Adaptive Modulation in Coded Cooperation under Rayleigh Fading Channels

Kan ZHENG\(^{1,2}\), Member, Lijie HU\(^{†}\), Ling WANG\(^{†}\), Wenbo WANG\(^{†}\), and Lin HUANG\(^{††}\), Nonmembers

SUMMARY Cooperative communication provides a new way of introducing spatial diversity to wireless systems. In order to increase the spectral efficiency of coded cooperative relaying system, the adaptive modulation technique is presented under Rayleigh fading channel in this paper. The source and relay adapt their modulation schemes based on the channel condition of all three links. Also, the channel information of all the links has to be known when choosing the modulation scheme by the scheme proposed in [5], which is quite difficult to meet in practical systems. This paper presents adaptive modulation schemes for the coded cooperation system under Rayleigh fading channels, which belong to throughput-oriented adaptive modulation mechanisms. Such mechanisms select the modulation scheme which maximizes the instantaneous system throughput. In coded cooperation systems, cooperating source and relay adapt their modulation schemes based on the channel condition of all three links, i.e. source to relay, source to destination and relay to destination. Also, considering the instantaneous channel information between the source and the relay is usually not known perfectly available at the destination, then we proposed an adaptive modulation scheme which doesn’t require the accuracy channel state information instantaneously. It can estimate the channel quality through collecting the previous transmission status averagely. This scheme can provide better performance than direct transmission and demonstrate only a slight drop against idealistic performance.

This paper is organized as follows. Section 2 gives the brief description of a system model and procedure of coded cooperation. Then, the throughput of the different systems are analyzed in Sect. 3. Next, the adaptive modulation schemes for the idealistic case and in absence of the instantaneous channel information between the source and relay in coded cooperation systems are described in Sect. 4. In Sect. 5, the simulation results are presented and discussed. Finally, Sect. 6 gives the conclusion.

Notations: A circularly symmetric complex Gaussian variance \(x\) with mean \(m\) and covariance \(R\) is denoted \(x \sim \text{CN}(m, R)\).

1. Introduction

Cooperative communication provides a new way of introducing spatial diversity in wireless systems where the mobile stations may not be able to support multiple antennas due to size or other constraints [1]. By creating a “virtual array” through cooperation, cooperative diversity emerges as a special form of spatial diversity. Recently some repetition-based cooperative diversity algorithms such as amplify-and-forward (AF), decode-and-forward (DF) are developed to fully exploit the spectral diversity for reducing the outage probability [2].

However, cooperative diversity schemes such as coded cooperation usually decrease the spectral efficiency of the system because of their repetition based structure [3],[4]. On the other hand, by adjusting the transmission parameters to the instantaneous link quality, link adaptation mechanisms aim at improving both spectral efficiency and link reliability. So far, the investigation on adaptive technology in cooperative network haven’t been fully carried out on [5]–[7]. Most of them focus on the adaptive modulation concept applied in amplify-and-forward scenarios in [6], [7]. Also, the authors in [5] study the performance of adaptive modulation with retransmission to maximize the data throughput in coded cooperation systems. However, they didn’t consider much about the practical issues. For example, since numbers of modulated symbols transmitted in two hops are different in their scheme, it is hard to directly apply it in practical systems with the pre-defined frame structure. Moreover, the channel information of all the links has to be known when choosing the modulation scheme by the scheme proposed in [5], which is quite difficult to meet in practical systems.

This paper presents adaptive modulation schemes for the coded cooperation system under Rayleigh fading channels, which belong to throughput-oriented adaptive modulation mechanisms. Such mechanisms select the modulation scheme which maximizes the instantaneous system throughput. In coded cooperation systems, cooperating source and relay adapt their modulation schemes based on the channel condition of all three links, i.e. source to relay, source to destination and relay to destination. Also, considering the instantaneous channel information between the source and the relay is usually not know perfectly available at the destination, then we proposed an adaptive modulation scheme which doesn’t require the accuracy channel state information instantaneously. It can estimate the channel quality through collecting the previous transmission status averagely. This scheme can provide better performance than direct transmission and demonstrate only a slight drop against idealistic performance.

