Performance Analysis of Digital Network Coding Based Two Way Amplify and Forward Relay Networks

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Abstract

Network coding is a prominent technique for relaying of packets from one end of the network to another end by the relay node. It combines the incoming packets into a coded packet at the relay node to increase the throughput of relay network. The performance of Digital Network Coding (DNC) to achieve the maximum possible information flow in a network and to provide efficient transmissions from the source to the end destinations via relay, with the widely known amplify and forward based protocol in Rician and Nakagami-m fading environment is examined. By increasing the Nakagami fading parameter–m and Rician-k factor, the link's quality between source and destination have been improved.

Index terms- *Digital network coding (DNC), Amplify-and-forward (AF), Recursive Systematic Convolutional Codes and Average Symbol error rate (SER) and Energy.*

I. INTRODUCTION

Network coding (NC) is a technique which improves the network's throughput and efficiency [1]. The information packets which are to be transmitted are combined linearly at intermediate nodes and are forwarded to their intended destinations by the relay. The destination can successfully retrieve the information intended to it by the knowledge of the manner in which the messages were combined and by cancelling their own information contributed by it. The network coding with two way relay communication provides improvement in throughput [2]. It consists of two source nodes 1 and 2 and a relay node R, where the source nodes have information to exchange with each other. The direct link between two sources is unavailable. This model is applied for wireless communication in which the relay node provides the coverage in the area between base station and mobile station. The capacity region of the two way relay network with analog network coding with beamforming at the relay node has been analyzed in [3]. The performance of two way relay network in terms of outage probability has been analyzed in [4]. The analysis of symbol error rate in two way amplify and forward relay network in Nakagami fading channel has been studied in [5], [6]. Ergodic capacity and outage probability has been analyzed for two way relay network in Rician fading channel in [7], [8]. The probability density function of signal to noise ratio for two hop amplify and forward relay network in Nakagami and Rician fading channel has been analyzed in [9] [10]. With the concept of network coding, the information can be exchanged in two time slots by Physical Network Coding [11], [12] also known as Analog Network Coding as shown in Fig 2 or in three time slots by Digital Network Coding [13] [14] as shown in Fig 3 compared with four transmission time slots required by the traditional relay networks as shown in Fig 1. In analog network coding, both sources transmit the information packets to the relay over a multiple access channel as shown in Fig 2. In step1, relay receives the information packets which consist of noisy signals due to interference between the signals of source 1 and source 2. The Amplify and Forward Protocol used in the relay to improve gain amplifies the noise and hence decrease in throughput at the destination. Digital network coding (DNC) means that the relay node XORs packets in the bit level to form the coded packet. DNC technique is shown in Fig 3; nodes 1 and 2 temporarily store their transmitted packets for later decoding. After two time slots, the relay has received the packets from both end receivers, encodes (XOR) and broadcasts them back to nodes 1 and 2 within one time slot. Nodes 1 and 2 each recover their packets by decoding (XOR) the received packet with the stored one. The number of transmission time slots reduces to three, one time slot less than in the relaying scheme. The two way relay network as shown in Fig 3 makes use of Digital network coding where the source 1 transmit the information packets to relay node in step 1, source 2 transmit the information packets to relay node in step 2 and in step 3 relay node combines the packets to form a coded packet and broadcast the packets to both sources simultaneously. Each source node retrieves the desired information by the knowledge of the information packet it contributes.

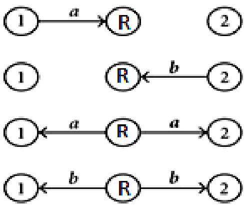

Fig 1 Traditional relay Coding

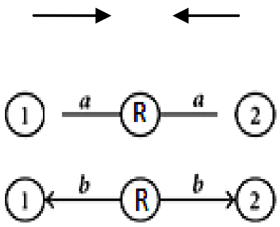

Fig 2 Analog Network Networks

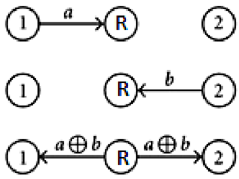

Fig 3 Digital Network Coding

From source 1 to relay node Rician fading environment is assumed and from source 2 to relay node Nakagami-m fading environment is assumed. An equal transmission power P_s is assumed at source nodes and in relay node. The instantaneous SNR from source 1 to relay node and source 2 to relay node is given by

