

# Throughput Improvement of Cooperative System Using Adaptive Relaying & Adaptive Modulation

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**Abstract**— In this paper, adaptive modulation is implemented for a selection combining Demodulate and Forward Relay system. In this method, the source and relay select the modulation type based on the channel quality measurement, which is the output SNR, to improve the total throughput of the system. The adaptation thresholds are computed by solving an optimization problem. The model is generalized for the N-relay system and the optimization problem is modified for this case. Adaptive modulation is then employed for the N-relay DMF system. Adaptive relaying method is also proposed for adaptive modulated DMF system to achieve BER constraint, attain maximum possible throughput and reduce the complexity of hardware. Another optimization problem and several novel algorithms are generated in this paper, to perform adaptive relaying adaptive modulated DMF system. The results demonstrate that employing the proposed methods improves the total throughput of the system by keeping the BER performance at the target level.

**Keywords**- Adaptive modulation; Adaptive relaying; Cooperative communication; Demodulate and Forward Relay; Selection combining

## I. INTRODUCTION

Cooperative technology allows a wireless system to coordinate among distributed antennas and attain significant performance gains and will be one of the main candidate technologies in many standard proposals for the fourth-generation wireless communication systems [1]. On the other hand, the use of multiple antennas (MIMO) may not be ideal for different situations because of increasing complexity and processing load [2] [3]. Cooperative systems have the similar advantages with less complexity [4]. In particular, three main cooperative methods have been proposed [5]; Amplify-and-Forward (AF) [6], Decode-

and-Forward (DF), and Estimate-and-Forward (EF) [7, 8]. In this paper, we use Demodulate and Forward (DMF) cooperative method [9] [10] [11], with selection combining at the destination. In this method the relay only demodulates the received signal and forwards it to the destination, using another modulation type. Decoding is just performed at the final receiver. This approach could reduce the latency, complexity of hardware as well as the energy consumption due to decoding in the relay [12].

Another key technology to attain high data rate services is adaptive rate transmission [13-15]. Variable rate transmission techniques have been proposed to improve the performance of wireless systems in

supporting several services. Adaptive rate transmission is the technique in which the information rate varies according to the quality of the channel [16-18].

In this contribution, we implement adaptive modulation for a selection combining DMF Relay system to improve the total throughput of the system. In this method, the source and relay select the modulation type based on the channel quality metric, which is the output SNR. To employ adaptive modulation, we need some switching thresholds for changing the modulation. In this paper, we compute these adaptation thresholds by solving the optimization problem introduced in [9]. We also generalize the model for the N-relay system and modify the optimization problem for this case. Then, we employ adaptive modulation for the N-relay DMF system. Besides, to achieve BER constraint and attain maximum possible throughput, we choose the number of relays in adaptation with system condition. We call this proposed method adaptive relaying.

The rest of the paper is organized as follows. Section II describes the system model and DMF cooperative system. In section III, Adaptive modulated DMF system for a single relay is considered. Generalized scheme for the N-relay scenario is considered in section IV. Section V introduces adaptive relaying adaptive modulated DMF system. The results and comprehensive discussions are presented in section VI. Finally Section VII concludes the paper.

## II. DMF COOPERATIVE SYSTEM

We consider a cooperative system with a single antenna source (S) and destination (D) and one relay (R). At the first time slot, source transmits signals to R and D, and then at the second time slot, the relay sends the signal to destination. System model is shown in figure 1. Since we are going to employ adaptive modulation method for this system, feedback channels from destination to source are considered in the model. The feedback data includes small frames, so we could consider the reverse channel to be error free.

Following equations describe the received signal at relay and destination:

$$y_{SD} = h_{SD}x + n_{SD} \tag{1}$$

$$y_{SR} = h_{SR}x + n_{SR} \tag{2}$$

where  $x$  is the transmitted signal, and  $h_{SD}$  and  $h_{SR}$  are the channel coefficients from S to R and S to D, respectively.  $n_{SD}$  and  $n_{SR}$  are additive complex Gaussian noises.

In DMF method the relay only demodulates the received signal and forwards it using another modulation type. The received signal at D in the second time slot can be expressed as:

$$y_{RD} = h_{RD}x_r + n_{RD} \tag{3}$$

where  $x_r$  is the re-modulated signal,  $h_{RD}$  is the channel coefficient from R to D, and  $n_{RD}$  is additive complex Gaussian noise.

