authors consider the STBC MIMO scheme in comparing the conventional (diversity) MIMO scheme. According to the channel using TDD (Time Division Duplex), basically the form of transmission models in the cooperative communication system is shown in Fig. 2.

In Fig. 2, source node sends information to relay node which will forward this information to the destination for later decoding the information. This method is utilization of diversity techniques which makes the higher performance of the cooperative communication system.

The transmission scenario for the cooperative MIMO communication system is shown in Fig. 3. As seen in this figure, source node sends information to relay node with utilization of TDD techniques. The relay node receives information from source node and then relay node will forward to destination in the next time slot. This method is the utilization of combination between diversity technique and MIMO

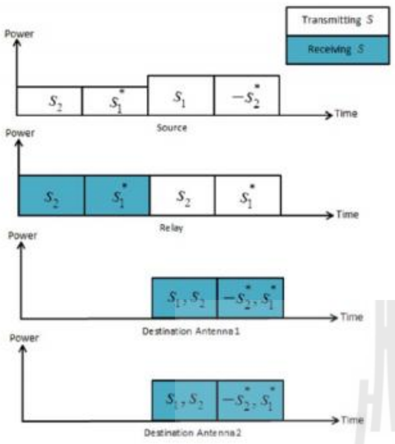

Fig.4: *Transmitting/Receiving Symbols of Source Node Relay Node and Destination Node for Cooperative MIMO Communication using Modified STBC Scheme.*

technique which makes the better performance of the cooperative MIMO communication system.

For the proposed cooperative MIMO system called as modified STBC scheme, it is shown in Fig. 4. The process of STBC system [27] encodes the input data symbols into both spatial and time domains. However, in cooperative MIMO system, the spatial domain splits data into multiple users. Hence, the method to set a block coding schemes is a necessary part to be designed. In this paper, the authors propose the sequence of transmitting symbols by modifying STBC scheme for cooperative MIMO users in wireless communications as shown in Fig. 4.

In Fig. 4, the overall data symbols are occurred within four symbol periods in order to perform one STBC block. The first two periods are the time of exchanging data symbols between source and relay. This is referred to the second step in the previous section. In this interval, the destination cannot obtain any data symbols from source because the transmitting power between source and relay is very little in comparing with the transmitting power between destination and source.

The time periods of the first symbol and the second symbol shown in Fig. 4 is the time that source node sends signals to the relay node. The received signal at relay node is expressed by

$$y_r = \sqrt{P_s} h_{s,r} s + n_{s,r} \quad When, \quad s = s_2, s_1^* \tag{1}$$

By assuming that both periods experience the same fading, then

$$y_r^{(1)} = \sqrt{P_s} h_{s,r} s_2 + n_{s,r} \tag{2}$$

$$y_r^{(2)} = \sqrt{P_s} h_{s,r} s_1^* + n_{s,r} \tag{3}$$

Where $h_{s,r}$ is the wireless channel from source node to relay node, $n_{s,r} \sim CN\left(0, \sigma_r^2\right)$ is complex AWGN including the effect of interference signal, P_s and s are the source node transmission power and transmission of symbols, respectively.

The signals at relay node have to go through the process that the relay node can receive signals for forwarding symbols. The two estimated symbols, $\tilde{s}_1$ and $\tilde{s}_2$, can be calculated by.

$$\tilde{s}_1 = h_{s,r} y_r^* \tag{4}$$

$$\tilde{s}_2 = h_{s,r}^* y_r \tag{5}$$

The time periods of the third symbol and the fourth symbol are the STBC MIMO transmission. The authors consider one source node, one relay node and one destination node. Then, the received signals of both antennas at the destination node can be expressed by equation (6) to equation (9)

$$y_{d1}^{(1)} = \sqrt{P_s} h_{s,d1} s_1 + \sqrt{P_r} h_{r,d1} s_{2r} + n_{s,r,d1}^{(1)} \tag{6}$$

$$y_{d1}^{(2)} = -\sqrt{P_s} h_{s,d1} s_2^* + \sqrt{P_r} h_{r,d1} s_{1r}^* + n_{s,r,d1}^{(2)} \tag{7}$$

Where $h_{s,d1}$ and $h_{r,d1}$ are the wireless channel from source node to destination node at the first antenna and the wireless channel from relay node to destination node at the first antenna, $n_{s,r,d1}^{(1)} \sim CN\left(0, \sigma_d^2\right)$ and $n_{s,r,d1}^{(2)} \sim CN\left(0, \sigma_d^2\right)$ are complex AWGN including the effect of interference signals at the first antenna, P_s and P_r is the transmission power of source node and relay node, respectively.

Considering the second antenna at destination node, the received signals are expressed by

$$y_{d2}^{(1)} = \sqrt{P_s} h_{s,d2} s_1 + \sqrt{P_r} h_{r,d2} s_{2r} + n_{s,r,d2}^{(1)} \tag{8}$$

$$y_{d2}^{(2)} = -\sqrt{P_s} h_{s,d2} s_2^* + \sqrt{P_r} h_{r,d2} s_{1r}^* + n_{s,r,d2}^{(2)} \tag{9}$$

Where $h_{s,d2}$ and $h_{r,d2}$ are the wireless channel from source node to destination node at the second antenna and the wireless channel from relay node to destination node at the second antenna, $n_{s,r,d2}^{(1)} \sim CN\left(0, \sigma_d^2\right)$ and $n_{s,r,d2}^{(2)} \sim CN\left(0, \sigma_d^2\right)$ are complex AWGN including the effect of interference signals at the second antenna.

Note that $s_1 = s_{1r}$ and $s_2 = s_{2r}$ because the link between relay node and source node in the second step mentioned earlier has the effects of fading channel as well. This might cause the uncertainty of symbol realization on relay node. However, most of the works in this area assume that relay node can perfectly retrieve all received symbols.

Then, at the destination, the process of extracting the data symbols from incoming signals is the same as described by normal STBC scheme. The two estimated symbols, $\tilde{s}_1$ and $\tilde{s}_2$, from the first antenna are calculated by.

$$\begin{aligned}\tilde{s}_1 =& h_{s,d1}^* y_{d1}^{(1)} + h_{r,d1}\left(y_{d1}^{(2)}\right)^* \\ &+ h_{s,d2}^* y_{d2}^{(1)} + h_{r,d2}\left(y_{d2}^{(2)}\right)^*\end{aligned} \tag{10}$$

$$\begin{aligned}\tilde{s}_2 =& h_{r,d1}^* y_{d1}^{(1)} - h_{s,d1}\left(y_{d1}^{(2)}\right)^* \\ &+ h_{r,d2}^* y_{d2}^{(1)} - h_{s,d2}\left(y_{d2}^{(2)}\right)^*\end{aligned} \tag{11}$$

4. ANALYSIS OF OUTAGE PROBABILITY

In this section, the outage probability of the proposed system is derived. The outage capacity is another popular performance index for communication techniques in fading channels. This outage is the situation that the message cannot be reliably decoded at the destination node. From an information theoretic standpoint, given the transmission rate R and the channel realization h, it can be said that the outage occurs if the channel capacity is less than the transmission rate, i.e., $\log_2(1 + \mathrm{SNR}\,|h|^2) < R$. Hence, the outage probability under the channel realization h can be expressed as the function of the transmission rate as given below [28].

$$\begin{aligned}P_{out}(R) &\triangleq \Pr\left(\log_2\left(1+\mathrm{SNR}\,|h|^2\right) < R\right) \\ &= \Pr\left(\mathrm{SNR}\,|h|^2 < 2^R - 1\right)\end{aligned} \tag{12}$$

The ε-outage capacity is then defined as the maximum transmission rate that can be achieved over the fading channel such that the outage probability is smaller than ε, i.e.,

$$C_\varepsilon = \underset{\{R:R\geq 0, P_{out}(R)\leq\varepsilon\}}{\arg\max} P_{out}(R) \tag{13}$$

Where $\varepsilon \in [0, 1]$ is a constant threshold.

The outage probability can be calculated by using the probability density function of the channel coefficient or the received SNR. For example, in the Rayleigh channel where the envelope of channel coefficient is Rayleigh distribution and the received SNR, $\mathrm{SNR}\,|h|^2$ is exponentially distributed with mean $\mathrm{SNR}\sigma_h^2$, the outage probability of the Rayleigh channel given the transmission rate R is expressed by

$$\begin{aligned}P_{out}(R) &= \Pr\left(\mathrm{SNR}\,|h|^2 < 2^R - 1\right) \\ &= 1 - \exp\left(-\frac{2^R-1}{\mathrm{SNR}\sigma_h^2}\right)\end{aligned} \tag{14}$$

Where P_{out} denotes the outage probability of the system that the destination performs detection based only on the received signals from the relay node. This scheme is identical to the conventional transmissions. In order to successfully transmit a codeword over both s-r and r-d links in this case, the rate of the codeword must be bounded by the capacity of both links by.

$$\begin{aligned}2R \leq \min\Big\{&\log_2\left(1+\mathrm{SNR}_{s,r}\,|h_{s,r}|^2\right) \\ &,\log_2\left(1+\mathrm{SNR}_d\,\|\mathrm{H}\|_{\mathrm{F}}^2\right)\Big\}\end{aligned} \tag{15}$$

Hence, the average end-to-end achievable rate is given by

$$\begin{aligned}C = \frac{1}{2}\min\Big\{&\log_2\left(1+\mathrm{SNR}_{s,r}\,|h_{s,r}|^2\right) \\ &,\log_2\left(1+\mathrm{SNR}_d\,\|H\|_F^2\right)\Big\}\end{aligned} \tag{16}$$

Following (14), yields

$$\begin{aligned}P_{out} = \Pr\Big(\frac{1}{2}\min\Big\{&\log_2(1+\gamma_{s,r}) \\ &,\log_2(1+\gamma_d)\Big\} < R\Big)\end{aligned} \tag{17}$$

Where C is the channel capacity and $\|H\|_F^2$ represents the squared Frobenius norm of the matrix H. The above formula can be further rewritten as,

$$\begin{aligned}P_{out} =& \Pr\left(\frac{1}{2}\log_2(1+\gamma_{s,r}) < R\right) \\ &+ \Pr\left(\frac{1}{2}\log_2(1+\gamma_{s,r}) \geq R\right) \\ &\times \Pr\left(\frac{1}{2}\log_2(1+\gamma_d) < R\right) \\ =& \Pr\left(\gamma_{s,r} < 2^{2R}-1\right) \\ &+ \Pr\left(\gamma_{s,r} \geq 2^{2R}-1\right) \\ &\times \Pr\left(\gamma_d < 2^{2R}-1\right)\end{aligned} \tag{18}$$