This paper is organized as follows. Section 2 gives the brief description of a system model and procedure of coded cooperation. Then, the throughput of the different systems are analyzed in Sect. 3. Next, the adaptive modulation schemes for the idealistic case and in absence of the instantaneous channel information between the source and relay in coded cooperation systems are described in Sect. 4. In Sect. 5, the simulation results are presented and discussed. Finally, Sect. 6 gives the conclusion.

Notations: A circularly symmetric complex Gaussian variance \(x\) with mean \(m\) and covariance \(R\) is denoted \(x \sim \text{CN}(m, R)\).

2. System Overview

2.1 System Model

As shown in Fig. 1(a), the source (S) transmits the signals directly to the destination (D) in the systems with direct transmission. In cooperative networks, besides the direct link between the S and the D, information also flows through relay (R) nodes, which help S to communicate with D as illus-
where $\alpha_{S}^{SD}$ modulator for trated in Fig. 1(b). All the channels including source to the destination (S-to-D), relay to the destination (R-to-D) and source to relay (S-to-R) are independent of each other and are assumed to be flat fading for the sake of simplification. However, the proposed technique in this paper could be easily extended to wideband systems that experience frequency selective fading channel.

The transmitted data is segmented in packets and protected against transmission errors with a channel encoder before being mapped to a particular signal constellation. At the $i$th frame with the duration of $T_{s}$, the $i$th output of the modulator for S is $s_{n}(i)$ and $\tilde{s}_{n}(i)$ for R. We assume that $E[|s_{n}(i)|^{2}] = E[|\tilde{s}_{n}(i)|^{2}] = P_{s}$, where $P_{s}$ is the average transmitted power. The corresponding signal received by D and R is

$$
\begin{align*}
    y_{n}^{SR}(i) &= \alpha_{n}^{SR} \cdot s_{n}(i) + \tilde{s}_{n}(i), \\
    y_{n}^{RD}(i) &= \alpha_{n}^{RD} \cdot s_{n}(i) + \tilde{s}_{n}(i), \\
    y_{n}^{SD}(i) &= \alpha_{n}^{SD} \cdot s_{n}(i) + \tilde{s}_{n}(i),
\end{align*}
$$

where $\alpha_{n}^{SR}$, $\alpha_{n}^{RD}$ and $\alpha_{n}^{SD}$ denote the independent complex fading channel gain from S to R, from R to D and from S to D, modeled as $\alpha_{n}^{SR} \sim \mathcal{CN}(0, \sigma_{SR}^{2})$, $\alpha_{n}^{RD} \sim \mathcal{CN}(0, \sigma_{RD}^{2})$ and $\alpha_{n}^{SD} \sim \mathcal{CN}(0, \sigma_{SD}^{2})$ with $\sigma_{SR}^{2} = E[|\alpha_{n}^{SR}|^{2}]$, $\sigma_{RD}^{2} = E[|\alpha_{n}^{RD}|^{2}]$ and $\sigma_{SD}^{2} = E[|\alpha_{n}^{SD}|^{2}]$ respectively. For slow fading (quasi-static) cases, the fading coefficients are constant within the transmission of the entire frame. Then, the index $i$ of channel fading coefficients can be omitted. Without loss of generality, we assume that the noise terms $\xi_{n}^{SR}(i)$, $\xi_{n}^{RD}(i)$ and $\xi_{n}^{SD}(i)$ have equal variances $\sigma_{N}^{2}$ and are modeled as $\xi_{n}^{SR}(i) \sim \mathcal{CN}(0, \sigma_{N}^{2})$, $\xi_{n}^{RD}(i) \sim \mathcal{CN}(0, \sigma_{N}^{2})$ and $\xi_{n}^{SD}(i) \sim \mathcal{CN}(0, \sigma_{N}^{2})$ respectively. Define the instantaneous signal-to-noise ratio (SNR) at link S-R, R-D and S-D as $\gamma_{n}^{SR} = |\alpha_{n}^{SR}|^{2} \tilde{\gamma}$, $\gamma_{n}^{RD} = |\alpha_{n}^{RD}|^{2} \tilde{\gamma}$, and $\gamma_{n}^{SD} = |\alpha_{n}^{SD}|^{2} \tilde{\gamma}$, respectively, with $\tilde{\gamma} = P_{s}/\sigma_{N}^{2}$.

