Performance of multi-relay cooperative communication using decode and forward protocol

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Abstract. Nowadays, the development of wireless communication systems will be refer to user cooperative communication system in which a source information can transmit data to a destination through a relay. This can reduce the effect of fading on wireless communication channel which is a major problem in wireless communication system that can degrade the system performance. In this paper, we investigate the performance of multi-relay cooperative communication using decode and forward protocol in terms of channel capacity, bit error rate (BER) and throughput. The use of decode and forward protocol in multi-relay cooperative communication offers cooperation among users to generate virtual multiple antennas to increase the channel capacity and also can give better system performance. Furthermore, the simulation model of the system and computer simulation is developed to evaluate the performance of multi-relay cooperative communication. The simulation result shows that the channel capacity increases as the value of signal to noise ratio (SNR) increases. Also, the channel capacity increases as the number of relays increases. Moreover, the performance of multi-relay cooperative communication performs better than a single-relay cooperative communication by using decode and forward protocol in terms of BER. Furthermore, multi-relay cooperative communication provides a good throughput of the system compared to a single-relay. Therefore, the multi-relay cooperative communication is useful to mitigate the effects of channel fading, increase the channel capacity, improve the system performance and provide a good throughput by exploiting decode and forward protocol.
Keywords: Cooperative communication, multi-relay, bit error rate, decode and forward protocol

Introduction

Recently, wireless communication is a highly demanded and ubiquitous part of modern life in communcation technology especially for mobile access. However, there are several challenges in wireless communication channel that suffers from multipath fading, shadowing and path loss effects (Ibrahim, 2008). These challenges have a great impact to the system performance degradation. Based on the facts, there are numerous solutions to solve the problems such as diversity technology (Kim, 2011), wireless relaying (Herhold, 2004), etc. The diversity or relaying technology can improve the performance of wireless communications in which the signal is separated the fading path during transmission by exploiting diversity in different channel dimensions (as time, frequency and space), and achieve diversity gains. In particular, diversity technique refers to multiple-input multiple-output (MIMO) which is desirable to equip wireless transceivers with multiple antennas to achieve spatial diversity gains. However, the technique is impractical due to wireless users may not be able to support size, cost, and power constraint of wireless devices, and a single terminal should have multiple antennas. To overcome such a case, cooperative communications can be the most promising alternative by applying a virtual distributed MIMO antenna system.

Cooperative communication is a communication system that refers to the cooperation among the users in transmitting the information. It is a powerful technique to combat fading and provide robust transmission in wireless communication system (Ekta, 2011; Wang, 2010). In the system, besides as a source, the user can also function as a relay.

Spatial diversity technique in cooperative communication system is very useful to be implied in a wireless communication system especially in cellular communication because it uses a single or multi-relay that functions as virtual multiple antennas in transmitting the information to the destination. Cooperative transmission by using relay nodes has ability to improve overall the system performance. A single-relay or multiple-relay is placed between a source and destination. The relay is first decode the transmitted signal and then forward the decoded signal to the destination. This method is called as decode and forward. It exploits signaling redudancy in time domain without violating causality in the relay network. It also does not cause noise amplification (Zhao, 2007). Since a wireless communication uses digital modulation, the decode and forward method is preferred to process the signal in the relay. It is possible to improve throughput, coverage, capacity, and realibility of wireless network (Lee, 2009). Thus the method may be the most suitable for mobile uplink communication systems. Therefore, this paper proposes a simulation model to evaluate the performance of multi-relay cooperative communication using decode and forward protocol.
This paper considers a cooperative communication system, where information is to be transmitted from a source to a destination through a multi-relay by using decode and forward protocol. The multi-relay can overhear the transmitted information and cooperated with the source to send its data. Then, transmitted data are combined at the destination using maximum ratio combining (MRC). The distance between source and relay or relay to destination is assumed equal. The speed of mobility for the source or destination is not considered in this paper. Furthermore, the link between source and destination is modelled as Fading channel with additive white gaussian noise (AWGN). By the asumptions, a computer simulation is developed using Matlab programming to evaluate several parameters that have impact on the performance of multi-relay cooperative communication including channel capacity, bit error rate (BER) and throughput. Finally, the parameters of the system performance are analyzed based on the simulation results.

