A Comparison of Transmission Schemes for Scalable Video over MIMO Relay Networks

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Abstract— **This paper investigates a comparison of transmission schemes for the scalable video over multiple-input multiple-output relay networks. We consider three time-division multiple-access cooperative schemes by using embedded space time codes with various degrees of broadcasting and receiving collision. In this paper, we assume that base station and relay station are equipped two antennas and mobile stations have only one antenna. The relay station operates decode-and-forward mode for cooperative transmission. The base station broadcasts scalable video bit stream by encoding embedded space time codes with the assistance of relay. Upon the amount of received information of each cooperative scheme, Mobile stations get the corresponding efficient decoding. With the help of relayed information, base layer retrieves better protection for ensuring the basic quality of scalable video. Visual quality is refined by enhancement layers carried in transmitted signal. We investigate the diversity performance of various schemes in term of bit error rate. Scalable video performance is also provided for comparing and evaluating the effectiveness of scalable video transmission schemes. Based on the need of users, it's possible to select the suitable scheme for trading off between the protection of base and enhancement layers.**

Keywords— **Fading relay channels, scalable video coding, space-time coding, broadcast channel.**

I. INTRODUCTION

The significant progresses of both wireless data communication and video compression technique have enabled digital wireless broadcast application such as digital video broadcast (DVB) and high-definition video on demand (HDVOD). On one hand, advanced multiple-input multiple-output (MIMO) wireless physical-layer technique has significantly increased the spatial diversity and spatial multiplexing [1]. On the other hand, the scalable video coding extension of the H.264/Advanced Video Coding (SVC) standard provides high coding efficiency and scalability. The scalable video content is split into scalable layers to provide the different quality of services (QoS). The base layer (BL) guarantees the basic quality of supported video performance, whereas the enhancement layers (ELs) provide the refinement information of the aforementioned base layer [2].

In designing scalable video transmission system, it is important to highly protect the BL for guaranteeing the basic video quality. Because the bit streams of different layers have different importance. Unequal error protection (UEP) and forward error correcting protection (FEC) are usually applied for the system according to the source significant information [3], [4].

Most mobile stations (MSs) have limited size and resource. Therefore, cooperative communications have been proposed in many works not only to exploit the spatial diversity without the need of multiple antennas at each one but also to combat or reduce the effect of fading without additional power or any sacrifice in bandwidth [5]–[8]. Three time-division multiple-access (TDMA) cooperative protocols were analysed and examined in [9]. The authors considered a simple fading relay channels where source, relay and destination are each equipped with single antenna transceiver. They provided the comparison of the aforementioned three TDMA protocols by using mutual information and outage capacity analysis.

Space time coding (STC) was applied to increase the spatial diversity with the famous one Alamouti's code proposed in 1998 [10]. C.-H. Kuo proposed embedded space time codes (E-STC) for broadcasting and cooperative transmission broadcast using E-STC, respectively [11], [12]. In [11], the E-STC was proposed for wireless multimedia broadcast with heterogeneous receivers. Receivers with low configuration decode only base layer information while the receivers with more antennas can retrieve more information of transmitted layers. To the best of our knowledge, the paper [12] was the first one which considered cooperative transmission using E-STC for scalable video broadcast system. The base station (BS) is equipped two antennas and each user has only one antenna transceiver. Multiple layers are broadcasted by BS, on the other end link, MSs with one antenna is able to decode BL information for experiencing the basis video quality. For cooperative transmission case, terminal with the help from other terminals working as relay terminal can decode more layers and get the full quality of supported video by provider. The authors use amplify-and-forward (AF) mode for relay terminal in cooperative communication. The cooperative transmission consists of two time slots. In the first time slot, the BS broadcasts multiple layers to relay station (RS) and MSs. The RS amplifies and forwards the received signal from BS to MSs in the second time slot. Because both the scalable layer information and noise are amplified at RS, so MSs can't get good decoding if the source-relay channel is not sufficiently reliable.