In the Rayleigh fading scenario, the $\gamma_{s,r}$ and γ_d are exponentially distributed with mean $\gamma_{s,r} = \mathrm{SNR}_{s,r}\,|h_{s,r}|^2$ and $\gamma_d = \mathrm{SNR}_d\,\|H\|_F^2$. Hence, we have

$$\begin{aligned}P_{out} =& 1 - \exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{s,r}}\right) \\ &+ \exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{s,r}}\right) \\ &\times\left(1-\exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_d}\right)\right) \\ =& 1 - \exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{s,r}}\right) \\ &+ \Big[\exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{s,r}}\right) \\ &-\exp\left(-\frac{2^{2R}-1}{\bar{\gamma}_{s,r}} - \frac{2^{2R}-1}{\bar{\gamma}_d}\right)\Big]\end{aligned} \tag{19}$$

Given, $e^{-x} \approx 1 - x$,then

$$P_{out} = 1 - \left(1 - \frac{2^{2R}-1}{\bar{\gamma}_{s,r}}\right) + \left(1 - \frac{2^{2R}-1}{\bar{\gamma}_{s,r}}\right) - \left(1 - \frac{2^{2R}-1}{\bar{\gamma}_{s,r}} - \frac{2^{2R}-1}{\bar{\gamma}_{d}}\right) \tag{20}$$

Consider the total power constraint by $P_s + P_r = P_T$ the authors can set $P_s = \beta P_T$ and $P_r = (1-\beta) P_T$, for some $0 \leq \beta \leq 1$, and $n_{s,r}^2 = n_d^2 = n_T^2$. Then, the outage probability can be approximated as.

$$\begin{aligned} P_{out} &= \frac{2^{2R}-1}{\mathrm{SNR}}\left(\frac{1}{\beta\left\|\mathrm{H}\right\|_F^2} + \frac{1}{(1-\beta)\left\|\mathrm{H}\right\|_F^2}\right) \\ &\quad + \frac{2^{2R}-1}{\mathrm{SNR}}\left(\frac{1}{(1-\beta)\,h_{s,r}^2}\right) \\ &= \frac{2^{2R}-1}{\mathrm{SNR}}\Bigg(\frac{1}{\beta\left\|\mathrm{H}\right\|_F^2} + \frac{1}{(1-\beta)\left\|\mathrm{H}\right\|_F^2} \\ &\quad + \frac{1}{(1-\beta)\,h_{s,r}^2}\Bigg) \end{aligned} \tag{21}$$

5. SIMULATION RESULTS

In this section, the fading channels are generated by Rayleigh distribution including with the complex additive white Gaussian noise (AWGN). The data symbols are randomly generated and modulated by BPSK modulation. The estimated channels are assumed to be perfect which means that the destination is also assumed with the full knowledge of channel information. The cooperative MIMO technique in wireless communication networks is assumed with the perfect synchronization of timing symbols. This assumption is possible for wireless communication networks because the wireless devices always adjust the time slot to base station from time to time. The ML decision is also assumed to be employed at the destination.

In fact, the selection scheme from literature as well as our proposed scheme add more complexities to the actual implementation of wireless communication in terms of overhead transmission and delay processing time. However, the selection schemes can offer a higher capacity, more energy saving and a lower outage probability. These benefits are valuable enough to be the significant factors for considering the tradeoffs to implement the proposed scheme in practice.

Firstly, in order to investigate the system performance of using cooperative MIMO technique, the system model in simulation is consisted of 1 source with one antenna, 1 relay with one antenna and 1 destination with two antennas. Three transmission schemes are compared here including cooperative diversity, cooperative MIMO and proposed method shown in Fig. 5. The cooperative diversity utilizes the advantage of diversity technique in receiver without MIMO technique. The cooperative MIMO is the cooperative system with MIMO technique but without modifying STBC scheme. Next, in order to investigate the system performance in term of outage probability, the results of two systems including with cooperative diversity [16] and proposed method are shown in Fig. 6 and Fig. 7. Also, the channel is generated by Rayleigh fading.

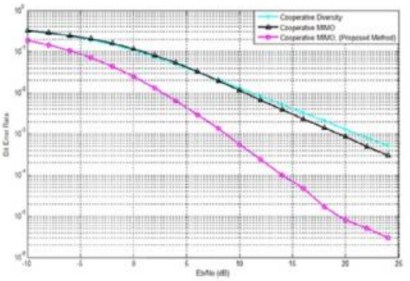

Fig.5: BER Comparison between the Proposed Method and Others.

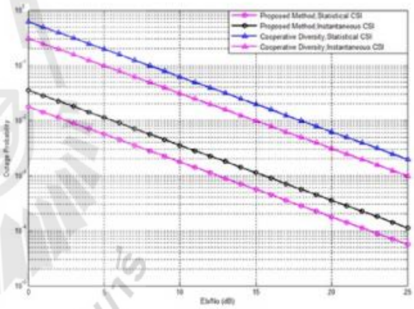

Fig.6: Outage Probability Performance Comparison between the Proposed Method and Diversity Scheme.

As seen in Fig. 5, there is no result of the method without modifying STBC scheme because it will provide the same result as the cooperative diversity communications. The results indicate that the cooperative MIMO transmission with proposed method provides the lowest BER. Also seen in Fig. 5, for 10^{-3} BER, the Eb/N0 at 8.5 can be achieved by using the proposed method while it must be attained at about 19 dB and 21 dB by using cooperative MIMO method and cooperative diversity method, respectively. The more benefits are obtained when Eb/N0 is higher. This is to confirm the success of the proposed method to implement for wireless communications.

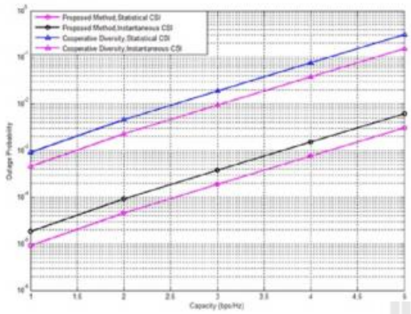

Fig.7: *Outage Probability versus Spectral Efficiency.*

In Fig. 6, the results indicate that the system performance in term of outage probability of the proposed method provides the lowest outage probability. Also seen in Fig. 6, for 10^{-3} P_{out}, the Eb/N0 at 10 dB in statistical CSI and the Eb/N0 at 10 dB in instantaneous CSI can be achieved by using the proposed method while it must be attained at 25 dB in statistical CSI and more than 25 dB in instantaneous CSI by using cooperative diversity method. In Fig. 7, the results indicate that the system performance in term of outage probability versus spectral efficiency of the proposed method provides the lowest outage probability. Also seen in Fig. 7, for 10^{-3} P_{out}, the 1 bps/Hz in statistical CSI and the 1.6 bps/Hz in instantaneous CSI can be achieved by using the proposed method while it must be attained at 3.8 bps/Hz in statistical CSI and more than 4.3 bps/Hz in instantaneous CSI by using cooperative diversity method. Considering fair-basis criteria of outage probability comparison, the proposed scheme is still able to provide the higher performance than the other.

Fig. 8 presents the outage probability versus distance between source node and relay node. The results indicate that the system performance in term of outage probability of the proposed method provides the lowest outage probability for any distances between source node and relay node. Fig. 9 shows the outage probability versus the allocation of transmitted power. This investigation is on the balance of the transmission power between source node and relay node. The transmitted power can be changed by the allocation of power factor. The results indicate that there is an optimal power allocation to minimize the outage probability. Hence, this might be useful to further investigate the efficiency of energy consumption.

6. CONCLUSIONS

In this paper, the performance analysis of cooperative MIMO technique using modified STBC scheme is presented to apply on wireless communications. It is based on the modification of STBC scheme for DF protocol. The outage probability and BER performances are investigated. The results conclude that the proposed system can offer a better BER and a lower outage probability than other methods.

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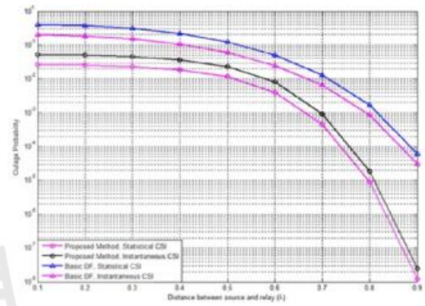

Fig.8: *Outage Probability versus Distance between Source Node and Relay Node.*

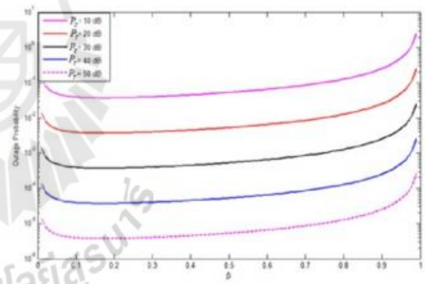

Fig.9: *Outage Probability versus the Allocation of Transmitted Power.*

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Performance Analysis of Modified STBC Scheme for Cooperative MIMO Communications

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***Abstract*— The cooperative MIMO communications is a new challenge to provide more reliable transmissions from the collaboration between users. Mostly, the MIMO employment is performed by using a simple diversity scheme. However, there are many MIMO schemes that can be implemented in practice. This paper proposes the modified STBC scheme for cooperative MIMO communications. Also the performance analysis of the proposed system in term of the data error rate and the outage probability is presented. The simulation results indicate that the proposed system can offer a better bit error rate and improve the outage probability than the diversity scheme.**

***Keywords*— Decode and Forward, Outage Probability, Cooperative MIMO Communications.**

I. Introduction

Currently, the communication technology has a huge role in everyday life. Wireless communication system is the most influent form of communications. There are commonly used due to its ease of installation but it needs to be developed effectively to get higher data transmission, freedom of movement and quality of communication that is reliable in providing good service so that the system can meet the requirements of multimedia data communication in the future. It is well known that MIMO wireless communication system [1] can support the need of high transmission data of multimedia communication in the future since the system can increase the channels of communication and choose to send data in the parallel channels. However, the MIMO operation requires multiple antennas at both transmitter and receiver which are not practical for mobile devices. In this light, the new challenge to increase the channels of communication as well as MIMO wireless communication system but no need to increase the number of antennas at the transmitter and the receiver is presented and called as cooperative MIMO communications [2] [3]. This technique depends on the conditionally transmitted data by allowing users in system to help each other to send their data like MIMO technique. This would cause virtual MIMO communications system. This technique can increase more channel diversity and can reduce the bit error rate (BER) of the system. However, the problem of fading in the channel due to noise of the signal sent by the delay and reflected in multipath of the channel resulted in signal distortion. Based on these problems, it is aware of the needs for communications to respond the demands of users increasing for the improved performance of communication system.