System Model

A) Multi-relay Cooperative Communication

In multi-relay cooperative communication, the cooperation among some users can be as a cooperative network where the user is stated as source, relay, and destination. In cooperative network, other user is needed to reach the coverage network of a destination user. In the implementation, many users in a network are to be many paths of transmission line. Channel system in cooperative communication is considered as mobile or fixed channel. As a mobile channel, the user is assumed in mobile condition when the transmitting process is in progress. The mobility can cause Doppler Effect. While for fixed channel, the user is assumed static or not moving when transmitting the information. Information processing at relay uses protocol in signaling method such as estimate and forward, amplify and forward, decode and forward (Chakrabarti, 2006).

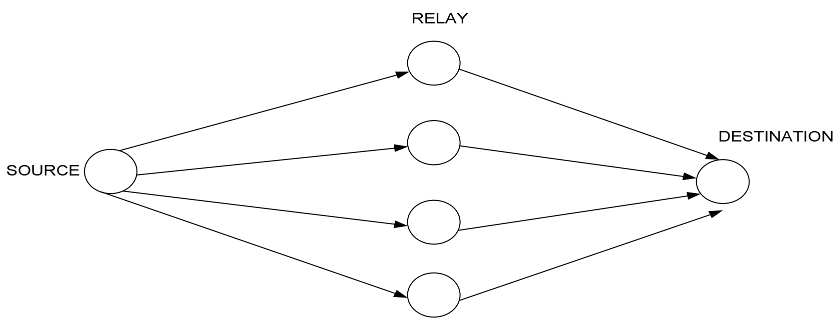

Figure 1. Cooperative communication system with four relays.

There are two receiving information methods at destination which are Selection Relaying and Incremental Relaying (Laneman, 2004). Under the best selection relaying method, destination only receives signal from the fastest relay that transmits the information from source, thus no need to combine the signal at destination if the destination has received the information signal from the fastest relay, then other relay is considered to be failed. This method is only applied if the signal at the destination has a good SNR without signal combining. While if incremental relaying method is applied, then the destination will amplify the signal by combining the received signals from all relays and choose the one with the best SNR. This method is usually used in decode and forward protocol since in this protocol the signal is not being amplified by the relay, thus it is needed to combine the signal at the destination. Nevertheless, it is possible to use this method in other protocols. In this paper, we use the decode and forward protocol with incremental relaying method using maximum ratio combining (MRC) as the combining technique. The model consists of one source, four relays and one destination as shown in Figure 1. First, source will transmit the information to each relay to be forwarded to destination. The destination will receive all information from relays before combining them using MRC method. If all the information received by the destination has no error then the destination will send acknowledgement (ACK) to source as a sign that the information has been received. The modulation technique used in this system is Binary Phase Shift Keying (BPSK) by fading distributed channel with AWGN.

B) Decode and Forward Protocol

A simple cooperative communication system by using decode and forward protocol is illustrated in Figure 2. The transmitted signal from user A (source) can be directly sent to a destination or it is sent through a relay (user B) to the destination. This strategy follows that the relay station decodes the received signal from the source node, re-encodes it and forwards it to the destination station. At decode and forward protocol, source will choose the closest node (from the same cell or nearest cell) with source destination line as the relay (Gamal, 2004). If source choose the node that far away from the relay, it is likely that the sensitivity of signal receiving is low. In this condition, it is possible to have an error of the received signal at the relay. On decode and forward protocol, relay will process and decode the information received from the source before it is sent to the destination using re-encoded process. In this way, relay functions only as the media without signal amplifying. If a system (node) can be a relay, then the system will forward the received information from source to destination but if the node cannot be as relay then the node will not respond to any signal sent by source, so the relay remains silent (Herhold, 2004). If the received information contains error then relay will send not-acknowledgement (NACK) to source which shows that source has to re-send signal to relay to be forwarded to destination. There is Cyclic Redundancy Check (CRC) at relay and destination that functions as error detection in decision making process using Automatic Repeat Request (ARQ) mechanism.

