Low Complexity Adaptive Transmission Scheme for Cooperative Networks with Decode-and-Forward Relay

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Abstract— In this paper, we consider adaptive quadratic amplitude modulation (QAM) for a cooperative network consists of a source, one decode-and-forward (DF) relay and a destination which are single antenna systems. For increasing the spectral efficiency of the system, we use adaptive modulation method for data transmission. We propose a new adaptive modulation scheme which has less complexity than available schemes. Then, we analyze average spectral efficiency (ASE), average bit error performance (ABEP) and outage probability of the proposed scheme. Computer simulation results corroborate our theoretical relations; furthermore, it shows that our proposed scheme has the same performance as maximum spectral efficiency scheme (MSES) with much lower complexity and has better performance than some other schemes.

Keywords—adaptive modulation, decode-and-forward relay, cooperative network, spectral efficiency, outage probability.

I. INTRODUCTION

In wireless communications, multipath fading due to transmission in all directions degrades the performance of the system. One effective way to combat fading is diversity. Cooperative diversity is an attractive form of diversity in which a relay assists source in conveying information to the destination [1], [2]. There are two types of relaying protocol which are used more often: amplify-and-forward (AF) and decode-and-forward (DF). In AF mode, relay only amplifies its received signal; then, retransmits it to destination. On the other hand, in DF mode, relay decodes and encodes its received signal and retransmits it.

The rate of transmission is a very important factor in communication systems. Using half-duplex relaying causes reduction in transmission rate. Adaptive modulation method is a useful technique to compensate this reduction [3], [4]. We can increase the rate of transmission when the quality of channel is well [5]. In fact, there is a trade-off between ASE and ABEP which we can maximize the ASE as well as having an acceptable ABEP.

References [6] and [7] considered a cooperative system in which the relay is kept silent and does not cooperate in transmission when the channel quality of direct path between source and destination is good. Furthermore, [8] analyzed

adaptive modulation method for incremental relaying system. In [9], variable-rate transmission of a cooperative system with AF fixed relay (AFFR) for Rayleigh fading has been considered.

In [10] adaptive modulation technique for a cooperative system with DF relay has been presented which has a complex receiver due to this assumption that two different modes are received at the destination. Reference [11] has avoided this assumption; but, it has not noticed signal-to-noise ratio (SNR) of source to relay link. In [12] two adaptive modulation methods minimum error rate scheme (MERS) and maximum spectral efficiency scheme (MSES) for a DF relaying system has been investigated; it has exploited the assumption of error-detector relay and get rid of error propagation due to erroneous detection at the relay. Adaptive modulation in a multiple-relay system using relay selection is an effective way to increase the ASE [13].

In this paper, we propose a new adaptive quadratic amplitude modulation scheme for a cooperative network with DF relay. The relay uses ML detector to reduce the probability of erroneous detection, and the assumption of having relay with capability of error detection is not valid here, and we take error propagation into account. We use a simple detector at destination without combining received signals from source and relay. We show that our proposed method has a good performance with low complexity.

The rest of this paper is organized as follows. In section II, we describe our cooperative system model. In section III, our proposed adaptive modulation scheme will be explained. In section IV, we will consider performance analysis of the system; average spectral efficiency, average bit error, and outage probability of our scheme will be analyzed in this section. Simulation and numerical results will be presented in section V. Finally, in section VI, conclusion is drawn.

Notation: $CN(0, a)$ denotes the circular symmetric complex normal distribution with zero mean and variance a . S-D and S-R-D exhibit source to destination link and source to relay to destination link, respectively. Source, relay and destination are shown by s , r and d , respectively. The channel coefficient between nodes $i \in \{s, r\}$ and $j \in \{r, d\}$

and the additive white Gaussian noise (AWGN) which is added to the node j due to transmission of signal from the node i are represented by h_{ij} and n_{ij} , respectively; they have distribution $CN(0, \sigma_{ij}^2)$ and $CN(0, N_0)$, respectively. In addition, the SNR between nodes i and j is shown by γ_{ij} and has the distribution

$$f_{\gamma_{ij}}(x) = \frac{1}{\gamma_{ij}} e^{-x/\gamma_{ij}} U(x). \quad (1)$$