In the past few years, cooperative communication has been a very active research field. Extensive researches have focused on the physical layer aspects of cooperative communications [4] [5]. Therefore, there are many developments of research in cooperative wireless communication systems in literature. In general, the cooperative transmission protocols used in the relay node are classified by either amplify-and-forward (AF) and decode-and-forward (DF) [2]. Recently, the works in [6] [7] [8] proposed the transmission technique in type of forwarding data information for cooperative communications. Then, the work in [9] proposed the amplify-and-forward protocol, using for the transmission of data in distributed forwarding data information to obtain MIMO channels for data transmission. However, the positions of the relay in cooperative communication system are varied in practice so the relay selection is very important issue for the cooperative MIMO communication. In [10], the authors point out that relay selection in cooperative communication depends on power transmission, distance and condition of channel. The solution of methods to choose relay is proposed by using the estimated channel and the coefficients of the signal in each path. In [11], it shows the method to select relay from consideration of signal-to-noise ratio throughout the path from the transmitter to the receiver.

However, in literatures the process of relay cooperation is done by forwarding and repeating the signal symbols on the allocated time slot. On the contrast, this paper proposes the utility of relay by creating the process of sending symbols based on STBC mode. By changing the symbols sent from source to relay ($S_1 \rightarrow \tilde{S}_1^*$ and $S_2^* \rightarrow \tilde{S}_2$), the destination can be easily detected as a typical STBC mode. The proposed cooperative MIMO technique is introduced to improve the system performance of wireless communication networks. The modified STBC scheme is selected to implement the virtual MIMO transmitter. By using the neighbouring antennas, the overall system can be operated as MIMO communication. It is interesting to see the improvement of using the proposed concept in wireless communication networks. In case of relay selection in literatures the process of relay cooperation is done by considering channel information and signal-to-noise ratio throughout the path from the transmitter to the receiver. This paper proposed the relay selection power scheme and the relay selection capacity scheme for using suitable in each situation because when the cooperative MIMO communication system want to get high rate transmission. Then the selection scheme considering the channel capacity which can support the transmission rate has been higher than the power scheme. But when the cooperative MIMO communication system wants to save energy for transmitting signal, then it chooses the power scheme using less energy than scheme considering the channel capacity. The remainder of the paper is as follows. Section II provides the details of system models. In Section III, the cooperative MIMO technique for wireless communications is described. In Section IV, explain the technique of modified STBC with cooperative MIMO communications. In Section V, the outage probability of the cooperative MIMO communications is derived. In Section VI, the comparison of performance between proposed scheme and others is presented. Finally, Section VII presents the conclusion.

II. System Model

Since the wireless communication network is considered in this paper, hence all wireless devices are assuming with only single antenna. They are connected to a base station which is assumed to be located at the center of a cell. We consider a system model as depicted in Figure 1, where each source, relay nodes have only single antenna and destination node (base station) has two antennas. The system in which a source node S transmits information to a destination node D with the help of the best relay node R_i. The channels considered in this system model are assumed to undergo AWGN, multipath, and slow fading. Source and relay nodes must know channel state information (CSI) between source and relay as well as between relay and destination, respectively.

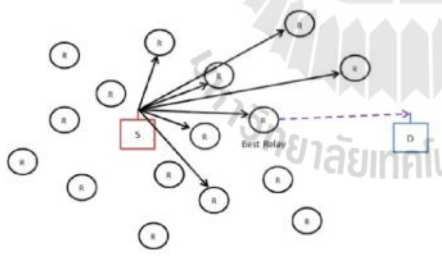

Fig. 1 System model of networks

III. Cooperative MIMO Technique For Wireless Communications

In general, wireless devices must have two transmit antennas in order to apply 2x2 Alamouti STBC MIMO systems. Although Ho-Jung An et. al. [12] applied pre-coding scheme with the STBC symbols to employ STBC with single antenna, but it costs a significant delay and suffers from AF protocol. In this paper, we proposed a technique to transmit virtual STBC symbols in order to apply with a single antenna system. The source and relay virtually offer the multiple antennas for the cooperation of transmitted symbols at the same STBC schemes to the destination. The proposed system works as given in the following steps.

- At the first step, the source makes agreement with the destination to transmit and receive by using the cooperative MIMO technique. The destination then find relays by sending the invitation message to all potential relays. The available relays will send the confirmation message to cooperate with source and destination. At this point, source, relays and destination are now ready to operate the system with cooperative MIMO technique.
- The second step is the pre-transmitting process. The source transmits symbols to relay. When the relay obtains symbols form source, then the relay will adjust or reformat symbols in the form of STBC coding schemes. This step is based on the perfect synchronization between source and relay and also including with the perfect knowledge of coding sequences.
- For the third step, the source and relay transmit simultaneously the coding symbols to the destination. The destination receives all signals from both source and relay by multiple receiving antennas. This process is as same as the normal MIMO system because the destination can virtually see the receiving signals come from one multiple antenna sources.

IV. Proposed STBC Scheme For Cooperative MIMO Technique

The process of STBC system encodes the input data symbols into both spatial and time domain. However, in cooperative MIMO system, the spatial domain splits into multiple users. Hence, the method to set a block coding schemes is a necessary part to be designed. In this paper, the authors propose the sequence of transmitting symbols by modifying STBC scheme for cooperative MIMO users in wireless communications as shown in figure 2.

In Figure 2, the overall data symbols are occurred within four symbol periods in order to perform one STBC block. The first two periods are the time of exchanging data symbols between source and relay. This is referred to the second step in the previous section. In this interval, the destination cannot obtain any data symbols from source because the transmitting power between source and relay is very little in comparing with the transmitting power between base station and source.

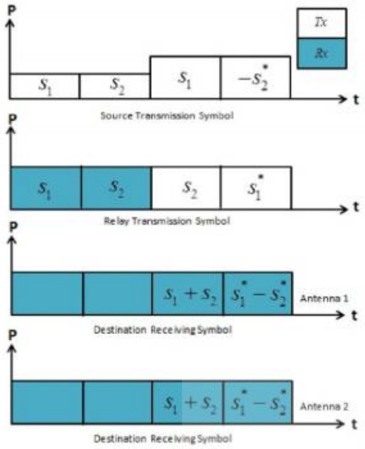

Fig. 2 modified STBC scheme for cooperative MIMO.

$$y_{d1}^{(1)} = \sqrt{P_s} h_{s,d1} s_1 + \sqrt{P_r} h_{r,d1} s_{2r} + n_{s,r,d1}^{(1)} \quad (1)$$

$$y_{d1}^{(2)} = -\sqrt{P_s} h_{s,d1} s_2^* + \sqrt{P_r} h_{r,d1} s_{1r}^* + n_{s,r,d1}^{(2)} \quad (2)$$

Where $h_{s,d1}$ and $h_{r,d1}$ are the wireless channel from source to destination at the first antenna and the wireless channel from relay to destination at the first antenna. $n_{s,r,d1}^{(1)} \sim \mathcal{CN}(0,\sigma_d^2)$ and $n_{s,r,d1}^{(2)} \sim \mathcal{CN}(0,\sigma_d^2)$ are complex AWGN including the effect of interference signal at the first antenna. P_s and P_r is the source transmission power and relay transmission power, respectively.

Considering the second antenna of destination, the two signals are expressed by

$$y_{d2}^{(1)} = \sqrt{P_s} h_{s,d2} s_1 + \sqrt{P_r} h_{r,d2} s_{2r} + n_{s,r,d2}^{(1)} \quad (3)$$

$$y_{d2}^{(2)} = -\sqrt{P_s} h_{s,d2} s_2^* + \sqrt{P_r} h_{r,d2} s_{1r}^* + n_{s,r,d2}^{(2)} \quad (4)$$

Where $h_{s,d2}$ and $h_{r,d2}$ are the wireless channel from source to destination at the second antenna and the wireless channel from relay to destination at the second antenna, $n_{s,r,d2}^{(1)} \sim \mathcal{CN}(0,\sigma_d^2)$ and $n_{s,r,d2}^{(2)} \sim \mathcal{CN}(0,\sigma_d^2)$ are complex AWGN including the effect of interference signal at the second antenna.

Note that the symbols transmitted by relay are defined by s_{1r} and s_{2r} when $s_1 = s_{1r}$ and $s_2 = s_{2r}$ because the link between relay and source in the second step mentioned in cooperative MIMO technique for wireless communications has the effects of fading channel as well. This might cause the uncertainty of symbol realization on relay. However, most of the works in this area assume that relay can perfectly retrieve every symbol.

Then, at the destination, the processes of extracting the data symbols from incoming signals are the same as described by normal STBC scheme. The two estimated symbols, $\tilde{s}_1$ and $\tilde{s}_2$ from the first antenna are calculated by.

$$\tilde{s}_1 = h_{s,d1}^* y_{d1}^{(1)} + h_{r,d1} \left(y_{d1}^{(2)}\right)^* + h_{s,d2}^* y_{d2}^{(1)} + h_{r,d2} \left(y_{d2}^{(2)}\right)^* \quad (5)$$

$$\tilde{s}_2 = h_{r,d1}^* y_{d1}^{(1)} - h_{s,d1} \left(y_{d1}^{(2)}\right)^* + h_{r,d2}^* y_{d2}^{(1)} - h_{s,d2} \left(y_{d2}^{(2)}\right)^* \quad (6)$$

V. Outage Performance

In this section, the outage probability of the proposed system is derived. The outage probability can be defined as the probability of unsatisfactory signal reception and represents the probability that the mutual information is less than a specified data rate. The mutual information between the source and the relay node is given by [14]

$$\begin{aligned} P_{out}(R) &\triangleq \Pr\left(\log_2\left(1+\mathrm{SNR}\,|h|^2\right) < R\right) \\ &= \Pr\left(\mathrm{SNR}\,|h|^2 < 2^R - 1\right) \end{aligned} \quad (7)$$

Where P_{out} denotes the outage probability is system and the desired average end-to-end rate is R the destination performs detection based only on the signal received from the relay. The scheme is identical to conventional transmissions. In order to successfully transmit a codeword over both s-r and r-d links in this case, the rate of the codeword must be bounded by the capacity of both links by.

$$2R \le \min\left\{\log_2\left(1+\mathrm{SNR}_{s,r}\left|h_{s,r}\right|^2\right), \log_2\left(1+\mathrm{SNR}_d\left\|\mathrm{H}\right\|_F^2\right)\right\} \quad (8)$$

