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Performance Evaluation of a FEC Encoded MIMO-OFDM Wireless Communication System on Color Image Transmission

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Abstract: In this study impact of concatenated block code (RS, BCH, Cyclic code) and interleaver with Space Time Trellis Code (STTC) on the performance of a Multiple-Input Multiple-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) wireless communication system on color image transmission has been investigated. The MIMO-OFDM system incorporates two digital modulations (QPSK, QAM) over an Additative White Gaussian Noise (AWGN) and other fading (Raleigh and Rician) channels for two transmit and two receive antennas. It implements Minimum Mean-Square-Error (MMSE) channel equalization technique is highly effective to combat inherent interferences under Rayleigh, Racian fading and Additive White Gaussian Noise (AWGN) channel. The transmitted color image is found to have retrieved effectively under noisy and fading situations. It has also been anticipated that the performance of the communication system degrades with the increasing of noise power.

Key words: Multiple-Input Multiple-Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), space-time stellis coding, Minimum Mean-Square-Error (MMSE) channel equalization

INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has become a popular technique for transmission of signals over wireless channels. OFDM has been adopted in several wireless standards such as Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB-T), the IEEE 802.11a Local Area Network (LAN) standard and the IEEE 802.16a Metropolitan Area Network (MAN) standard. With the advent of next Generation (4G) broadband wireless communications, the combination of Multiple-Input Multiple-Output (MIMO) wireless technology with Orthogonal Frequency Division Multiplexing (OFDM) has been recognized as one of the most promising techniques to support high data rate and high performance. The MIMO-OFDM has a great potential to meet up the stringent requirement for boosting up the transmit diversity and mitigation of the detrimental effects due to multipath fading. With the development of various time and frequency-selective channel coding techniques, the MIMO-OFDM will enable a much more reliable and robust transmission over the harsh wireless environment. In the present study, concatenated coded (Cyclic, BCH and RS coding with interleaving) Space-Time Trellis Coding (STTC) using 4PSK modulation with 4 states for 2 transmitters and data rate of 2 bps/Hz has been used. It provides significant coding gain and a better performance for a given bandwidth compared to uncoded modulation schemes. The STTC encoder combines modulation and trellis coding with QAM constellation to transmit information over multiple transmit antennas and MIMO channels. At the receiver, MMSE equalization technique is used to separate transmitted symbols without enhancing the noise (Stuber *et al*., 2004; Wei Zhang *et al*., 2007; Jafarkhani, 2005).

MATERIALS AND METHODS

We assume that a simulated MIMO-OFDM wireless communication system depicted in Fig. 1, utilizes space time trellis coding scheme. In such a communication system, two transmit antennas (Tx_1 and Tx_2) and two receive antennas (Rx_1 and Rx_2) and 256-tone OFDM are