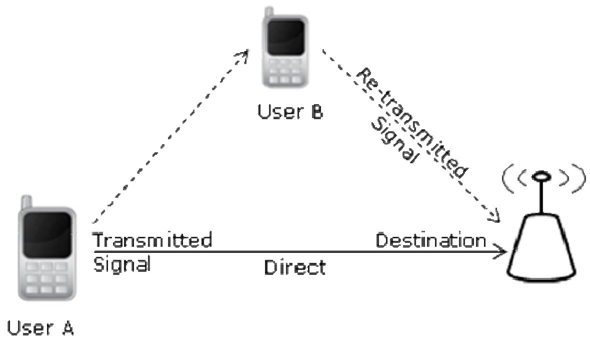

Figure 2. Conventional a single-relay decode and forward.

Materials and Methods

The method used in this research is first conducting the literature study related to the concept of multi-relay cooperative communication and decode and forward protocol from various references. Then, identify the performance parameters for multi-relay cooperative communication using the decode and forward protocol. Next, modeling of multi relay cooperative communication is developed as shown in Figure 3 that is used to make a computer simulation by using MATLAB programming. In the Figure 3, the input data is sent to the relay through encoding and modulation processes where the signal suffers from fading and AWGN. The relay selection method is decode and forward. At the relay, decision is processed using CRC, and then decode and re-encode the signal before sending to the destination through BPSK modulation and decoding process to obtain the output data. Finally, the simulation results are analyzed in terms of channel capacity, BER and throughput of multi-relay cooperative communication using decode and forward protocol. The results are also compared to the performance of a single-relay cooperative communication.

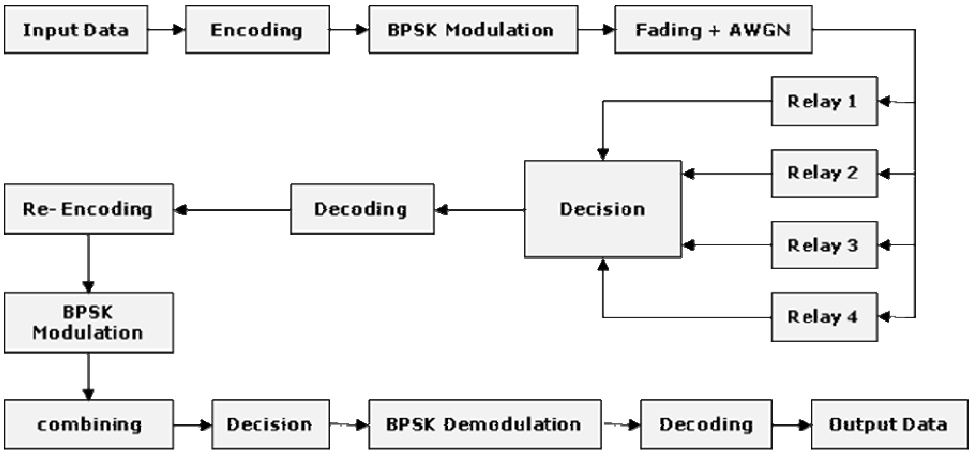

Figure 3. Computer simulation model for Multi-relay cooperative communication.

Results and Discussion

The performance of the proposed model is investigated in this section. We have simulated for the system which consists of one source, four relays and one destination. It is assumed that the distance from each other is equal. The path loss and average SNR are also assumed to be the same. The other simulation parameters are summarized in Table 1.
Table. 1 Simulation parameters.