Hence, the average end-to-end achievable rate is given by

$$C = \frac{1}{2}\min\left\{\log_2\left(1+\mathrm{SNR}_{s,r}\left|h_{s,r}\right|^2\right), \log_2\left(1+\mathrm{SNR}_d\left\|\mathrm{H}\right\|_F^2\right)\right\} \quad (9)$$

Following from (7), we obtain

$$P_{out} = \Pr\left(\frac{1}{2}\min\left\{\log_2\left(1+\gamma_{s,r}\right), \log_2\left(1+\gamma_d\right)\right\} < R\right) \quad (10)$$

Where C is channel capacity, $\|\mathrm{H}\|_F^2$ represents the squared Frobenius norm of the matrix H , and. The above formula can be further obtained as,

$$P_{out} = \Pr\left(\gamma_{s,r} < 2^{2R}-1\right) + \Pr\left(\gamma_{s,r} \ge 2^{2R}-1\right)\Pr\left(\gamma_d < 2^{2R}-1\right) \quad (11)$$

In the Rayleigh fading scenario, the SNR $\gamma_{s,r}$ and γ_d are exponentially distributed with mean $\overline{\gamma}_{s,r} = P_s h_{s,r}^2 / n_{s,r}^2$ and $\overline{\gamma}_d = P_T \|\mathrm{H}\|_F^2 / n_{s,r}^2$. Hence, we have

$$P_{out} = 1-\exp\left(-\frac{2^{2R}-1}{\overline{\gamma}_{s,r}}\right)+\left[\exp\left(-\frac{2^{2R}-1}{\overline{\gamma}_{s,r}}\right) -\exp\left(-\frac{2^{2R}-1}{\overline{\gamma}_{s,r}}-\frac{2^{2R}-1}{\overline{\gamma}_{d}}\right)\right] \quad (12)$$

Given, $e^{-x} \approx 1-x$. Hence, we obtained

$$P_{out} = \frac{2^{2R}-1}{\overline{\gamma}_{s,r}}+\frac{2^{2R}-1}{\overline{\gamma}_{d}} \quad (13)$$

Given the total power constraint $P_s + P_r = P_T$, we can set $P_s = \beta P_T$ and $P_r = (1-\beta)P_T$, for some $0 \le \beta \le 1$, and let $n_{s,r}^2 = n_d^2 = n_T^2$ the outage probability can be approximated as.

$$P_{out} = \frac{2^{2R}-1}{\text{SNR}}\left(\frac{1}{\beta\|\text{H}\|_F^2}+\frac{1}{(1-\beta)\|\text{H}\|_F^2}+\frac{1}{(1-\beta)h_{s,r}^2}\right) \quad (14)$$

For β is the allocation of power.

VI. Simulation Results

In this section, the fading signals are generated by Rayleigh distribution including with the complex additive white Gaussian noise (AWGN). The data symbols are randomly generated and modulated by BPSK modulation. The estimated channels are assumed to be perfect which means that the destination is also assumed with the full knowledge of channel information. The cooperative MIMO technique in wireless communication networks is assumed with the perfect synchronization of timing symbols. It is possible for wireless communication networks because in fact the wireless devices always adjust the time slot to base station from time to time. The ML decision is also assumed to be processed at the destination.

Firstly, in order to investigate the system performance of using cooperative MIMO technique, the system model in simulation is consisted of 1 source with one antenna, 1 relay with one antenna and 1 destination with two antennas. Three transmission schemes are compared here including cooperative diversity, cooperative MIMO and proposed method show in figure 3. Next, in order to investigate the system performance of using outage probability, the system compared here including cooperative diversity [14] and proposed method show in figure 4 and figure 5. Also, the channel is generated by Rayleigh fading. Figure 3 shows the BER comparison of cooperative MIMO transmissions between cooperative diversity, cooperative MIMO and proposed method. The cooperative diversity utilizes the advantage of diversity technique in receiver. This can improve the performance of wireless communications. In Figure 3, there is no result of the method without modifying STBC scheme because it will provide the same result as the cooperative diversity communications. The results indicate that the cooperative MIMO transmission with proposed method provides the lowest BER. Also seen in Figure 3, for 10^{-3} BER, the about 8.5 dB Eb/N0 can be achieved by using the proposed method while it must be attained at Eb/N0 about 19 dB and 21 dB by using cooperative MIMO method and cooperative diversity method. The more benefit is obtained when Eb/N0 is higher. This is to confirm the use of proposed method to implement for wireless communications.

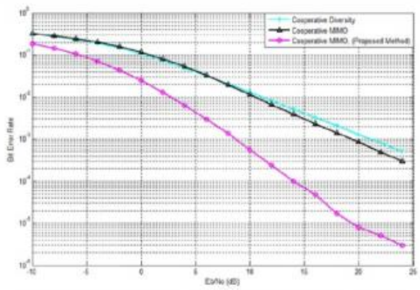

Fig. 3 BER comparison between the proposed mehod and others.

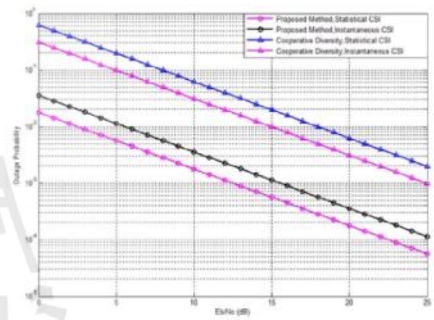

Fig. 4 Outage probability performance comparison between the proposed method and diversity scheme.

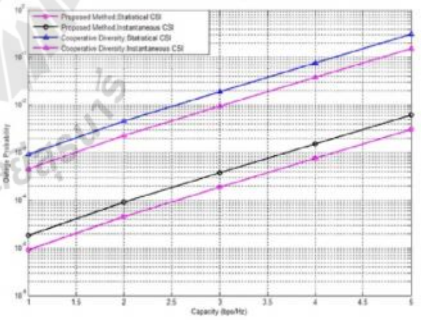

Fig. 5 Outage probability versus spectral efficiency.

In Figure 4, the results indicate that the system performance of using outage probability with proposed method provides the lowest outage probability. In Figure 4, for 10^{-3} P_{out} the 12 dB in statistical CSI and 15 dB in instantaneous CSI P_{out} can be achieved by using the proposed method while it must be attained at P_{out} 25 dB in statistical CSI and more than 25 dB in instantaneous CSI by using cooperative diversity method. In Figure 5, the results indicate that the system performance of using outage probability versus spectral efficiency with proposed method provides the lowest outage probability. Also in Figure 5, for 10^{-3} P_{out} the 1 bps/Hz in statistical CSI and 1.6 bps/Hz in instantaneous CSI P_{out} can be achieved by using the proposed method while it must be attained at 3.8 bps/Hz in statistical CSI and more than 4.3 bps/Hz in instantaneous CSI by using cooperative diversity method.

VII. CONCLUSIONS

In this paper, the cooperative MIMO technique is proposed to apply on wireless communications. It is based on the modification of STBC scheme and is applied for DF protocol. The outage probability and BER performances are investigated. The results conclude that the proposed system can offers a better BER and a lower outage probability than other methods.

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Performance Enhancement of Mobile Networks using Cooperative MIMO Technique

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Abstract—**It is well known that Multiple-Input Multiple-Output (MIMO) system provides both spatial and diversity gains by using multiple antennas at both mobile and base stations. However, the mobile station cannot effort multiple antennas due to small and limited dimension. Therefore, the MIMO technique cannot be successfully operated. In this light, the cooperative MIMO technique enables a mobile user with single antenna to realize a virtual multiple antennas by using the antennas of neighboring users. As a result, the mobile user can experience the full benefits of MIMO system. In literatures, the cooperative MIMO technique using Space-Time Block Codes (STBC) is created by the relay capability of neighbor users. However, the devices of all users have the same potential to detect symbols. Therefore, this paper proposes the STBC scheme by changing the symbol order from source to relay in order to be easily performed as MIMO at the destination. The simulation results reveal that it is possible to obtain a better error performance as well as a higher channel capacity by using the proposed scheme for mobile cellular networks.**

Keywords-cooperative MIMO; STBC; Amplify-and-Forward; Decode-and-Forward; transmit diversity.

I. INTRODUCTION

The Fourth-Generation (4G) wireless system aims to offer the broadband multimedia services at the rate of around 100Mbps-1Gbps. The peak-transmit power increases with data transmission rate and reducing the cell size is an efficient way to avoid larger transmit power while increasing the data transmission rate [1]-[3]. In order to comprehend much higher data rate transmission with low transmit power in multihop, virtual cellular network (VCN) was proposed [4].

Relay nodes based cooperative communication has emerged as a promising solution to increase spectral and power efficiency as well as network coverage, and also to reduce outage probability for the next generation wireless networks. A cooperative communication system consists of source, relay, and destination which have been accepted as a virtual Multiple-Input Multiple-Output (MIMO) system, because it can provide a transmit diversity instead of implementing multiple antennas at wireless nodes in wireless communication. Although MIMO systems provide many advantages and achieve spatial diversity, they cannot be served to provide diversity when the wireless portable devices, especially for mobile stations, cannot support multiple antennas due to size and power limitations.

Therefore, there are many developments of research in cooperative wireless communication systems in literature. In general, the cooperative transmission protocols used in the relay node are classified by either amplify-and-forward (AF) and decode-and-forward (DF)[5]. Recently, in [6] the single relay and the AF protocol was considered and the simulation results have been shown that the STBC with pre-coding scheme (STBC-PC) can always achieve the low BER (bit error rate) at the low SNR (Signal to Noise Ratio). Particularly, even if the reduction of performance were proposed by using the statistical characteristics of channel, it can acquire performance advantage as ever and the proposed method is more useful when the channel impairment of a direct link exists. In mobile network, the mobile station cannot connect to the base station because that source is out of reach from the destination and the direct link cannot exist. Thus the dual-hop relaying cooperation is a feasible method to assist the mobile network. Bletsas et. al. [7] presented an opportunistic relaying scheme which used high SNR among multiple cooperating terminals, but this scheme considered only one relay. Abbas El Gamal et. al.[8] analytically proved that link delays can change the nature of cooperation in a network and hence its capacity. Therefore, the main goal of this paper is to analyze and improve the performance of system, especially for mobile cellular networks.