II. SYSTEM MODEL

We consider a cooperative network with one source, one half-duplex relay operating in DF mode and one destination which are single antenna systems as depicted in Fig. 1. Transmitted symbol from the source receives to the destination via two paths. One path is the S-D, and another is through the S-R-D. The destination does not combine the received signals from these two paths, and one of them is selected for decoding which is based on our scheme. The received signal at the destination transmitted by the source is

$$y_{sd} = h_{sd}s + n_{sd} \quad (2)$$

where s is the transmitted symbol. The destination knows the CSI of the S-D and uses ML detector. Now, we focus on transmission via S-R-D. The received signal at the relay is

$$y_{sr} = h_{sr}s + n_{sr}. \quad (3)$$

We assume that the relay knows the CSI of the source to the relay link; therefore, it decodes the symbol using ML detector; then, retransmits it to the destination as

$$y_{rd} = h_{rd}\hat{s} + n_{rd} \quad (4)$$

where $\hat{s}$ is the detected symbol at the relay. The destination also knows the CSI of the relay to the destination link and uses ML detector.

We consider $\gamma_{\min}$ as the equivalent SNR of the S-R-D where

$$\gamma_{\min} \triangleq \min(\gamma_{sr}, \gamma_{rd}). \quad (5)$$

III. ADAPTIVE MODULATION SCHEME

The source transmits a symbol using 2^n -QAM modulation for $n = 2, 3, \dots, N$ adaptively which N is the maximum spectral efficiency. The quantity of n is determined based on maximizing the spectral efficiency of system as well as having an appropriate bit error performance. We set a threshold for bit error performance of system which is represented by BEP_{th} . The BEP of a link using 2^n -QAM modulation can be approximated as [14]

$$BEP = A(n)Q\left(\sqrt{\frac{3\gamma}{2^n - 1}}\right), \quad n \geq 2 \quad (6)$$

where γ is the SNR of the link, and

Fig. 1. System model

$$A(n) \triangleq \frac{4(\sqrt{2^n - 1})}{n\sqrt{2^n}}. \quad (7)$$

If the SNR of a link is in the $[\gamma_k, \gamma_{k+1})$ interval, we send data from that link using 2^k -QAM modulation. According to (6), the SNR thresholds can be expressed as

$$\gamma_n = \frac{2^n - 1}{3} \left(Q^{-1} \left(\frac{BEP_{th}}{A(n)} \right) \right)^2, \quad 2 \leq n \leq N. \quad (8)$$

Note that $\gamma_{N+1} = \infty$, and the outage condition is expressed when the SNR is less than γ_2 ; in this case $n = 0$.

As we mentioned before, the source can send its symbol to the destination via two paths. Generally, it chooses one path for transmission. This selection is accomplished based on maximizing spectral efficiency while the BEP should be less than BEP_{th} . As a result, the selected link (SL) for transmission is determined as [12]

$$SL = \begin{cases} S-D, & \text{if } \{\gamma_{sd} \geq \gamma_{\lfloor N/2 \rfloor + 1}\} \text{ or} \\ & \text{if } \left\{ \gamma_n \leq \gamma_{sd} \leq \gamma_{n+1} \text{ and } \gamma_{\min} \leq \gamma_{2n}, n = 2, \dots, \lfloor N/2 \rfloor \right\} \\ S-R-D, & \text{otherwise} \end{cases} \quad (9)$$

IV. THEORETICAL ANALYSIS OF PERFORMANCE

In this section, we examine the performance of the system in terms of ASEP, ABEP and probability of outage.

A. ASEP Analysis

Using the proposed scheme, the average spectral efficiency of the system is

$$\eta = \sum_{n=\lfloor N/2 \rfloor + 1}^N n \times \Pr\{\gamma_n \leq \gamma_{sd} \leq \gamma_{n+1}\} + \sum_{n=2}^{\lfloor N/2 \rfloor} n \times \Pr\{\gamma_n \leq \gamma_{sd} \leq \gamma_{n+1}, \gamma_{\min} \leq \gamma_{2n}\} + \sum_{n=0}^{\lfloor N/2 \rfloor} \sum_{\substack{k=K_n \\ k \neq 1}}^N \frac{k}{2} \times \Pr\{\gamma_n \leq \gamma_{sd} \leq \gamma_{n+1}, \gamma_k \leq \gamma_{\min} \leq \gamma_{k+1}\} \quad (10)$$

where $K_n = 2$ if $n = 0$ and $K_n = 2n$ if $n \neq 0$. According to (1) and (5), the PDF of $\gamma_{\min}$ is

$$f_{\gamma_{\min}}(x) = \left(\frac{1}{\bar{\gamma}_{sr}} + \frac{1}{\bar{\gamma}_{rd}} \right) e^{-x \left(\frac{1}{\bar{\gamma}_{sr}} + \frac{1}{\bar{\gamma}_{rd}} \right)} U(x). \quad (11)$$