2.2 Procedure of Coded Cooperation Transmission

The framework of coded cooperation in [2] is used in our paper. In a cooperative network, two or more nodes share their information and transmit jointly as a virtual antenna array. This enables them to achieve higher data rates and diversity than they could have individually. Coded cooperation provides significant performance gains for a variety of channel condition. In addition, by allowing different code rates and partitions, it also has a great degree of flexibility to adapt to channel condition. Figure 2 shows the procedure of coded cooperation transmission.

The source bits of the source are segmented into blocks of $K$ bits, including cyclic redundancy check (CRC) bits. Each information source block is encoded by a rate $R_{e} = K/N$ code generating $N = K/R_{e}$ bits. Let us assume that each codeword of length $N$ can be divided into two parts of length $N_{1}$ and $N_{2}$ with $N_{1} + N_{2} = N$. The first $N_{1}$ bits are self-decodable while the second $N_{2}$ bits are the parity bits that can be efficiently punctured without failing to decode the original message.

In the first transmission phase, the source sends $N_{1}$ bits which are overhead by the relay and destination. These $N_{1}$ bits are made up of $K$ information bits and $N_{1} - K$ parity bits. Then, the codeword received at $R$ is decoded and checked by using CRC. When the relay decodes the information bit correctly or not (which can be checked by using CRC), it will send ACK or NACK to the source. If no error, the original $K$ bits can be recovered and then used to compute the remaining $N_{2}$ bits of the codeword. Otherwise, the relay will keep silent in the second transmission phase. The level of cooperation is defined as $\rho = N_{2}/N$.

In the second transmission phase, if cooperation is happened, the relay transmits $N_{2}$ bits to the destination. Otherwise, the source will send the remaining $N_{2}$ bits by itself after being informed by NACK. After the destination decodes the $K$ source bits from the received $N_{1} + N_{2}$ bits, the ACK or NACK will be sent to the source according to the result of CRC checking.

3. Throughput Analysis on Coded Cooperation Systems

3.1 Under Direct Transmission

To better understand the data throughput for coded cooperation, let us first take a close look at that for direct transmission, i.e. only non-cooperative transmission.

Figure 3(a) shows frame structure of the direct transmission, where the source transmits each packet directly to the destination. The source bits are first segmented into blocks with size of $\tilde{K}$ bits including cyclic redundancy check (CRC) bits. Each source block is encoded and punctured into a $\tilde{N}$-bit codeword with the code rate $\tilde{R}_{c} = \tilde{K}/\tilde{N}$. Then,
these coded bits are modulated into the $\tilde{M}$ symbols with $\tilde{Q}$ bits per symbol. So the data throughput from $S$ to $D$ can be written as
\[ \tilde{\xi} = \tilde{M} \tilde{Q} \tilde{R}_c [1 - \tilde{P}_c (\gamma_n^{SD})] / T_s \] (2)
where $\tilde{P}_c (\gamma_n^{SD})$ is the average packet-error rate (PER) for the quasi-channel $S$-to-$D$ in non-cooperative transmission. Note that $\tilde{P}_c (\gamma_n^{SD})$ depends on the size $\tilde{N}$, the channel quality $\gamma_n^{SD}$ of $S$-to-$D$ and code rate $\tilde{R}_c$. For fair comparison, the same system parameters for channel coding for each modulation and coding scheme (MCS) are used for both direct transmission and coded cooperative transmission, i.e. $\tilde{K} = K$, $\tilde{N} = N$ and $\tilde{R}_c = \tilde{R}_c$.

3.2 Under Coded Cooperation Transmission

Now let us consider cooperative communication in a dual-hop wireless network where information is transmitted from the source to the destination with the frame structure as shown in Fig. 3(b).

As described in the previous section, the source sends $M_1$ modulated symbols with $Q_1$ bits per symbol to $D$ and $R$ in the first time slot, containing the first $N_1 = M_1 Q_1$ bits with code rate $R_1 = K / N_1$. Depending on whether the relay can decode the original $K$ bits from these $N_1$ bits, the second $N_2$ bits are modulated as $M_2$ symbols with $Q_2$ bits per symbol and transmitted by the source or relay in the second time slot.

Since the frame structure is usually pre-defined in practical wireless communication systems, it is assumed that the duration of the direct transmission phase (i.e. 1st time slot) and that of cooperation transmission phase (i.e. 2nd time slot) are kept unchanged in this paper. Also, on the assumption of centralized control strategy, the modulation schemes for direct and cooperation transmission are adjusted together with the same order, i.e. $Q = Q_1 = Q_2$.

