Comparison of Selection and Maximal Ratio Combining in Cooperative Network Coding with AF and DF

Muhammad Iqbal[1,5], Suwadi[2], Wirawan[3], Rina Pudjiastuti[4]

[123]*Department of Electrical Engineering, Institut Teknologi Sepuluh November, Surabaya, Indonesia*

[4,5]*Universitas Telkom, Bandung, Indonesia*

[1,5]iqbal14@mhs.ee.its.ac.id, [2]suwadi@its.ac.id,

[3]wirawan@its.ac.id, [4]rinapudjiastuti@telkomuniversity.ac.id

Abstract – Cooperative communication of network coding system is a technique used to overcome the problems of multipath fading, despite the obstacles that still occur are not yet optimal SNR to be good performance. In this paper the author provides a solution by considering two concepts combining which used selection combining (SC) and maximal ratio combining (MRC). By using two general strategies relay protocols of cooperative that amplify-and-forward (AF) and decode-and-forward (DF). Components of the measurement are to calculate the bit error rate (BER) and throughput. Results of the research are SC value BER better than MRC, because network coding have fading coefficient MRC becomes greater than SC only choose one of the best signal. Throughput which on using MRC and SC resulted greater value using network coding than without using network coding.

Keywords: Cooperative, Network Coding, AF, DF, MRC and SC

I. INTRODUCTION

Spatial diversity is a technique that uses multiple antennas such as multiple input multiple output (MIMO), which has proven effective in increasing network capacity. But not all the concept of multiple antennas suitable for wireless communication devices, because the communication device requires a small device. To overcome these problems introduced by the term spatial diversity antennas without much physically, in terms of cooperative communications [1] [2]. The communication cooperative system works on using a single antenna physical and uses the concept of virtual MIMO to increase network capacity.

Strategies relay needed to determine the type of protocol relay to be used, there are two types of families are transparent protocol and regenerative protocol, some of transparent protocol relay that are amplify-and-forward (AF), linear-process-and-forward (LnF), while for the regenerative protocol relay are decode-and-forward (DF), estimate-and-forward (EF), purge-and-forward (PG), and others. In [3], Zhang explained about the advantages of using the AF and DF cooperative relay for secure communication using techniques Wyner's wiretap channels, the result is that the AF and DF safer without using a relay protocol, this experiment is on wireless channels. In [4], describe AF and DF relay protocol, parameters used to measure the energy efficiency, the result showed that the DF to produce more energy-efficient values. Cognitive Radio (CR) communication and cooperative use as improved bandwidth efficiency [5], using a cooperative strategy relay AF and DF, the results obtained AF is better than the results of simulation and analysis, although the value obtained is not so significant, but it proved to increase throughput in the system. The author in [6], proposed a merger of AF and DF using Nakagami-m fading channels that are independent, because cooperative systems using maximal ratio combining (MRC) in the method of analysis. The results that technique can work on any fading channel conditions, some problems such as the complexity and performance associated with the use of two strategies the relay. The first paper discussed the network coding with TWRC [7], using the relay as a node broadcast on wireless channels. In paper [8], discussed the channel-decoded scheme of network coding (CNC), using a repeat accumulate (RA) on TWRC.

Results of some studies literature has not been discussion of the comparison between the MRC and SC using network coding cooperative scheme. In the cooperative system scheme can not be separated from the relay usage scenarios, this research will use a dual-hop relay or TWRC (Two-way Relay Channel) which is the basis of the structure of wireless communication in some research community.

In this research will be discussed issues related to cooperative to overcome the issue of multiple fading, researchers have proposed a network coding techniques to relay strategy using AF and DF, compare the parameters with maximal ratio combining and selection combining. Throughput and SNR is a component of the result of the use of cooperative network coding.

