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Adaptive Video Transmission over Wireless MIMO System

Jia-Chyi Wu, Chi-Min Li, and Kuo-Hsean Chen
National Taiwan Ocean University
Department of Communications, Navigation and Control Engineering
Taiwan

1. Introduction

There has been an interesting issue in multimedia communications over wireless system in recent years. In order to achieve high data rate wireless multimedia communications, spatial multiplexing technique (Foschini & Gans, 1998; Wolniansky et al. 1998) has recently developed as one of the most noteworthy techniques as multiple-input and multiple-output (MIMO) systems. If the channel state information is perfectly available at the transmitter (Driessen & Foschini, 1999; Burr, 2003), we can maximize the channel capacity to design a realizable video transmission system. Under channel capacity limitation, the chapter presents how to employ joint source-channel coding algorithm with adequate modulation techniques to get the possibly best performance in the system design. Adaptive video coding to the varying channel conditions in real-time is well matched to MIMO systems for an optimized video transmission. An important matter in designing adaptive video transmission system is how often the feedback of the channel state information should be carried out. In fact, the feedback interval is mainly decided by the channel characteristics. For wireless fading channels, the feedback information needed to be able to capture the time varying channel characteristics for a true adaptive transmission. Song & Chen (2007, 2008) proposed adaptive algorithm design to utilized partial channel state information from receiver for layered scalable video coding (SVC) transmission over MIMO system. There are some interesting topics related in adaptive video transmission over wireless multimedia communication systems can be found in (Chen & He, 2006).
In our proposed system, we investigate the system performance of a joint MPEG-2 coding scheme with convolutional channel coding and space time block coding (STBC) techniques, associated with suitable modulation method (BPSK or QPSK), for video data transmission over a wireless MIMO system with Rayleigh fading noises. Rates assigned to MPEG-2 source code and convolutional channel code as well as space-time block code schemes are based on the feedback information from Performance Control Unit (PCU) under system channel capacity limitation, which ensures the proposed system achieved the best performance compared to a conventional designed system. In a conventional way, source coding and channel coding are designed to accomplish the best system performance respectively. With simply combining the best source coding scheme with the best channel coding scheme together, the system does not promise a better overall performance.

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Consequently, the present algorithm employs joint source-channel coding scheme and MIMO concept to get the best performance in the system design over fading channel.

We are interested in the joint source-channel coding with modulation scheme design under the channel capacity constraint consideration in a MIMO system. Figure 1 shows joint source-channel codes under the combination of various source coding rates and various channel coding rates. Source coding is concerned with the efficient representation of a signal. While bit errors in the uncompressed signal can cause minimal distortion, in its compressed format a single bit error can lead to significantly large errors. For data, channel coding is necessary to overcome the errors resulted from transmission channel. We have noticed that combining source coding with adequate channel coding, we should be able to achieve a better system performance. Assuming that the overall system transmission rate $r = k/n$, where k is the source coding rate and n is the channel coding rate. In Fig. 1, we have found that a better performance (with a lower distortion) can be promised when we increase the source coding rate k, while we increase the channel coding rate n, a higher bit error rate (a lower system performance) happened under the same E_b/N_0, signal-to-noise ratio (SNR) criterion. Therefore, we would like to design a transmission system with higher source coding rate k but lower channel coding rate n to achieve a higher overall transmission rate r. Since the overall transmission rate r is under channel capacity limitation, we have to justify the concept with proper method to design transmission system.

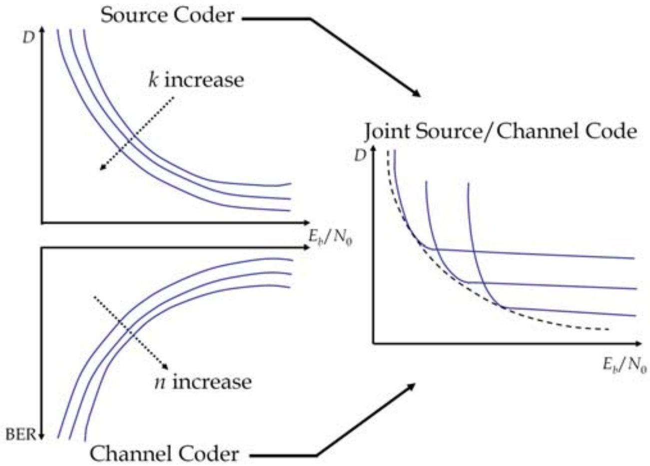


Fig. 1. Joint source and channel coding with different rates

The overall transmission rate r can be obtained by source coding rate k cooperated with channel coding rate n. We will not satisfy the system performance while we have a high source compression ratio (lower k) with strong channel protection (lower n). In turns, if we apply a low source compression ratio (higher source coding rate k with low distortion) but a high channel coding rate n (weak channel protection capability) to the system, which may result in higher bit error rate (BER) performance, we are not satisfactory with the reconstructed signal from the received high BER data. It is quite clear that we have to find a better match between source coding rate and channel coding rate to assure an acceptable system performance.

