ERROR-RESILIENT VIDEO TRANSMISSION FOR 3-D SIGNAL OVER COOPERATIVE-MIMO SYSTEM

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ABSTRACT

The multiple input multiple output (MIMO), cooperative communication and three dimensional (3-D) video coding are three state-of-the-art techniques. The combination between the cooperative system with MIMO is useful to provide a high data rate with a high quality of 3-D video services. By taking the advantages of these techniques, this paper presents 3-D video transmission over cooperative MIMO system. The proposed system based on a partitioning scheme, which uses adaptive allocation of Variable Length Codes (VLCs) with Unequal Error Protection (UEP) scheme for left and right views. In this scheme, video data is partitioned according to its importance into high priority (HP) and low priority (LP) coefficients. Because the video signal is usually sensitive to bit error, two methods are proposed. The first proposed technique is to interleave the Resynchronization pattern between VLCs to isolate the propagation of errors over the video stream. The second method is to improve the performance of the video decoder decision at lower values of Signal to Noise Ratio (SNR). Simulation results demonstrate the effectiveness of the proposed schemes.

1. INTRODUCTION

In recent years, there has been an increasing interest in the transmission of three-dimensional (3-D) video services over a wireless system. 3-D video is a new area and getting very popular with advances in display technologies. The news applications of 3-D entertainment will make 3-D technology the next generation of home and mobile entertainment [1].

High data rates are required for video transmission, and even more so for 3-D video. Spatial modulation multiplexing techniques such as a multiple input multi output (MIMO) have been developed to address this issue. Furthermore, due to the size and power constraints with increasing the number of antennas in MIMO - cellular mobile devices, cooperative diversity is employed to harness the spatial diversity without deploying multiple antennas. In addition, the combination between MIMO with 1 to 3 antennas and cooperative communications improves the video system performance [2].

Video transmission generally uses compression technique based on variable length codes (VLCs) to overcome the problem of channel bandwidth limitations. In addition, VLCs are usually very sensitive to bit error. A one bit error can propagate to many VLCs. Furthermore, error propagation causes a synchronization loss between the encoder and the decoder. In some cases, this leads to entire system breakdown.Therefore, error resilient techniques are required to minimize the effect of error propagation [3].

The video coding currently adopts unequal error protection (UEP) to prevent the error propagation through the VLC bits. This method depends on partitioning the video data into different fractions of visual importance. The most important part is called the high-priority (HP) coefficients which can be decoded to reconstruct the video with acceptable quality. The other VLCs are called the low-priority (LP) coefficients which represent the less important data, and they are used to improve the video quality. Furthermore, the number of HP-VLCs depends on the non-zero coefficients in each video block. By partitioning the data and applying better error protection to the VLCs of HP-coefficients, more robust bit streams can be achieved [4][5].

Many different approaches have been proposed in order to improve video transmission over the wireless communication system. In [6], a simple scheme is introduced to investigate the system performance of MPEG-2- coding scheme with a joint of convolution channel coding and MIMO based on space-time block code (STBC) techniques over Rayleigh fading noises. In addition, in [7], a MIMO system based on full multiplexing structure is proposed. This MIMO system is designed to load more important video layers based on adaptive channel selection (ACS) to sub-channel, which has a higher signal to noise ratio (SNR). In [8], a method is proposed to increase the transmission throughput through improving the modulation order of sub-channels. Moreover, several hybrid MIMO systems are proposed in [9] and [10]. However, the fixed structures of proposed schemes make them are far from channel changing, which needs to present techniques to overcome the error propagation between video signals in the decoder side. In addition, the proposed systems lack spatial diversity gain and might be ineffective in fading channel environments.

To address the above mentioned issues, this paper proposes a new UEP scheme for 3-D video transmission over cooperative MIMO system. The proposed UEP scheme can be achieved by isolating the HP-VLCs coefficients using a discrete cosine transform (DCT) technique. This method gives the ability to determine the importance of coefficients in each block adaptively. In addition, the proposed method is complemented by another method, which improves the decoding decision in 3-D video decoder when high distortion is present.

The remainder of the paper is organized as follows: The design of Cooperative-MIMO system and 3-D encoder is described in Section II. The Simulation of 3-D video transmission over cooperative-MIMO system and results are illustrated in Section III. Finally, the conclusion is presented Section IV.