In the rest of the paper as follows. Chapter I, Introduction about MIMO problems to overcome multipath fading. In chapter II System Description, a model cooperative system, amplify-and-forward, decode-and-forward, and MRC. In Chapter III, research model, discussed about cooperative network coding. In chapter IV, simulated bit error rate DF and AF with maximal ratio combining (MRC) and selection combining (SC) analysis of the data, and gave results of the simulations that have been proposed. In Chapter V, the conclusion of the results that have been obtained.

II. SYSTEM DESCRIPTION

In general, a simple cooperative communications consists of two nodes (one as a source and one as a relay) that communicates with the same destination, each node consists of only one antenna. Cooperative function is divided into two phase, cooperative transmission and direct transmission. In figure 2.1 is an illustration of the cooperative communication system. Direct Link (DL) is a direct communication between node S and node D with links (S, D), where S is the transmitter and D is receiver

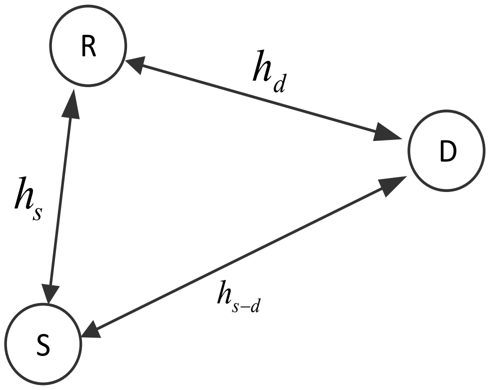

Figure 2.1 Cooperative Communication

We describe mathematical model of the transmit signals and receive signals with amplify-and-forward (AF) and decode-and-forward (DF) relay system. Data information sent between the S-R is $s_1(t)$ and D-R is $s_2(t)$, then the function of network coding is $f(s_1, s_2)$ which is the XOR operation

$$x_r = s_1 \oplus s_2 \tag{1}$$

QPSK modulation :

$$s_1 = (a_1[1] + jb_1[1], .., a_1[M] + jb_1[M]) \tag{2}$$

$$s_2 = (a_2[1] + jb_2[1], .., a_2[M] + jb_2[M]) \tag{3}$$

$$x_r = \begin{pmatrix} (a_1[1] + jb_1[1], .., a_1[M] + jb_1[M]) \\ \oplus\ (a_2[1] + jb_2[1], .., a_2[M] + jb_2[M]) \end{pmatrix} \tag{4}$$

Received signal at relay :

$$y_r = s_1 + s_2 + n_r \tag{5}$$

Thus, the received signals at S and D

$$y_s = x_r + n_s \tag{6}$$

$$y_d = x_r + n_d \tag{7}$$

Fading coefficients used in the model is additive white gaussian noise (AWGN) with two-way relay channel (TWRC) is modeled in equation 2 and 3. Where every noise has i.i.d, $n_s \sim \aleph(0, N_1)$, $n_d \sim \aleph(0, N_2)$, $n_r \sim \aleph(0, N_r)$.

2.1 *Amplify-and-forward (AF)*

In the relay protocol strategy to amplify-and-forward (AF). In the first timeslot of $T/_2$ second. Node S and D, transmit information simultaneously. Symbol which is broadcast at the relay node is

$$x_r(n) = \alpha y_r(n) \tag{8}$$

Where α is the coefficient of amplify. With an average symbol used in relay P_r. Accordingly, α can be determined with the following formulation :

$$\alpha = \sqrt{\frac{P_r}{|h_s|^2 P_s + |h_d|^2 P_d + n_r B}} \tag{9}$$

Where B is a flat fading bandwidth is fading coefficient between source and relay. At node S, the received symbol is :

$$y_s(n) = h_s x_r(n) + n_r(n) \tag{10}$$

At node S, signal information received is

$$y_s(n) = h_s x_r(n) + n_s(n)$$

$$= h_s \alpha (h_s \sqrt{P_s} x_s(n) + h_d \sqrt{P_d} x_b(n) + n_s(n) \tag{11}$$