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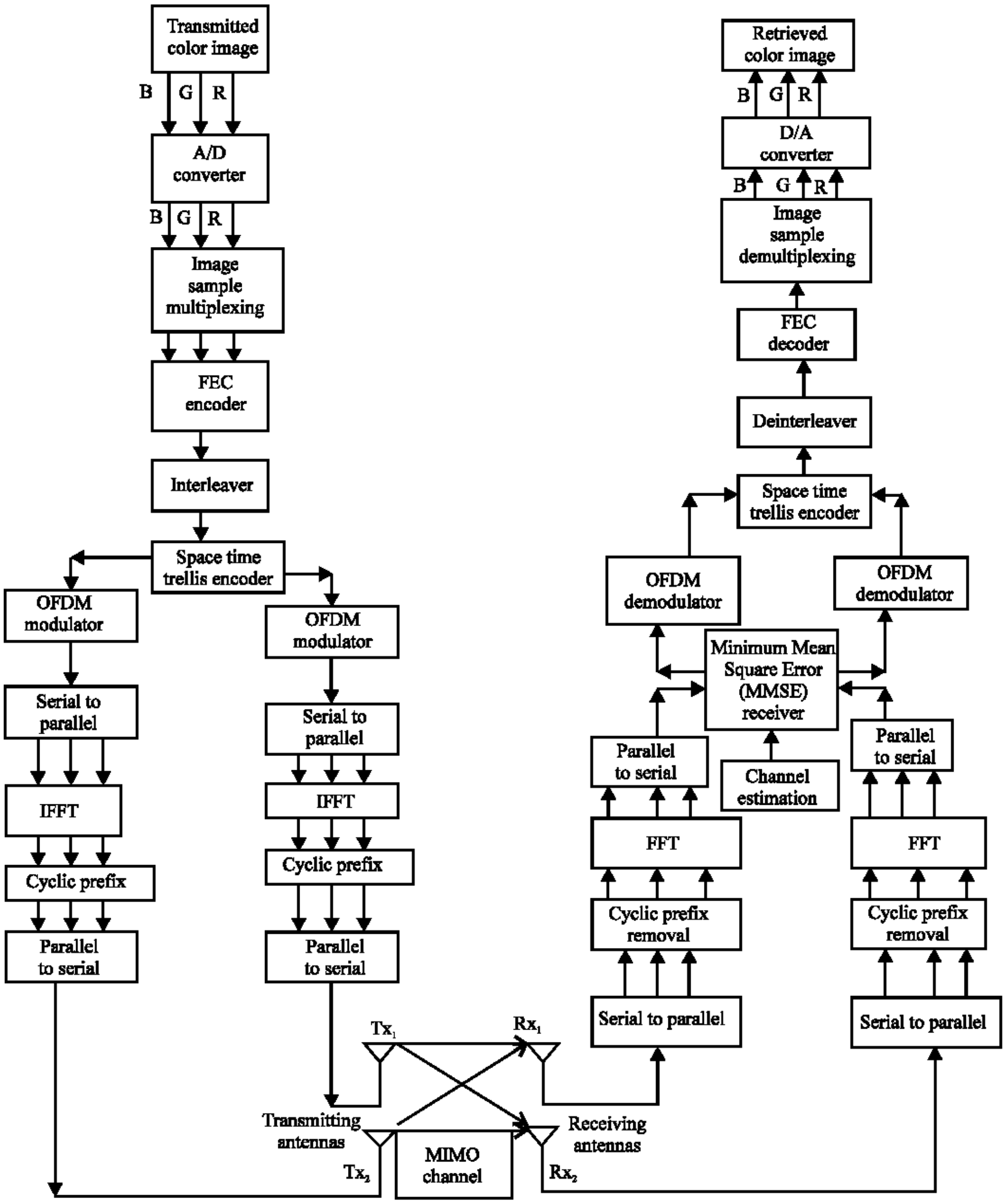

Fig. 1: Block diagram of a space-time-strellis coded MIMO-OFDM wireless communication system

used. As an input information source, a non-compressed digital color (RGB) image in Joint Photographic Experts Group (JPEG) format is used. The standard image is discretized into raster of 180×140 picture elements and the analog transmission signals RGB are converted into digital image components after analog-to-digital conversion (Tomáš, 2003). The digital image samples of each RGB components are multiplexed serially and fed into FEC encoder. In Forward Error Correcting (FEC) encoding scheme, the multiplexed input binary data stream is ensured against transmission errors with various FEC codes such as Reed Solomon (RS), Bose-Chadhuri-Hocquenghem (BCH) and Cyclic Code (CC) and are interleaved. The Reed Solomon (255, 239, 8) block code based on the Galois field GF(2^8).

The value of v_i is determined by with a symbol size of 8 bits is chosen that processes a block of 239 symbols and can correct up to 8 symbol errors calculating 16 redundant correction symbols. The Bose-Chadhuri-Hocquenghem (BCH) encoder and the Cyclic encoder use codes in (127, 64) and (15, 11, 4) format respectively. The FEC encoded data are fed into STTC encoder. The encoder structure for a 4-PSK scheme with two transmit antennas and memory order v of its STTC coding section is shown in Fig. 2. The binary information bits are spatially demultiplexed into two sub streams, x_t^1 and x_t^2 and are fed into the upper and lower branches of the STTC encoder with x_t^1 being the most significant bit. The memory orders of the upper and lower branches are v_1 and v_2, respectively, where $v = v_1 + v_2$.

$$v_i = \left\lfloor \frac{v+i-1}{2} \right\rfloor, i = 1,2 \qquad (1)$$

$\lfloor x \rfloor$ denotes the largest integer smaller than x.

The two streams of input bits are delayed and multiplied by coefficient pairs (a_p^1, a_p^2) and (b_q^1, b_q^2) respectively, where $a_p^i, b_q^i \in \{0, 1, 2, 3\}$, i = 1, 2, p = 0, 1,…, v_1, q = 0, 1,…, v_2.