In this paper, we apply E-STC for different fading relay channels over MIMO relay networks. We make a comparison of various transmission schemes for scalable video. Our work is related to the papers [9]–[12]. In MIMO relay networks where two antennas are equipped at BS and RS, only one antenna at MSs to account for size and resource constraint. The RS operates decode and forward (DF) mode. Upon more independently received signal, the MSs get better decoding efficiency with the higher video layer. Our main contributions are summarized as follows.

- We establish a unified framework for the combination of E-STC and fading relay channels over MIMO relay networks. Three possible transmission schemes are compared for video wireless broadcast system. The MSs get benefits from fading relay channels for giving more protection with a guarantee of the BL decoding. They, moreover, retrieve EL for enjoying the full quality of SVC bit stream.
- Both layers are orthogonal space time block codes (OSTBC). Consequently, we use the Alamouti's code decoding technique standard for decoding enhancement layers provides lower complexity than minimum mean-square error (MMSE) equalizer which was used in the papers [11].
- The bit error rate (BER) analysis and scalable video performance are respectively used to investigate the spatial diversity and the effectiveness of the three possible transmission schemes in term of peak signal to noise ratio (PSNR).
- Based on the need of users and comparison result, it's possible to select the suitable transmission scheme.

The rest of this paper is organized as follows. Section II describes transmission schemes over MIMO relay networks. Section III provides BER performance and the related scalable video performance analyses. We conclude in Section IV.

For notation in this paper, the bold lower case letter indicates a vector and the bold upper case letter represents a matrix. Superscript $(\cdot)^*$ denotes complex conjugate for scalar and element-wise complex conjugate for matrix. Matrix element $a_{j,i}$ denotes the entity in the jth row and i^{th} column of the matrix $\mathbf{A}$. $CN(\mu, \sigma^2)$ represents the circular symmetric complex Gaussian random variable with mean μ and variance σ^2.

II. TRANSMISSION SCHEMES OVER MIMO RELAY NETWORKS

A. Transmission Systems

The fading relay channel of a video broadcast system is depicted in Figure 1. We assume that the propagation environment is flat fading Rayleigh channel in which the channel coefficient remains unchanged during the transmission of single space time block code. The channel state information (CSI) is estimated perfectly at receivers. The BS encodes the media source into OSTBC and broadcasts to MS_k with the assistance of the RS terminal. The MS_k denotes the kth mobile station. Suppose that SVC video is

encoded/decoded by JSVM software [13]. The video bit stream is partitioned into two layers with unequal importance: a BL and an EL. The both layers are sent to BS for broadcasting through independent paths from two antennas by using quadrature phase shift keying (QPSK) modulation and E-STC. The goal of cooperative communication is the guarantee of BL transmission. In DF mode, the received signal from BS is demodulated and decoded before retransmission. The RS decodes only the BL from received signal instead of all scalable layers for increasing the protection of the BL.
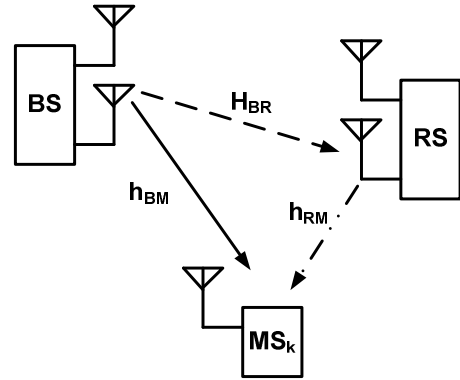
Figure 1. Fading relay channel of a video broadcast system.

Three possible transmission schemes used for scalable video over MIMO relay networks are summarized in Table I.

Scheme I. The BS broadcasts both layers in the first time slot to RS and MSs. In the second time slot, BS sends both layers and the RS sends decoded BL to MSs at the same time. MSs receive the superposition of two signals.