$$\gamma_1 = P_s\,|h_1|^2/N_0 \qquad (1)$$

$$\gamma_2 = P_s\,|h_2|^2/N_0 \qquad (2)$$

The average transmission power is $\gamma_0 = P_s/N_0$ and variances of h_1 and h_2 are $\Omega_1 = \mathbb{E}\{h_1{}^2\}$ and $\Omega_2 = \mathbb{E}\{h_2{}^2\}$. The Probability distribution function of instantaneous SNR [15] γ_1 *and* γ_2 is given by,

$$f_{\gamma_1}(\gamma) = \frac{K+1e^{-K}}{\gamma_1} e^{\frac{-(K+1)\gamma}{\gamma_1}} I_0\left(2\sqrt{\frac{K(K+1)\gamma}{\gamma_1}}\right) \qquad (3)$$

$$f_2(\gamma) = \frac{m^m}{\gamma_2{}^m\Gamma(m)}\beta^{m-1} e^{\frac{m\beta}{\gamma_2}} \qquad (4)$$

Where the parameter *m* is the Nakagami fading parameter and *k* is the Rician factor. For k=0, the Rayleigh fading is experienced and for k= ∞, no fading (AWGN) is experienced. Similarly for m= $\frac{1}{2}$ one-sided Gaussian distribution is experienced, m=1 converges to Rayleigh distribution and when m= ∞, no fading is experienced.

The remaining of this paper is organized as follows. Section II briefly describes the system model. Section III presents the performance analysis of Average Symbol error rate and Energy. Section IV presents simulation and discussion results and finally Section V concludes this work.

II. SYSTEM MODEL

Packets flow inside the nodes A and B to the relay are shown in Fig 4.

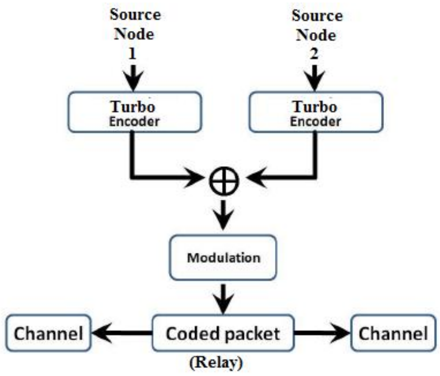

Fig 4. System model showing the packets flow from the end nodes to the relay node.

Packets in binary level will be converted to coded packets by Turbo encoders, after forming the coded packet; both packets will be XOR in the bit level to form one coded packet. Two RSC Encoders are made parallel and separated by an interleaver to spread out burst errors through providing scrambled information to the second RSC encoder to form the Turbo Encoder by concatenating them as shown in Fig 5.

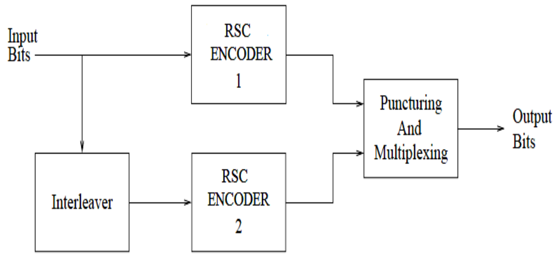

Fig 5 Turbo Encoder

Then convert incoming packets from binary level to signal level by using modulation technique. After this, the packets are ready to be sent over independent wireless channels to the relay node simultaneously.

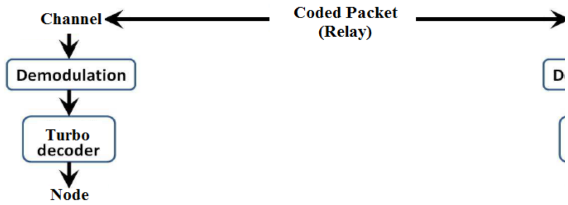

Fig 6 System model showing the packets flow from relay to the end nodes

The packets from each channel are combined to form a coded packet by the relay node to optimize the data flow in the network. Then the relay node broadcast the coded packet to the destination by converting the packets from symbols to binary level by using the demodulation technique.