However, in literatures the MIMO process of relay cooperation is done by forwarding and repeating the signal symbols on the allocated time slot. On the contrast, this paper proposes the utility of relay by creating the process of sending symbols based on STBC mode. By changing the symbols sent from source to relay ($S_1 \rightarrow \tilde{S}_1^*$ and $S_2^* \rightarrow \tilde{S}_2$), the destination can be easily detected as a typical STBC mode. The proposed cooperative MIMO technique is introduced to improve the system performance of mobile cellular networks. The STBC is selected to implement the virtual MIMO transmitter. By using the neighboring antennas, the overall system can be operated as MIMO communication. It is interesting to see the improvement of using the proposed concept in mobile networks. The remainder of the paper is as follows. Section II provides the details of system models. In Section III, the cooperative MIMO technique for mobile networks is described. In Section IV, explain technique STBC with cooperative MIMO mobile network in system. In Section V, the comparison of BER performance between proposed scheme and others is presented. Finally, Section VI presents the conclusion.

II. System Model

Since the mobile cellular network is considered in this paper, hence all wireless devices are assuming with the same mobile phone with only single antenna. They are connected to a base station which is assumed to be located at the center of a cell. We consider a system model as depicted in Figure 1, where each source, relay nodes have only single antenna and destination node (base station) has two antennas.

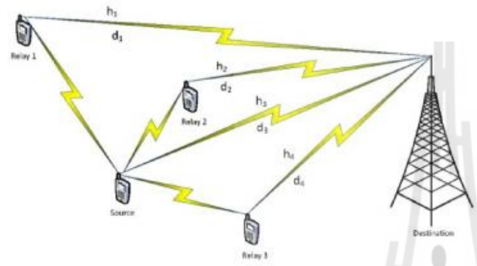

Figure 1. System model of mobile cellular networks.

The channels considered in this system model are assumed to undergo AWGN, path loss, and slow fading. Source and relay nodes must perfectly know channel state information (CSI) between source and relay as well as between relay and destination, respectively.

Consider network system, we configured path loss by two ray model (1) in [9].

$$P_r = P_t G_r G_t \frac{h_r^2 h_t^2}{d^4} \quad (1)$$

Where P_r and P_t are the receiving and transmitting power, G_r and G_t are receiving and transmitting antenna gain, h_r and h_t are the height of receiver and transmitter, and d is distance between transmitter/receiver, respectively. Moreover, multiple relays may receive, adjust, and retransmit the signals. The destination can combine the bit sequences from multiple relays and employ maximum likelihood (ML) decision completely, because we assume that the faded versions of each transmitted sequences in any relaying paths are completely independent.

III. Cooperative MIMO Technique for Mobile Cellular Networks

In general, a mobile station must have two transmit antennas in order to apply 2x2 Alamouti STBC MIMO systems. Although Ho-Jung An et. al. [6] applied pre-coding scheme with the STBC symbols to employ STBC with single antenna, but it costs a significant delay and suffers from AF protocol. In this paper, we proposed a technique to transmit virtual STBC symbols in order to apply with a single antenna system. The source and relay virtually offer the multiple antennas for the cooperation of transmitted symbols at the same STBC schemes to the destination. The proposed system works as given in the following steps.

- At the first step, the source makes agreement with the destination to transmit and receive by using the cooperative MIMO technique. The destination then find relays by sending the invitation message to all potential relays. The available relays will send the confirmation message to cooperate with source and destination. At this point, source, relays and destination are now ready to operate the system with cooperative MIMO technique.
- The second step is the pre-transmitting process. The source transmits symbols to relay. When the relay obtains symbols form source, then the relay will adjust or reformat symbols in the form of STBC coding schemes. This step is based on the perfect synchronization between source and relay and also including with the perfect knowledge of coding sequences.
- For the third step, the source and relay transmit simultaneously the coding symbols to the destination. The destination receives all signals from both source and relay by multiple receiving antennas. This process is as same as the normal MIMO system because the destination can virtually see the receiving signals come from one multiple antenna source.

IV. Proposed STBC Scheme For Cooperative MIMO Technique

The process of STBC system encodes the input data symbols into both spatial and time domain. However, in cooperative MIMO system, the spatial domain splits into multiple users. Hence, the method to set a block coding schemes is a necessary part to be designed. In this paper, the authors propose the sequence of transmitting STBC symbols for cooperative MIMO users in mobile networks as shown in fig.2.

In Figure 2, the overall data symbols are occurred within four symbol periods in order to perform one STBC block. The first two periods are the time of exchanging data symbols between source and relay. This is referred to the second step in the previous section. In this interval, the destination cannot obtain any data symbols from source because the transmitting power between source and relay is very little in comparing with the transmitting power between base station and source.

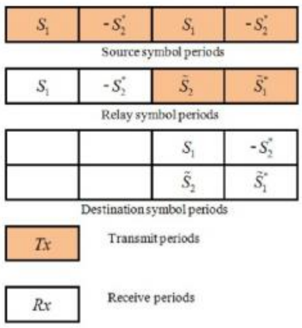

Figure 2. 2x2 STBC scheme for cooperative MIMO.

The third and fourth symbol periods are the STBC MIMO transmission. When, we considered one source one relay and one destination. Then, the two signals obtained at the first antenna of the destination [10] can be expressed by

$$y^1_{d_{\frac{3}{4}T}} = s_1 h_1 + \tilde{s}_2 h_3 + n_1 \quad (2)$$

$$y^1_{d_{\frac{4}{4}T}} = \tilde{s}_1^* h_3 - s_2^* h_1 + n_2 \quad (3)$$

Where T is the overall time of sending symbols from source to destination, , h_1 and h_3 are the wireless channel from source to destination at the first antenna and the wireless channel from relay to destination at the first antenna, n_1 and n_2 are complex AWGN including the effect of interference signal at the first antenna .

Considering the second antenna of destination, the two signals are expressed by

$$y^2_{d_{\frac{3}{4}T}} = s_1 h_2 + \tilde{s}_2 h_4 + n_3 \quad (4)$$

$$y^2_{d_{\frac{4}{4}T}} = \tilde{s}_1^* h_4 - s_2^* h_2 + n_4 \quad (5)$$

Where h_2 and h_4 are the wireless channel from source to destination at the second antenna and the wireless channel from relay to destination at the second antenna, n_3 and n_4 are complex AWGN including the effect of interference signal at the second antenna .

Note that the symbols transmitted by relay are defined by $\tilde{s}_1$ and $\tilde{s}_2$ because the link between relay and source in the second step mentioned in Section III has the effects of fading channel as well. This might cause the uncertainty of symbol realization on relay. However, most of the works in this area assume that relay can perfectly retrieve every symbol.

Then, at the destination, the process of extracting the data symbols from incoming signals are the same as described by normal STBC scheme. The two estimated symbols, $\hat{s}_1$ and $\hat{s}_2$, from the first antenna are calculated by.

$$\hat{s}_1 = h_1^* y^1_{d_{\frac{3}{4}T}} + h_3 y^{1*}_{d_{\frac{4}{4}T}} \quad (6)$$

$$\hat{s}_2 = h_3^* y^1_{d_{\frac{3}{4}T}} - h_1 y^{1*}_{d_{\frac{4}{4}T}} \quad (7)$$

Similarly, for the second antenna, the two symbols are estimated by

$$\hat{s}_1 = h_2^* y^2_{d_{\frac{3}{4}T}} + h_4 y^{2*}_{d_{\frac{4}{4}T}} \quad (8)$$

$$\hat{s}_2 = h_4^* y^2_{d_{\frac{3}{4}T}} - h_2 y^{2*}_{d_{\frac{4}{4}T}} \quad (9)$$

V. SIMULATION RESULTS

In the simulation, the propagation channel is modelled by path loss including with fading and noise. For path loss model, two ray propagation model is adopted in this paper because it is a well known model used for coverage prediction in mobile networks. The fading signals are generated by Rayleigh distribution including with the complex additive white Gaussian noise (AWGN). The data symbols are randomly generated and modulated by BPSK modualtion. The estimated channels are assumed to be perfect which means that the destination is also assumed with the full knowledge of channel information. The cooperative MIMO technique in mobile networks is assumed with the perfect synchronization of timing symbols. It is possible for mobile networks because in fact the mobile always adjust the time slot to base station from time to time. The ML decision is also assumed to be processed at the base station.

Firstly, in order to investigate the system performance of using cooperative MIMO technique, the system model in simulation is consisted of 1 source with one antenna, 1 relay with one antenna and 1 destination with two antennas. Three transmission schemes are compared here including AF, DF and proposed methods. Also, the channel is generated by Rayleigh fading. Figure 3 shows the BER comparison of cooperative MIMO transmisstions bewteen AF, DF and proposed methods. The results indicate that the cooperative MIMO transmission with proposed method provides the lowest BER. Also seen in Figure 3, for 10^{-2} BER, the 3 dB Eb/N0 can be achieved by using the proposed method while it must be attained at SNR about 5 dB and 9 dB by using the DF and AF methods. For 10^{-3} BER, the 8 dB Eb/N0 can be achieved by using the proposed method while it must be attained at SNR about 13 dB and 20 dB by using the DF and AF methods. The more benefit is obtained when Eb/N0 is higher. This is to confirm the use of proposed method to implement for mobile cellular networks.

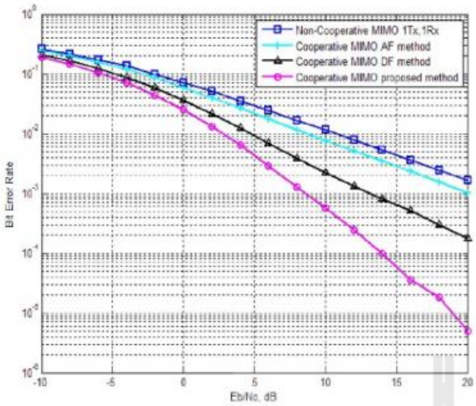

Figure 3. BER comparison of cooperative MIMO transmisstions bewteen AF, DF and proposed methods.

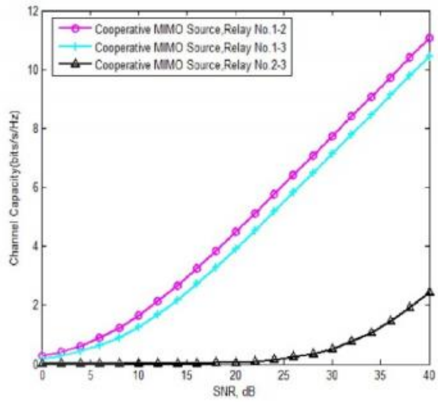

Figure 5. Channel capacity (bits/s/Hz) versus SNR (dB), with two relays.

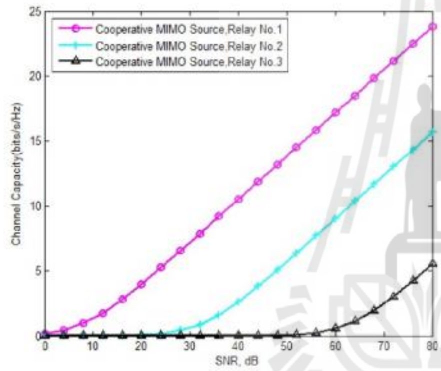

Figure 4. Channel capacity (bits/s/Hz) versus SNR (dB), with one relay.