For selection combining scheme, the error will only occur when the two copies were incorrect at destination. Therefore, the BER at the destination is computed as  $BER = P_e^{direct} P_e^{relay}$  [9].  $P_e^{direct}$  is the

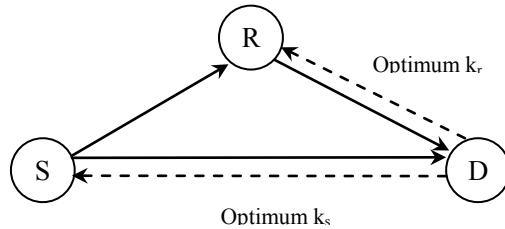


Fig. 1: Cooperative system model with feedback channel

probability of error when receiving directly from the source that is represented by  $P_{eSD}$ .  $P_e^{relay}$  is the error probability when receiving through relay. The destination detects the correct bit through relay path, if at the both S-R and D-R paths the bit is received correctly. Therefore, based on the probability theory, the BER can be written as:

$$BER = P_{eSD}(\bar{\gamma}_{SD})[1 - (1 - P_{eSR}(\bar{\gamma}_{SR}))(1 - P_{eRD}(\bar{\gamma}_{RD}))] \tag{4}$$

where  $P_{eSR}$  and  $P_{eRD}$  are the BER of the SR and RD, respectively.  $\gamma_{SD} = \frac{E_s}{N_0} |h_{SD}|^2$ ,  $\gamma_{SR} = \frac{E_s}{N_0} |h_{SR}|^2$  and

$\gamma_{RD} = \frac{E_s}{N_0} |h_{RD}|^2$  are the received SNR, so we have

$$\bar{\gamma}_{SD} = \frac{E_s}{N_0} \sigma_{SD}^2, \quad \bar{\gamma}_{SR} = \frac{E_s}{N_0} \sigma_{SR}^2 \quad \text{and}$$

$\bar{\gamma}_{RD} = \frac{E_s}{N_0} \sigma_{RD}^2$  as the average SNRs.  $\sigma^2$  is the

variance of Rayleigh distribution. In the same characteristic for all Rayleigh channels, it is assumed similar average SNR for all paths

In this paper we compute the BER of all SR, RD and SD paths using the simplified equation (5) of [19]:

$$P_e(\bar{\gamma}) \approx \frac{1}{M} \frac{4b(\sqrt{M}-1)}{\pi\sqrt{M}} \left( \frac{2(M-1)}{3} \right)^d \times \left( \int_0^{\pi/2} \sin^{2d} \theta d\theta - \frac{(\sqrt{M}-1)}{\sqrt{M}} \int_0^{\pi/4} \sin^{2d} \theta d\theta \right) (\bar{\gamma})^{-d} \tag{5}$$

in which  $M = 2^k$  determines the modulation mode, and  $b=d=1$  for Rayleigh channel.



In [9] an optimization problem is proposed to maximize the total throughput ( $R_{total}$ ) for the DMF cooperative system under the constraint of the received BER requirement:

$$problem \quad P_1: \begin{cases} \max_{k_s, k_r} & R_{total}(k_s, k_r) \\ s.t.: & BER \leq P_{e,max} \end{cases}$$

where  $R_{total} = \frac{1}{T_s(k_s) + T_r(k_r)}$ .

To describe this concept of throughput, it should be noted that a frame of L bits with the rate of W symbol/sec is transmitted during the time, defined as  $T_i = L/(k_i W)$  [9], where i=s for source and i=r for relay. The total time of transmission is  $T_s + T_r$ . Assuming that each frame consists of the fixed number of symbols with the constant symbol rate, the average throughput of the system depends only on the total time of bit transmission, which in turn, is dependent on the number of bits per symbol ( $k_i$ ). Maximizing  $R_{total}$  is simplified to maximizing the expression  $\frac{k_s k_r}{(k_s + k_r)}$ .

In this paper, we use this optimization problem to compute the optimum switching thresholds for adaptive modulation.