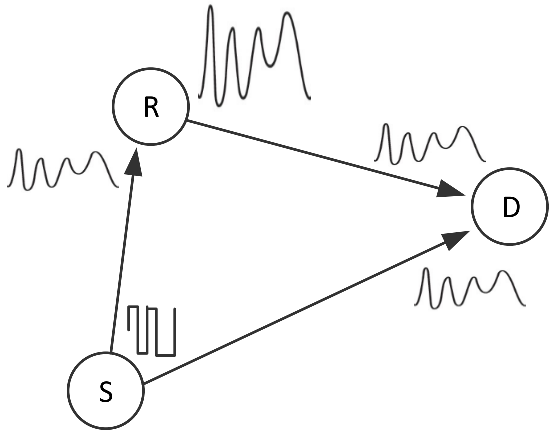

Figure 2.2 *Amplify-and-Forward*

2.2 Decode-and-forward (DF)

First proposed by Sendonaris, et al [9], using code-division multiple access (CDMA) to implement the decode-and-forward for the cooperative transmission. Scheme used two users who are connected to each other. Each user has a spreading code is denoted by $s_1(t)$ and $s_2(t)$, Signal amplitude is denoted by is d_i where, $i = 1,2..n$. Signal amplitude is denoted by $a_{i,j}$. So that every user (S_i and D_i) can be described with the information signal

$$S_i(t) = [a_{11} d_1^1 s_1, a_{12} d_1^2 s_1, a_{13} d_1^2 s_1 + a_{14} d_2^2 s_2] \tag{13}$$

$$D_i(t) = [a_{21} d_2^1 s_2, a_{22} d_2^2 s_2, a_{23} \hat{d}_1^2 s_1 + a_{24} d_2^2 s_2] \tag{14}$$

In the first interval, every user send information data to be transmitted. Each user detects the information received from the second information. At a later stage combining information with linear combinations, every multiplication adapted to the spreading code. Power is transmitted at each interval has a different value / variable, a different power systems needed to improve the optimization of conditions.

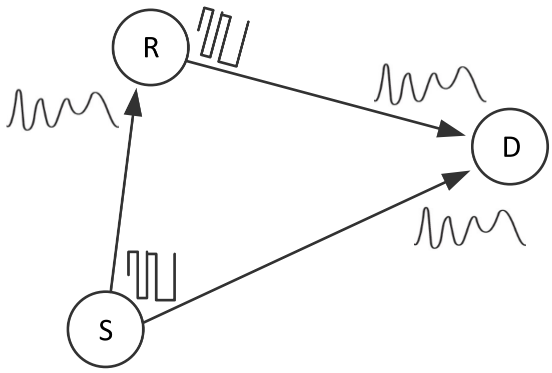

Figure 2.3 *Decode-and-Forward*

In Figure 2.3 Decode-and-forward (DF) process, **S** as a broadcast transmitter to sends information on neighboring nodes, **R** and **D** being targeted delivery of information sent by **S**. In the DF, **R** will translate the information signal is accompanied by noise channel fading so that the signal will decrease the signal level. **R** will restore the data reduced information (decoding),, so that the data will be returned intact as the start signal at the transmitter. In this method is not the strengthening of the signal level at **R**.

At TWRC communication by using DF as the carrier medium. In the first timeslot of $T/2$ seconds, between nodes $\boldsymbol{S}$ and $\boldsymbol{D}$ in the coded with symbols. At receiver symbol on the relay are:

$$y_r(n) = \sqrt{P_s}h_s x_s(n) + \sqrt{P_d}h_d x_d(n) \quad (15)$$

where $x_s(n)$ and $x_d(n)$ represents a symbol unit-variance coded.

2.3 Combining Technique

Combining technique is a method for combining signals same information but have different fading and eventually obtained the information signal mixed results. combining algorithm is given in figure 2.4. Combining algorithm distinguished from the way multiplication operation with the signal gain factor. There are three major combining algorithms [10]: Selection Combining (SC), Maximal Ratio Combining (MRC) and Equal Gain Combining (EGC).