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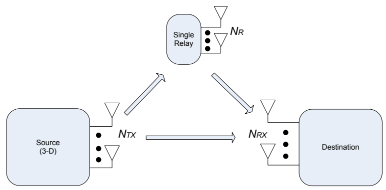

Figure 1: The Cooperative MIMO system.

2. COOPERAIVE MIMO DESIGN FOR 3-D VIDEO TRANSMISSION

In this section, the design of the cooperative MIMO system is described with inner components of the 3-D video transmitter using UEP.

2.1 Cooperative MIMO description

The cooperative MIMO architecture for 3-D video transmission is shown in Fig.1 [11][12]. As shown in Fig.1, N_{TX} represents the transmitter antennas and N_{RX} is receiver antennas. In addition, the relay has N_R antennas. Furthermore, assuming that the source-destination, source-relay and relay-destination channels are modelled as quasi-static Rayleigh fading channels, and they are represented by matrices H_{sd} , H_{sr} and H_{rd}, respectively. The fading coefficients in these matrices remain constant over a packet, and they are independent according to the Rayleigh distribution. The used relay also is assumed that gives a maximum SNR at destination node comparing to other possible relays which are existed in the network. At the first hop, the packet is sent to the destination and the relay. Each packet has a signal vector defined as:

$$s = [s_1, s_2, \cdots, s_{N_{TX}}]^T \tag{1}$$

At the direct link , the j_{th} element of the received signal vector y^{sd} at the destination is given by:

$$y_j^{(sd)} = \left(\sum_{i=1}^{N_{TX}} \sqrt{P_s} h_{j,i}^{(sd)} s_i \right) + n_j^{(sd)}, \quad j = 1,2,...,N_{RX} \tag{2}$$

where P_s is the transmitted symbol power at the source node.$h_{j,i}^{(sd)} \in H_{sd}$ denotes the channel coefficient from the i_{th} antenna of source to the j_{th} antenna of destination. $n^{(sd)}$ is the additive white Gaussian noise (AWGN), and its elements are independent and identically distributed (i.i.d.) as $n_j^{(sd)} \sim CN\big(0, \sigma_{sd}^2\big)$for $j = 1,2,...,N_{RX}$. At the first hop of the relay link, the relay ,which has k_{th} antennas, receives the signal $y^{(sr)}$.The received signal at relay is given by:

$$y_k^{(sr)} = \left(\sum_{i=1}^{N_{TX}} \sqrt{P_s} h_{k,i}^{(sr)} s_i \right) + n_k^{(sr)}, \quad k = 1,2,...,N_R \tag{3}$$

where $h_{k,i}^{(sr)} \in H_{sr}$denotes the channel coefficient from the i_{th} antenna of source to the k_{th} antenna of relay, and the AWGN noise $n^{(sr)}$ satisfies with $n_k^{(sr)} \sim CN\big(0, \sigma_{k,R}^2\big)$ for $k = 1,2,\ldots,N_R$. In the second time slot, the relay performs the Amplify and Forward (AF) protocol on received signals.The AF is proposed because it is lower complexity than decode and forward (DF) scheme. In AF protocol the relay, firstly, normalizes the received signals to yield a normalized signal $y_k^{(sr)}$ with $\mathbf{E}[|y_k^{(sr)}|^2] = 1$ and multiply the received signal $y_k^{(sr)}$ by the gain:

$$G_k = \frac{1}{\sqrt{\mathbf{E}\left[|y_k^{(sr)}|^2 |h^{(sr)}|^2\right]}} = \frac{1}{\sqrt{\left(\sum_{i=1}^{N_{TX}} P_s |h_{k,i}^{(sr)}|^2\right) + \sigma_{k,R}^2}} \quad k = 1,2,\ldots,N_R \tag{4}$$

where $\mathbf{E}[\cdot]$ stands for the mathematical expectation. After that, the relay forwards the signals to the destination. The j_{th} element of the received signals $y^{(rd)}$ at the destination is given by:

$$\begin{aligned} y_j^{(rd)} &= \sum_{k=1}^{N_{N_R}} \sqrt{P_r} h_{j,k}^{(rd)} G_k y_k^{(sr)} + n_j^{(rd)} \\ &= \left(\sum_{k=1}^{N_R} \frac{\sqrt{P_r P_s} h_{j,k}^{(rd)} \cdot \left(\sum_{i=1}^{N_{TX}} h_{k,i}^{(sr)} s_i \right)}{\sqrt{\left(\sum_{i=1}^{N_{TX}} P_s |h_{k,i}^{(sr)}|^2 \right) + \sigma_{k,R}^2}} \right) \\ &+ \left(\sum_{k=1}^{N_R} \frac{\sqrt{P_r} h_{j,k}^{(rd)}}{\sqrt{\left(\sum_{i=1}^{N_{TX}} P_s |h_{k,i}^{(sr)}|^2 \right) + \sigma_{k,R}^2}} + n_j^{(rd)} \right) \\ & j = 1,2,\ldots,N_{RX} \end{aligned} \tag{5}$$