The encoder outputs are computed as:

$$C_t^{\,k} = \sum_{p=0}^{v_1} x_{t-p}^1 . a_p^k + \sum_{q=0}^{v_2} x_{t-q}^2 . b_q^k \bmod 4, k = 1,2 \qquad (2)$$

and are fed into two OFDM modulating channels.

In each OFDM transmitting channel with 256 subcarriers, the STTC encoded symbolic data streams are first passed through OFDM modulator which performs an IFFT on blocks of length 256 followed by a parallel-to-serial conversion. A Cyclic Prefix (CP) of length L_{cp} (0.1×256) containing a copy of the last L_{cp} samples of the parallel-to-serial converted output of the 256 point IFFT is then prepended. The resulting OFDM symbols of length 256 + L_{cp} are lunched simultaneously from the individual transmit antenna. The CP is essentially a guard interval which serves to eliminate interference between OFDM symbols and turns linear convolution into circular convolution such that the channel is diagonalzed by the FFT. In the receiver the indivitual signals are passed through OFDM demodulators which first discard the CP and then perform an 256 point FFT. The outputs of the OFDM demodulators are finally separated and decoded using Minimum Mean-Square Error (MMSE) channel equalization algorithm.

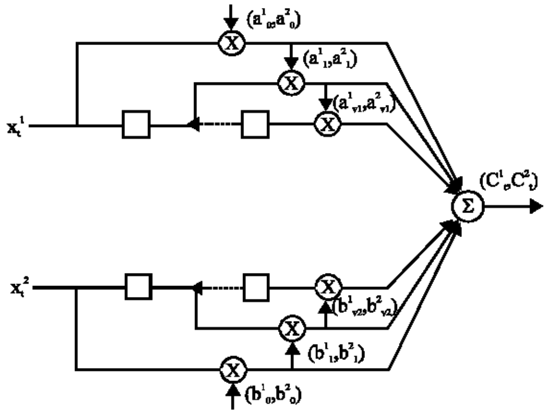

Fig. 2: STTCM encoder for 4-PSK scheme

Let us assume that the memory less MIMO channel, H is random and spatially white and its entries (path gains), $h_{i,j}$ are the independent and identically distributed zero-mean Gaussian random variables for multipath Rayleigh fading. In case of Rician fading, the channel has a fixed LOS component and the received signal equals the superposition of a complex Gaussian component and a LOS component. The Gaussian random variables are uncorrelated and not zero mean. The path gains are constant during one OFDM block symbol and vary independently from one OFDM block to another. At any time slot t, the complex path gain $h_{i,j}$ from a transmitting antenna i to a receiving antenna j, the transmitted complex symbol, c_t^i and the received complex symbol, r_t^j can be written as:

$$r_t^j = \sum_{i=1}^{2} h_{i,j} c_t^i + n_t^j \qquad (3)$$

Where, n_t^j is the AWGN sample for receiving antenna j in time t. The noise samples are independent samples of a zero-mean complex Gaussian random variable with spectral density $N_o/2$ per dimension (Goldsmith, 2005; Ngo *et al.*, 2007). In matrix notation, the received signal (Eq. 3) can be written as:

$$R = Hc + n \qquad (4)$$

Where:

n = The noise vector

H = The fading (Rayleigh/Rician) channel matrix

The eigen decomposition of the channel matrix, H is given by:

$$H = U\Sigma V^H \qquad (5)$$

Where:

Σ = A 2×2 matrix with the singular values of H, $\{\sqrt{\lambda_1}, \sqrt{\lambda_2}\}$ as its main diagonal elements

U and V = 2×2 and 2×2 unitary matrices respectively

The solution of the linear MMSE is given by:

$$\hat{c} = \left(\frac{1}{SNR} I_{N_R} + H^H H \right)^{-1} H^H \times R \qquad (6)$$

Where:

Superscript ^{H} = The superscript denotes the complex conjugate transpose

I_{N_R} = The identity matrix (UU^T)

SNR = The signal to noise ratio

The MMSE receiver can minimize the overall error caused by noise and mutual interference between the co-channels signals which is also at the cost of reduced signal separation quality (Chent *et al.*, 1993; Baro *et al.*, 2000).