### III. ADAPTIVE MODULATED DMF SYSTEM

Adaptive modulation is a technique that attempts to increase the average throughput of the system by switching between modulation modes depending on the quality of the channel. When the channel quality is satisfactory, a high order modulation is used to transmit as many bits per symbol as possible. When the channel is hostile, the modulation mode is switched to a low order one to reduce the error probability. Since different levels of QAM are usually used in order to rate adaptation, adaptive modulation is also known as adaptive QAM; AQAM. In order to adapt the AQAM modes, a metric corresponding to the near instantaneous channel quality is required. In this work we use the same metric as the one used in [13-18] that is the instantaneous output SNR. The first important step in achieving an acceptable adaptation performance is finding the most appropriate thresholds through which the transmitter would adapt itself to the channel state. The thresholds are to be chosen so that the BER, as the performance criteria, remains below a specific value. Comparing the metric by the pre-determined thresholds, the system decides about the appropriate modulation mode for the next symbol.

BPSK, QPSK, 16-QAM and 64-QAM have been considered as the four different modes in adaptive modulation, since they are widely used in many existing standards [20-22]. In this paper we use the optimization problem ( $P_1$ ) to compute the required switching thresholds, jointly for source and relay. The following algorithm describes the procedure.

<b>Algorithm 1</b>	
0)	Initialization: $\bar{\gamma} = \bar{\gamma}_0$
1)	Solve $P_1$ and find optimum $[k_s, k_r]$
2)	$\bar{\gamma} = \bar{\gamma} + \bar{\gamma}_{step}$
3)	Go to 1.

$\bar{\gamma}_0$  is the average SNR in which BER remains below  $P_{e,max}$  for  $[k_s, k_r]=[1,1]$ . Table I lists the results when  $P_{e,max}$  is  $10^{-3}$ .

TABLE I: Optimum adaptation thresholds

$\bar{\gamma}$ (dB)	8	10	12	14
$[k_s, k_r]$	[1,2]	[1,6]	[2,6]	[6,6]

By using the above thresholds, adaptive modulation procedure is done in the way that is described by the following algorithm.

<b>Algorithm 2</b>	
If $\bar{\gamma} < \bar{\gamma}_0$	feedback $[k_{s0}, k_{r0}]$ to S & R
If $\bar{\gamma}_i < \bar{\gamma} < \bar{\gamma}_{i+1}$	feedback $[k_{si}, k_{ri}]$ to S & R
If $\bar{\gamma} > \bar{\gamma}_{max}$	feedback $[k_{smax}, k_{rmax}]$ to S & R

in our case  $[k_{s0}, k_{r0}]=[1,1]$  and  $[k_{smax}, k_{rmax}]=[6,6]$ .

### IV. GENERALIZED SCHEME FOR N RELAYS

In this section DMF method and adaptive modulation are implemented for the N-relay scenario. Figure 2 shows the system model in this situation. The source transmits the information signal to the destination and all the N relays, as in following equations:

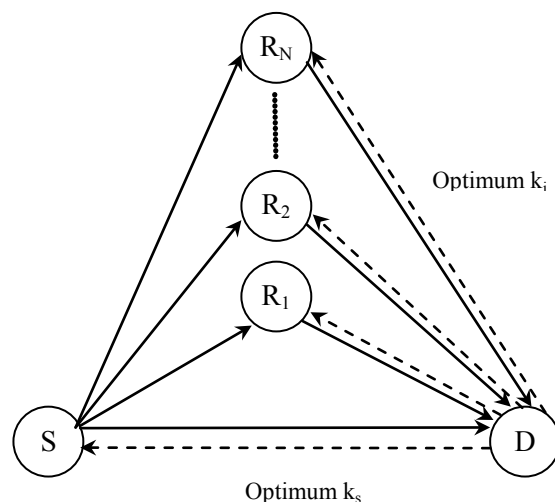


Fig. 2 Cooperative system model with feedback channel for N relays



$$y_{SD} = h_{SD}x + n_{SD} \tag{6}$$

$$y_{Si} = h_{Si}x + n_{Si} \quad i = 1, \dots, N \tag{7}$$

All the N relays send the re-modulated signals to the destination:

$$y_{iD} = h_{iD}x_i + n_{iD} \tag{8}$$

In this case BER of the system is computed through following equation

$$BER = P_e^{direct} \prod_{i=1}^N P_{e,i} \tag{9}$$

where  $P_{e,i}$  is the BER due to  $i^{th}$  relay.

