RATE-OPTIMAL VIDEO TRANSMISSION OVER MIMO CHANNELS

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ABSTRACT

In this paper, we propose a low complexity method for optimal video transmission over a quasi-static Rayleigh fading channel utilizing multiple transmit and receive antennas. Under the assumption that the total transmission bandwidth is fixed, our method jointly selects the optimal Space-Time Code (STC) with fixed and finite signal alphabet and the optimal Reed-Solomon (RS) channel code rate with fixed codeword length to protect a video bitstream against channel bit errors. The numerical results of our scheme in comparison with alternative schemes, reveal its performance advantage over other schemes for different video sequences.

Index Terms— STC, H.264 codec, Reed-Solomon codec

1. INTRODUCTION

Providing an acceptable level of Quality of Service (QoS) for multimedia streaming applications over wireless channels still faces many challenges. Fading effects of wireless channels cause high bit error rates and therefore decrease the quality of the transmitted video sequence. To that end, many different approaches have been proposed to improve the performance of these applications.

Some of the proposed methods try to protect the video bitstream using the features of video bitstreams like Intra frame coding rate [1], [2], Fine Granularity Scalability (FGS) feature [3], [4], data partitioning [5] and other features.

On the other hand, other approaches may focus on channel coding resources to improve the transmission quality. Utilizing Multiple Input Multiple Output (MIMO) wireless systems for video transmission is one such approach that has received a great deal of attention, recently. Utilizing these systems can increase channel capacity and reliability of transmission, but achieving these benefits requires the use of coding techniques that can utilize the channel resources efficiently. Combining a Block Turbo Code (BTC) and a Space-Time Block Code (STBC) to transmit a video sequence over a 2×1 MIMO system, the authors of [6] propose an adaptive scheme that can offer both the error correction capability of BTC and the diversity gain of STBC. In [7], a Diversity Embedded Space Time Code (DESTC) [8] is used for transmitting layered video bitstreams. A comparison of Spatial Multiplexing (SM) and STBC is proposed for video applications in [9]. We note that all of the techniques noted above use fixed STCs and/or channel codes.

In this work, we provide a decision algorithm to jointly select the source coding rate $\mathcal{R}_S$, the channel coding rate $\mathcal{R}_C$, and the transmit diversity gain d necessary for optimizing the performance of a video transmission application under different channel conditions. While we consider a 2×2 MIMO system, we note that our method can be simply applied to other MIMO systems with a larger number of transmit-receive antennas. Assuming a fixed total transmission budget and signal constellation, our proposed algorithm selects parameters $\mathcal{R}_S$, $\mathcal{R}_C$, and d such that the recovery probability of a received video sequence is maximized. We also investigate the low computation complexity of our proposed algorithm.

The rest of this paper is organized as follows. In Section 2, we describe the transmission system used in this work. In Section 3, we describe our proposed decision algorithm and three other alternatives against which we compare the performance of our algorithm. In Section 4, we provide the results of our proposed method and compare them to the alternative techniques. Finally, we conclude the paper in Section 5.

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2. DESCRIPTION OF TRANSMISSION SYSTEM

In this section, we introduce a system for transmitting a video bitstream using $\mathcal{N}_T$ transmit and $\mathcal{N}_R$ receive antennas. In this system, we use the JSVM [10] implementation of H.264 as the video codec, an RS codec [11] with a byte long channel coding symbol size, and without loss of generality Quadrature Phase-Shift Keying (QPSK) modulation as a fixed and finite signal constellation. We assume that the average Signal-to-Noise Ratio (SNR) of the channel can be provided to our proposed Decision Algorithm running in the transmitter at each coherence time. In turn, the Decision Algorithm chooses the optimal encoding bit rate, RS rate, and the type of STC. The operating details of the Decision Algorithm are described in Section 3.