The most significant criterion in designing a transmission system is the channel capacity limitation. The available channel capacity restricts the overall transmission rate r, which is the rate between source coding rate k and channel coding rate n. We have to consider source coding rate, channel coding rate, and the corresponding modulation type all together simultaneously to cope with the channel capacity limitation. Assuming channel capacity limitation is one bit/transmission, we are asked to keep overall transmission rate $r \le 1$ bit/channel-use, which can be achieved only with $k \le n$. Therefore, we will keep our system rate design with $r \approx 1$ and $r \le 1$, that is, $k \approx n$ and $k \le n$. Furthermore, space-time block coding (STBC) algorithm was introduced (Alamouti, 1998; Tarokh et al., 1999) as an effective transmit diversity technique to resist fading effect. For a fixed number of transmit antennas, its decoding complexity increases exponentially with the transmission rate. The proposed algorithm employs joint source-channel coding scheme with STBC technique to get the best performance in MIMO systems design.

1.1 Outline

The rest of the chapter is organized as follows. Section 2 describes the system configuration adopted in this proposed algorithm. Experimental results for performance of the overall adaptive video transmission system compared with a conventional scheme over Rayleigh fading channel are shown in Section 3. Finally, a summary and conclusions are presented in Section 4.

2. System configuration

We are interested in the joint source-channel coding with modulation scheme design under the channel capacity constraint consideration in a MIMO system. We have applied the integrated transmission system design method (Daut & Ma, 1998) for digital transmission of video signals over noisy channels. To transmit a given video bit stream efficiently, we propose a joint source-channel coding system as shown in Figure 2.

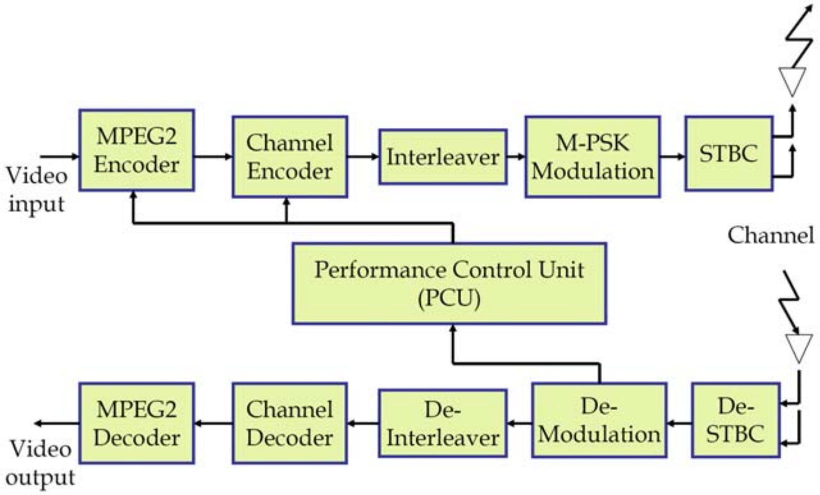
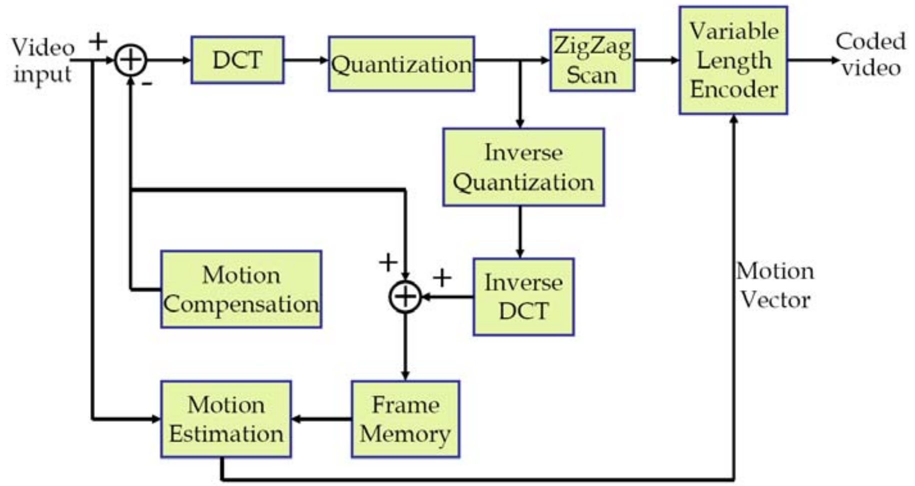