Scheme II. The BS communicates to RS and MSs at the first time slot with both layers. In the second time slot, only RS communicates to MSs.

Scheme III. The BS communicates to RS and MSs in the first time slot with only BL. In the second time slot, BS broadcasts both layers and the RS transmits BL to MSs at the same time.

TABLE 1. THREE DIFFERENT TRANSMISSION SCHEMES

Scheme Time Slot	I	II	III
1	BS→RS, MSs (both layers)	BS→RS, MSs (both layers)	BS→RS, MSs (only BL)
2	BS→MSs (both layers), RS→MSs (BL)	RS→MSs (BL)	BS→MSs (both layer), RS→MSs (BL)

B. Transmitter Design

Suppose that the transmit power at RS is equal to the transmit power at BS which is determined according to the available CSI at RS. The BS sends a code block within two consecutive time slots represented by

$$\mathbf{S} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \tag{1}$$

where s_{it} is the modulated symbol from i^{th} antenna at time slot t.

We modify the E-STC developed in [12] so that the BS transmits two layer sources. We use orthogonal Alamouti's code for both layers instead of only first layer in [12]. In each code block, the first layer carries modulated symbols x_1 and x_2, and second layer conveys modulate symbols y_1 and y_2. The transmission matrix of the first layer $\mathbf{C_1}$ is represented as

$$\mathbf{C_1} = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \tag{2}$$

And the second layer code block $\mathbf{C_2}$ is

$$\mathbf{C_2} = \begin{bmatrix} y_1 & -y_2^* \\ y_2 & y_1^* \end{bmatrix} \tag{3}$$

Because the most important layer is base layer, $\mathbf{C_1}$ is assigned higher transmit power. Supposing that $\mathbf{C_1}$ and $\mathbf{C_2}$ use same QPSK modulation technique. The transmitted symbol is the superposition of both layers.

$$\mathbf{S} = \mathbf{C_1} + \rho \mathbf{C_2} \tag{4}$$

where $\rho < 1$ is amplitude ratio of second layer to first layer.

Absolutely, the interference of both layers is able to occur and could be dealt with orthogonal space time code. The goal of the proposed system is to provide better scalable layers transmission. The quality and performance between both layers could be traded off by adjusting the signal power ρ.

C. Receiver Design

First we consider non-cooperative case, the MS_k receives signal directly from BS expressed by

$$r_b = \sqrt{\frac{P_b}{2}} h_{BM} \mathbf{S} + n_{BM} \tag{5}$$

where P_b is BS power, h_{BM} denotes channel vector, $n_{BM} \sim CN(0,1)$ is additive white Gaussian noise (AWGN) with zero mean and variance one.

MS_k only receives one signal comprising both layers from BS. The standard Alamouti decoding principle is available to recover the base layer $\mathbf{C_1}$.

$$\widehat{x_{b1}} = \mu[h_{BM1}^* r_{b1} + h_{BM2} r_{b2}^*]$$
$$\widehat{x_{b2}} = \mu[h_{BM2}^* r_{b2} + h_{BM1} r_{b1}^*] \tag{6}$$

where $\widehat{x_{bj}}$ is the jth estimated symbol of BL, $\mu = 1/(|h_{BM1}|^2 + |h_{BM2}|^2)$ is the normalization factor, h_{BMj} denotes channel coefficient at j^{th} antenna, r_{bj} indicates the received signal at j^{th} time slot.

To decode EL, we subtract out the term with $\mathbf{C_1}$ in r_b of (5)

$$\Delta r_b = r_b - h_{BM}\widehat{\mathbf{C_1}} \tag{7}$$

where Δr_b denotes the residual vector of the remaining layer consisting of noise. The standard Alamouti decoding principle is also used to decode enhancement layer $\mathbf{C_2}$.

Next we consider fading relay channels in order to achieve spatial diversity with the assistance of the RS.

