PROGRESSIVE IMAGE TRANSMISSION OVER OFDM SYSTEMS USING MULTIPLE ANTENNAS

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ABSTRACT

A Joint source-channel coding (JSCC) scheme for SPIHT coded image transmission over OFDM systems with spatial diversity is proposed where no feedback channel is available. By using diversity techniques, the fading effects can be dramatically decreased and we show that subchannels in OFDM systems are indeed flat Rayleigh fading channels and approach Gaussian noisy channels when the diversity gain gets large, as a result, the system performance can be improved. The simulation results are presented with different number of antennas and different multipath delay and Doppler spread.

1. INTRODUCTION

The public's desire for multimedia communications over mobile wireless channels combined with the increasing demands for Internet access suggests a very promising future for wireless data services. For multimedia communications, the delay constraint limits the use of Automatic Repeat reQuest(ARQ), and in some cases the feedback channel is not available such as broadcasting service. The unequal importance property and delay constraint of multimedia data suggests the use of joint source-channel coding (JSCC) scheme [1][3][4].

Most of the JSCC schemes focus on the Binary Symmetric Channel (BSC) or additive white Gaussian noise (AWGN) channel where the Bit Error Rate or signal-to-noise ratio (SNR) is constant. To deal with fading channels in wireless communications, the fading channel is modeled as two state Gilbert-Elliot model and the JSCC normally aims at the BER of *bad* channel status [5]. However, this scheme is not optimal when channel is in *good* condition.

In this paper, a joint source-channel coding scheme for progressive image transmission over orthogonal frequency division multiplexing (OFDM)[8] systems with spatial diversity is proposed where neither feedback channel nor CSI is available at transmitter. Multimedia transmission over asymmetric digital subscriber lines (ADSL) have been studied recently where the channel is assumed to be time-invariant [2]. For high bit-rate wireless communications, OFDM is an attractive technique to be used because of its simplicity in dealing with frequency-selective, time-dispersive wireless fading channels [8]. Diversity techniques, including spatial, frequency and time domain diversity, have been suggested to decrease the fading effect.

Though spatial diversity can be available at both transmitter (Tx) and receiver (Rv), most of past work has focused on exploiting receiver diversity [7]. However, it may not be practical to install more than two antennas at mobile terminal because of the space and power limitations. A common techniques to solve this problem is to use multiple transmit antennas at base station to provide transmit diversity, which have been studied recently such as space-time block code (STBC) [10][11].

The remainder of the paper is organized as follows. In Section 2, the system structure and the channel property of OFDM system with STBC is introduced. In Section 3, a JSCC scheme is proposed for image transmission over OFDM system using STBC; In Section 4, simulation results are presented under different diversity gain and fading parameters. Finally, conclusions are reached.

2. SYSTEM DESCRIPTION

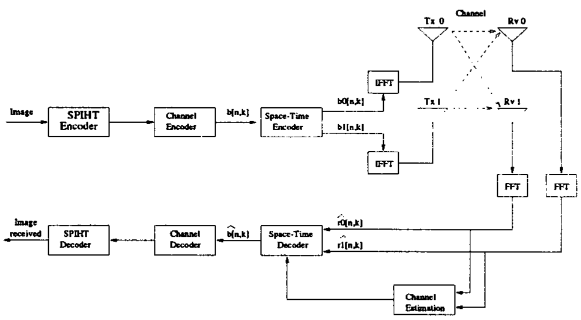

Figure 1: The system structure for joint source channel image transmission over OFDM channels using multiple antennas.

The system structure is shown in Fig.1. The image coding algorithm used is SPIHT (Set Partitioning In Hierarchical Tree) [13]. The output of SPIHT encoder is progressive such that wherever the transmission is stopped, the received data can be used to reconstruct an image with corresponding quality. The SPIHT bitstream is packetized into source-packets and then channel coding protected. The resulted codewords are of equal size and treated as OFDM blocks to the transmitter. The STBC with N transmitter antennas and M receiver antennas is denoted as STBC (N, M).

The channel impulse response between transmit antenna i and receive antenna j at OFDM symbol n is

$$h_{ij}[n,\tau] = \sum_{p=1}^{P} \alpha_{ij,p}(nT_f)\delta(\tau - \tau_{ij,p}), \qquad (1)$$

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where P is the number of multipaths in the channel model, $\alpha_{ij,p}(n)$'s are independent complex Gaussian random processes with zero mean and variance $\sigma_{ij,p}^2$ which is normalized such that $\sum_{p=1}^{P}\sigma_{ij,p}^2 = 1$, $\tau_{ij,p}$ is the delay of the pth path between Tx i and Rv j, T_f being the OFDM symbol interval. All the $\alpha_{ij,p}$'s are mutually independent for different i, j and p. The corresponding channel frequency response at subchannel k is

$$H_{ij}[n,k] = \sum_{p=1}^{P} \alpha_{ij,p}(nT_f)\exp\{-j2\pi k\Delta f \tau_{ij,p}\}. \quad (2)$$

where Δf is the bandwidth of each subchannel in OFDM.