Parameter	Specification
Number of input	10^5 bit
Modulation type	BPSK
Number of source	1
Number of relays	4
Number of destination	1
Combining technique	MRC
Channel	Fading and AWGN
Range of SNR	0 dB – 30 dB

A) Channel Capacity

Channel capacity is the maximum rate at which information can be communicated across a noisy channel with arbitrary reliability. It is affected by interference in the channel due to the effect of using the radio wave in wireless communication. To reduce the interference and enhance the channel capacity, it is suggested to use multi antennas. Then, the channel capacity can be calculated using the below equation (Berber, 2001).

$$c=\frac{1}{2}\log_2\left(1+\frac{s}{N}\right)=\frac{1}{2}\log_2\left(1+g^2\left[1+\frac{\pi}{4}(m-1)\right]\frac{p}{N}\right)$$

Where ς is a constant with value 1, while *P/N* is the value of *S/N* which is usually called SNR. The total of transmission power is stated as *P* and the number of relays is *m*. The source allocates the same amount of transmission power for each relay, it is stated as *P/m*.

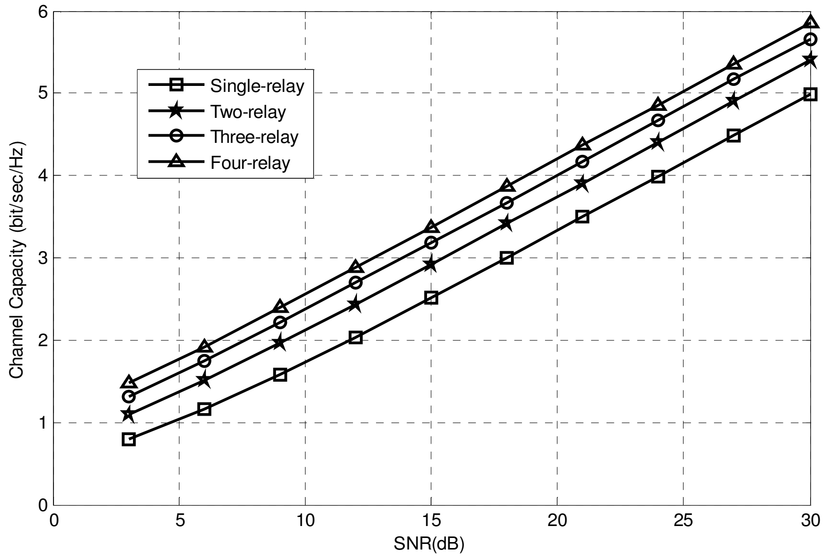

Figure 4. Channel capacity performance by increasing the number of relays.

Figure 4 shows the value of channel capacity to SNR for a single-relay to four relays. SNR value is about 3 to 30 dB. As we can see that the channel capacity increases as the SNR value increases. For SNR 10 dB, the channel capacity for a single-relay, two relays, three relays and four relays are 1.8 bit/sec/Hz, 2.2 bit/sec/Hz, 2.3 bit/sec/Hz, and 2.5 bit/sec/Hz, respectively. For SNR 20 dB, the channel capacity for a single-relay, two relays, three relays and four relays are 3.4 bit/sec/Hz, 3.7 bit/sec/Hz, 4 bit/sec/Hz, and 4.2 bit/sec/Hz, respectively. The figure shows that for SNR 30 dB, the channel capacity for a single-relay, two relays, three relays and four relays are 5 bit/sec/Hz, 5.4 bit/sec/Hz, 5.6 bit/sec/Hz, and 5.8 bit/sec/Hz, respectively. The results show channel capacity for multi-relay is better than a single relay in the cooperative communication. So, by allowing the system to have multi-relay, it can improve the spectral efficiency of the system. Future wireless systems are characterized by large user-capacity, high speed, and high reliability. Based on fact that cooperative communication has ability to increase channel capacity. Therefore, the required large capacity of network can be considered to applied the multi-relay system.