The total throughput for the N-relay system is now calculated using equation (10), which is the generalization of the throughput concept.

$$R_{total} = \frac{1}{T_s(k_s) + \sum_{i=1}^N T_i(k_i)} \tag{10}$$

The optimization problem that maximize  $R_{total}$  now should be modified to find optimum modulation for the source and all the N Relays:

$$problem \quad P_2 : \begin{cases} \max_{k_s, k_i} & R_{total}(k_s, k_i) \\ s.t.: & BER \leq P_{e,max} \end{cases}$$

Considering fixed frame size and symbol rate, maximizing  $R_{total}$  is simplified to maximizing the

expression  $\frac{1}{\frac{1}{k_s} + \sum_{i=1}^N \frac{1}{k_i}}$ .

To implement adaptive modulation, we should first find switching thresholds for all the relays and source. Hence they can change the modulation in adaptation with the channel quality. This leads to improving the total throughput of the system. Using Algorithm 1 for problem (P<sub>2</sub>) we can compute optimum  $[k_s, k_i]$  for  $i=1, \dots, N$ .

Table II lists the results for N=2, when  $P_{e,max}$  is  $10^{-3}$ .

TABLE II: Optimum adaptation thresholds for N=2.

$\bar{\gamma}$ (dB)	4	6	8	12
$[k_s, k_1, k_2]$	[1,4,2]	[2,4,2]	[4,4,4]	[6,6,6]

By using the above thresholds adaptive modulation procedure is performed in the way similar to what described by the Algorithm 2. For the 2-relay system,  $[k_{s,0}, k_{1,0}, k_{2,0}] = [1, 1, 1]$  and  $[k_{s,max}, k_{1,max}, k_{2,max}] = [6, 6, 6]$ . The destination feedbacks  $[k_s, k_i]$  to the source and all the N relays.

#### V. ADAPTIVE RELAYING ADAPTIVE MODULATED DMF SYSTEM

As it was seen in the throughput computation, increasing the number of relays leads to decreasing maximum throughput. However, in this paper the purpose is increasing the throughput. To improve the throughput, less number of relays should be involved. On the other hand, reducing relays, leads to decaying BER. To achieve BER constraint and attain maximum possible throughput, we have to deal with a kind of trade off. In lower SNRs we can use more relays to achieve desired BER. By increasing the SNR we can eliminate the relays gradually, with the condition that BER is kept at the desired level. Therefore, by increasing SNR the cooperating relays will be decreased adaptively and consequently, throughput increases while BER constraint still remains under a target value. Decreasing the number of cooperating relays also reduces the hardware complexity.

In this section, we compute the minimum number of relays required for achieving the BER constraint in each SNR. In this step, BPSK modulation is considered for source and all relays. To compute the optimum number of relays, we solve the following problem, at every SNR:

$$problem \quad P_3 : \begin{cases} \min & N \\ s.t.: & BER \leq P_{e,max} \end{cases}$$

The initial modulation was BPSK in the above step. However, higher order modulations might also accomplish BER threshold with the same number of relays and similar SNR. So it is preferred to use higher order modulations that leads to increasing throughput. To find the preferable modulation, we solve the optimization problem P<sub>2</sub> for all SNRs due to the selected relay number. The following two algorithms describe the above steps.

**Algorithm 3**

$$\forall \bar{\gamma} \text{ SOLVE } P_3$$

**Algorithm 4**

$$\forall \bar{\gamma} \text{ for "N" resulted of Algorithm 3, SOLVE } P_2$$

The results due to above algorithms make the data that will be used during adaptation procedure explained in the algorithm 5.