Under the assumption of quasi-static Rayleigh fading, the fading channel remains constant during the channel coherence time referred to as T. During each coherence time, one Group of Pictures (GOP) of the video bitstream are fully transmitted. First, the input video sequence is encoded with the specified bit rate. Then, the RS coding block encodes this bitstream with the selected RS rate. After applying QPSK modulation, the STC block encodes the sequence with the selected STC. Finally, the bitstream is transmitted to the receiver over a wireless channel through $\mathcal{N}_T$ antennas.

To capture the temporally correlated bit error pattern caused by a fading wireless transmission medium, we utilize the two state Gilbert-Elliott (GE) Markov chain. Utilizing the GE model, we can calculate the probability of having n bit errors when transmitting k bits as follows:

$$\mathcal{P}(n,k) = \mathcal{P}(n,k,G) + \mathcal{P}(n,k,B) \quad (1)$$

where $\mathcal{P}(n,k,G)$ and $\mathcal{P}(n,k,B)$ are the probability of having n bit errors in a k bit transmission and ending up in the GOOD state and BAD state, respectively. The details of calculating these probabilities can be found in [3]. Using Equation (1), the probability of RS symbol error $\mathcal{P}_{RS}$ is then calculated as follows:

$$\mathcal{P}_{RS} = 1 - \mathcal{P}(0, 8) \tag{2}$$

In this work we utilize a 2-transmit 2-receive MIMO system. The STC options considered in this work are 2×2 Alamouti [12] [13] and V-BLAST [14], [15], [13] codes. Fig. 1 compares the probability of symbol errors ($\mathcal{P}_{RS}$) for Alamouti and V-BLAST codes with transmit diversity gains of two and one, respectively.

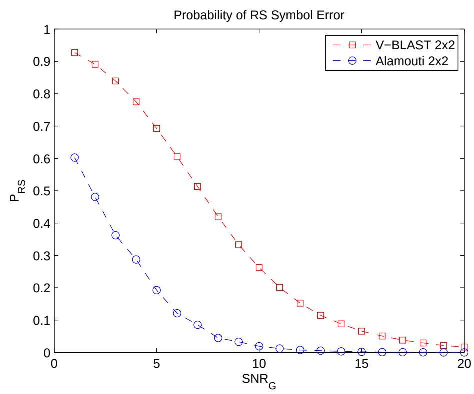

Fig. 1. A comparison of RS symbol error probabilities when utilizing an STC with two different transmit diversity gains.

At the receiver side, the received signals at $\mathcal{N}_R$ antennas are decoded by the STC decoder block and demodulated. The RS decoder attempts at recovering the bit errors. Finally, the bitstream is sent to the video decoder block to generate the video sequence for user viewing.

3. DECISION ALGORITHMS

The quality of a video bitstream transmitted over a wireless channel depends on many parameters such as, source coding parameters, channel coding rate, STC design, modulation, and channel conditions. Utilizing a fixed QPSK modulation and a fixed block size RS code, this section focuses on two independent parameters, the source coding rate $\mathcal{R}_S$ (and consequently RS channel coding rate $\mathcal{R}_C$) and the STC transmission diversity gain d (and consequently the transmission rate r).

We note that the parameter d affects the probabilities of bit error in each state of the channel model and consequently the probability of RS symbol error, $\mathcal{P}_{RS}$, i.e., the higher the value of parameter d, the lower the value of $\mathcal{P}_{RS}$. Fig 1 represents the effect of different transmit diversity gains on $\mathcal{P}_{RS}$ for these two STC codes.
On the other hand, the parameter r affects the maximum source coding bit-rate and the channel coding rate. Choosing a larger value for r lets us transmit a source bitstream with a higher value of $\mathcal{R}_S$ and therefore a higher quality. Alternatively, choosing a smaller value for r allows us to apply a stronger protection against bit errors. In what follows, we provide two tables. In the first table, we show the effect of source coding bit rate on the source distortion. In the second table, we represent maximum possible RS coding rates associated with each choice of the ordered pair $(\mathcal{R}_S, d)$.

Table 1 shows the distortion caused by the utilized video coder at different encoding rates and the corresponding quality of the decoded video for two different sequences, Foreman and Akiyo. We consider thirteen discrete values of source coding rates for each video sequence. As expected, the compression distortion of an encoded sequence increases as the encoding bit rate decreases.