B) Bit Error Rate

In the computer simulation, we have simulated a single-relay and multi-relay cooperative network using decode and forward protocol with different rates of convolutional codes. Decode and forward relay has capability introduced in the relay for decoding incoming signal and then retransmitting the signal to the destination. The threshold decoding is to ensure that signal forwarded by the relay is reliable since the number of times, reliably detected signal is relayed to the destination that has an impact on the cooperation benefit. Therefore, the BER of decode and forward of relays is an important system performance criterion. However, a major problem with the decode and forward protocol is not simply to realize the cooperative diversity due to it is possible for retransmission of erroneously decoded information by the relays. To solve this problem, an error detection code can be added at the source. In this paper, we consider to used convolutional code as an error correction code. The following figures show the performance of BER to SNR using BPSK modulation under the channel that distributed by fading and AWGN. From the figure, it can be observed that there is difference in the BER performance between a single relay and multi-relay cooperative communication using decode and forward protocol with convolutional Encoder rates of 1/2 and 1/3 for code length *L*=3. Total bit used in this simulation is 10^5 bits with valid BER up to 10^{-5}.

Figure 5 shows the BER performance for multi-relay cooperative communication with convolution code with rate of ½. Using cooperative communication with BER 10^{-3}, the SNR for a single relay to four relays are about 14 dB, 13 dB, 12 dB, and 11 dB, respectively. It means that there is difference 1 dB between cooperative communication with one relay and two relays, and 2 dB between cooperative communication with a single-relay and three relays, and 3 dB between cooperative communication with a single-relay and four relays. Whereas user cooperative communication with BER=10^{-5}, the SNR value is 25 dB for cooperative communication with a single-relay, with two relays is 23 dB, with three relays is 22 dB, and with four relays is 21 dB. This means that there is difference about 2 dB between cooperative communication with a single-relay and two relays, 3 dB between one relay and three relays, and 4 dB between a single-relay and four relays.

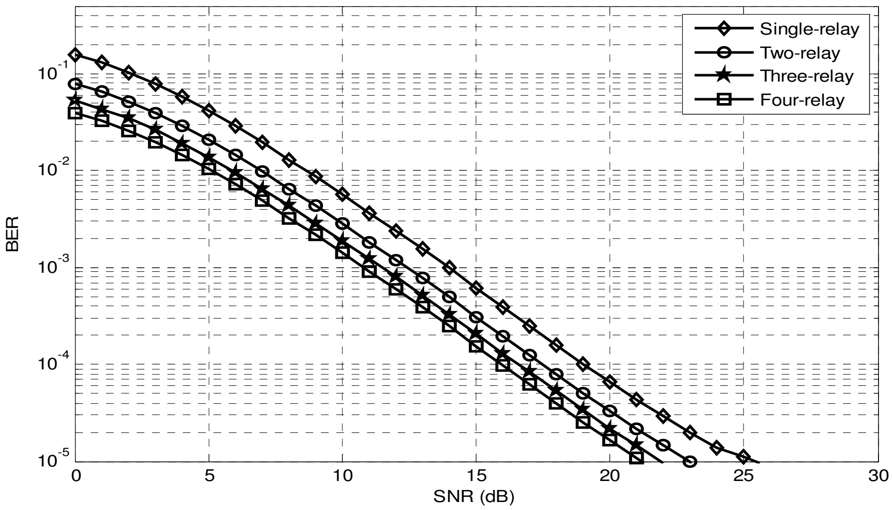

Figure 5. The BER performance for cooperative communication with convolutional encoder rate ½ and *L* = 3.