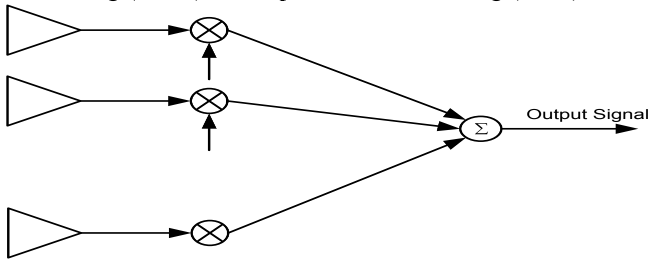

Figure 2.4 Combining Model

1) **Selection Combining (SC)**

The first approach is the algorithm combining signal, selection combining (SC). One alternative technique to obtain the highest SNR signal received by the detection of multiple antennas. Equations can be written from the following weighting factors:

$$\alpha_k = \begin{cases} 1, & if\ \gamma_k > \gamma_{k'}, \forall k' \neq k, \\ 0, & others \end{cases} \quad (16)$$

Where $\gamma_k \triangleq P|h_k|^2/\sigma_k^2$. Value antenna that has the highest SNR weighting value of 1, while the other antennas that do not have a weighting higher-value 0. Then for the results of the selection combining SNR can be written to the equation:

$$\gamma_{SC} = \max_{k=1,..,N_r} \gamma_k \quad (17)$$

Where, γ_{SC} resulted signal SC at receiver, while γ_k received signal at receiver.

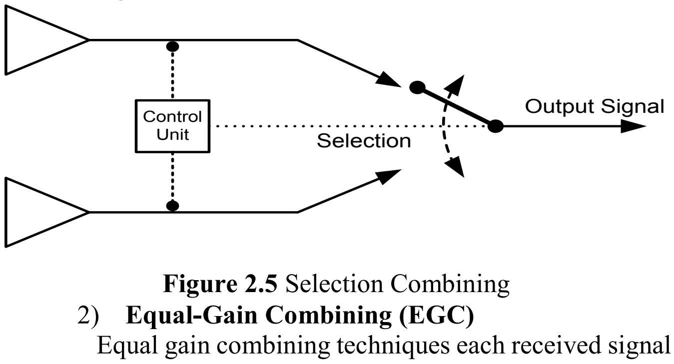

Figure 2.5 Selection Combining

2) **Equal-Gain Combining (EGC)**

Equal gain combining techniques each received signal at the antenna number will be the multiplication of the weighting factor complex that is compensated from the rotational phase of each channel. Complex weighting factors can be written to the equation:

$$\alpha_k = e^{-j\phi_k} \quad for\ k = 1,2,\dots,N_r \quad (18)$$

In this technique will get a coherent phase at the receiver and improve the signal at the receiver. Note that the magnitude of the weighting factors $|\alpha_1|, |\alpha_2|, \dots, |\alpha N_r|$ has the same value and does not depend on the value of SNR of each link. Outcome of the equal gain combing (EGC).

$$\tau_{EGC}[n] = \sum_{k=1}^{N_r} \alpha_k y_k[n]$$

$$= \sum_{k=1}^{N_r} e^{-j\emptyset k}\left(\sqrt{P}|h_k|e^{j\emptyset k}x[n] + w_k[n]\right)$$

$$= \sqrt{P}\left(\textstyle\sum_{k=1}^{N_r}|h_k|\right)x[n] + \sum_{k=1}^{N_r} e^{-j\emptyset k}w_k[n] \quad (19)$$

Description $\tau_{EGC}[n]$ is signal results in destination, $y_k[n]$is received signal at destination, k is number of links

For SNR values on outcomes equal-gain combining is:

$$\gamma_{EGC} = \frac{E\left[\left|\sqrt{P}\left(\sum_{k=1}^{N_r}|h_k|\right)x[n]\right|^2\right]}{E\left[\left|\sum_{k=1}^{N_r} e^{-j\emptyset k}w_k[n]\right|^2\right]}$$

$$= \frac{P\left(\sum_{k=1}^{N_r}|h_k|\right)^2 E[|x[n]|^2]}{\sum_{k=1}^{N_r} E\,[|e^{-j\emptyset k}w_k[n]|]^2}$$

$$= \frac{P\left(\sum_{k=1}^{N_r}|h_k|\right)^2}{\sum_{k=1}^{N_r}\sigma_k^2} \quad (20)$$

In figure 2.6 an illustration of the equal gain combining work, this technique is the sum all signal information received.