where P_r is the total power shared among the relay antennas. $h_{j,k}^{(rd)} \in H_{rd}$ denotes the channel coefficient from the k_{th} antennas of relay to the j_{th} antenna of destination, and the AWGN noise $n^{(rd)}$ satisfies with $n_j^{(rd)} \sim CN\big(0, \sigma_{rd}^2\big)$ for $j = 1,2,\ldots,N_{RX}$.

In order to obtain the cooperative diversity gain, the maximal ratio combining technique in [13] is used at the destination in order to add coherently the signals of direct and the temporal delayed signals of relay link.

2.2 3-D video transmitter using UEP

Several different coding methods for 3-D video sequence have been proposed. The mixed resolution stereo coding (MRSC) is chosen because it is appropriate for low rate applications such as mobile services [14]. This method can be implemented by down sampling one of the views such as right view and up sampling back to the original resolution at the decoder. This yields different views with special resolutions and without losing many contents of the overall 3-D video quality.

The inner structure of the proposed 3-D video transmitter using UEP is shown in Fig.2.The UEP is proposed to protect the most important information (HP-VLCs) of left and right view. The VLCs after Run-length process are classified according to their important using Partitioner. The coefficients

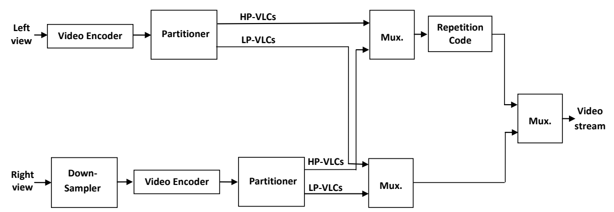

Figure 2: The proposed 3-D video transmitter using proposed UEP technique.

such as header information (Resynchronization pattern, motion vectors (MV) and the number of HP-VLCs of each 8x8 block), and the visual importance coefficients, are classified as HP-VLCs, while the remaining VLCs are considered as LP-VLCs. This proposed method can be explained as following: The 8x8 pixel block of I-frame or non-zero block of P-frame is encoded using DCT and Run-length technique. The VLCs of each block are separated to HP-VLCs and LP-VLCs coefficients. The HP-VLCs are protected using one of Forward Error Correction techniques such as repetition code, while the LP-VLCs are transmitted without protection.

3. SIMULATION OF 3-D VIDEO TRANSMISSION OVER COOPERAIVE MIMO SYSTEM AND RESULTS

The proposed 3-D video encoder and decoder are implemented using MATLAB. The cooperative MIMO is also designed according to cooperative MIMO model in Section II. The following assumptions are considered in the simulation.

- The repetition code (3,1) is used to protect the HP-VLCs coefficients.
- Bullinger video sequence is used with 25 frames-per-second.
- Each video sequence of left and right view has three frames.The first frame represents the intra or I-frame and remaining frames represent the inter frames or P-frames.
- For simplicity, the 3-D encoder and decoder are designed to deal only with the luminance components of video signal.
- The 3-D video transmitter uses binary phase shift keying (BPSK) to modulate the video data.

The parameters of simulation as following:

- The dimension of left image is 176x144 pixels.
- The down sampling of the left-view to right-view is 2:1.
- The Resynchronization pattern is chosen with minimum length and with the condition that is not existing in the Run-length lookup table. Therefore, it is selected to be: 1111111 000 011 1001010011 001111 .
- The Resynchronization pattern locates at each ten block.
- The source, relay and destination use 2 x 2 MIMO system and employ full-diversity using Alamouti scheme [15].
- The 3-D video transmitter transmits a packet with length = 100 symbols.

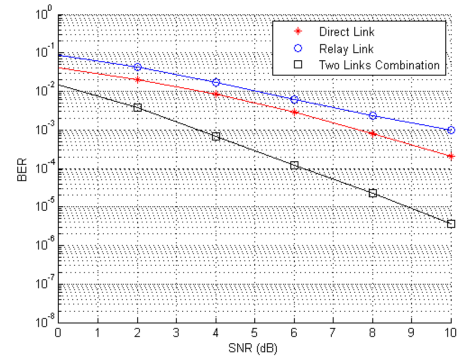

Figure 3: BER for cooperative MIMO system performance when γ_{sd}=γ_{sr}=γ_{rd}.