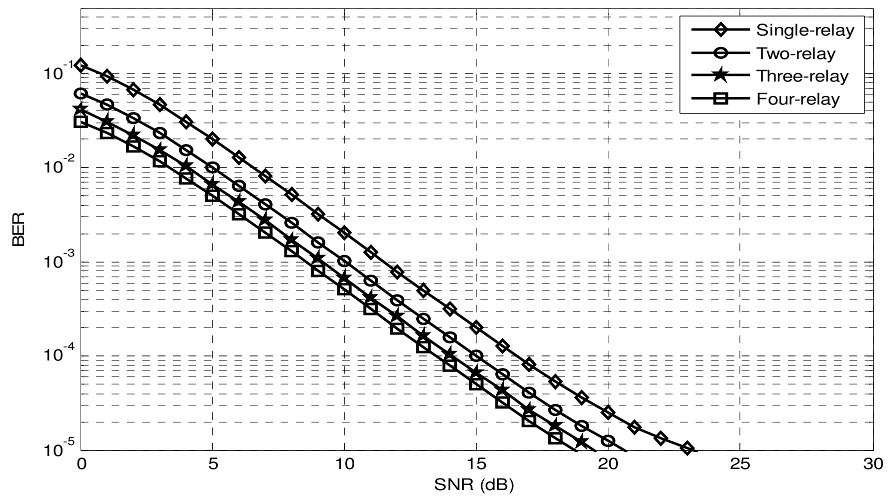

Figure 6. The BER performance for cooperative communication with convolutional encoder rate 1/3 and *L* = 3.

When convolutional code with rate of 1/3 is applied, the BER performance is shown in Figure 6. To reach BER of 10^{-3}, the SNR values for cooperative communication with a single-relay to four relays are about 11 dB, 10 dB, 9 dB, and 8 dB, respectively. While for BER is 10^{-5}, the required SNR for a single-relay to four relays are 23 dB, 20,5 dB, 19,5 dB, and 18,5 dB, respectively. We can see that the BER of multi-relay outperforms the BER of a single-relay system. For instance, 4,5 dB can be save in order to acheive the same BER of 10^{-5} when the number of relays in the system is four relays. It can concluded that the BER performance for multi-relay is better than a single-relay. Furthermore, the BER performance is improved by using lower rate of convolutional encoder. The improvement of the BER is noticeable due to the diversity gain improvement in the cooperative transmission. Increasing the number of relays in the system can further improve the diversity gain.

C) Throughput

Throughput can be defined as the size of data that can be sent from the source to the destination for each unit of time. The relationship between throughput and SNR value against the number of relays can be expressed as (Dai, 2006)

$$T = \frac{1}{2}\log_2(1+\rho\sum_{j=0}^{N_j}\| h_j \|)^2$$

where T is throughput, N_j is number of relays, ρ is SNR value and h_j is fading channel coefficient.

Figure 7 shows the The relationship between throughput and SNR value against the number of relays in the proposed model of cooperative communication with one to four relays. For the SNR is 15 dB, the throughput for a single-relay to four relays are 2 bit/s, 3 bit/s, 3.7 bit/s, and 4.2 bit/s, respectively. When SNR is 30 dB, the throughput for a single-relay to four relays are 2.5 bit/s, 3.5 bit/s, 4.2 bit/s and 4.6 bit/s, respectively. From these results, we can see that the throughput of cooperative communications is affected by increasing the value of SNR where the throughput increases as the value of SNR increases. It shows that the throughput gain is remarkable when the number of relays is increasing from a single-relay to four-relay. So, the number of relays in the cooperative communication also influences the throughput in which the throughput increases as the number of relays increases.

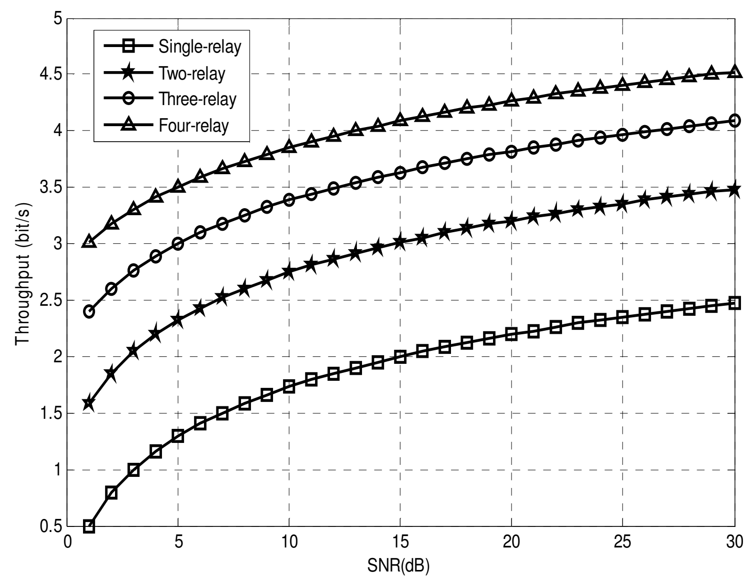

Figure 7. Throughput performance by increasing the number of relays.