Table 2 represents the maximum possible RS coding rates for Foreman and Akiyo sequences. The transmission rate r of Alamouti STC for Foreman and Akiyo QCIF sequences are considered to be 280kbit/s and 116kbit/s, respectively. Further, the transmission rates of V-BLAST STC are twice as those of the associated Alamouti STC. It is important to note that the RS coding rate is defined as follows:

$$\mathcal{R}_C = \frac{\mathcal{B}_P}{\mathcal{B}_D} \times 100$$

where $\mathcal{B}_D$ is the total data rate and $\mathcal{B}_P = r - \mathcal{B}_D$ is the total parity rate. As the total bandwidth in the case of using Alamouti STC is less than $\mathcal{R}_S$ for Encoding entries 1 through 6, we refrain from using these values for the choice of $d = 2$.

In what follows, we introduce four decision algorithms. The first three rate-optimal schemes use the probability of sequence recovery ψ_{seq} as the optimization metric and the last one is a distortion-optimal method.

Table 2. Maximum RS coding rates at different source rates and transmit diversity gains.

	Foreman_qcif		**Akiyo_qcif**	
	d=1	**d=2**	**d=1**	**d=2**
$\mathcal{R}_C1$	11	-	20	-
$\mathcal{R}_C2$	24	-	32	-
$\mathcal{R}_C3$	40	-	47	-
$\mathcal{R}_C4$	57	-	62	-
$\mathcal{R}_C5$	77	-	76	-
$\mathcal{R}_C6$	94	-	88	-
$\mathcal{R}_C7$	111	6	108	4
$\mathcal{R}_C8$	132	16	115	8
$\mathcal{R}_C9$	153	27	132	16
$\mathcal{R}_C10$	172	36	153	27
$\mathcal{R}_C11$	195	48	164	32
$\mathcal{R}_C12$	212	56	177	39
$\mathcal{R}_C13$	234	67	190	45

3.1. Opt Scheme

This scheme is proposed to optimally utilize the channel resources for the described video transmission system. It chooses the best source/channel/space-time encoding parameters for the ivideo bitstream by solving the following optimization problem:

$$\max_{(\mathcal{R}_\mathbf{S}, \mathbf{d})} \psi_{seq} \tag{3}$$

where the recovery probability of a sequence ψ_{seq} is calculated using Algorithm (1) for a pair of source coding rate and diversity gain $(\mathcal{R}_S, d)$ when the SNR_G of the GE channel is §. In this algorithm, $\mathcal{P}_{RS}$ represents the probability of RS codeword recovery, B is the size of RS codeword, P is the number of parities in each RS codeword, $\mathcal{N}_T$ shows the number of transmit antennas, and d is the transmit diversity gain of the selected STC. Further, the value of P depends on $\mathcal{R}_C$ for the current selection of $(\mathcal{R}_S, d)$ in Table 2. To solve the optimization problem of (3), we provide a fast search scheme by limiting the search area based on the selected parameter set in other

Table 1. The video compression distortion at different encoding rates.

	Foreman Sequence			**Akiyo Sequence**		
	Rate (Kbit/s)	**Distortion**	**PSNR (dB)**	**Rate (Kbit/s)**	**Distortion**	**PSNR (dB)**
Encoding1	254	7.2498	39.5275	97	3.3662	42.8593
Encoding2	226	8.3427	38.9177	88	3.8789	42.2437
Encoding3	200	9.6119	38.3027	79	4.5074	41.5915
Encoding4	179	11.0797	37.6855	72	5.227	40.9482
Encoding5	159	12.7107	37.0891	66	5.9735	40.3685
Encoding6	145	14.2672	36.5874	62	6.7636	39.829
Encoding7	133	16.0705	36.0705	56	7.7092	39.2607
Encoding8	121	18.0368	35.5692	54	8.8419	38.6653
Encoding9	111	20.2992	35.056	50	10.0572	38.106
Encoding10	103	23.1809	34.4795	46	11.6839	37.4549
Encoding11	95	26.3542	33.9223	44	13.2504	36.9085
Encoding12	90	29.6777	33.4065	42	15.1377	36.3302
Encoding13	84	33.7217	32.8517	40	17.7639	35.6354

Algorithm 1 Calculate ψ_{seq} for $(\mathcal{R}_S, d)[\S]$

Calculate $\mathcal{P}_{RS}$ for STC code with d, utilizing Equation (2) for $\S$.