RESULTS AND DISCUSSION

Computer simulation using digital image transmission has been performed to evaluate the BER performance of the concatenated coded MIMO-OFDM system under different modulation schemes. Figure 3 demonstrates the simulation results on deployment with three FEC block coding (Cyclic, BCH and RS) under an AWGN channel. On comparison, it is observable that the system shows comparatively much better performance in RS coding (Fig. 3a and b). On the other hand, the system performance is not satisfactory in Cyclic coding for QAM and QPSK modulations.

As compared improved by 33.73 and 31.39 dB for a typical SNR value of 4 dB in case of QAM and QPSK modulations. In Fig. 4a and b, it is quite obvious that the

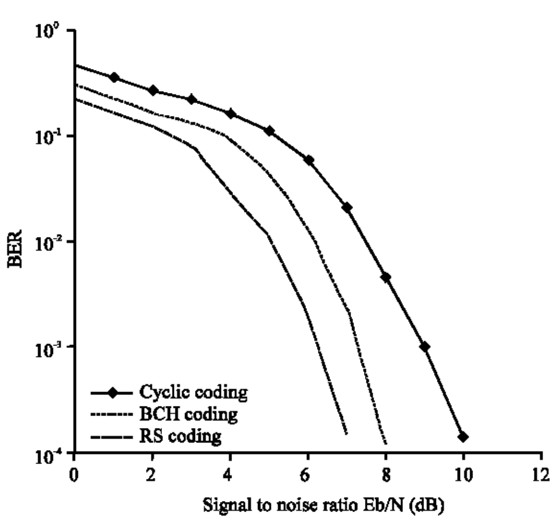

Fig. 3: BER performance comparison with different block coding in a Space-time trellis coded 2×2 MIMO-OFDM system under Additive White Gaussian Noise channel and digital modulation, (a) QAM modulation and (b) QPSK modulation

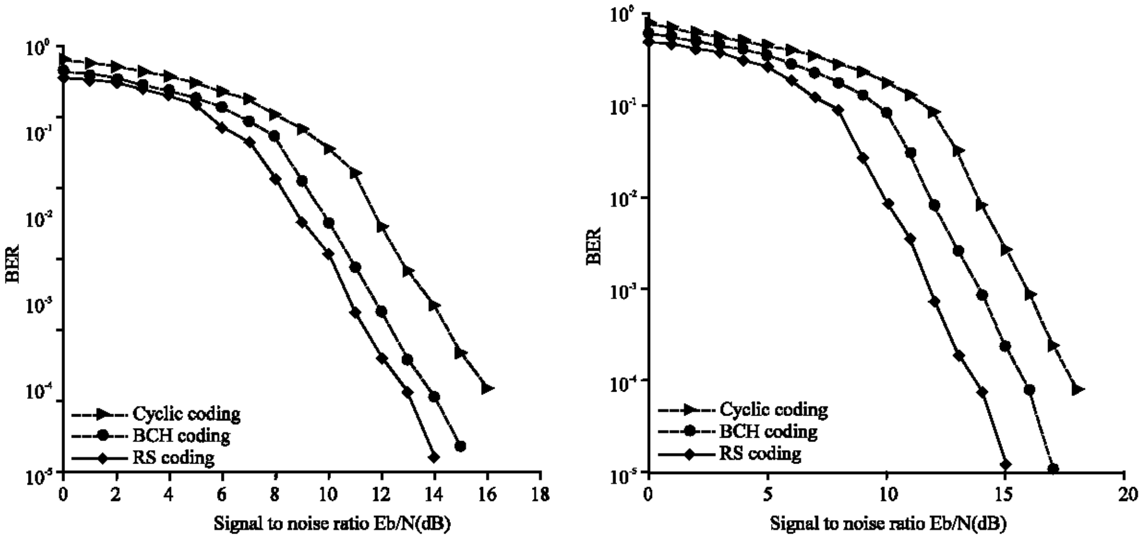

Fig. 4: BER performance comparison with different block coding in a Space-time stellis coded 2×2 MIMO-OFDM system under Raleigh fading channel and digital modulation, (a) QAM modulation and (b) QPSK modulation