**Algorithm 5**

If $0 < \bar{\gamma} < 1$ , $N = 3$ ; $k_s = 1, k_{r_1} = 2, k_{r_2} = 1, k_{r_3} = 1$
If $1 < \bar{\gamma} < 2$ , $N = 3$ ; $k_s = 1, k_{r_1} = 4, k_{r_2} = 2, k_{r_3} = 1$
If $2 < \bar{\gamma} < 3$ , $N = 2$ ; $k_s = 1, k_{r_1} = 1, k_{r_2} = 1$
If $3 < \bar{\gamma} < 4$ , $N = 2$ ; $k_s = 1, k_{r_1} = 2, k_{r_2} = 1$
If $4 < \bar{\gamma} < 5$ , $N = 2$ ; $k_s = 1, k_{r_1} = 4, k_{r_2} = 2$
If $5 < \bar{\gamma} < 6$ , $N = 2$ ; $k_s = 1, k_{r_1} = 6, k_{r_2} = 6$
If $6 < \bar{\gamma} < 7$ , $N = 2$ ; $k_s = 2, k_{r_1} = 4, k_{r_2} = 2$
If $7 < \bar{\gamma} < 8$ , $N = 1$ ; $k_s = 1, k_{r_1} = 1$
If $8 < \bar{\gamma} < 9$ , $N = 1$ ; $k_s = 1, k_{r_1} = 2$
If $9 < \bar{\gamma} < 10$ , $N = 1$ ; $k_s = 1, k_{r_1} = 6$
If $10 < \bar{\gamma} < 11$ , $N = 1$ ; $k_s = 1, k_{r_1} = 6$
If $11 < \bar{\gamma} < 12$ , $N = 1$ ; $k_s = 2, k_{r_1} = 4$
If $12 < \bar{\gamma} < 13$ , $N = 1$ ; $k_s = 2, k_{r_1} = 6$
If $13 < \bar{\gamma} < 14$ , $N = 1$ ; $k_s = 4, k_{r_1} = 6$
If $\bar{\gamma} \geq 14$ , $N = 1$ ; $k_s = 6, k_{r_1} = 6$

## VI. RESULTS AND DISCUSSIONS

In this section, some results are provided. Figure 3 shows the BER of the DMF-SC cooperative system for  $[k_s, k_r] = [1, 1]$  and all modulation modes of Table 1. We use BER curve due to  $[k_s, k_r] = [1, 1]$  to find  $\bar{\gamma}_0$ . The curves state that as modulation mode increases, BER performance of the system decreases. However for all of these curves, there is an SNR threshold that BER remains below  $10^{-3}$ . The optimization problem is used to find the corresponding thresholds. Using these thresholds in adaptive modulation procedure, we could improve the total throughput of the DMF-SC system. Figure 4 shows the normalized throughput of the system which improves as a result of changing the modulation mode of source and relay, adaptively. The BER performance of the adaptive-modulated DMF-SC system is shown in figure 5 in comparison with the non-adaptive system. It is clear in this figure that the BER of adaptive modulated system remains below  $10^{-3}$  which is the expected value.

Figure 6 shows the BER performance of the N-relay system, for  $N=2$ . The figure compares the performance of this system with the one-relay system when the source and all the relays use similar modulation; BPSK or 64-QAM. It is apparent in the figure that when more relays are employed, the number of independent paths and consequently the diversity order increase. It leads to improvement of the BER performance of the system.

In the figures 7-9 we employed N-relay model and extracted the curves for  $N=2$ . Figure 7 shows the BER of the system for  $[k_s, k_1, k_2] = [1, 1, 1]$  and all modulation modes of Table II. We use the BER curve when all the relays and the source use BPSK, to find

$\bar{\gamma}_0$ . For each of these curves, there is an SNR threshold that BER remains below  $10^{-3}$ . The modified optimization problem is used to find the corresponding thresholds. Using these thresholds in adaptive modulation procedure, we could improve the total throughput of the 2-relay DMF-SC system. Figure 8 shows the normalized throughput of the system which is enhanced as a result of changing the modulation mode of the source and all the relays. The BER performance of the adaptive-modulated 2-relay DMF-SC system is shown in figure 9 in comparison with the non-adaptive system. It is apparent that the BER of adaptive modulated system remains below the target level.

In figures 10-13 we performed the algorithms due to adaptive relaying system, described in section V. Figure 10 shows the result of algorithm 3, for BER constraint of  $10^{-3}$ . As apparent in this figure, for SNRs below 2dB, at least 3 relays should cooperate so that the BER of  $10^{-3}$  could be achieved. The number of relays reduces to 2, for SNRs between 2 and 6 dB. For SNRs more than 7dB, we can use only 1 relay to achieve BER of  $10^{-3}$ . In figure 11 the BER of the system is shown for  $N=1, 2$  and 3 relays. The same modulation BPSK or 64-QAM is used for all nodes. The curves re-demonstrate that, for more number of relays, the BER performance of the system improves. However, increasing the number of relays leads to decreasing maximum throughput. This value is equal to 3 for single-relay system, is 2 for 2-relay system and is equal to 1.5 for 3-relay system. To combat this problem and at the same time keeping BER at the target level, we use adaptive relaying along with adaptive modulation as described in algorithm 5. The result is shown in figure 12 that is the normalized throughput of the system. The throughput gradually increases and reaches the maximum of 3, for SNRs more than 14dB. However that, if we use 2 relay for all SNRs, as done in figure 8, the system could attain maximum throughput of 2. On the other hand, the BER of this system is shown in figure 13, which is below  $10^{-3}$  for all SNRs. Whereas, if we use 1-relay for all SNRs, the BER does not reach  $10^{-3}$  until 6dB (figure 5).