Conclusions

This paper has been proposed a model to investigate the performance of multi-relay cooperative communication using decode and forward protocol. In order to evaluate the system performance, several parameters have been identified including channel capacity, bit error rate (BER) and throughput of the multi-relay cooperative communication. The proposed model has been used to develop the computer simulation by using Matlab programming to obtain the parameters of the system performance. The simulation results showed that capacity channel of the system is increased as the SNR values and number of relays are increased. The BER of multi-relay cooperative communication performs better when the lower rate of convolutional code is employed in the system. However, the information rate of the system becomes slower than the expected rate. The improvement of the BER performance is noticeable due to the diversity gain improvement in the multi-relay cooperative communication. Furthermore, the throughput of system is also impacted by number of relays and the SNR values, where throughput increases as the SNR values and number of relays are increased. So that, the proposed multi-relay cooperative communication using decode and forward protocol will be an interesting candidate for future wireless communication that requires large capacity, lower BER and high throughput.

References

Berber S., Naqvi H., Temerinac M., Kovacevic, V. 2001. Capacity Calculation for Multi-Relay Channel In Presence Of Noise And Fading. Recent Researches in Communications and IT. 271-276.

Chakrabarti A., Sabharwal A., Aazhang, B. 2006. Cooperative Communication. Rice University.

Dai L., Chen W., Letaife B.K., Cao Z. 2006. A Fair Multiuser In Cooperation Protocol for Increasing the Throughput in Energy–Constrained Ad–hoc Networks. IEEE ICC 2006. 8: 3363-3368.

Ekta H., Upadhyay. 2011. Multiple Relay aided Cooperative Communication Scheme. International Journal of Electronics & Communication Technology, 2(2): 46-49.

Gamal E.A, Mammen J., Prabhakar B., Shah D. 2004. Throughput-Delay Trade Off In Wireless Network. IEEE INFOCOM 2004.

Gurrala K.K., Das S. 2012. Impact of Relay Location on the Performance of Multi-relay Cooperative Communication. International Journal of Computer Networks and Wireless Communications, 2 (2): 226-231.

Herhold P., Zimmerman E., Fetteweis G. 2004. A Simple Cooperative Extension to Wireless Relaying. Technische Universitat Dresden, Vodavon Mobile Communication System, Dresden, Germany.

Ibrahim A.S., Sadek A.K., Su W., Liu R.J.K. 2008. Cooperative communications with Relay-Selection: When to Cooperate and Whom to Cooperate With?. IEEE Transaction on Wireless Communications, 7(7): 2814-2827.

Kim J., Michalopoulos S.D., Schober R. 2011. Diversity Analysis of Multi-User Multi-Relay Networks. IEEE Transactions on Wireless Communications, 10(7): 2380-2389.

Laneman J.N., Prasanna Tse., David N.C., Wornell, G.W. 2004. Cooperative Diversity In Wireless Networks: Efficient Protocols and Outage Behavior. IEEE Transaction on Information Theory, 50(12): 3062-3080.

Lee Y., Tsai M.H. 2009. Performance of Decode-and-Forward Cooperative Communications Over Nakagami-m Fading Channels. IEEE Transaction on vihicle technology, 58(3): 1218-1228.

Wang J., Liang J., Muhaidat S. 2010. Distortion Exponents for Multi-Relay Cooperative Networks with Limited Feedback. IEEE Transactions on Vehicular Technology, 59(7): 3417-3426.

Zhao J., Kuhn M., Wittneben A., Bauch G. 2007. Cooperative Transmission Schemes for Decode-and-Forward relaying. The 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'07).