Scheme I. The signal matrix at the RS and the signal vector received at MS_k in the first time slot are given as, respectively

$$R_r = \sqrt{\frac{P_b}{2}} H_{BR} \mathbf{S} + N_{BR} \tag{8}$$

$$r_{b,1} = \sqrt{\frac{P_b}{2}} h_{BM} \mathbf{S} + n_{BM} \tag{9}$$

where $r_{b,j}$ is the received signal at j^{th} time slot, $n_{BR} \sim CN(0,1)$ and $n_{BM} \sim CN(0,1)$ are additive white Gaussian noise (AWGN). The RS receives the signal from BS and uses the available standard decoding technique for decoding data before retransmission. In the second time slot, BS and RS communicate to MS_k at the same time. The received signal is the superposition of two signals.

$$r_{b,2} = \sqrt{\frac{P_b}{2}} h_{BM}\mathbf{S} + \sqrt{\frac{P_r}{2}} h_{RM}\widehat{\mathbf{C_1}} + \tilde{n} \tag{10}$$

where the effective noise term $\tilde{n} = n_{BM} + n_{RM}$, $P_r = P_b$ is transmit power at RS.

MS_k receives two signals within two time slots of (9), (10), respectively. These two signals are sent to the maximum likelihood detector for decoding BL.

$$\widehat{x_{b1}} = \mu \begin{bmatrix} h_{BM11}^* r_{b1,1} + h_{BM21} r_{b2,1}^* \\ +(h_{BM12}^* + h_{RM1}^*)r_{b1,2} + (h_{BM22}+h_{RM2})r_{b2,2}^* \end{bmatrix}$$
$$\widehat{x_{b2}} = \mu \begin{bmatrix} h_{BM21}^* r_{b2,1} + h_{BM11} r_{b1,1}^* \\ +(h_{BM22}^*+h_{RM2}^*)r_{b2,2} + (h_{BM12} + h_{RM1})r_{b1,2}^* \end{bmatrix} \tag{11}$$

where h_{BMjt} denotes channel coefficient of jth antenna and time slot t from BS to MS_k, h_{RMt} indicates channel coefficient from RS to MS_k at time slot t of second transmission from RS to MS_k, $r_{bi,j}$ represents the received signal at i^{th} time slot of jth transmission, the normalization factor μ is given as

$$\mu = \frac{1}{\left(\begin{array}{c} |h_{BM11}|^2 + |h_{BM21}|^2 \\ +|(h_{BM12} + h_{RM1})|^2 + |(h_{BM22} + h_{RM2})|^2 \end{array}\right)} \tag{12}$$

In order to decode EL, we need to get the residual matrix ΔR_b by subtracting the both received signals with $\mathbf{C_1}$.

$$\Delta \mathbf{R}_b = \begin{bmatrix} r_{b,1} - h_{BM}\widehat{\mathbf{C_1}} \\ r_{b,2} - (h_{BM} + h_{RM})\widehat{\mathbf{C_1}} \end{bmatrix} \tag{13}$$

where $\Delta r_{bi,j}$ represents the residual received signal at i^{th} time slot of jth transmission, the normalization factor μ is given as

The estimation of EL is determined by the same above decoding technique.

Scheme II. The received signal at RS and MS_k are similar to Eq. (8), (9). In the second time slot, only RS sends signal to MS_k after decoding, re-encoding and forwarding.

$$r_{b,2} = \sqrt{\frac{P_r}{2}} h_{RM}\widehat{\mathbf{C_1}} + n_{RM} \tag{14}$$

Eq. (11) and (12) are used to decode BL. we subtract out the term with $\mathbf{C_1}$ in r_b of (9) for estimating EL.