As it is seen in figure 12, a local drop happened at SNR=7dB and after that, it begins to increase over again. This is the point in which the system switches from 2 relays to 1 relay. In 1-relay system, less order modulation satisfies BER constraint, at this SNR. So, a local throughput reduction happens. However, the throughput has a regular improvement and after 14dB, it reaches its maximum possible value of 3, while BER is always kept below  $10^{-3}$ .



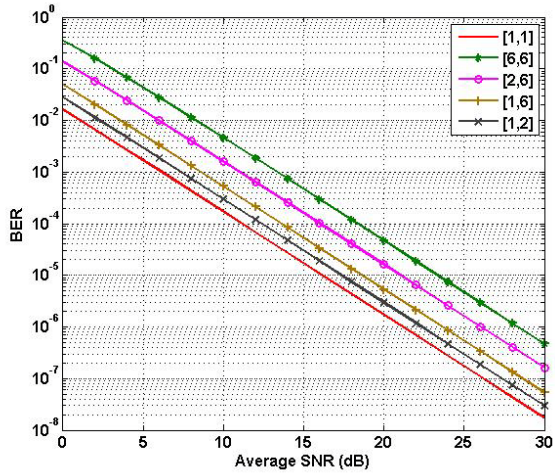


Fig. 3 BER of the DMF-SC cooperative system for different  $[k_s, k_r]$

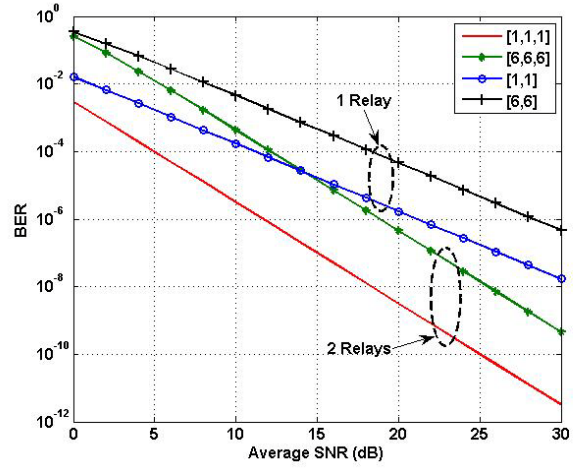


Fig. 6 BER of the DMF-SC cooperative system, comparing 1-relay and 2-relay systems.

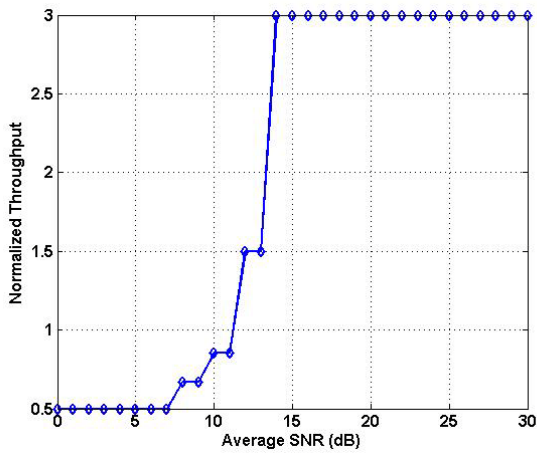


Fig. 4 The normalized throughput of the adaptive-modulated DMF-SC cooperative system