Fig. 2. Proposed adaptive video transmission system block diagram

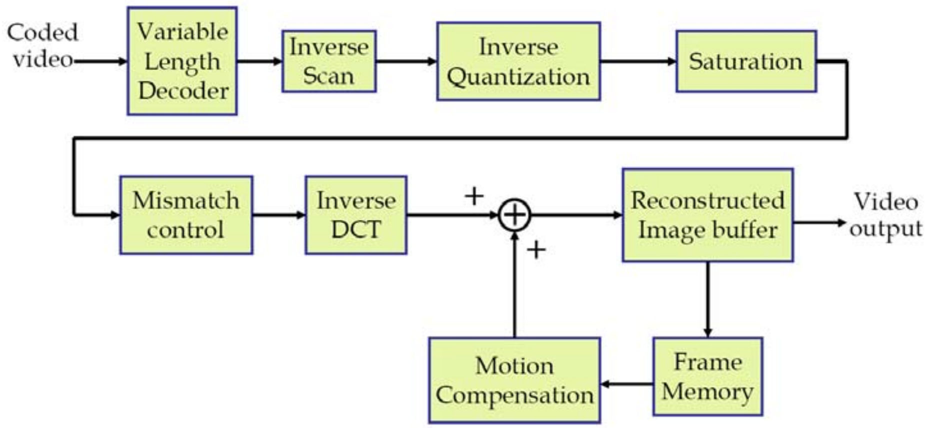
In this proposed system, the video sequence is first source coded by a MPEG2 scheme (Sikora, 1997). In order to reduce the system complexity of decoding, after the source coding stage, we use convolutional code and STBC in channel coding. The interleaver is adopted which is effected resisting burst error in wireless channel. There are two modulation techniques employed to be selected, BPSK or QPSK. The channel capacity is limited to one bit/transmission.

2.1 MPEG2 video source coding

The proposed adaptive video transmission system has been experimentally tested using an MPEG2 source coding algorithm provided from MPEG.ORG website.



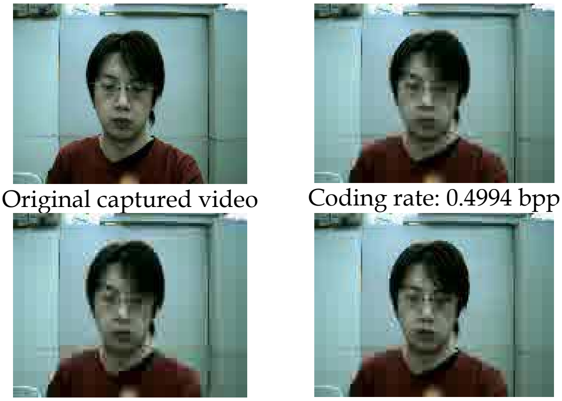
(a) MPEG2 Encoder



(b) MPEG2 Decoder

Fig. 3. MPEG2 video coding block diagram

Figure 3 shows the video coding and decoding block diagram of MPEG2 scheme, in which we can change the coding bit rate of MPEG2 to obtain the required source compression ratio. In the proposed system, there are three MPEG2 video coding rates adopted and the resulted compressed video frames compared with the original test video is shown in Fig. 4. The source coding scheme is MPEG2 format and there are 160×120 pixels in every frame. It can be seen that the video quality is better with MPEG2 coding rate 0.6659 bit/pixel (bpp) among the three tested coding rates.



Original captured video — Coding rate: 0.4994 bpp

Coding rate: 0.3986 bpp — Coding rate: 0.6659 bpp

Fig. 4. Video quality comparison of original and MPEG2 compressed test video frames

2.2 Channel coding – convolutional coding and space-time block coding

In order to reduce the channel error effect and to improve the system performance while transmitting video signals over wireless channel, we have employed the convolutional encoder and maximum-likelihood Viterbi hard decision decoder for channel error correction. Figure 5 shows a typical 1/2 recursive systematic convolutional (RSC) code scheme with generator function $G(D)=[1,(1+D^2)/(1+D+D^2)]$ (Proakis, 2001). After the convolutional encoding, the processed data is fed into a random interleaver to reduce burst error effect in wireless channel. The convolutional coding rates provided in this proposed system are set as 2/5, 1/2, and 2/3, respectively. The channel coding rate selected is corresponding to the MPEG2 source coding rate to satisfy the channel capacity limitation to one bit/transmission. For the system simulation, we have adopted two modulation types: BPSK and QPSK. The corresponding coding rates and modulation types are listed in Table 1. In order to receive a decent quality video sequence over wireless MIMO system with good coding gain real time, we have selected convolutional code and space time block code (STBC) for the channel coding. It has been known that a transmission system with antenna diversity can achieve reliable communication over wireless channel. Antenna diversity is achieved by employing spatially separated antennas at the transmitter and/or receiver. The advantage with multiple antennas scheme is that it results in a drastic increase in the channel capacity (Foschini & Gans, 1998). Alamouti (1998) introduced an efficient scheme which involves using two transmit antennas and one receive antenna (2×1 STBC code) for a wireless communication system. Tarokh et al. (1999) generalized the Alamouti scheme with STBC code to an arbitrary number of transmit antennas. STBC codes do not in general