Moreover, γ_{sd} and $\gamma_{\min}$ are independent. We define $\chi(k, x)$ as

$$\chi(k, x) \triangleq e^{-\gamma_k/x} - e^{-\gamma_{k+1}/x}. \quad (12)$$

As a result, the average spectral efficiency can be computed as

$$\eta = \sum_{n=1}^N n \chi(n, \bar{\gamma}_{sd}) + \sum_{n=2}^{\lfloor N/2 \rfloor} n e^{-\gamma_{2n} \left(\frac{1}{\bar{\gamma}_{sr}} + \frac{1}{\bar{\gamma}_{rd}} \right)} \chi(n, \bar{\gamma}_{sd}) + \sum_{n=0}^{\lfloor N/2 \rfloor} \sum_{\substack{k=K_n \\ n \neq 1}}^N \frac{k}{2} \chi(n, \bar{\gamma}_{sd}) \chi \left(k, \frac{\bar{\gamma}_{sr} \bar{\gamma}_{rd}}{\bar{\gamma}_{sr} + \bar{\gamma}_{rd}} \right). \quad (13)$$

B. ABEP Analysis

Average bit error of a system is the average bits in error to the average transmitted bits ratio. Therefore, the ABEP of the system can be expressed as

$$ABEP = \frac{1}{\eta} \left(\sum_{n=\lfloor N/2 \rfloor + 1}^N n \times ABEP_{sd_1} + \sum_{n=2}^{\lfloor N/2 \rfloor} n \times ABEP_{sd_2} + \sum_{n=0}^{\lfloor N/2 \rfloor} \sum_{\substack{k=K_n \\ n \neq 1}}^N \frac{k}{2} \times ABEP_{srd} \right) \quad (14)$$

where $ABEP_{sd_1}$ is the ABEP when $\gamma_{sd} \geq \gamma_{\lfloor N/2 \rfloor + 1}$, and $ABEP_{sd_2}$ is the ABEP when $\gamma_{sd} \leq \gamma_{\lfloor N/2 \rfloor + 1}$ and $\gamma_{\min} \leq \gamma_{2n}$ and $ABEP_{srd}$ is the ABEP when $\gamma_{sd} \leq \gamma_{\lfloor N/2 \rfloor + 1}$ and $\gamma_{\min} \geq \gamma_{2n}$.

We have the following definition

$$\mu(\gamma_\alpha, \gamma_\beta, x, \lambda) \triangleq \int_{\gamma_\alpha}^{\gamma_\beta} Q(\sqrt{\lambda y}) x e^{-yx} dy. \quad (15)$$

This integral equation has been solved in [12, Appendix 3]. Using (15), the $ABEP_{sd_1}$ can be computed as

$$ABEP_{sd_1} = \int_{\gamma_n}^{\gamma_{n+1}} A(n) Q \left(\sqrt{\frac{3y}{2^n - 1}} \right) f_{\gamma_{sd}}(y) dy = A(n) \mu \left(\gamma_n, \gamma_{n+1}, \frac{1}{\bar{\gamma}_{sd}}, \frac{3}{2^n - 1} \right). \quad (16)$$

The quantity of $ABEP_{sd_2}$ is

$$ABEP_{sd_2} = \int_{\gamma_n}^{\gamma_{n+1}} \int_0^{\gamma_{2n}} A(n) Q \left(\sqrt{\frac{3y}{2^n - 1}} \right) f_{\gamma_{\min}, \gamma_{sd}}(x, y) dx dy = A(n) \left(1 - e^{-\gamma_{2n} \left(\frac{1}{\bar{\gamma}_{sr}} + \frac{1}{\bar{\gamma}_{rd}} \right)} \right) \mu \left(\gamma_n, \gamma_{n+1}, \frac{1}{\bar{\gamma}_{sd}}, \frac{3}{2^n - 1} \right). \quad (17)$$

We can compute $ABEP_{srd}$ approximately as

$$ABEP_{srd} \approx \int_{\gamma_n}^{\gamma_{k+1}} \int_{\gamma_k}^{\gamma_{k+1}} A(k) Q \left(\sqrt{\frac{3z}{2^k - 1}} \right) f_{\gamma_{\min}, \gamma_{sd}}(z, y) dz dy = A(k) \chi(n, \bar{\gamma}_{sd}) \mu \left(\gamma_k, \gamma_{k+1}, \frac{1}{\bar{\gamma}_{sr}} + \frac{1}{\bar{\gamma}_{rd}}, \frac{3}{2^k - 1} \right). \quad (18)$$