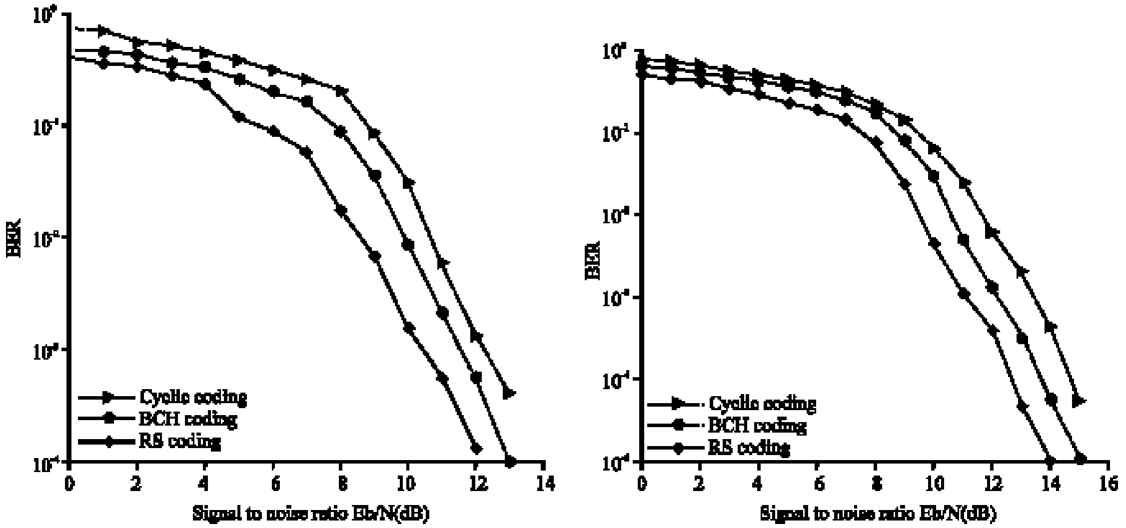

Fig. 5: BER performance comparison with different block coding in a Space-time stellis coded 2×2 MIMO-OFDM system under Racian fading channel and digital modulation, (a) QAM modulation and (b) QPSK modulation

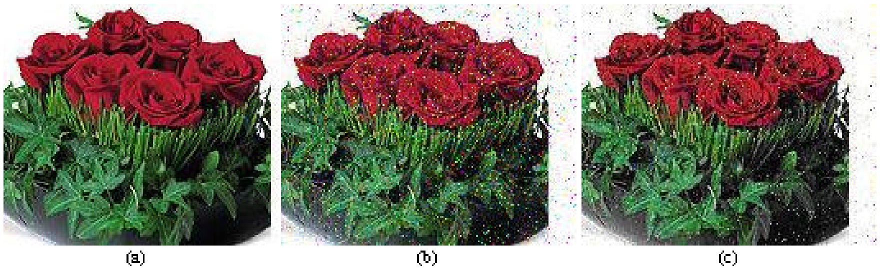
(a) (b) (c)

Fig. 6: (a) Transmitted color image, (b) Retrieved color image in Rayleigh fading channel and (c) Retrieved color image in Rician fading channel

degradation of the system performance is significant in Cyclic coding under Raleigh fading channel. The system gives satisfactory performance in RS coding to Cyclic coding, the BER performance of the MIMO-OFDM system in RS coding is shown in Fig. 4.

On critical examination of both Fig. 4a and b, it is found that the BER performance of the MIMO-OFDM system is improved in QAM modulation as compared to QPSK modulation by 0.22 dB for a typical SNR value of 5 dB. In such a typical SNR value, the improvement of the system performance on comparing Cyclic coding with RS are 3.88 and 2.27 dB, respectively in case of QAM and QPSK modulations. Finally we study the BER performance of the system under Rician fading channel (Fig. 5).

Figure 5a shows better performance in QAM modulation. The bit error rate for QPSK and QAM modulations for a SNR value of 5 dB are 0.2223 and 0.174, respectively viz. the BER performance is improved by 1.55 dB. The transmitted and retrieved color images under fading channels for a typical SNR value of 5 dB and QAM modulation are shown in Fig. 6-c, respectively. The image quality in Rician fading with BER value of 0.0045 is comparatively better than that in Rayleigh fading (BER = 0.1523).

CONCLUSION

In this contribution, we have studied the performance of a concatenated FEC encoded MIMO-OFDM system adopting both diversity (STTC) and channel coding schemes.

A range of system performance results highlights the impact of channel coding under fading channels. In the context of system performance, it is observed that the implementation of QAM digital modulation technique in concatenated FEC encoded MIMO-OFDM system provides satisfactory result.

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