After all the received signals are summed, then the sum of the signal is detected to obtain the estimates of the transmitted data. This technique is better than selective combining technique because this technique all of the received signal is processed simultaneously estimating data transmitted.

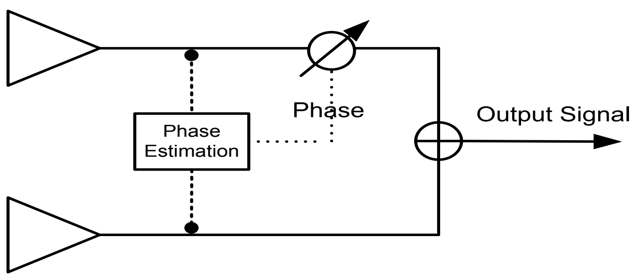

Figure 2.6 Equal Gain Combining

3) **Maximal Ratio Combining**

MRC technique is the best technique of combining. This is because all of the received signal is processed simultaneously, moreover each signal is multiplied by the coefficient conjugate each channel signal.

For the EGC and SC using channel-state-information (CSI) for determining the weighting factor, only with the weighting factor can not produce optimal value. To cope with the concept of multiple antennas that are spatial diversity by selecting the maximum weighting factor of SNR received, with a lower error value. Therefore, maximal ratio combining

(MRC) have to overcome these problems. The weighting factor of the MRC are:

$$\alpha_k = \frac{h_k^*}{\sigma_k^2} = \frac{|h_k|e^{-j\emptyset k}}{\sigma_k^2}, for\ k = 1, \dots, N_r \quad (21)$$

As for the outcome of the MRC

$$\tau_{MRC}[n] = \sum_{k=1}^{N_r} \alpha_k\left(\sqrt{P}h_k x[n] + w_k[n]\right)$$

$$= \sqrt{P}\left(\sum_{k=1}^{N_r} \alpha_k h_k\right)x[n] + \sum_{k=1}^{N_r} \alpha_k w_k[n]$$

$$= \sqrt{P}\left(\sum_{k=1}^{N_r} \frac{|h_k|^2}{\sigma_k^2}\right)x[n] + \sum_{k=1}^{N_r} \frac{h_k^*}{\sigma_k^2} w_k[n] \quad (22)$$

And the SNR of MRC is :

$$\gamma_{MRC} = \frac{P\left(\sum_{k=1}^{N_r} \frac{|h_k|^2}{\sigma_k^2}\right)^2}{E\left[\left|\sum_{k=1}^{N_r} (h_k^*/\sigma_k^2)\, w_k[n]\right|^2\right]}$$

$$= \frac{P\left(\sum_{k=1}^{N_r} \frac{|h_k|^2}{\sigma_k^2}\right)^2}{\sum_{k=1}^{N_r} \frac{|h_k|^2}{\sigma_k^2}} = \sum_{k=1}^{N_r} \gamma_k \quad (23)$$

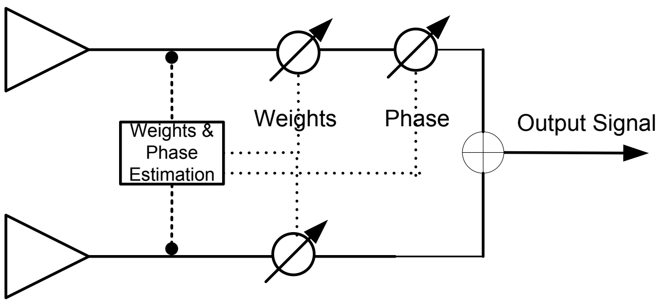

Figure 2.7 Maximal Ratio Combining

In the figure 2.7 is a technique similar to the technique of combining equal gain, namely the sum all signal information received then the sum is detected to obtain the estimates of the transmitted data. The difference this technique with equal gain combining technique is the MRC techniques each received signal will be multiplied by the conjugate of the channel coefficient that has passed.