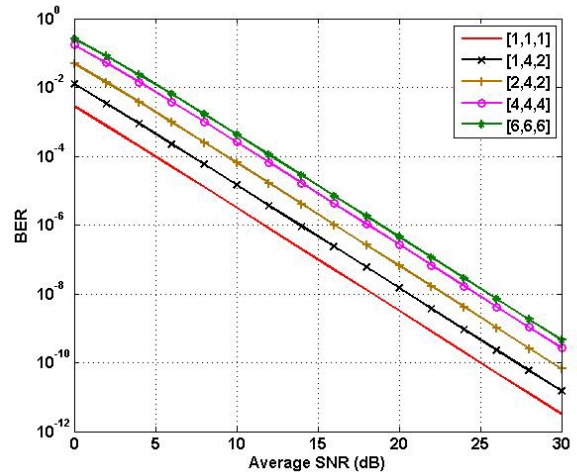


Fig. 7 BER of the 2-relay DMF-SC cooperative system for different modulations

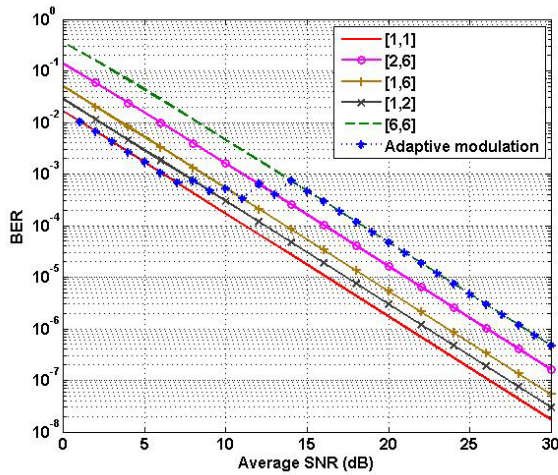


Fig. 5 The BER of the adaptive-modulated DMF-SC cooperative system

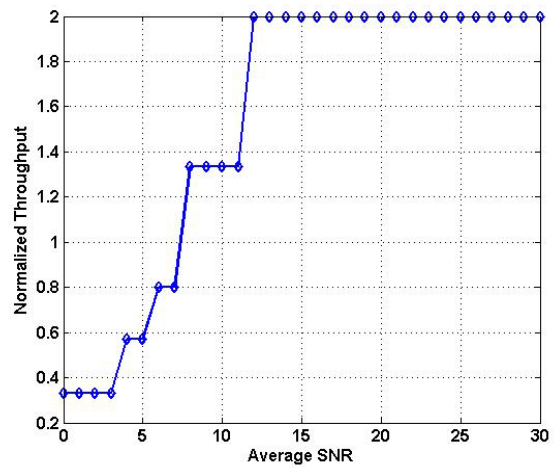


Fig. 8 The normalized throughput of the adaptive-modulated 2-relay DMF-SC cooperative system



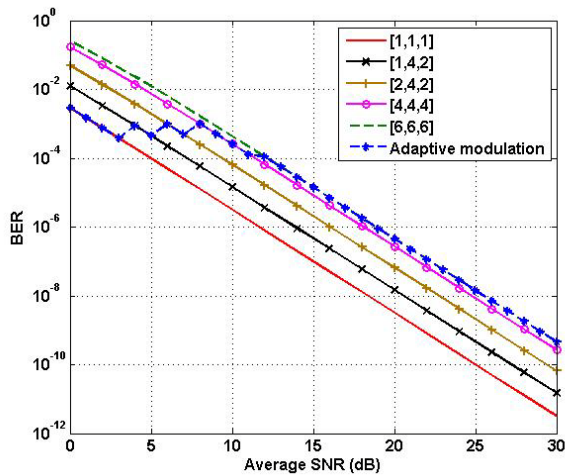


Fig. 9 The BER of the adaptive-modulated 2-relay DMF-SC cooperative system

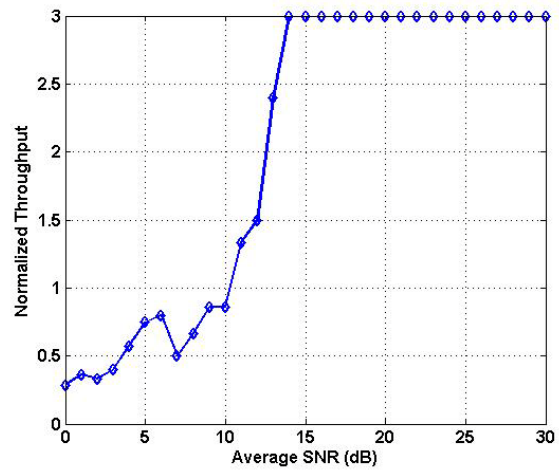


Fig. 12 The normalized throughput of the adaptive-modulated DMF-SC cooperative system, with adaptive relaying