$\psi_{RS} = \sum_{i=0}^{\lfloor P/2 \rfloor} \binom{B}{i} \mathcal{P}_{RS}{}^{i} (1 - \mathcal{P}_{RS})^{(B-i)}$

$\psi_{seq} = (\psi_{RS})^{\mathcal{N}_T - d + 1}$

channel conditions. Algorithm (2) describes the search scheme. In this algorithm, R_{min} shows the lowest source bit-rate, d_{max} is the highest diversity gain of possible STCs and $Threshold$ represents the lowest acceptable probability of recovery which is set to 0.995 in this work.

Algorithm 2 Decision Algorithm

$(\mathcal{R}_S, d)[0] = (R_{min}, d_{max})$
for $\S = 1$ to 20 **do**
  $(\mathcal{R}_S, d)[\S] \leftarrow (\mathcal{R}_S, d)[\S - 1]$
  if $(\mathcal{R}_S, d)[\S] \neq (R_{max}, d_{min})$ **then**
    Calculate ψ_{seq} for $(\mathcal{R}_S, d)[\S]$
    while $\psi_{seq} \geq Threshold$ & $\mathcal{R}_S[\S] < R_{max}$ **do**
      $\mathcal{R}_S[\S] \leftarrow \mathcal{R}_S[\S] + 1$
      Calculate ψ_{seq} for $(\mathcal{R}_S, d)[\S]$
    end while
    while $\psi_{seq} \geq Threshold$ & $d[\S] > d_{min}$ **do**
      $d[\S] \leftarrow d[\S] - 1$
      Calculate ψ_{seq} for $(\mathcal{R}_S, d)[\S]$
    end while
  end if
end for

3.2. Fixed STC Scheme

Fixed STC scheme selects the best source and RS coding rate, $(\mathcal{R}_S, \mathcal{R}_C)$, necessary to maximize the recovery probability of the sequence ψ_{seq}, while the transmit diversity gain d and rate r are known for the fixed STC used by the system. Having a fixed transmit rate, the algorithm chooses the source rate and consequently the maximum possible RS coding rate which satisfies (3). Since we have considered two different STC codes, $d1R_s$ and $d2R_s$ schemes select the best source rate and consequently RS coding rate for STC codes with $d = 1$ and 2, respectively.

3.3. Fixed Source Rate Scheme

Fixed Source Rate scheme selects an STC with a transmit diversity gain of d, necessary to maximize the recovery probability of the sequence ψ_{seq}, while the source coding rate $\mathcal{R}_S$ is fixed. Assuming the source rate is fixed, the algorithm selects the best STC code and consequently the RS coding rate that satisfies (3). Since we have considered thirteen different source rates for each input sequence, $R_{s1}d, R_{s2}d, \cdots, R_{s13}d$, the scheme selects the best STC and consequently RS coding rate for each of these source coding rates.

3.4. Distortion Optimal Scheme

We use Distortion Optimal (DistOpt) scheme to introduce an upper bound value on the performance of our Opt scheme. Knowing the performance of the codec for each given set of parameters and specified channel condition, we choose the optimal parameter set to minimize the distortion of the received video at the receiver using exhaustive search.