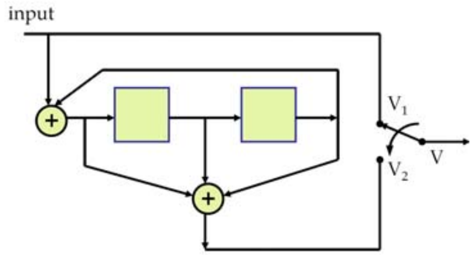


Fig. 5. Recursive systematic convolutional (RSC) encoder, coding rate = ½

Type	Transmission rate ($r = k/n$)	Channel coding rate, n (Convolutional)	Source coding rate, k (MPEG2)	Modulation type
A	0.9965 bit	2/5	0.3986 bpp	BPSK, QPSK
B	0.9988 bit	1/2	0.4994 bpp	BPSK, QPSK
C	0.9989 bit	2/3	0.6659 bpp	BPSK, QPSK

Table 1. Corresponding source-channel coding rate to achieve transmission rate, $r \approx 1$ bit.

provide any coding gain, therefore, it may need to be combined with an outer channel coding scheme to provide such coding gains. We then select convolutional code and space time block code for the channel coding. To simplify the analysis, we consider the simple STBC $\boldsymbol{G}_2$ encoder (Alamouti, 1998). The input symbol vector of the STBC encoder is denoted as $\boldsymbol{S} = [S(0), S(1), \ldots, S(2N-1)]^T$, where N is the number of the subcarriers. Let $\boldsymbol{S}_1 = [S(0), S(1), \ldots, S(N-1)]^T$ and $\boldsymbol{S}_2 = [S(N), S(N+1), \ldots, S(2N-1)]^T$, after the STBC encoder, the generated STBC $\boldsymbol{G}_2$ coded data symbols are

$$G_2^{STBC} = \overset{\xrightarrow{\text{antenna}}}{\begin{bmatrix} S_1 & S_2 \\ -S_2^* & S_1^* \end{bmatrix}} \Big\downarrow \text{time} \tag{1}$$

It can be found that, at time T, the first antenna sends out symbol $\boldsymbol{S}_1$ and the second antenna sends out symbol $\boldsymbol{S}_2$; at time T+1, the first antenna sends out symbol $-\boldsymbol{S}^*_2$ and the second antenna sends out symbol $\boldsymbol{S}^*_1$. It is easy to show that the inner product of matrix $\boldsymbol{G}_2$ is zero, which means the data within matrix $\boldsymbol{G}_2$ are orthogonal to each other. The space diversity types applied in this proposed system are 2×2, 2×1, and 1×2, respectively. Figure 6 suggests a 2×2 STBC $\boldsymbol{G}_2$ coded diversity transmission block diagram. The received signals can be represented as follows,

$$r_1(t) = S_1 h_1 + S_2 h_2 + n_1 \tag{2}$$

$$r_2(t+\tau) = -S^*_2 h_1 + S^*_1 h_2 + n_2 \tag{3}$$

$$r_3(t) = S_1 h_3 + S_2 h_4 + n_3 \tag{4}$$

$$r_4(t+\tau) = -S^*_2 h_3 + S^*_1 h_4 + n_4 \tag{5}$$

where S_1 and S_2 are the transmitted signals (* represents complex conjugate), h_1~h_4 are the channel fading coefficients between transmitter antennas and receiver antennas as shown in

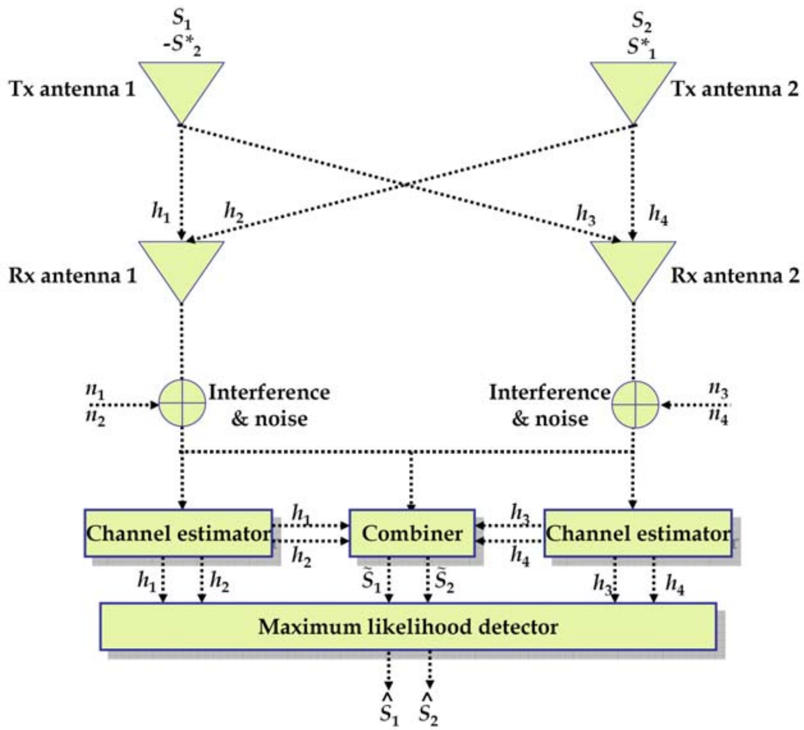


Fig. 6. A 2×2 STBC $\boldsymbol{G}_2$ coded diversity transmission block diagram

Antennas	Rx antenna 1	Rx antenna 2
Tx antenna 1	h_1	h_3
Tx antenna 2	h_2	h_4

Table 2. Channel impulse response between transmitter and receiver

Table 2, and $n_1 \sim n_4$ are corresponding AWGN channel noise. The coefficients h_1, h_2, h_3, and h_4 can be represented as the following,