III. Research Model

In this part of the system research model by using network coding, in figure 3.1. Scenario cooperative that the communication between the S-R-D and S-D, so that when the S-D can not be reached then the communication can be helped by relay R. System combining used is selection combining (SC) and maximal ratio combining (MRC). In this research, also using a relay forwarding in general, ie amplify-and-forward (AF) and decode-and-forward (DF). Step test in the protocol between the SC AF compared with MRC, views of components BER and throughput, as well as the workings of the DF.

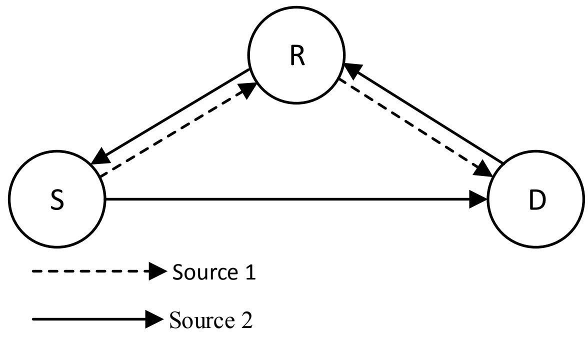

Figure 3.1 Cooperative Network Coding

In figure 3.1 the scheme cooperative communication system using network coding, S and D (source 1 and source 2) is the source and the receiver, so first timeslot during phase I, S and D transmit data information at the same time, this term is called the phase MAC, then the timeslot 2 data deployed simultaneously, with the previous relay process network coding with exlusive-OR (XOR), the phase of this broadcast information on a channel through which the data is assured because there is a process to encode the data, so it requires the original source data to see the information sent from a sender.

SNR at the receiver is γ_{sd}, γ_{sr}, and γ_{rd} which is in the weighting of each link [11], mathematical equations can be written as follows :

$$\gamma_{sd} = \frac{E_s}{n_o}|h_{sd}|^2, \gamma_{sr} = \frac{E_s}{n_o}|h_{sr}|^2, \gamma_{rd} = \frac{E_s}{n_o}|h_{rd}|^2 \quad (24)$$

SNR in equation (16) are independent exponentially distributed random variables, by using modulation QPSK with maximal ratio combining at receiver between γ_{sd} and γ_{rd}, can be expressed by :

$$P_{e,MRC}(\gamma_{sd}, \gamma_{rd}) =$$

$$Q\left(\frac{1}{\pi}\int_0^{\pi-\theta_0} \exp\left(\frac{-\gamma_{sd}sin^2\theta_0}{sin^2\theta}\right)\exp\left(\frac{-\gamma_{rd}sin^2\theta_0}{sin^2\theta}\right)d\gamma_{sd}d\gamma_{rd}\right) \quad (24)$$

Where Q(.) denoted by gaussian Q-Function :

$$\gamma_{sd} = (|h_{sd}|^2)E_s/N_o \quad (25)$$

$$\gamma_{rd} = (|h_{rd}|^2)E_s/N_o \quad (26)$$

IV. Simulation Results

In this chapter, we present show some numerical result to influence cooperative with network coding. Simulation environment used matlab software. The result of the simulation is a process that describes of the research model. The scenario used in this paper is to use a scheme of cooperative network coding, using schemes forwarding that amplify-and-forward (AF) and decode-and-forward (DF) by comparing the two strategies combining that selection combining (SC) and maximal ratio combining (MRC). Component parameters used are the bit error rate (BER) and throughput.