4. RESULTS

In this section, we provide numerical results of our proposed transmission method and compare it with the other three alternative schemes. For the GE chain, we apply transitioning probabilities of $\gamma = 0.99875$ and $\beta = 0.875$ associated with average burst lengths of 800 and 8 bits where γ is the self transitioning probability for the GOOD state and similarly β is the self transitioning probability for the BAD state. We choose an SNR range of $[0, 20]$dB for the GOOD state of the GE chain and set $SNR_{\mathcal{B}} = 0.1 \times SNR_{\mathcal{G}}$ to differentiate between the two states. While we have experimented with a variety of sequences, we only report our results for Foreman and Akiyo sequences.

Fig. 2 compares the performance of Fixed Source Rate, Fixed STC, DistOpt, and Opt schemes. It shows that Opt scheme outperforms Fixed STC scheme for both STC cases. Further, d2Rs outperforms d1Rs for lower SNR values. This is due to the fact that an STC with a higher transmit diversity gain provides a more reliable channel. On the other hand, d1Rs achieves a better quality at higher SNR values. This is because of the better throughput of the STC code it uses.

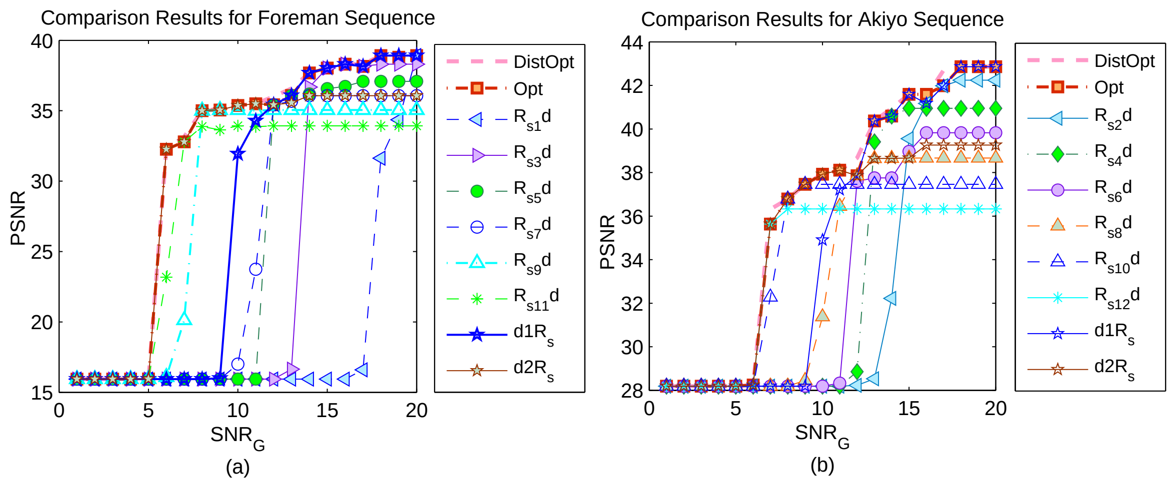

Fig. 2. Comparison results of Opt, Fixed STC, Fixed Source Rate, and DistOpt methods for (a) Foreman, and (b) Akiyo sequences.

Fig. 2 also illustrates that Opt scheme outperforms Fixed source Rate scheme for all values of source coding rates. We note that lower source coding rates allow for using higher RS coding rates or an STC code with a higher transmit diversity gain. Fixed Source Rate scheme can achieve a better quality compared to a case in which the RS rate is higher, i.e., when the channel performance is poor. On the other hand, the quality of decoded video with a lower source coding rate is less than that of a case with a high source coding rate. This means that Fixed Source Rate scheme can perform better under good channel conditions for high rate sources. We note that the performance of Opt scheme is comparable with that of the DistOpt scheme.

5. CONCLUSION

In this paper, we proposed a video transmission system with an efficient decision algorithm for selecting different transmission parameters. This algorithm uses the recovery probability of a sequence as the optimization metric and selects source, STC code, and consequently the RS coding rate to maximize this optimization metric in each coherent time of a wireless channel. We compared the performance of the proposed scheme with three other alternative methods. Our results illustrated that our proposed solution addresses performance-complexity tradeoff. While in this work two transmit and receive antennas are used, the scheme can be applied to other antenna configurations as well.

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