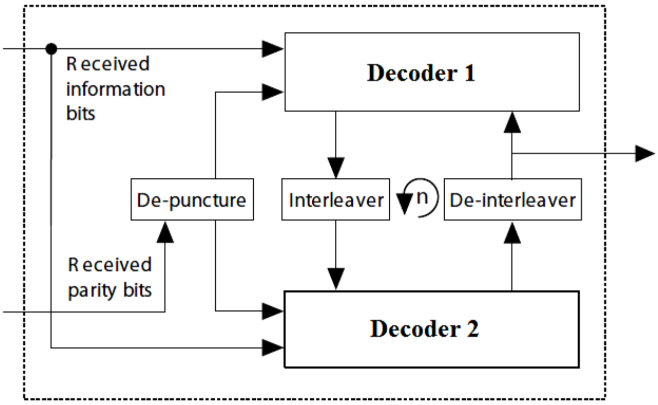

Fig 6 Turbo Decoder
Fig 7 Turbo Decoder

A well known efficient turbo decoder is used for decoding to minimize the probability of error, consist of two constituent decoder, interleaver/de interleaver to add randomness to the codes are used as shown in Fig 7.
The demultiplexer consists of noisy input from the turbo encoder. The two types of decoders used here are SOVA decoder and Log Map decoder. The inputs are first given to SOVA to decode correctly the erroneous frames; further Log Map decoder is applied for decoding the remaining erroneous frames. The decoder generates the soft outputs to calculate the reliability information for each estimated bits. Thus the destination retrieves the desired information efficiently by Digital Network Coding.

III. PERFORMANCE ANALYSIS

(a) Symbol Error Rate (SER)

The formula for calculating the closed form expressions of SER [15] is given by

SER=$aE\gamma\left[Q\left(\sqrt{2b\gamma}\right)\right]$ (5)

Where $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{\frac{y^2}{2}}\,dy$ and $[a, b > 0]$. The terms a and b are the parameters of the BPSK modulation.
Integrating eqn (5) leads to

SER=$\frac{a\sqrt{b}}{2\sqrt{\pi}}\int_0^{\infty}\frac{F\gamma_{s1}(z)}{\sqrt{z}}e^{-bz}\,dz$ (6)

$$\text{SER}=\frac{a\sqrt{b}}{2\sqrt{\pi}}\int_0^{\infty}\frac{e^{-b\gamma_{th}}}{\sqrt{\gamma_{th}}}d_{\gamma_{th}} - \frac{a\sqrt{b}}{\sqrt{\pi}}\frac{(k+1)(m-1)!e^{-k}}{\gamma_1\Gamma(m)} \quad (7)$$

$$\sum_{g=0}^{\infty}\sum_{q=0}^{m-1}\sum_{v=0}^{q}\sum_{l=0}^{g}\frac{1}{(g!)^2q!}\binom{q}{v}\binom{g}{l}\left(\frac{k(k+1)}{\gamma_1}\right)^g\left(\frac{\gamma_1}{K+1}\right)^{\frac{l-y+1}{2}}$$

$$\left(\frac{2m}{\gamma^2}\right)^{q+\frac{l-v+1}{2}}\int_0^{\infty}\gamma_{th}^{\;q+g\frac{3}{2}-1}\exp\left(-(b+\frac{2m}{\gamma_2}+\frac{K+1}{\gamma_1})\gamma_{th}\right)$$

$$K_{l-v+1}\left(2\gamma_{th}\sqrt{\frac{2m(k+1)}{\gamma_2\gamma_1}}\right)d\gamma_{th}$$

The inner integration in (7) can be evaluated as

SER=

$$\frac{a}{2}-\frac{a\sqrt{b}e^{-k}(k+1)(m+1)!}{\gamma_1\Gamma(m)}\sum_{g=0}^{\infty}\sum_{q=0}^{m-1}\sum_{v=0}^{q}\sum_{l=0}^{g}\frac{1}{(g!)^2q!}$$

$$\binom{q}{v}\binom{g}{l}\left(\frac{K(K+1)}{\gamma_1}\right)^g\left(\frac{2m}{\gamma_2}\right)^{q+\frac{l-y+1}{2}}\left(\frac{\gamma_1}{K+1}\right)^{\frac{l-y+1}{2}}$$