Scheme III. The BS only broadcasts BL to RS and MSs at the first time slot. The signal matrix at the RS and the signal vector received at MS_k in the first time slot are given as, respectively

$$R_r = \sqrt{\frac{P_b}{2}} H_{BR} \mathbf{C_1} + N_{BR} \tag{15}$$

$$r_{b,1} = \sqrt{\frac{P_b}{2}} h_{BM} \mathbf{C_1} + n_{BM} \tag{16}$$

The received signal at MS_k in the second time slot is similar to Eq. (10). Both layers can be decoded by using same Alamouti decoding standard as scheme I.

III. PERFORMANCE EVALUATION

A. Bit Error Rate Performance

In this section, we investigate the effectiveness of the various transmission schemes by using BER performance simulation. The analysis of each scheme is provided to give the optional choice for each application according the trade off of different importance of scalable layers. We also make a comparison with non-cooperative transmission case in which MS_k only receives one signal consisting of the BL and EL.
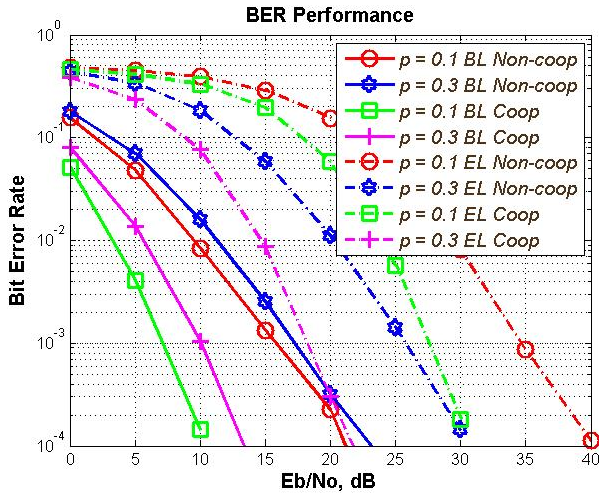
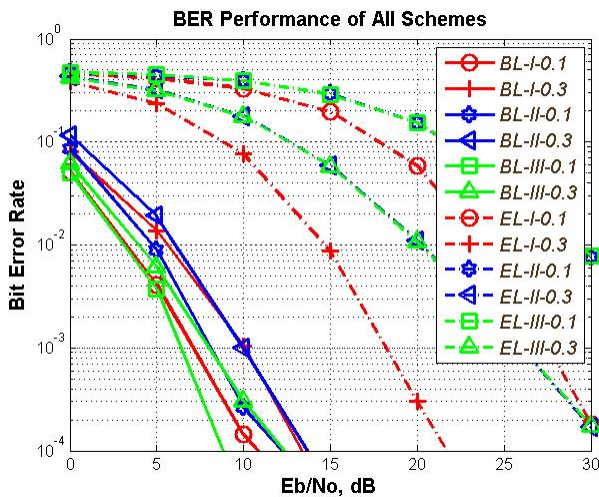**Figure 2.** The BER performance of Scheme I.

Figure 3. The BER performance of all schemes with the various amplitude ratio value, ρ. The elements in the legend are ordered as (layer name, scheme order, ρ).

The BER performance with QPSK modulation of both cooperative and non-cooperative transmissions for Scheme I is shown in Figure 2. The solid lines and dash-dot lines represent the BER of BL and ELs, respectively. The results show that MSs can decode both layers and enjoy the full quality of

scalable video. The solid lines with square maker and plus maker are the BER of BL of Scheme I with amplify ratio values $\rho = 0.1$ and $\rho = 0.3$, respectively. Scheme I significantly provides 12dB better protection for base layer at BER of 10^{-4}. The BER of EL of Scheme I also give 7dB better performance than non-cooperative. Different values of amplify ratio give different BER performance.