$$h_i = \alpha_i e^{j\theta_i},\ i = 1, 2, 3, 4 \tag{6}$$

Assuming that the channel impulse responses can be fully estimated, we then are able to reconstruct $\tilde{S}_1$ and $\tilde{S}_2$ with the received signals, r_1, r_2, r_3, and r_4 by the following equations:

$$\tilde{S}_1 = h_1^* r_1 + h_2 r_2^* + h_3^* r_3 + h_4 r_4^* \tag{7}$$

$$\tilde{S}_2 = h_2^* r_1 - h_1 r_2^* + h_4^* r_3 - h_3 r_4^* \tag{8}$$

Substituting r_1, r_2, r_3, and r_4 from equations (2) ~ (5) into equations (7) and (8), we have,

$$\tilde{S}_1 = (\alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2) S_1 + h_1^* n_1 + h_2 n_2^* + h_3^* n_3 + h_4 n_4^* \tag{9}$$

$$\tilde{S}_2 = (\alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2)S_2 - h_1 n_2^* + h_2^* n_1 - h_3 n_4^* + h_4^* n_3 \quad (10)$$

Finally, we can decode S_i by applying Maximum Likelihood Detector (MLD) rule if and only if:

$$\begin{aligned}(\alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2)|S_i|^2 - \tilde{S}_1 S_i^* - \tilde{S}_1^* S_i \\ \le (\alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2)|S_k|^2 - \tilde{S}_1 S_k^* - \tilde{S}_1^* S_k, \quad \forall i \ne k\end{aligned} \quad (11)$$

To realize the channel coding rate effect under wireless Rayleigh fading channel with AWGN noise conditions, we have performed the experiment for 2×2 system antenna structure with three convolutional coding rates: 2/5, 1/2 and 2/3, respectively. The resulted system performance is shown in Figure 7. The system performance is improved with lower channel coding rate in the experiment. It can be found from Fig. 7, rate 2/3 convolutional coded system is with the worst bit error rate (BER) performance, where rate 2/5 convolutional coded system shown the best BER performance at the same SNR conditions. On the other side, system with lower channel coding rate (2/5 in this case) resulted in slower overall transmission rate. Therefore, if we may alternate the source coding rate corresponding to the channel coding rate, we are able to remain a consistent transmission rate which achieves channel capacity with considerable system BER performance.

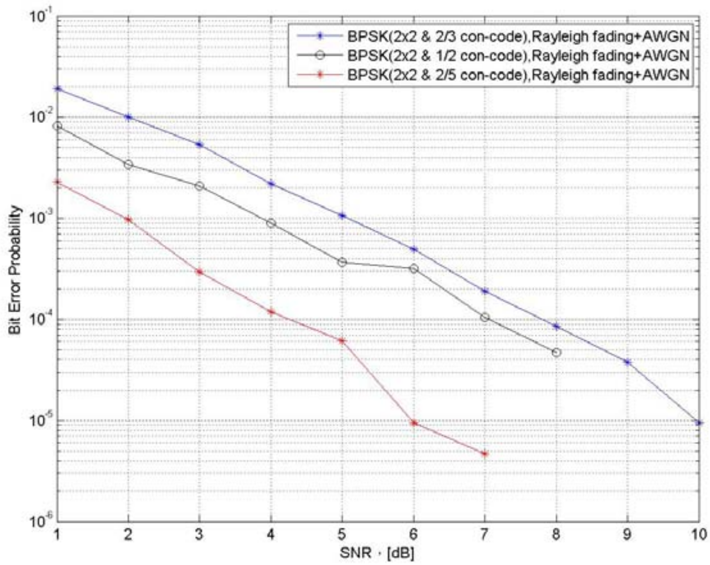


Fig. 7. Bit error rate (BER) performance of three concolutional channel coding rates under Rayleigh fading channel with AWGN noise in a 2×2 MIMO system.

2.3 Performance Control Unit (PCU)

Rates assigned to MPEG2 source coding and convolutional channel coding schemes as well as STBC space diversity selection are based on the feedback information from Performance Control Unit (PCU) under system channel capacity limitation, which ensures the given system achieved the best performance compared to conventional systems. PCU is the key components in the adaptive system design, where we have assigned three PCU states to report the changeable overall transmission status as shown in Table 3.