(8)

$$\frac{\left(4\sqrt{\frac{2m(K+1)}{\gamma_2\gamma_1}}\right)^{l-v+1}}{\left(b+\frac{2m}{\gamma_2}+\frac{K+1}{\gamma_1}+2\sqrt{\frac{2m(K+1)}{\gamma_2\gamma_1}}\right)^{q+g+l-v+\frac{5}{2}}}$$

$$\frac{\Gamma\left(q+g+l-v+\frac{5}{2}\right)\Gamma\left(q+g-l+\frac{1}{2}\right)}{\Gamma(q+g+2)}$$

F

$$\left(q+g+l-v+\frac{5}{2}, l-v+\frac{3}{2}; q+g+2; \frac{b+\frac{2m}{\gamma_2}+\frac{K+1}{\gamma_1}-2\sqrt{\frac{2m(K+1)}{\gamma_2\gamma_1}}}{b+\frac{2m}{\gamma_2}+\frac{K+1}{\gamma_1}+2\sqrt{\frac{2m(K+1)}{\gamma_2\gamma_1}}}\right),$$

Where F (.,. ;.;.) is the hyper geometric function. $\Gamma(.)$ is the gamma function, a and b are parameters of the modulation schemes. The closed form expression derived in (8) provides the theoretical results over Rician and Nakagami-m fading channels. Thus by varying the values of k and m, the theoretical average SER vs. SNR curves are plotted for BPSK modulation.

(b) Analysis of Energy consumed by the Packets through the
Channel

The formula for minimizing the energy consumed by the packets transmitting in the channel can be given as

$$\sum_{i=1}^{N-1} f_i \; P_i(R_i) \qquad (9)$$

$$P_i(R_i) = \frac{2^{R_i-1}}{g_i} \qquad (10)$$

where the value i from 1 to N-1 correspond to the mode at which transmission between source, relay and destination takes place P_i is the power transmitted, R_i is the rate at which power is transmitted and g_i is the channel gain

IV. SIMULATION STUDY

(a) Analysis of Symbol Error Rate (SER)

Here, we present the simulation results to evaluate the analytical expressions of symbol error rate of digital network coding at the relay. From Fig 8, 9, 10 by fixing the Nakagami- m value at the mobile station and changing the Rician-K value at the base station, a significant performance gain can be achieved.

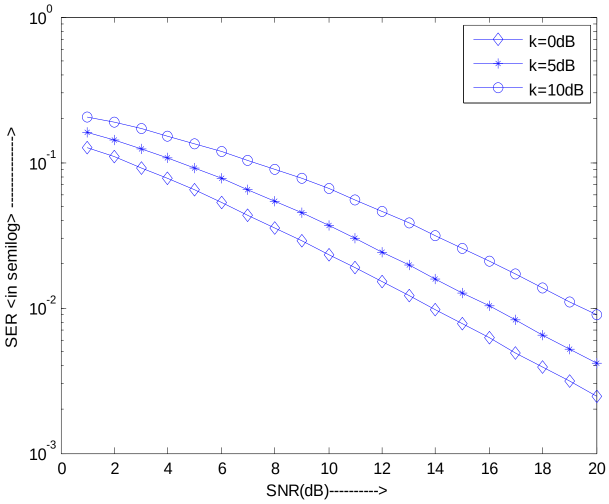

Fig 8 Nakagami factor (m=1)