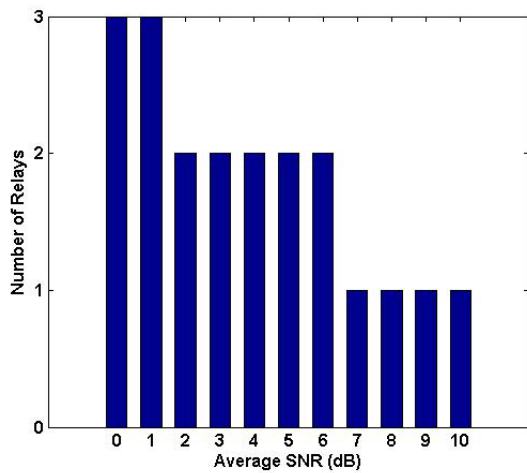


Fig. 10 The minimum number of relays that achieves BER constraint.

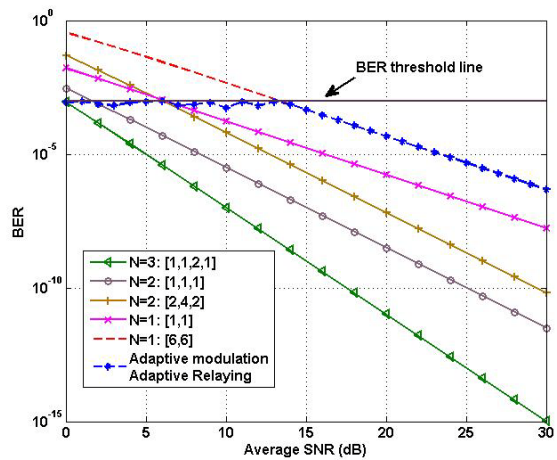


Fig. 13 The BER of the adaptive-modulated DMF-SC cooperative system, with adaptive relaying

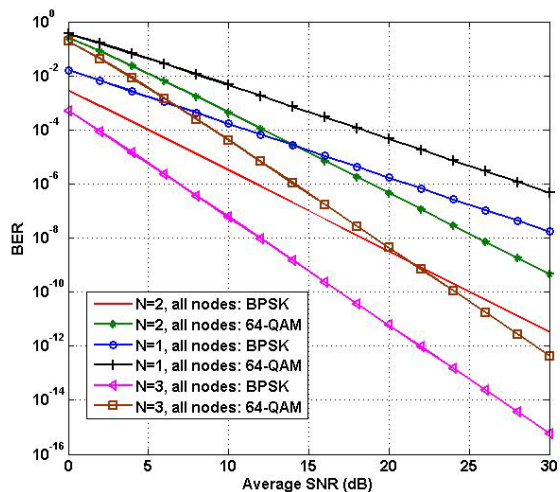


Fig. 11 BER of the DMF-SC cooperative system, comparing 1-relay, 2-relay and 3-relay systems.

### VII. CONCLUSION

In this paper, we implemented adaptive modulation for a DMF cooperative system, when the destination employs selection combining for data detection. In the proposed method, the source and relay select the modulation type based on the channel quality metric, which is the output SNR. To employ adaptive modulation, some switching thresholds are required. In this paper, we computed these adaptation thresholds by solving an optimization problem. Using these thresholds in adaptive modulation procedure, we improved the total throughput of the DMF-SC system. We also developed the model for the N-relay system and modified the optimization problem for this case. Then, by employing adaptive modulation for the N-relay DMF system, we enhanced the throughput while keeping the BER at a target level. However, increasing the number of relays leads to decreasing maximum throughput, and reducing relays, causes decaying BER. To achieve BER constraint and attain maximum possible throughput we proposed an adaptive relaying method. In this method, by increasing the SNR we eliminated the relays gradually, so the hardware complexity reduced. We also implemented adaptive



modulation for adaptive relaying DMF system. Therefore, we proposed a method that attains maximum possible throughput, achieves BER constraint, and reduces the complexity of hardware.

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