Random data were 10^5 bits, with QPSK modulation parameters. BER using AWGN channel modulation, in this case we can showed the following equation [12]:

$$BER_{M-PSK} = \frac{2}{log_2M}Q\left(\sqrt{\frac{2E_b log_2M}{N_0}}sin\frac{\pi}{M}\right) \quad (27)$$

Where erfc is the complementary error function and $\frac{E_b}{N_0}$ is the ratio of bit energy to noise. The function of the erfc can be related to the Q function, the equation is :

$$Q(x) = \frac{1}{2} erfc\left(\frac{x}{\sqrt{2}}\right) \tag{28}$$

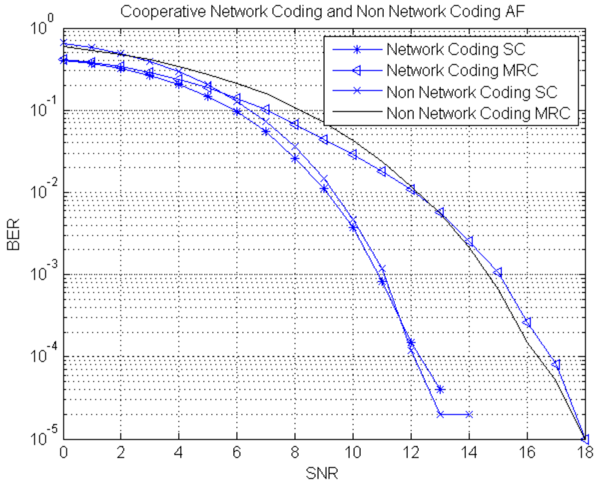

Figure 4.1 BER Network Coding AF

In figure 4.1, the comparison between the functions of cooperative network coding and without network coding, relay protocol used using amplify-and-forward, by comparing the selection combining (SC) with maximal ratio combining (MRC). From the results it can be seen that non-network coding nearing BER on network coding, in principle for the BER on network coding gives less good results due to the addition on the side of the relay, but the results given impact is not significant.

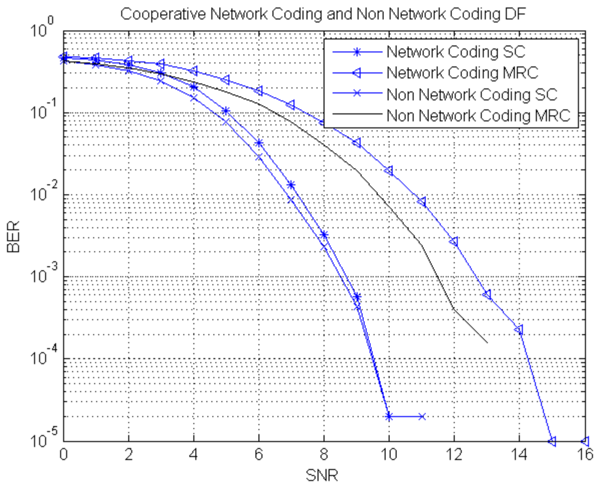

Figure 4.2 BER Network Coding DF

In figure 4.2, BER cooperative network coding with decode-and-forward, that compares the selection combining (SC) and maximal ratio combining (MRC), the results showed that the SC has better results than the MRC, this is because the MRC on the network coding has a number of fading channels more than SC, SC only select one channel fading of the best uses. Of course it is becoming a reference parameter that not all techniques combining become better at using MRC.