PCU state	BER after CTS state feedback	Convolutional code rate	MPEG2 code rate	No. of receiver antenna
State A: $H = 0$	BER = 0 %	2/3	0.6659 bpp	2
State B: $H = 1$	BER ≤ 20%	1/2	0.4994 bpp	2
State C: $H = -1$	BER > 20%	2/5	0.3986 bpp	1

Table 3. System state assignment of PCU

We adopt first-order Markov chain to describe the system states transfer (Daut & Ma, 1998). The present state is associated with the one-step adjacent state as shown in Figure 8. We have set-up three states to collaborate with the variable Rayleigh fading channel conditions. The three states is arranged to form a circular situation where the state transition is made according to Table 3, the system state assignment of PCU. On Fig. 8, H is the output status index of the PCU. We have assigned that, $H = 0$ is the "state A" index, system with good channel condition and a fast channel coding rate ($n = 2/3$) is assigned; $H = 1$ is the "state B" index, the channel is in an "OK" condition and the transmission data need more protection (channel coding rate $n = 1/2$); $H = -1$ is the "state C" index, channel condition has degraded and the channel code with good protection has to be utilized ($n = 2/5$).

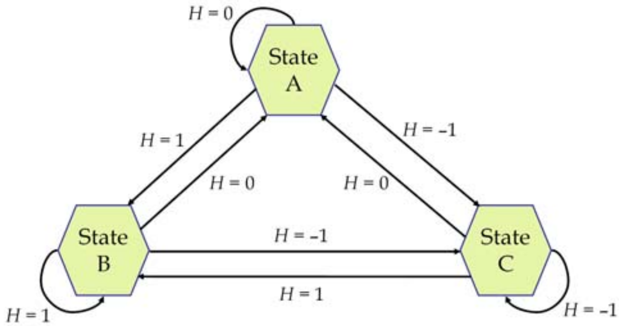


Fig. 8. System state transition diagram

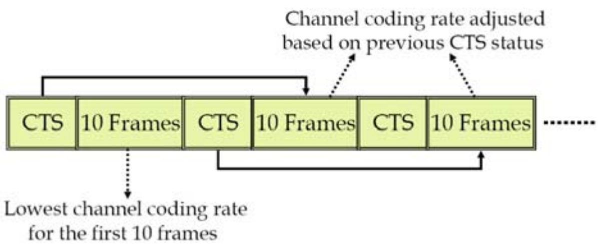


Fig. 9. Transmission rate adjustable for MPEG2 video frames

In the simulation experiment, we first send Command Testing Sequence (CTS), consisting of 10 bits stream of "1", which is attached in front of the transmitted data stream as shown in

Fig. 9. After receiver been channel decoded the received data sequence, the BER information of the CTS is fed-back to the transmitter site as a status index *H* to adjust the next transmission status as shown in Table 3.

3. System performance analysis

Under the channel capacity constraint, which we assumed in the simulation experiment is 1 bit/transmission; we have proposed an adaptive MPEG2 video transmission over wireless MIMO system. Based upon the feedback information index from Performance Control Unit, we adjust the compression rate of MPEG-2 video coder jointly with associated convolutional channel code rate to reach the 1-bit channel capacity limitation. We have also utilized the space diversity with 2×2, 2×1 or 1×2 antenna configurations to obtain an accessible system performance. We have adopted three types of rate assignment as shown in Table 1. According to the feedback error rate information from test sequence as shown in Table 3, we can choose adequate joint code rate assignment (system state, Fig. 8) with suitable space diversity STBC to achieve the best system performance.

3.1 Experiment procedure

System transmission simulation is based on the system block diagram shown in Fig. 2. The experiment procedures are provided as follows, (1) capture video image streams from video camera and applied MPEG2 video coding scheme to produce a better data compression ratio and then stored as an MPEG file (*.mpg); (2) the MPEG2 coded video file is fed into a convolutional encoder, a random interleaver (size = 1024), M-PSK modulation and STBC encoder, consecutively; (3) the resulted data streams are transmitted through wireless Rayleigh fading channel with AWGN noises. For the proposed adaptive video transmission system, we have assigned three combinations of the joint source-channel code transmission rate adjusted to be nearly but not greater than 1 bit/transmission ($r \approx 1$ and $r \leq 1$) associated with proper M-PSK modulation scheme (as listed in Table 1).

The system simulation transmitted a total of 30 video frames, each transmission (10 video frames) will be added up a 10 bits Command Testing Sequence before transmitted over wireless channel consisting of Rayleigh fading and AWGN noises. With appropriate selection of receiver antenna numbers (as shown in Table 3), we have gained space diversity to improve system performance. At the receiver end, de-modulation, de-interleaving, and de-coding procedures are provided to reconstructed MPEG video. After received the feedback error rate information of the CTS sequence, a status index *H* of the PCU is fed-back to the transmitter site to adjust the next 10 video frames transmission status as shown in Table 3.