In order to analyze the data throughput, we let $P_1 (\gamma_n)$ denote the average PER of the signals with codeword size $N_1 = M_1 Q$ and rate $R_1$ on the assumption that the SNR of this link is $\gamma_n$. Similarly, $P_c (\gamma_n)$ denotes the average PER with codeword size $N = (M_1 + M_2) Q$ and rate $R_c$ if the SNR of this link is $\gamma_n$.

There are two possible operation modes in coded cooperation systems, i.e. non-cooperative mode and cooperative mode. In case of non-cooperation, which happens with the possibility of $P_1 (\gamma_n^{SR})$, the destination receives the whole packet with the average PER of $P_c (\gamma_n^{SD})$ from the source itself. When the source and relay transmit the data cooperatively, which happens with the probability of $1 - P_1 (\gamma_n^{SR})$, the $N$ bits received at the destination include $N_1$ bits from the source with $\gamma_n^{SD}$ and the remaining $N_2$ bits from the relay with $\gamma_n^{RD}$. Therefore, in order to estimate the average PER of the whole packet with these two instantaneous $\gamma_n^{SD}$ and $\gamma_n^{RD}$, the method of exponential effective SIR mapping (EESM) has to be used [8].

The basic idea of EESM is to map the multiple instantaneous channel state into a single scalar value, termed as an effective SNR, i.e. $\gamma_n^{eq}$. Then, this effective SNR is used to find an estimate of the packet-error probability from basic additive white Gaussian noise (AWGN) link-level performance. By EESM, the effective SNR in the cooperative mode can be expressed as
\[ \gamma_n^{eq} = -\beta \ln \frac{M_1 \exp (-\frac{\gamma_n^{RD}}{\beta}) + M_2 \exp (-\frac{\gamma_n^{SD}}{\beta})}{M_1 + M_2} \] (3)
where $\beta$ is a parameter that must be optimized from link-level simulation results for each combination of the modulation and coding rate.

Then, the data throughput from $S$ to $D$ with coded cooperation can be written as
\[ \xi = (M_1 + M_2) Q \cdot \tilde{R}_c / T_s \cdot \{ [1 - P_1 (\gamma_n^{SR})][1 - P_c (\gamma_n^{eq})] \]
\[ + P_1 (\gamma_n^{SR})[1 - P_c (\gamma_n^{SD})] \} \] (4)
where $P_1 (\gamma_n^{SR})$ is the average PER of the first $N_1$ bits over the $S$-to-$R$ channel, $P_c (\gamma_n^{SD})$ denotes the average PER for $S$-to-$D$ channel when $S$ transmits the whole packet $N$ bits by itself and $P_c (\gamma_n^{eq})$ represents the average PER for the cooperative fading channel when the destination receives first $N_1$ bits from $S$ and the remaining $N_2$ bits from $R$.

4. Adaptive Modulation Scheme for Coded Cooperation

Cooperative diversity schemes such as coded cooperation usually decrease the spectral efficiency of the system because of their repetition-based structures. In this paper, we aim to increase the spectral efficiency of the coded cooperation system by adaptive modulation scheme.

4.1 SNR Estimation

Adaptive modulation is typically based on the received SNR. In practice, the SNR is usually unknown at the transmitter and must be estimated by the receiver. So a dedicated pilot sequence $p = \{p(1), p(2), \cdots, p(L)\}$ of length $L$, sent by the source or the relay, is time-multiplexed with the modulated data in each time slot as shown in Fig. 4.
Let us take the link between the source and the destination as an example for illustration. According to (1), the received pilot signal at the destination in the nth frame can be written as

\[ y_{SD}^n(i) = \alpha_{SD}^n p(i) + \epsilon_{SD}^n(i), \quad i \in \{1, 2, \cdots, L\} \]  

where the channel fading coefficient \( \alpha_{SD}^n \) is assumed to be constant over the entire frame. Then, the channel with least square (LS) principle and SNR estimate with minimum mean square error (MMSE) principle can be formulated as [9]

\[ \bar{\alpha}_{SD}^n = \frac{\sum_{i=1}^{L} y_{SD}^n(i) p^*(i)}{\sum_{i=1}^{L} |p(i)|^2} \]  

\[ \bar{\epsilon}_{SD}^n = \frac{\left| \sum_{i=1}^{L} y_{SD}^n(i) p^*(i) \right|^2}{\sum_{i=1}^{L} |p(i)|^2 \sum_{i=1}^{L} |y_{SD}^n(i)|^2 - \left( \sum_{i=1}^{L} y_{SD}^n(i) p^*(i) \right)^2} \]  

This method also can be used to estimate the channel and its SNR of other links like S-to-R and R-to-D.