The image compression ratio for left view:

$$I-frame = \frac{8\times176\times144}{12615} \simeq \frac{1}{16}$$

$$P-frame = \frac{8\times176\times144}{1429} \simeq \frac{1}{142}$$

In addition, the image compression ratio for right view:

$$I-frame = \frac{8\times88\times72}{3991} \simeq \frac{1}{14}$$

$$P-frame = \frac{8\times88\times72}{500} \simeq \frac{1}{101}$$

The cooperative MIMO system performance is shown in Fig.3. Where the values of $SNR_{sd}(\gamma_{sd})$,$SNR_{sr}(\gamma_{sr})$ and $SNR_{rd}(\gamma_{rd})$ are same. As shown in Fig.3, the performance of the direct link is better than the relay link.This return to AF process which amplifies the received noise at relay and forwards it to the destination. In addition, the combination at the destination using MRC method improves the BER and maximizes the received SNR at the destination.Furthermore, the improvement of BER values leads to improve (Peak Signal to Noise Ratio) PSNR values at 3-D decoder output.It is clearly shown in Fig.3, the BER values have been improved by 4 dB compared to the direct link and 6 dB compared to the relay link at the BER of 10^{-3}.

In the case of the noisy channel, most VLCs could not be reconstructed. In some cases, the video decoder loses synchronization with the video encoder and reconstructs the wrong video coefficients. To overcome these problems, this paper proposes two error resilient methods.The first method is to insert the Resynchronization pattern between video blocks. This method is useful to minimize and isolate the error propagation between the video blocks. Furthermore, it is suitable in the case whom the level of the noise is not high. In addition, the effect of noise appears as distortion on reconstructed video sequence.The second method is to make the video decoder decide to neglect the LP-VLCs coefficients which suffer from noise, and reconstruct the video sequence depends on HP-VLCs. This method is useful when the level of noise

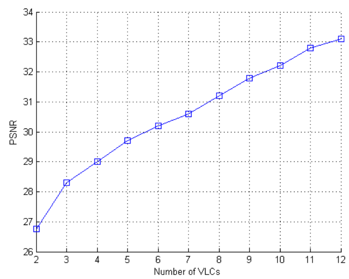

Figure 4: PSNR of reconstructed video sequence versus the variation in the number of VLCs.

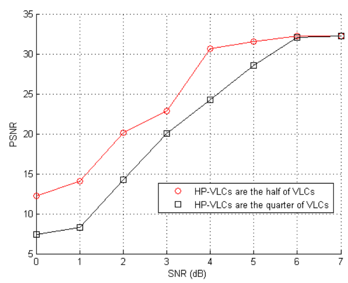

Figure 5: PSNR of reconstructed video sequence versus the variation in the number of VLCs.

is high. Furthermore, it gives the decoder the ability to reconstruct the video signal until the SNR is improved.
It is worth mentioning that, the importance of VLCs is arranged gradually from first VLC to the last VLC per 8x8 block. In this way, the numbers of HP-VLCs can be determined. In addition, as shown in Fig.4, the quality of reconstructed video sequence is directly proportional to increase the number of VLCs per block. Moreover, the increased number of VLCs improves the quality of the reconstructed video sequence, but this reduces the efficiency of the video compression. Therefore, the best performance can be achieved by making a careful balance between the number of HP-VLCs and the efficiency of video compression. In addition, the second method could achieve this goal. In the proposed method, the 3-D encoder adaptively allocates the HP-VLCs of each block to get acceptable quality of reconstructed video sequence. The proposed method considers either the half number of VLCs per block is HP-VLCs or the quarter number of total VLCs per block is HP-VLCs. This depends on the required quality of video sequence and the system performance over the noisy channel. To evaluate 3-D video quality by the objective joint PSNR which is calculated as $PSNR_j = 10.\log_{10}\left(\frac{255^2}{(MSE_l+MSE_r)/2}\right)$ where $MSEl$ and $MSEr$ represent the mean square error between original and reconstructed left and right sequences respectively [16]. The evaluation of these two schemes is shown in Fig.5. From this figure, the first scheme (the half number of VLCs per block) is better PSNR than the second scheme (the quarter number of total VLCs per block) by 8 dB. Therefore, more protection of VLCs makes a significant improvement of PSNR values. Fig.6 and Fig.7 show the $PSNR_j$ of left and