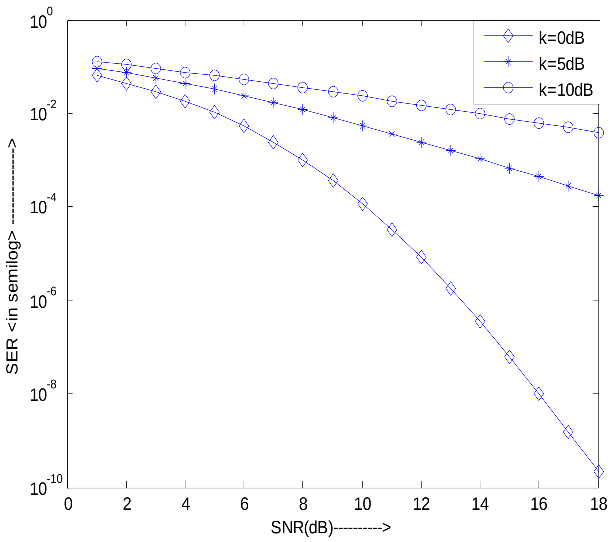

Fig 9 Nakagami factor (m=2)

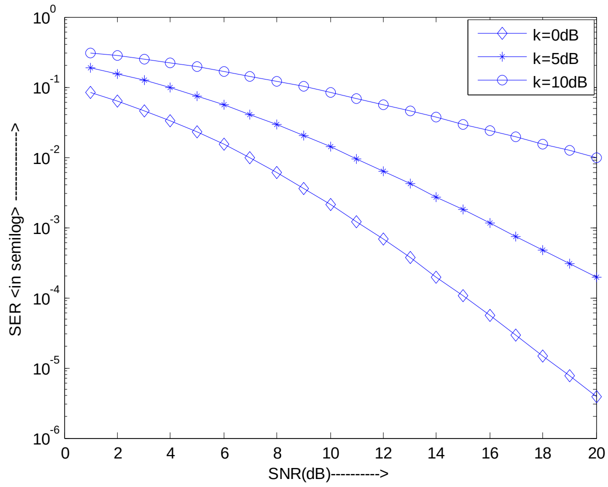

Fig 10 Nakagami factor (m=3)

TABLE I GAIN FOR DIFFERENT M AND K VALUES

m value	K value	Gain
m=1	K=0dB to K=5dB	2 dB
	K=5dB to K=10dB	3 dB
m=2	K=0dB to K=5dB	3 dB
	K=5dB to K=10dB	5 dB
m=3	K=0dB to K=5dB	4 dB
	K=5dB to K=10dB	9 dB

From the Table I it is clear that by fixing the Nakagami- m factor and increasing the K factor the improvement in gain can be achieved and also by increasing the value of m high gain can be achieved as shown in Fig 8, 9, 10.

(b)Analysis of Energy consumed by bits per packet in the channel

The bits per packet that are passed in the channel to the destination consume energy. By digital network coding energy consumption is reduced. Fig 11 shows the Energy consumed by bits per packet in the channel use.

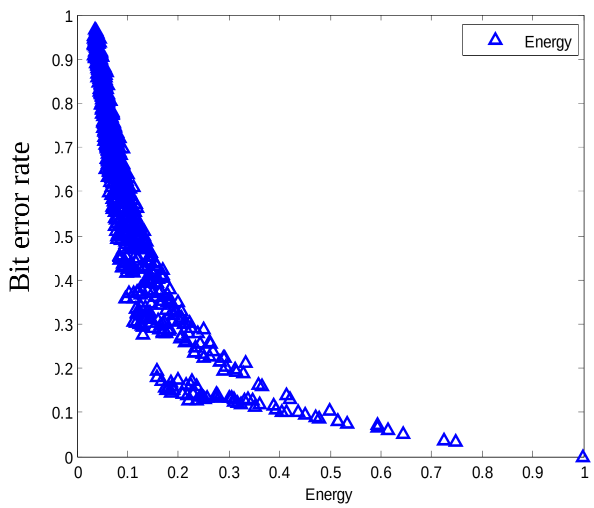

Fig 11 Energy vs. Bit error rate

V. CONCLUSIONS

In this paper, for two way relay networks, the Digital Network Coding has been analyzed at the relay in terms of symbol error rate and energy consumed by the packets in the channel. Both Rician and Nakagami fading channels were encountered. The theoretical results have been validated using simulation. We showed that by fixing the Nakagami-m factor and increasing the K factor the improvement in gain can be achieved and also by increasing the value of m high gain can be achieved. Energy consumed by bits/packet has also been reduced.

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