These estimates will guide the transceiver to decide the proper modulation scheme that fits the current transmission characteristics. Usually, the better SNR, the higher modulation scheme will be applied to the transmission.

4.2 Adaptive Modulation Scheme

In coded cooperation systems, the source and the relay should choose their modulation schemes based not only on their own channel quality to the destination but also on the channel of their partner to the destination. According to (4), the data throughput \( \xi \) depends on the qualities of all the channels including the links S to D, R to D, and the link S-to-R. For the adaptive modulation, the data throughput will be computed based the SNRs at the destination on the assumption of each possible modulation scheme. Then, the modulation option with the maximum data throughput will be selected and the decision is made at the destination and feedback to S and R.

At the destination, the SNRs of the links including S to D and R to D can be estimated by using the dedicated pilot sequence as introduced before. However, it is quite difficult for D to know the exact channel state information of S-to-R link, which is used to estimate \( P_1(\gamma_{SR}^n) \). On the other hand, only when the channel of S-to-R link is reliable, i.e. the relay can decode the first \( N_1 \)-bit codeword in the first phase, the cooperative transmission will be happened in the second phase. So the destination can get the limited information about S-to-R link through the knowledge whether the cooperative transmission is happened successfully or not. Therefore, instead of \( P_1(\gamma_{SR}^n) \), we propose to use the simplified factor \( P_1(n) \) in (4) to estimate the throughput performance. This factor \( P_1(n) \), reflecting a quality estimate of S to D link, is generated through collecting the previous transmission status averagely as

\[ P_1(n) = \frac{W-1}{W} P_1(n-1) + \frac{1}{W} f_{SR}^n, \quad n > 0 \]  

\[ P_1(0) = 1 \]

where \( W \) is the size of the average window depending on the coherent time of the fading channel, and \( f_{SR}^n \) is the flag of the transmission status of the nth frame, i.e. \( f_{SR}^n = 0 \) in case of cooperative transmission, otherwise, \( f_{SR}^n = 1 \).

Therefore, the proposed adaptive modulation scheme in coded cooperation transmission can be summarized as shown in Fig. 5.

5. Simulation Results

The performances of the proposed strategy for cooperation communication are evaluated by simulations and discussed in this section. Turbo code used for direction transmission and coded cooperation transmission is a Parallel Concatenated Convolutional Code (PCCC) with two 8-state constituent encoders, whose generator polynomials is \( G(1, 13/11) \) and its overall rate of 1/3, i.e. \( R_c = R_1 = 1/3 \) [10]. The source block has \( M_1 + M_2 = 300 \) modulated symbols and \( M_1, M_2, R_1 \) depend on the cooperation level \( \rho \) (e.g. if \( \rho = 1/2, M_1 = 150, M_2 = 150, R_1 = 2/3; \) if...
\( \rho = 33\%, M_1 = 200, M_2 = 100, R_1 = 1/2 \). Three modulation and coding schemes (MCS) including QPSK, 16QAM and 64QAM modulation are applied in this section. For comparison, the same length of codeword is used for direction transmission and coded cooperation transmission, i.e. \( \tilde{N} = N = 600 \) with \( \tilde{K} = K = 200 \) for MCS1, \( \tilde{N} = N = 1200 \) with \( \tilde{K} = K = 400 \) for MCS2 and \( \tilde{N} = N = 1800 \) with \( \tilde{K} = K = 600 \) for MCS3, respectively. The values of \( \beta \) for each MCS are generated by our simulations with the common-used method in [11] and shown in Table 1. The independent fading links are generated by using Jakes Model having a U-shape Doppler power spectrum with maximum doppler spreading of 10Hz. For the channel and SNR estimation, the length of pilot sequence is assumed to be 5, i.e. \( L = 5 \). With the reference to Fig. 1, we mostly consider representative scenarios that corresponding to those in which \( R \) is located either close to \( S \) or in the middle of \( S \) and \( D \); the corresponding average output SNRs \((\tilde{\gamma}_{SR}, \tilde{\gamma}_{RD}, \tilde{\gamma}_{SD})\) in logarithmic-scale are \((\tilde{\gamma} + 10 \text{ dB}, \tilde{\gamma}, \tilde{\gamma})\) and \((\tilde{\gamma} + 5 \text{ dB}, \tilde{\gamma} + 5 \text{ dB}, \tilde{\gamma})\), respectively.