Next, the task of choosing relays has been studied. As a result, there are three relays to be the choice of cooperative MIMO technique as shown in Figure 1. This study aims to examine the difference distances of the relay choices. It is interesting to observe whether the system performance is changed when choosing a different relay. The channel capacity is a figure of merit to judge the performance of mobile networks. The expression of channel capacity [11] can be expressed by

$$C = \frac{1}{2}\min\left(\log_2\left(1+SNR_{S,R}\right), \log_2\left(1+SNR_D\right)\right) \quad (10)$$

When C is the channel capacity, $SNR_{S,R}$ is signal-to-noise ratio at the source to relay, SNR_D is signal-to-noise ratio at the source to destination. Also, the authors assume the receiving antenna gain and transmitting antenna gain with using ref. in [12]. The source and relay height are 2m and the destination height is 50m. The distances of destination to source is 200m. The distances from source to relay No.1, relay No.2 and relay No.3 are 100m, 150m and 250m, respectively.

Figure 4 and 5 shows the channel capacity performance when using one and two relays, respectively. The simulation results indicate that the location of relays play a significant role on channel capacity. Also noticed in the results, the use of two relays can save the transmitting power. For example, the channel capacity of 5 bits/s/Hz at 22 dB SNR can be accomplished by using the cooperation between source with relay No.1 and 2, while it must be attained at SNR of 24 dB by using the cooperation between source with relay No.1 only.

VI. CONCLUSIONS

In this paper, the cooperative MIMO technique is proposed to apply on mobile networks. It is based on a STBC MIMO scheme and DF protocol. The proposed method can significantly improve the BER performance. Moreover, the investigations on the relay locations have been examined. The results indicate that the location of relay plays main role on channel capacity and the choice of number of relays is still interesting to study further.

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บทคัดย่อ

บทความนี้ได้นำเสนอการวิเคราะห์ประสิทธิภาพระบบสื่อสารร่วมมือแบบไมโม โดยใช้การส่งผ่านแบบถอดรหัสและส่งต่อ ในช่องสัญญาณที่มีการจางหายแบบเรย์ลีห์ โดยในการทดลองนี้จะกำหนดให้ช่องสัญญาณทั้งหมดเป็นอิสระต่อกัน และการรับ-ส่งข้อมูลจะกำหนดให้ไม่มีการรบกวนกันระหว่างรีเลย์ ซึ่งในบทความนี้แสดงถึงอัตราการผิดพลาดของการส่งสัญญาณข้อมูลของระบบการสื่อสารร่วมมือแบบไมโมโดยใช้การมอดูเลตแบบ BPSK และแสดงถึงความน่าจะเป็นที่สัญญาณจางหายในของระบบการสื่อสารร่วมมือแบบไมโม ซึ่งผลลัพธ์ที่ได้จากการจำลองแบบระบบที่นำเสนอเปรียบเทียบกับระบบการสื่อสารร่วมมือแบบไดเวอร์ซิตี้ ซึ่งระบบที่นำเสนอสามารถช่วยลดความผิดพลาดของบิตข้อมูลที่รับได้และความน่าจะเป็นที่สัญญาณขาดหายลดลง

Abstract

This paper presents the analysis of cooperative MIMO communications system. By using decode and forward (DF) cooperative communications with rayleigh fading channel. In this simulation, we also fix the channel links to be totally independent and no inter-relay interference is considered in the system. In this paper represents the error rate of the transmission of the cooperative MIMO communications system with using BPSK modulation and represents the outage probability that in this system. From the result, the proposed system compare with cooperative diversity system. The proposed system can reduce the bit error of the data obtained and the outage probability is lower.

คำสำคัญ

Decode and Forward, Outage Probability, Cooperative MIMO Communications.

1. บทนำ

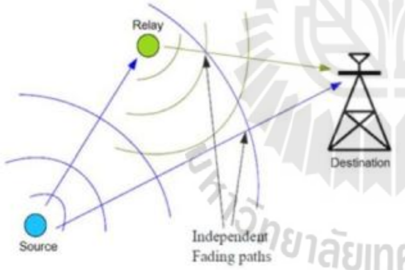
ในปัจจุบันเทคโนโลยีด้านการสื่อสาร นับว่ามีบทบาทในชีวิตประจำวันเป็นอย่างมาก การสื่อสารที่ให้ทั้งความสะดวกรวดเร็ว และถูกต้องมากขึ้นเท่าไหร่ ก็จะยิ่งตอบสนองต่อความต้องการของผู้ใช้งานมากยิ่งขึ้นเท่านั้น ระบบการสื่อสารแบบไร้สาย นับว่าเป็นการสื่อสารอีกรูปแบบหนึ่ง ที่มีผู้นิยมใช้เป็นจำนวนมากเนื่องจากให้ความสะดวกในการใช้งาน แต่จะตอบสนองและเกิดประโยชน์กับผู้ใช้งานมากที่สุดนั้น จะต้องมีการพัฒนาต่อไปอีก ไม่ว่าจะเป็นเรื่องประสิทธิภาพในการรับการส่งข้อมูลที่สูงขึ้น อิสระในการเคลื่อนที่ได้และคุณภาพในการสื่อสารที่มีความน่าเชื่อถือในการให้บริการที่ดี เพื่อให้ระบบสามารถที่จะรองรับกับความต้องการ การสื่อสารข้อมูลแบบสื่อประสมในอนาคตได้

เป็นที่รู้กันดีว่าระบบสื่อสารไร้สายแบบไมโม(Multiple-Input Multiple-Output: MIMO) [1] สามารถรองรับความต้องการดังกล่าวในอนาคตได้ หลักการเบื้องต้นที่ทำให้ระบบสื่อสารไร้สายแบบไมโม มีคุณสมบัติดังที่กล่าวมา คือการใช้งานชุดสายอากาศที่มีมากกว่าหนึ่งชุด ติดตั้งทั้งที่เครื่องส่งและเครื่องรับ ซึ่งการเพิ่มจำนวนของสายอากาศนี้จะส่งผลให้ระบบสามารถเพิ่มช่องทางในการสื่อสารและเพิ่มทางเลือกในการส่งข้อมูลในช่องสัญญาณที่ดีที่สุด อย่างไรก็ตามในปัจจุบันมีระบบสื่อสารไร้สายชนิดหนึ่ง ซึ่งสามารถรองรับความต้องการ การส่งข้อมูลในอนาคตและเพิ่มทางเลือกในการส่งข้อมูลในช่องสัญญาณที่ดีที่สุดได้เช่นเดียวกับระบบสื่อสารไร้สายแบบไมโม และไม่จำเป็นต้องเพิ่มจำนวนของสายอากาศที่เครื่องส่งและเครื่องรับ การสื่อสารดังกล่าวนี้เรียกว่า การสื่อสารร่วมมือ (Cooperative Communications) [2],[3] ดังแสดงตามรูปที่ 1 ซึ่งอาศัยเทคนิคการส่งต่อข้อมูลโดยให้ผู้ใช้งานในระบบทำหน้าที่ช่วยส่งต่อข้อมูลไปยังเครื่องรับ ซึ่งจะทำให้เกิดระบบการสื่อสารแบบไมโมเสมือน (Virtual MIMO Systems)[4] ขึ้นมาได้ เทคนิคนี้ช่วยเพิ่มความหลากหลายของช่องสัญญาณ (Diversity)ให้มากขึ้น ซึ่ง

ส่งผลให้อัตราความผิดพลาดบิต (Bit Error Rate: BER) ของระบบโดยรวมลดลง แต่ปัญหาจากการเฟดดิง (Fading) ที่เกิดขึ้นในช่องสัญญาณเนื่องจากสัญญาณรบกวน (Noise) ความล่าช้าของสัญญาณที่ส่งมา (Delays) และจากการสะท้อนในหลายทิศทาง (Multi-Path) ของช่องสัญญาณ มีผลให้เกิดการผิดเพี้ยนของสัญญาณ (Distortion) ซึ่งจะส่งผลทำให้อัตราความผิดพลาดบิตที่เครื่องรับมีค่าสูงขึ้น

จากปัญหาเหล่านี้ ผู้วิจัยได้เล็งเห็นถึงความต้องการของการสื่อสารที่ให้ทั้งความสะดวก รวดเร็ว และถูกต้องมากขึ้นที่ต้องตอบสนองต่อความต้องการของผู้ใช้งานให้มากยิ่งขึ้น กล่าวคือระบบการสื่อสารต้องสามารถทำให้อัตราความผิดพลาดบิตที่เครื่องรับมีค่าลดลง และสามารถขจัดสัญญาณแทรกสอดที่เข้ามารบกวนระบบ เพื่อจะได้ประสิทธิภาพของระบบการสื่อสารนั้นดีขึ้น

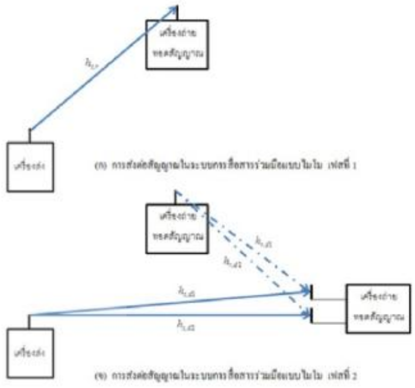
บทความนี้เป็นการนำเสนอการวิเคราะห์ระบบการสื่อสารร่วมมือแบบไมโม โดยใช้การส่งผ่านแบบถอดรหัสและส่งต่อในช่องสัญญาณที่มีการจางหายแบบเรย์ลีห์ โดยแบบจำลองระบบนำเสนอในส่วนที่ 2 ประสิทธิภาพการสื่อสารร่วมมือแบบไมโมอธิบายในส่วนที่ 3 ผลการทดสอบจะกล่าวในส่วนที่ 4 และสรุปผลในส่วนสุดท้าย