C. Probability of Outage Analysis

We can conclude from the proposed scheme in (9) that the system is in outage when both γ_{sd} and $\gamma_{\min}$ are less than γ_2 . Therefore, the probability of being in outage is

$$P_{outage} = F_{\gamma_{\min}, \gamma_{sd}}(\gamma_2, \gamma_2) = \left(1 - e^{-\frac{\gamma_2}{\bar{\gamma}_{sd}}} \right) \left(1 - e^{-\gamma_2 \left(\frac{1}{\bar{\gamma}_{sr}} + \frac{1}{\bar{\gamma}_{rd}} \right)} \right). \quad (19)$$

V. SIMULATION AND NUMERICAL RESULTS

In this section, we compare our theoretical results by computer simulation results. We set $BEP_{th} = 10^{-3}$ and $N = 8$. We consider two cases for showing the effect of relay position between the source and the destination and their distances. In one case, we will consider $(\bar{\gamma}_{sd}, \bar{\gamma}_{sr}, \bar{\gamma}_{rd}) = (\gamma, 5\gamma, 5\gamma)$, and in the other case, we assume $(\bar{\gamma}_{sd}, \bar{\gamma}_{sr}, \bar{\gamma}_{rd}) = (\gamma, \gamma, 5\gamma)$. Our results are plotted as a function of γ and are compared with MERS and MSER methods [12] and AFFR scheme [9].

Fig. 2. Average spectral efficiency comparison for $(\gamma, 5\gamma, 5\gamma)$.

In Fig. 2 the simulated ASE of our proposed method and its theoretical relation have been plotted and have been compared with MERS, MSES and AFFR methods for $(\gamma, 5\gamma, 5\gamma)$ case. It can be seen that our simulation result corroborates our theoretical relation. We should note that in MERS and MSES methods, the relay is assumed to be error-free, and if an error is occurred, the relay does not cooperate in transmission which is not a practical assumption. Moreover, in these methods, the destination should combine the received signal from the S-D and the S-R-D signal when the relay cooperates in transmission. Therefore, they have a more complex receiver than that of our scheme. Notwithstanding these overheads, we can see that the ASE of our scheme is much better than MERS and very close to MSES; furthermore, it outperforms AFFR scheme.

Fig. 3. Average spectral efficiency comparison for $(\gamma, \gamma, 5\gamma)$.

Fig. 4. Average bit error performance comparison for $(\gamma, \gamma, 5\gamma)$.

In Fig. 3 the plotted curves in Fig. 2 have been depicted for $(\gamma, \gamma, 5\gamma)$ case. We can conclude the same results as Fig. 2 about comparing our proposed scheme with MERS, MSES and AFFR methods.

In Fig. 4 we have compared the ABEP of different methods for the case of $(\gamma, 5\gamma, 5\gamma)$. It can be seen that the ABEP of our proposed method is close to that of MSES in high SNRs. Maximizing ASE was our main purpose and our scheme has much better ASE performance compared with MERS and AFFR method; although, their ABEP is better than our scheme; they need larger overhead and complexity. By the way, a good match between theoretical and simulation result of ABEP is seen.

Fig. 5. Outage probability comparison for the case $(\gamma, 5\gamma, 5\gamma)$.

Fig. 6. Outage probability comparison for the case $(\gamma, \gamma, 5\gamma)$.

The outage probability of our scheme has been plotted in Fig. 5 for $(\gamma, 5\gamma, 5\gamma)$. We can see that the slope of outage curve for our method and that of MERS and MSES schemes are the same which shows that they have equal diversity order. The slight difference between our proposed scheme and other schemes is due to the effect of source to relay link. Furthermore, the analytical and simulation results are match.

The same comparison as Fig. 5 is done in Fig. 6 for outage probability of $(\gamma, \gamma, 5\gamma)$.

VI. CONCLUSION

In this paper, we proposed a new scheme for adaptive quadratic amplitude modulation in a cooperative network consists of one source, one DF relay and one destination. Then, we analyzed average spectral efficiency, average bit error performance, and outage probability of the system using the proposed scheme. Simulation results showed that our theoretical equations are match with computer simulations; moreover, it showed that despite having a simple receiver and considering a practical system without having relay with detecting error capability, the performance of our proposed scheme is close to that of MSES method and is better than some other methods.

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