5.1 With Ideal Channel and SNR Estimation

Here the instantaneous channel state and SNR are assumed to be known ideally at the receiver. Let us first discuss the error rate advantages of coded cooperation. On the assumption of ideal channel quality of the link from \( S \) to \( R \), i.e. no error is happened during transmission, we compare the performances between the direct transmission and coded cooperation in Fig. 6. In the direct transmission, all the \( N \) bits transmitted by \( S \) are over the same channel fading coefficient (i.e. \( a_n^{SD} \)) of the slow fading channel from \( S \) to \( D \). On the other hand, on the assumption of successful coded coopera-

\begin{table}[h]
\centering
\caption{MCS vs. \( \beta \) value.}
\begin{tabular}{|c|c|c|c|}
\hline
MCS & Modulation & \( R_c \) & \( \beta \) \\
\hline
1 & QPSK & 1/3 & 1.69 \\
2 & 16QAM & 1/3 & 4.22 \\
3 & 64QAM & 1/3 & 16.92 \\
\hline
\end{tabular}
\end{table}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig6}
\caption{PER comparison of direction transmission and coded cooperation with ideal CSI/SNR.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig7}
\caption{Normalized throughput comparison of coded cooperation with/without adaptive modulation \((\tilde{\gamma}_{SR}, \tilde{\gamma}_{RD}, \tilde{\gamma}_{SD}) = (\tilde{\gamma} + 10 \text{ dB}, \tilde{\gamma}, \tilde{\gamma})\).}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig8}
\caption{Normalized throughput comparison of coded cooperation with/without adaptive modulation \((\tilde{\gamma}_{SR}, \tilde{\gamma}_{RD}, \tilde{\gamma}_{SD}) = (\tilde{\gamma} + 5 \text{ dB}, \tilde{\gamma} + 5 \text{ dB}, \tilde{\gamma})\).}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig9}
\caption{Normalized throughput comparison of coded cooperation with/without adaptive modulation \((\tilde{\gamma}_{SR}, \tilde{\gamma}_{RD}, \tilde{\gamma}_{SD}) = (\tilde{\gamma} + 3 \text{ dB}, \tilde{\gamma}, \tilde{\gamma})\).}
\end{figure}
the fixed modulation in both scenarios. Next, let us compare the throughput performance of systems with adaptive modulation in the direct transmission and coded cooperation under two different scenarios in Fig. 9 and Fig. 10 respectively. We can find that the coded cooperation with adaptive modulation outperforms direct transmission with adaptive modulation. Compared with the scenario in which $R$ is located close to $S$, the coded cooperation with adaptive modulation leads to more obvious gains in the low and medium SNR region under the scenario where $R$ is in the middle of $S$ and $D$. On the other hand, more throughput gain is achieved for the scheme with $\rho = 1/3$ than the scheme with $\rho = 1/2$. It is because more $N_1$ bits are transmitted in the first phase with smaller cooperation level $\rho$, which increases the probability of successful cooperative transmissions as shown in Fig. 11. For example, the scenario in which $R$ is located close to $S$, the throughput gain is 0.05 bits/symbol with $\rho = 1/2$ and 0.13 bits/symbol with $\rho = 1/3$ at $\bar{\gamma} = 12$ dB.

5.2 With Channel and SNR Estimation

On the assumption of the channel and SNR estimation as explained in Sect. 4, the performance of adaptive modulation with the simplified estimation of $P_1(\gamma^S_R)$ will be studied in this part. According to the coherent time of the fading channel, here we set the window size $W$ as 64. In order to evaluate the accuracy of simplified estimation, the root mean squared error (RMSE) of $P_1(n)$ is defined as

$$\text{RMSE} = \sqrt{\mathbb{E}[|P_1(\gamma^S_R) - P_1(n)|^2]}$$  \hspace{1cm} (9)$$

where $\mathbb{E}[x]$ denotes the expectation of the random process $x$.