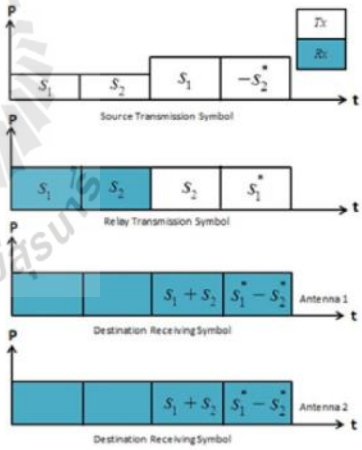
รูปที่ 1 ระบบการสื่อสารร่วมมือ

2. แบบจำลองระบบ

การส่งสัญญาณในระบบการสื่อสารร่วมมือแบบไมโม ในบทความนี้ประกอบด้วย เครื่องส่งทำหน้าที่ส่งสัญญาณข้อมูล รีเลย์ทำหน้าที่ส่งต่อสัญญาณที่รับได้จากเครื่องส่งไปยังเครื่องรับปลายทางและเครื่องรับทำหน้าที่รับสัญญาณข้อมูลของเครื่องส่งและรีเลย์แล้วทำการถอดรหัสสัญญาณข้อมูลเพื่อที่จะนำไปใช้งานต่อไป ซึ่งในการส่งต่อสัญญาณข้อมูลจากรีเลย์ไปยังเครื่องรับ จะเป็นการพิจารณาการส่งสัญญาณโดยใช้โปรโตคอล DF ผ่านช่องสัญญาณที่มีการจางหายแบบเรย์ลีห์ดังแสดงในรูปที่ 2



รูปที่ 2 การส่งต่อสัญญาณในระบบการสื่อสารร่วมมือแบบไมโม



รูปที่ 3 การร่วมใช้ช่องสัญญาณของระบบการสื่อสารร่วมมือแบบไมโม

จากรูปที่ 2 การส่งต่อสัญญาณในระบบการสื่อสารร่วมมือแบบไมโม เครื่องส่งจะทำหน้าที่ส่งสัญญาณไปยังเครื่องรับปลายทาง และรีเลย์จะทำหน้าที่ส่งต่อสัญญาณที่สามารถรับได้จากเครื่องส่งไปยังเครื่องรับปลายทาง โดยกำหนดให้มีอัตราการกล้ำสัญญาณแบบเต็มอัตรา ซึ่งหมายถึงประสิทธิภาพในการใช้งานความกว้างแถบความถี่เท่ากับ 1 bps /Hz และพิจารณาผลรวมของกำลังส่งสัญญาณเท่ากับผลรวมของกำลังส่งจากเครื่องส่ง กับรีเลย์จะได้ ซึ่ง คือ กำลังงานรวมทั้งหมดในระบบ ระบบสื่อสารไร้สายร่วมมือนี้ จะมีการเข้าถึงช่องสัญญาณได้หลายวิธีการ แต่ในบทความนี้เป็นการพิจารณาโดยจะมีช่วงเวลาในการส่งสัญญาณ ตามการร่วมใช้ช่องสัญญาณแบบแบ่งเวลา (Time division multiple access: TDMA) ซึ่งรูปแบบของการร่วมใช้ช่องสัญญาณของระบบการสื่อสารร่วมมือ โดยทั่วไปนั้นจะเป็นการส่งสัญญาณไปยังเครื่องรับดังแสดงรูป 3 ส่วนการร่วมใช้ช่องสัญญาณในระบบการสื่อสารร่วมมือแบบไมโมเป็นการใช้ประโยชน์จากความหลากหลายของช่องสัญญาณเพื่อทำให้ระบบสามารถถอดรหัสสัญญาณข้อมูลได้ดีขึ้น แสดงในรูป 3 ในบทความนี้เป็นการส่งสัญญาณในรูปแบบเหมือนของระบบสื่อสารแบบไมโม โดยจะเห็นการร่วมใช้ช่องสัญญาณได้จากรูป 3 โดยจะเห็นว่า เป็นการประยุกต์เอาเทคนิคการเข้ารหัสเชิงพื้นที่เวลาแบบ Alamouti [5] มาใช้ในการส่งต่อสัญญาณข้อมูล หากพิจารณาตามรูปแบบการเข้าถึงช่องสัญญาณแบบหลายทางโดยการแบ่งเวลาดังรูปที่ 3 แล้ว จะสามารถแบ่งช่วงเวลาของการส่งสัญญาณออกเป็น 2 เฟสเวลาหลักๆได้ ดังต่อไปนี้คือ เฟสแรกเครื่องส่งทำการส่งสัญญาณข้อมูลไปยังรีเลย์และในเฟสที่สองรีเลย์จะทำการเปลี่ยนสัญญาณข้อมูลให้มีความสัมพันธ์กับเครื่องส่งเพื่อให้เครื่องรับสามารถรับสัญญาณข้อมูลได้เป็นแบบการเข้ารหัสเชิงพื้นที่เวลาแบบ Alamouti

3. ประสิทธิภาพของระบบการสื่อสารร่วมมือแบบไมโม

สัญญาณแทรกสอดและสัญญาณรบกวนในระบบสื่อสารซึ่งจะทำให้ประสิทธิภาพของระบบสื่อสารนั้นลดลงโดยทั่วไปจะใช้อัตราส่วนสัญญาณต่อสัญญาณรบกวน เป็นพารามิเตอร์เพื่อบ่งบอกถึงประสิทธิภาพของการสื่อสาร ว่ามีโอกาสได้รับสัญญาณที่มีความผิดเพี้ยนมากน้อยเพียงใด ในขณะที่มีสัญญาณรบกวนเข้ามา ซึ่งจำเป็นต้องใช้ความน่าจะเป็นและสถิติ (Probabilities and Statistics) มาคำนวณ โดยสัญญาณรบกวนนั้นเป็นสิ่งที่คาดการณ์ได้ยาก ดังนั้นขนาดและเฟสของมันจะเป็นไปแบบสุ่ม(Random) ตามเวลา ในบทความนี้ จะแสดงผลด้วยค่าความน่าจะเป็นของสัญญาณขาดหาย (Outage Probability) ซึ่งแสดงถึงความน่าจะเป็นของระบบจะน่าจะทำงานได้ต่อพลังงานที่ทำการส่งข้อมูล

การวัดประสิทธิภาพของระบบการสื่อสาร ดัชนีที่สำคัญที่ใช้ทำการประมาณประสิทธิภาพคือ ความน่าจะเป็นของสัญญาณขาดหาย [6] ซึ่งสามารถคำนวณโดยการใช้ ฟังก์ชั่นความหนาแน่นของความน่าจะเป็น (Probability Density Function: PDF) ของค่าสัมประสิทธิ์ของช่องสัญญาณหรืออัตราส่วนสัญญาณต่อสัญญาณรบกวนที่สามารถทำการรับได้จากทฤษฎีข้อมูลอัตราการส่งผ่านข้อมูล ผ่านช่องสัญญาณปรากฏการณ์ที่จะเกิดเหตุการณ์ที่ไม่สามารถส่งผ่านข้อมูลได้นั้นเกิดจากอัตราการส่งผ่านข้อมูลมีค่าน้อยกว่าความจุช่องสัญญาณ ซึ่งสามารถหาความน่าจะเป็นของสัญญาณขาดหายได้จาก

$$
\begin{aligned}
P_{out}(R) &\triangleq \Pr\left(\log_2\left(1+\mathrm{SNR}\,|h|^2\right) < R\right) \\
&= \Pr\left(\mathrm{SNR}\,|h|^2 < 2^R - 1\right)
\end{aligned} \tag{1}
$$

เมื่อ P_{out} คือความน่าจะเป็นของสัญญาณขาดหายและ h คือช่องสัญญาณในการส่งข้อมูล จากรูปที่ 2 จะสามารถพิจารณาความน่าจะเป็นของสัญญาณขาดหายได้จาก

$$C = \frac{1}{2}\min\left\{\log_2\left(1+\mathrm{SNR}_{s,r}\left|h_{s,r}\right|^2\right), \log_2\left(1+\mathrm{SNR}_d\,\|\mathrm{H}\|_F^2\right)\right\} \tag{2}$$

ดังนั้นความน่าจะเป็นของสัญญาณขาดหายจะได้เป็น

$$P_{out} = \Pr\left(\frac{1}{2}\min\left\{\log_2\left(1+\gamma_{s,r}\right), \log_2\left(1+\gamma_d\right)\right\} < R\right) \tag{3}$$

เมื่อ C คือความจุช่องสัญญาณของระบบการสื่อสารร่วมมือ

แบบไมโม กำหนดให้ $\gamma_{s,r} = \mathrm{SNR}_{s,r} \left|h_{s,r}\right|^2$ และ $\gamma_d = \mathrm{SNR}_d \left\|\mathbf{H}\right\|_F^2$ จากสมการที่ (3) สามารถเปลี่ยนรูปจะได้

$$P_{out} = \Pr\left(\gamma_{s,r} < 2^{2R} - 1\right) + \Pr\left(\gamma_{s,r} \geq 2^{2R} - 1\right)\Pr\left(\gamma_d < 2^{2R} - 1\right) \quad (4)$$

จัดรูปแบบสมการใหม่ด้วยการแจกแจงแบบเอ็กโปเนนเชียล (Exponential Distribution)จะได้

$$P_{out} = 1 - \exp\left(-\frac{2^{2R}-1}{\overline{\gamma}_{s,r}}\right) + \left[\exp\left(-\frac{2^{2R}-1}{\overline{\gamma}_{s,r}}\right) - \exp\left(-\frac{2^{2R}-1}{\overline{\gamma}_{s,r}} - \frac{2^{2R}-1}{\overline{\gamma}_d}\right)\right] \quad (5)$$

เมื่อ $e^{-x} \approx 1 - x$ จัดรูปสมการใหม่จะได้

$$P_{out} = \frac{2^{2R}-1}{\overline{\gamma}_{s,r}} + \frac{2^{2R}-1}{\overline{\gamma}_d} \quad (6)$$

กำหนด $P_s = \beta P_T$, $P_r = (1-\beta)P_T$, $P_s + P_r = P_T$ ส่วน $0 \leq \beta \leq 1$ ให้ $n_{s,r}^2 = n_d^2 = n_T^2$ จะได้ความน่าจะเป็นของสัญญาณขาดหายของระบบการสื่อสารร่วมมือแบบไมโม

$$P_{out} = \frac{2^{2R}-1}{\mathrm{SNR}}\left(\frac{1}{\beta\left\|\mathbf{H}\right\|_F^2} + \frac{1}{(1-\beta)\left\|\mathbf{H}\right\|_F^2} + \frac{1}{(1-\beta)h_{s,r}^2}\right) \quad (7)$$