The Figure 3 shows the BER performance of all schemes at $\rho = 0.1$ and $\rho = 0.3$. BER behaviour of BL is always better than EL in all cases. It means that the protection of BL is better than EL. In case of amplitude ratio $\rho = 0.1$, Schemes I, II and III have nearly same BER behaviour of base layer, but EL of Scheme I is observed for 7 dB better performance at BER of 10^{-2} since MS_k gets two information signals of ELs. On the other hand of $\rho = 0.3$, the third scheme exhibits the best BER behaviour of BL and experiences same performance of layer 2 with Scheme II. The scheme II gives the best performance of energy efficiency because BS only broadcasts signal at the first time slot. We increase the value of ρ to enhance the importance of EL. The performance of ELs with $\rho = 0.3$ is much better than $\rho = 0.1$. Therefore, the trade off between BL and ELs could be operated by controlling the ρ value.

B. Scalable Video Performance

For the comparison of video quality, the Foreman sequence is partitioned into two layers with same size and SNR scalability by using JSVM 9.19 reference software [13]. The sequence contains 150 frames with the frame rate of 15 frames/s. The group of picture (GOP) is 16, and the resolution of both layers is 352x288. We use the peak signal to noise ratio in order to evaluate the scalable video performance given in Figure 4.
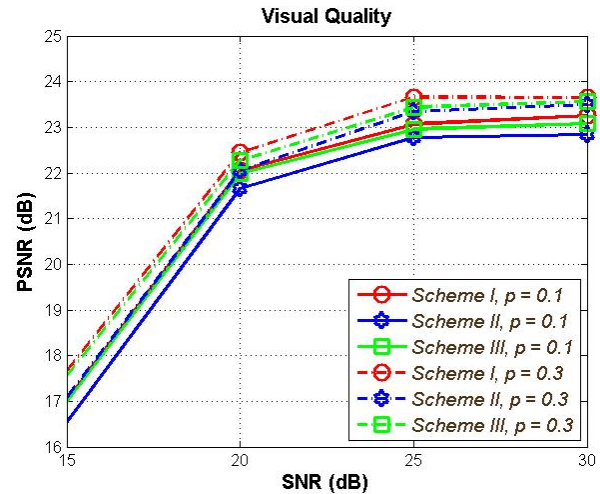
Figure 4. Video quality PSNR versus channel SNR of the Foreman sequence.

The results show that the PSNR of all schemes with various ρ values is quite different. We don't consider the channels with SNR lower than 15 dB since there is no meaning of the PSNR below 20 dB. Otherwise, for the channels with SNR range from 20-30 dB, the scheme I obtains better video quality

of average 0.3 dB gain than others. This is reasonable since the BER performance of the BL keeps unchanged at around 10^{-5} while the EL behaviour is getting better. Therefore, the receivers can decode successfully both layers with more refinement information and get the SNR scalability. The PSNR of scheme II is the lowest although having the same BER behaviour of the EL because the scheme III gets the better BER performance of the BL. Secondly, the video quality with $\rho = 0.3$ gives average 0.5 dB gain better performance than $\rho = 0.1$ from the range 20-30 dB since the MSs get more refinement information while getting same base layer information.

IV. CONCLUSIONS

In this paper, we investigate the comparison of transmission schemes for scalable video broadcast system over MIMO relay networks in order to provide higher protection of base layer. The simulation results show that all cooperative schemes could be used for conveying scalable video. MSs with cooperative communication could be guaranteed the basic video quality. Scheme I gives average 0.3 dB gain better than others because the refinement information carried in embedded STC provides the improvement of visual quality and helps users enjoy the full quality of supported SVC bit stream. The scheme II is average 0.3 dB gain worse than scheme III but providing more energy-efficiency. The uniform PSNR gaps are generally around 0.5 dB between various schemes with different amplitude ratio values. Based on the need of users and provided service, the trade off between the protection of base and enhancement layers are considered by adjusting the power dividing factor to select the suitable scheme.

For future work, the scalable video broadcast system could be significantly improved by considering the integration of error concealment, advanced channel coding and network coding. The combination and optimized design for practical video broadcast system are the attractive research and challenging topic.

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