3.2 Simulation results

The bit error rate (BER) performance versus SNR for different space diversity schemes over Rayleigh fading and AWGN channel is shown in Figure 10. It is assumed that the amplitudes of fading noise from each transmitter antenna to each receiver antenna are mutually uncorrelated Rayleigh distributed and that the average signal power at each receiver antenna from each transmitter antenna is the same. Furthermore, we assumed that the receiver has perfect knowledge of the channel conditions. The simulation results of two transmitter antennas and two receiver antennas (2×2) STBC coded system shows the best

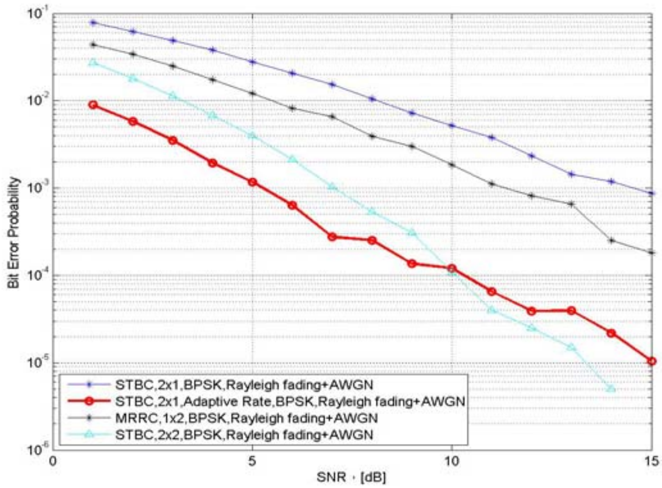


Fig. 10. The BER performance comparison of STBC systems (2/3 convolutional coded) and the proposed adaptive system (with 2×1 antennas structure) over Rayleigh fading channel.

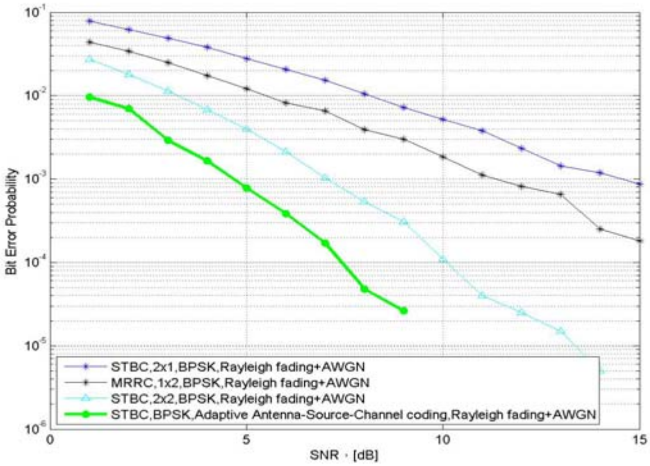


Fig. 11. The BER performance comparison of STBC systems and the proposed adaptive system over Rayleigh fading channel (the number of receiver antenna is adaptive).

BER performance at higher SNR values (> 10dB), while the worst performance goes to the 2x1 STBC coded system. The proposed adaptive coding system with 2x1 (in this case, number of antenna is fixed) space diversity can improve the system performance especially in lower SNR (< 10dB) situation, and with close performance as the 2x2 STBC coded system in SNR > 10 dB environment. The BER system performance can be improved more with adaptive receiver antenna numbers (as given in Table 2) of the proposed scheme as shown in Figure 11. It is about 2.5 dB SNR gain at the same BER condition for the proposed system.

We have extended the total transmitted video frames to 100 for the experiment, each transmission (10 video frames) is added up a 10 bits CTS before transmitted over wireless

Rayleigh fading channel. From Figure 12, we have noticed that the proposed adaptive coding system with 2x2 (fixed antenna numbers) space diversity is outperformed the conventional systems: 2x2 STBC coded scheme, 2x1 STBC coded scheme, and 1x2 maximal ratio receive combining (MRRC) scheme. Figure 13 shows the reconstructed video frames of the proposed PCU controlled adaptive system (in Fig. 10, SNR = 9 dB, BER ≈ $7x10^{-4}$).

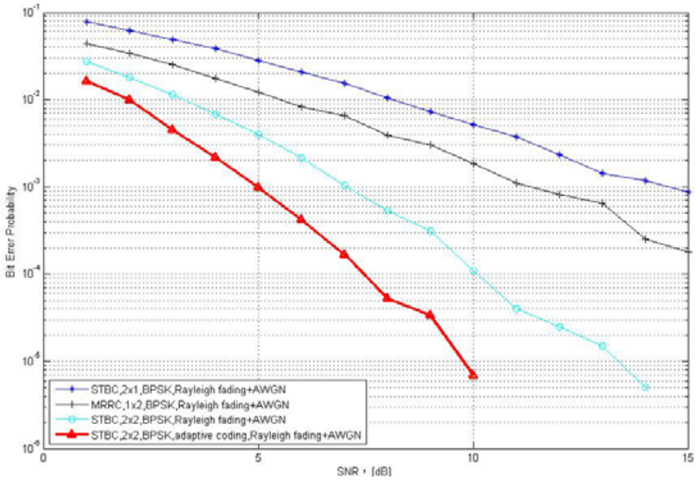


Fig. 12. The BER performance comparison of STBC systems (2/3 convolutional coded) and the proposed adaptive system (with 2×2 antennas structure) over Rayleigh fading channel. (100 video frames transmitted)