เมื่อ β คือค่าการจัดสรรการใช้พลังงาน

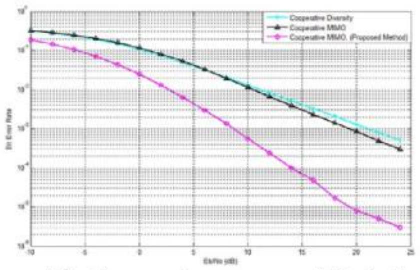
4. ผลการทดสอบ

เพื่อให้ทราบถึงสมรรถนะของระบบการสื่อสารร่วมมือแบบไมโมที่นำเสนอ ในบทความนี้ จึงได้มีการเปรียบเทียบประสิทธิภาพของระบบการสื่อสารร่วมมือแบบไมโมด้วยการจำลองแบบในคอมพิวเตอร์ ซึ่งพารามิเตอร์ที่จะใช้ทำการวัดประสิทธิภาพในระบบนี้ได้แก่พารามิเตอร์ต่างๆดังนี้

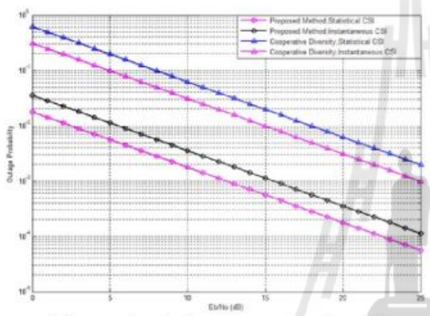
โดยประสิทธิภาพของระบบสารสื่อสารร่วมมือแบบไมโม ในส่วนนี้เป็นการพิจารณาถึงการผิดพลาดในการส่งต่อสัญญาณข้อมูลจากเครื่องส่งและรีเลย์ไปยังเครื่องรับโดยกำหนดให้เครื่องส่งติดตั้งสายอากาศ 1 ชุด รีเลย์ติดตั้งสายอากาศ 1 ชุด และเครื่องรับติดตั้งสายอากาศ 2 ชุด ส่งสัญญาณข้อมูลผ่านช่องสัญญาณที่มีการจางหายแบบเรลีย์ โดยพิจารณาเปรียบเทียบกับระบบการสื่อสารร่วมมือแบบเพิ่มความหลากหลายของช่องสัญญาณและการสื่อสารร่วมมือแบบไมโม ซึ่งการจำลองแบบของระบบการสื่อสารร่วมมือแบบไมโมที่ได้นำเสนอข้างต้น เป็นพิจารณาการจำลองแบบในคอมพิวเตอร์ ประสิทธิภาพอัตราความผิดพลาดของการตัดสินบิตข้อมูลของระบบการสื่อสารร่วมมือแบบไมโมที่ได้ทำการออกแบบแสดงดังรูปที่ 4

ประสิทธิภาพของความน่าจะเป็นของสัญญาณขาดหายเป็นการแสดงถึงโอกาสที่การส่งสัญญาณของระบบการสื่อสารร่วมมือแบบไมโมที่ได้ทำการนำเสนอนั้น จะไม่สามารถที่จะทำงานได้ โดยในส่วนนี้เป็นการจำลองแบบของความน่าจะเป็นของสัญญาณขาดหายที่ได้ทำการวิเคราะห์ผลทางคณิตศาสตร์ตามสมการที่ (7) ซึ่งทำการจำลองแบบด้วยข้อมูลของสถานะของช่องสัญญาณแบบทันทีทันใด (Instantaneous Channel State Information:Instantaneous CSI) หรือข้อมูลของสถานะของช่องสัญญาณระยะสั้น [7] คือข้อมูลที่บ่งบอกสถานะของช่องสัญญาณในช่วงเวลาขณะนั้นแบบสั้นเพื่อใช้ปรับแต่งสัญญาณให้มีคุณภาพดีขึ้น ซึ่งสามารถเห็นได้จากที่เครื่องส่งและรีเลย์จัดสรรพลังงานในการส่งมากที่สุดของความจุช่องสัญญาณและทำการจำลองแบบด้วยข้อมูลของสถานะของช่องสัญญาณแบบสถิติ(Statistical Channel State Information: Statistical CSI) หรือข้อมูลของสถานะของช่องสัญญาณระยะยาว [8] หมายถึงคุณสมบัติทางสถิติของช่องสัญญาณที่ทำให้รู้ถึงสถานะของช่องสัญญาณ ซึ่งสามารถเห็นได้จากที่เครื่องส่งและรีเลย์จัดสรรพลังงานในการส่งน้อยที่สุดของความจุช่องสัญญาณ โดยแบ่งการจำลองแบบเป็นความน่าจะเป็นของสัญญาณขาดหายต่อพลังที่ใช้ส่งสัญญาณข้อมูล ความน่าจะเป็นของสัญญาณขาดหายต่ออัตราการส่งสัญญาณข้อมูล ความน่าจะเป็นของสัญญาณขาดหายเมื่อระยะห่างของรีเลย์มีการเปลี่ยนแปลงและ ความน่าจะเป็นของสัญญาณขาดหายต่อดัชนีการจัดสรรพลังงาน ซึ่งแสดงตามรูปที่ 5 ถึง รูปที่ 7 ตามลับดับ

จากรูปที่ 5 ถึงรูปที่ 7 แสดงถึงประสิทธิภาพของความน่าจะเป็นของสัญญาณขาดหายในรูปแบบต่างๆ โดยรูปที่ 5 แสดง

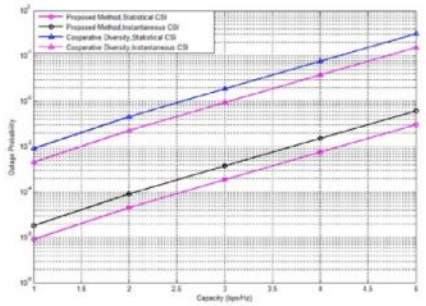


รูปที่ 4 อัตราความผิดพลาดของการตัดสินบิตข้อมูลเปรียบเทียบกับระบบการสื่อสารร่วมมืออื่น

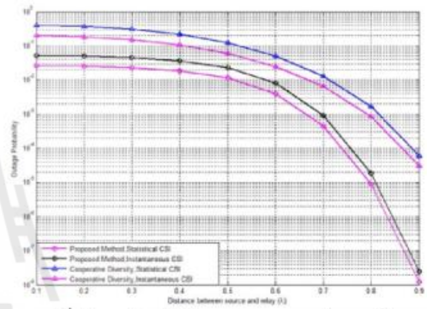


รูปที่ 5 ประสิทธิภาพของความน่าจะเป็นของสัญญาณขาดหายเทียบกับอัตราการส่งสัญญาณข้อมูล

ถึงความน่าจะเป็นของสัญญาณขาดหายต่อการใช้พลังงานในการส่งสัญญาณข้อมูล ซึ่งนำระบบการสื่อสารร่วมมือแบบไมโมที่ได้ทำการนำเสนอเทียบกับระบบการสื่อสารร่วมที่ใช้วิธีการส่งสัญญาณข้อมูลโดยใช้ความหลากหลายของช่องสัญญาณ จากรูประบบการสื่อสารร่วมมือแบบไมโมที่ได้ทำการออกแบบมีโอกาสที่สัญญาณจะขาดหายต่ำกว่าระบบการสื่อสารร่วมที่ใช้วิธีการส่งสัญญาณข้อมูลโดยใช้ความหลากหลายของช่องสัญญาณ จากรูปที่ 6 แสดงถึงประสิทธิภาพของความน่าจะเป็นของสัญญาณขาดหายเทียบกับประสิทธิภาพสเปกตรัม (Spectral Efficiency) โดยเป็นการนำเสนอระบบการสื่อสารร่วมมือแบบไมโมที่ได้ทำการการสื่อสารร่วมมือแบบไมโมที่ได้ทำการนำเสนอ เมื่อทำการเพิ่มอัตราการส่งข้อมูลให้



รูปที่ 6 ประสิทธิภาพของความน่าจะเป็นของสัญญาณขาดหายเทียบกับประสิทธิภาพสเปกตรัม



รูปที่ 7 ประสิทธิภาพของความน่าจะเป็นของสัญญาณขาดหายเมื่อระยะรีเลย์มีการเปลี่ยนแปลง

สูงขึ้นโอกาสที่สัญญาณจะขาดหายต่ำกว่าระบบการสื่อสารร่วมที่ใช้วิธีการส่งสัญญาณข้อมูลโดยใช้ความหลากหลายของช่องสัญญาณ ส่วนรูปที่ 7 แสดงถึงประสิทธิภาพของความน่าจะเป็นของสัญญาณขาดหายเมื่อระยะรีเลย์มีการเปลี่ยนแปลง โดยเป็นการนำเสนอระบบการสื่อสารร่วมมือแบบไมโมที่ได้ทำการนำเสนอเทียบกับระบบการสื่อสารร่วมที่ใช้วิธีการส่งสัญญาณข้อมูลโดยใช้ความหลากหลายของช่องสัญญาณ จากรูประบบการสื่อสารร่วมมือแบบไมโมที่ได้ทำการนำเสนอ เมื่อทำการเปลี่ยนแปลงตำแหน่งของรีเลย์จากเครื่องส่งไปยังเครื่องรับ โอกาสที่สัญญาณจะขาดหายในช่วงที่รีเลย์อยู่ใกล้เครื่องส่ง มากกว่าเครื่องรับและโอกาสที่สัญญาณ

จะขาดหายต่ำกว่า ระบบการสื่อสารร่วมที่ใช้วิธีการส่งสัญญาณข้อมูลโดยใช้ความหลากหลายของช่องสัญญาณ

5. บทสรุป

บทความนี้นำเสนอการวิเคราะห์ประสิทธิภาพของระบบการสื่อสารร่วมมือแบบไมโมด้วยพารามิเตอร์ต่างๆ เช่นการผิดพลาดของบิตข้อมูลที่สามารถรับได้ ความน่าจะเป็นที่สัญญาณจะมีการขาดหาย โดยทำการเปรียบเทียบกันกับระบบการสื่อสารร่วมมือแบบไดเวอร์ซิติ้ ในรูปแบบการทำงานที่แตกต่างกันไป ซึ่งแสดงให้เห็นถึงประสิทธิภาพของระบบการสื่อสารร่วมมือแบบไมโมที่นำเสนอนั้นสามารถช่วยลดการผิดพลาดของบิตข้อมูลของระบบลงและสามารถเพิ่มประสิทธิภาพของระบบให้สูงขึ้น

6. เอกสารอ้างอิง

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BIOGRAPHY

Mr. Thossaporn Chanpuek was born in May 14, 1980 in Nakhon Ratchasima province, Thailand. He received the Bachelor's Degree in electronic engineering from Vongchavalitkul University, in 2001 and Master's Degree Dhurakij Pundit University in computer and telecommunication engineering, in 2010. He served in position of lecturer at Division of Industry Education, Nakhon Ratchasima Rajabhat University since 2015. At present, he is working towards his Ph.D. degree in telecommunication engineering at Suranaree University of Technology.