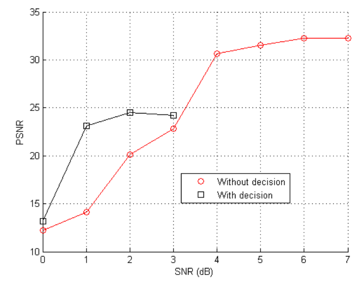

Figure 6: PSNR of reconstructed right and left view when HP-VLCs are the half number of total VLCs per block and γ_{sd}=γ_{sr}=γ_{rd}.

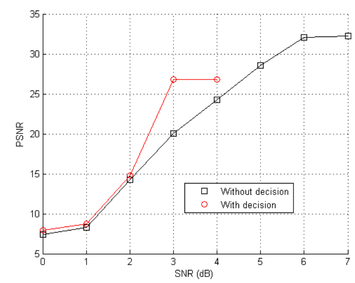

Figure 7: SNR of reconstructed right and left view when HP-VLCs are the quarter number of total VLCs per block and γ_{sd}=γ_{sr}=γ_{rd}.

right view versus SNR, where the SNR is assumed to be the same between all cooperative MIMO nodes. As shown in these figures, the decoder depends either on HP-VLCs and LP-VLCs streams to reconstruct the left and right view or to decide to reconstruct them depending on only HP-VLCs.
As shown in Fig.6 and Fig.7, although the HP-VLCs of left and right view are protected in the encoder side, the recovery of the video signal is almost impossible at low SNR values. This is mainly due to the excessive errors on the bitstream which change the most VLCs values. Consequently, the distortion effect is propagated through the reconstructed video sequence.Furthermore, this propagation case to make the 3-D video decoder to loss the synchronous with 3-D video encoder. The proposed method to overcome this problem is to make the decoder neglect temporary the LP-VLCs stream and depend on HP-VLCs to reconstruct the video signal. This method can give the ability to display the video sequences at low SNR values until the SNR is improved. In addition, as shown in Fig.6, the gain of PSNR is 20 dB and 7 dB in Fig.7.The improvement of PSNR is clearly observed in these figures at low values of SNR (0-3) in Fig.6 and SNR (2-4) in Fig.7.In addition, the PSNR values in Fig.7 between SNR=0-1 are the same with and without the decision, this due to the most VLCs are not protected comparing to the VLCs in Fig.6.
For the comparative purpose, Fig.8 shows the reconstructed second frame (P-frame) at different decoder behaviour when SNR= 3 dB. As shown in part c and d of Fig.8, the effect of error can be overcome by the decoder decision which makes

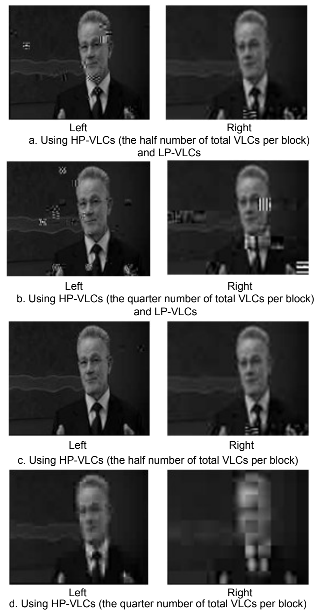

Figure 8: Reconstructed second frame when SNR= 3 dB.

the display the video sequence at low SNR but on the little losing of video quality.This losing of video quality could not be sensed in the case of HP-VLCs are the half of total VLCs per block, but be an inconvenient in the event of HP-VLCs are the quarter of total VLCs per block.

4. CONCLUSION

In this paper, the transmission of 3-D video signals over a cooperative MIMO system is presented. The proposed method utilizes error resilient video techniques to overcome error propagation in the 3-D video stream. The proposed approach uses a resynchronization pattern to improve the decoder performance at low SNR. The partitioning scheme based on the separation the VLCs of the left and right view within each block, and they are classified into HP and LP coefficients. In addition, the UEP is proposed to give a high protection to the most important coefficients (HP). The study also shows that the decoder can overcome the error propagation between reconstructed video frames. This can be achieved by depending on high protection stream. This method gives the ability to control the decoder operation and minimize the effect of errors on the recovered video sequence. This is achieved by using relatively few additional coefficients in the encoded bitstream.

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