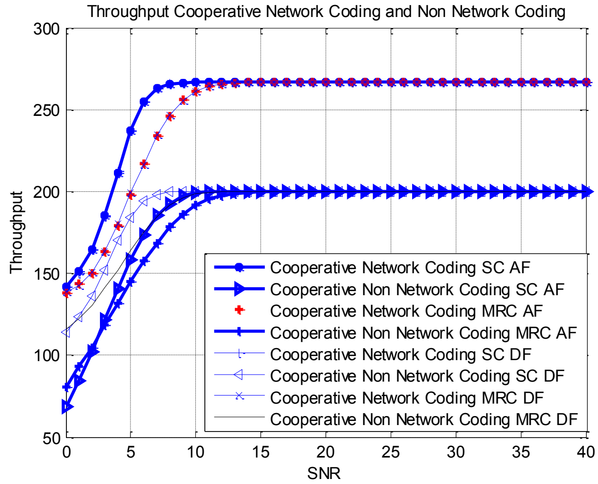

Figure 4.3 Throughput Network Coding AF-DF

In figure 4.3 are shown that thoughput between amplify-and-forward (AF) and decode-and-forward (DF) using network coding, the resulting performance looks good on SC and MRC using network coding throughput better than non-network coding. At the saturation point difference between network coding and non-network coding provide the difference 270-200 = 70 kbps. It is evident that the use of network coding can improve throughput performance.

V. Conclusion

This paper has investigated about cooperative communication system with network coding, by comparing the forward relay with combining strategy. Forward relay using two common models that amplify-and-forward (AF) and decode-and-forward (DF), while the strategy combining using selection combining (SC) with maximal ratio combining (MRC). In the research that the performance of network coding for BER, slightly worse than the non-network coding, but network coding throughput great value when compared to non-network coding. The characteristics of the network coding, SC produce a more optimal BER compared with MRC, this is because of two fading channels are used, the SC only use one channel fading the best while at the MRC calculations must take into the weight and phase.

References

[1] G. Kramer, I. Maric, and R. D. Yates, *Cooperative Communications*. Boston: Now Publishers Inc, 2007.
[2] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior," *IEEE Trans. Inf. Theory*, vol. 50, no. 12, pp. 3062–3080, Dec. 2004.
[3] P. Zhang, J. Yuan, J. Chen, J. Wang, and J. Yang, "Analyzing Amplify-and-Forward and Decode-and-Forward Cooperative Strategies in Wyner's Channel Model," in *2009 IEEE Wireless Communications and Networking Conference*, 2009, pp. 1–5.

[4] T. Wang, “Comparison of the energy efficiency for decode-and-forward and amplify-and-forward two-way relaying,” in *2013 5th IEEE International Conference on Broadband Network Multimedia Technology (IC-BNMT)*, 2013, pp. 232–236.
[5] D. Hu and S. Mao, “Cooperative Relay in Cognitive Radio Networks: Decode-and-Forward or Amplify-and-Forward?,” in *2010 IEEE Global Telecommunications Conference (GLOBECOM 2010)*, 2010, pp. 1–5.
[6] S.-Q. Huang, H.-H. Chen, and M.-Y. Lee, “On performance bounds of mixed amplify-and-forward and decode-and-forward cooperative relay systems,” in *2011 6th International ICST Conference on Communications and Networking in China (CHINACOM)*, 2011, pp. 521–527.
[7] Y. Wu, P. A. Chou, and S.-Y. Kung, “Information exchange in wireless networks with network coding and physical-layer broadcast,” in *Conference on Information Sciences and Systems*, 2005.
[8] S. Zhang and S. C. Liew, “Channel coding and decoding in a relay system operated with physical-layer network coding,” *IEEE J. Sel. Areas Commun.*, vol. 27, no. 5, pp. 788–796, Jun. 2009.
[9] A. Sendonaris, E. Erkip, and B. Aazhang, “User cooperation diversity. Part I. System description,” *IEEE Trans. Commun.*, vol. 51, no. 11, pp. 1927–1938, Nov. 2003.
[10] Y.-W. P. Hong, W.-J. Huang, and C.-C. J. Kuo, *Cooperative Communications and Networking: Technologies and System Design*. Springer Science & Business Media, 2010.
[11] M. S, K. S, N. V, and B. K, “Maximal ratio combining based cooperative diversity system using incremental relaying,” in *2014 International Conference on Communications and Signal Processing (ICCSP)*, 2014, pp. 1755–1759.
[12] K. D. Rao, *Channel Coding Techniques for Wireless Communications*. Springer India: Springer 2015, 2015.