4. Conclusions

Video transmission over MIMO systems offers numerous new research opportunities. Lots of new researches are originated from the fundamental change in data transmission from single link to multiple simultaneous links in the MIMO systems. In this study, we applied joint source-channel coding with modulation scheme to design an adaptive video transmission over wireless MIMO system. The bit rates of MPEG2 video can be adaptive to associate with the convolutional channel codes and space-time block code (STBC) under the channel capacity constraint consideration. In order to be consistent with the channel capacity constraint (which is set to be 1 bit/transmission), there are three rate combination types of the joint source-channel coding algorithm as shown in Table 1. From the simulation results, we found that the space diversity and the channel code rate both are important factors influenced reconstructed video quality. The simulation results shows that two transmitter antennas and two receiver antennas (2×2) STBC coded system demonstrates the best BER performance, while the worst performance goes to the 2×1 STBC coded system. The system performance is also improved with lower channel coding rate in the experiment. It can be found from the simulation, rate 2/3 convolutional coded system is with the worst bit error rate performance, where rate 2/5 convolutional coded system shown the best BER performance at the same SNR conditions.

In this study, the proposed adaptive system can choose an adequate transmission rate and the number of receiver antennas based on the channel condition. With the feedback BER

Fig. 13. The reconstructed video frames of the proposed PCU controlled adaptive system.

information provided by the performance control unit (PCU), the proposed system is able to choose an appropriate source-channel rate to transmit video. Therefore, the transmitted video quality may keep at an almost uniform level over a Rayleigh fading channel condition. The study has ensured the proposed system achieved a better BER performance compared to conventional systems.

5. References

Alamouti, S. (1998). A Simple Transmit Diversity Technique for Wireless Communications, *IEEE Journal Selected Areas on Communications*, Vol. 16, 1451–1458

Burr, A. (2003). Capacity Bounds and Estimates for the Finite Scatterers MIMO Wireless Channel, *IEEE Journal on Selected Areas in Communications*, Vol. 21, 812–818

Chen, C. & He, Z. (2006). Signal Processing Challenges in Next Generation Multimedia Communications, *China Communications*, Vol. 4 (5), 20-29

Daut, D. & Ma, W. (1998). Integrated Design of Digital Communication Systems for Fixed Channel Conditions, *Proceedings of International Telecommunication Symposium*, Vol. I, 10-15

Daut, D. & Modestino, J. (1983). Two-Dimensional DPCM Image Transmission over Fading Channel, *IEEE Transactions on Communications*, Vol. 31 (3), 315-328

Driessen, P. & Foschini, G. (1999). On the Capacity Formula for Multiple Input-Multiple Output Wireless Channels: a Geometric Interpretation, *IEEE Transaction on. Communications*, Vol. 47 (2), 173–176

Foschini, G. & Gans, M. (1998). On the Limits of Wireless Communications in a Fading Environment when using Multiple Antenna, *Wireless Personal Communications*, Vol. 6 (3), 311–335

Proakis, J. (2001). *Digital Communications*, Fourth Edition. ISBN 0-07-232111-3, McGraw-Hill, New York, USA.

Sikora, T. (1997). MPEG Digital Video-Coding Standards, *IEEE Signal Processing Magazine*, Vol. 14, 82-100

Song, D. & Chen, C. (2008). Maximum-Throughput Delivery of SVC-based Video over MIMO Systems with Time-Varying Channel Capacity, *Journal of Visual Communication and Image Representation*, Vol. 19, 520-528

Song, D. & Chen, C. (2007). Scalable H.264/AVC Video Transmission over MIMO Wireless Systems with Adaptive Channel Selection Based on Partial Channel Information, *IEEE Transactions on Circuits and Systems for Video Technology*, Vol. 17 (9), 1218-1226

Tarokh, V.; Jafarkhani, H. & Calderbank, A. (1999). Space-Time Block Codes from Orthogonal Designs. *IEEE Transactions on Information Theory*, Vol. 45 (5), 1456–1467

Wolniansky, P. ; Foschini, G.; Golden, G. & Valenzuela, R. (1998). V-BLAST: An Architecture for Realizing Very High Data Rates over the Rich-Scattering Wireless Channel, *Proceedings of IEEE International Symposium on Signals, Systems and Electronics*, 295-300

Yin, L., Chen; W., Lu, J. & Chen, C. (2004). Joint Source Channel Decoding for MPEG-2 Video Transmission, *Proceedings of SPIE Conference on Multimedia Systems and Applications*, Vol. 5600, 128-136

Zeng, X. & Ghrayeb, A. (2006). Performance Bounds for Combined Channel Coding and Space-Time Block Coding with Receive Antenna Selection, *IEEE Transactions on Vehicular Technology*, Vol. 55 (4), 1441-1446