With the estimated CSI and SNR, the performances is evaluated in case that only the average SNR of the link from $S$ to $R$ is varied and the qualities of other links are assumed to be fixed, i.e. $\bar{\gamma}_{RD} = 15$ dB and $\bar{\gamma}_{SR} = 10$ dB. Firstly, Fig. 12 shows the RMSE performances with different cooperation level. With the increase of the SNR of the link from $S$ to $R$, the RMSE becomes less, which means more reliability of
the proposed simplified estimation. Then, the corresponding normalized throughout performances are given in Fig. 13. It can be seen that the throughput difference between two methods, i.e., using $P_1(\bar{\gamma}_{SR})$ or $P_1(n)$, are quite small, which demonstrates the effectiveness of the simplified method.

Figure 14 and Fig. 15 compares the normalized data throughput of three schemes with ideal or practical channel estimation under the scenario of $(\bar{\gamma}_{SR}, \bar{\gamma}_{RD}, \bar{\gamma}_{SD})=(\bar{\gamma}, 15 \text{ dB}, 10 \text{ dB})$, where different cooperation level $\rho$ is assumed respectively. In the case that the estimated SNR of $S$-to-$R$ link is known at $D$, the $P_1(\gamma_{SR}'')$ is used for throughput computation in coded cooperation systems. Otherwise, the simplified scheme using $P_1(n)$ can be applied. Firstly, in case of ideal CSI and SNR estimation, we can find that the performance degradation due to the simplified method using $P_1(n)$ instead of $P_1(\gamma_{SR}'')$ is small, e.g., the throughput loss is only 0.05 bits/symbol at $\bar{\gamma} = 12 \text{ dB}$ in case of $\rho = 1/2$ as shown in Fig. 14 while 0.02 bits/symbol in case of $\rho = 1/3$ in Fig. 15. Secondly, with the estimated CSI and SNR through pilot sequence of $L = 5$, the performance loss due to estimation error is only around 0.4 or 0.2 bits/symbol in the region of low or medium SNR. Meanwhile, the coded cooperation systems with proposed adaptive modulation scheme with/without simplified method still outperform the direct transmission when estimated CSI and SNR are used.

6. Conclusion

In this paper, we have proposed the adaptive modulation scheme that can maximize the data throughput in systems employing coded cooperation relaying. Also, considering that the instantaneous channel information between the source and the relay is usually not available at the destination, the simplified estimation of the channel quality between the source and relay through collecting the previous transmission status statistically is given. Simulation results have been presented to demonstrate the normalized throughput improvement by adaptive modulation schemes in coded cooperation systems.

References

[10] 3GPP TS 25.212, “Multiplexing and channel coding (FDD),”

Kan Zheng received the B.S., M.S. and Ph.D. degrees from Beijing University of Posts&Telecommunications, China, in 1996, 2000 and 2005 respectively, where he is currently an associate professor. From April 2000 to October 2001, he was a system development engineer at TD-SCDMA R&D centre of Siemens (Ltd) at Beijing, China. His current research interests lie in the field of signal processing for digital communications, with emphasis on PHY/MAC algorithms in cooperative wireless networks.

Lijie Hu received the B.S. degree from Beijing University of Posts&Telecommunications (BUPT), China, in 2007, where she is working for M.S. degree. Her current research interests include link adaption algorithms in wireless cooperative systems.

Ling Wang received the B.S. and M.S. degrees from Beijing University of Posts&Telecommunications (BUPT), China, in 2005 and 2008, respectively. Her current research interests include PHY/MAC algorithms in MIMO-OFDM systems.

Wenbo Wang received his B.S., M.S. and Ph.D. degrees from Beijing University of Posts&Telecommunications (BUPT), China, in 1986, 1989 and 1992 respectively. He is currently a professor and dean of school of Telecommunication Engineering of BUPT. His research interests include signal processing, mobile communications and wireless network.

Lin Huang received the B.S. and M.S. from Beijing University of Posts & Telecommunications, China, in 2002 and 2005 respectively. Now she works on Orange Labs, France Telecom R&D, Beijing, China. Her current research interests lie in the field of cognitive/cooperative communication schemes.