We have proved the following Proposition [9]

Proposition 1 *When OFDM is used in a frequency-selective, time-dispersive Rayleigh fading environment, each subchannel is flat Rayleigh fading channel.*

2.1. A Space-Time Block Coding Scheme for OFDM

An OFDM systems with two transmit antennas is proposed here. The single carrier STBC for two transmitter antennas is proposed by Alamouti [10]. Tarokh *et al* extended it to a general STBC by orthogonal design [11]. An OFDM block is denoted as a complex vector $b(n)$. There are N_s complex subsymbols in $b(n)$ denoted as $b(n,k), k = 1,2,\cdots,N_s$, where N_s is the total number of subchannels.

Assume there are two transmit antennas and one receive antenna. Two OFDM blocks $b(n)$ and $b(n+1)$ are collected from the output of signal mapper where each subsymbol is mapped to a point in a signal constellation set. The OFDM blocks for transmit antenna 0 and 1 after STBC encoding are denoted as $b_0(n), b_0(n+1)$ and $b_1(n), b_1(n+1)$, respectively. For subchannel k, the STBC encoder works as follows

$$\begin{aligned} b_0(n,k) &= b(n,k), \quad & b_0(n+1,k) &= -b^*(n+1,k) \\ b_1(n,k) &= b(n+1,k), \quad & b_1(n+1,k) &= b^*(n,k) \end{aligned} \quad (3)$$

where $*$ denotes complex conjugate. Assume the channel state is constant over two OFDM symbol intervals, we have $H_i[n,k] = H_i[n+1,k] = H_i(k) = C_i(k)e^{-j\theta_i(k)}$, where $i = 0, 1$.

The received subsymbols at subchannel k after FFT demodulation are:

$$\begin{aligned} r(n,k) &= H_0(k)b_0(n,k) + H_1(k)b_1(n,k) + w(n,k) \\ r(n+1,k) &= H_0(k)b_0(n+1,k) + H_1(k)b_1(n+1,k) \\ &\quad + w(n+1,k) \end{aligned} \quad (4)$$

where $w(n,k), w(n+1,k)$ are AWGN noise with variance N_0. The outputs of the STBC combiner at receive antenna are [10]:

$$\begin{aligned} \tilde{b}(n,k) &= [C_0^2(k) + C_1^2(k)]b(n,k) \\ &\quad + H_0(k)^* w(n,k) + H_1(k)w^*(n+1,k) \\ \tilde{b}(n+1,k) &= [C_0^2(k) + C_1^2(k)]b(n+1,k) \\ &\quad - H_0(k)w^*(n+1,k) + H_1^*(k)w(n,k) \end{aligned} \quad (5)$$

The variables in (5) are then sent to the maximum likelihood detector. It is straightforward to implement $M \geq 2$ receiver antennas to get more diversity gains[10]. It is shown in [10][11] that the (M,N) STBC scheme is equivalent to $(1, MN)$ receiver diversity using maximal ratio combining (MRC) in terms of diversity gain.

We have the following Proposition [9]

Proposition 2 *In a frequency-selective Rayleigh fading environment, the frequency response of subchannels in OFDM using* (N, M) *STBC can be modeled as parallel, independent Gaussian noisy channels when* $MN \to \infty$.

3. JOINT SOURCE CHANNEL CODING FOR OFDM USING STBC

The SPIHT encoded bitstream is to be transmitted over OFDM systems using (N, M) STBC. The transmission rate is R_t bit-per-pixel (bpp). There are N_s subchannels in the OFDM and each subchannel is modulated by a complex symbol from a M-ary modulation set of size M_{ary}. The SPIHT stream is packetized into L source-packets of size B_i bits for packet i, $i = 1,2,\cdots,L$, L is the total number of OFDM blocks decided by R_t such that $L \leq \lfloor \frac{R_t HW}{N_s \log_2 M_{ary}} \rfloor$, where H and W is the dimension of the image. For channel coding, we assume that a finite set of code rate is provided. These channel codes operate on source packets which are CRC-16 outer coded first. The resulted codewords are of equal length and are subsequently transmitted as OFDM blocks. Reed-Solomon (RS) channel code is used because of its bursty error correction capability. Each OFDM block b_i is a RS codeword $RS(N, K_i)$ over $GF(2^m)$, $N = \frac{N_s \log_2 M_{ary}}{m}$ is the number of RS code symbols in each OFDM block, $K_i = \frac{B_i}{m}$ is the number of RS information symbols in OFDM block b_i. The error-correction failure probability of OFDM block b_i is denoted as $P_e(b_i)$. We assume that the probability of undetected error is zero because of CRC-16 error detection. For SPIHT bitstream, if a packet cannot be decoded correctly then the subsequent packets could not be used to improved the quality of the source.

The JSCC algorithm is to look for a source packetization scheme $\mathcal{A}^* = \{K_1^* m, K_2^* m, \cdots, K_L^* m\}$ such that the average Peak-Signal-to-Noise-Ratio (PSNR) or number of source information received is maximized [4][5][6]. The major difference between the method proposed here and the previous approaches is that, in our scheme, the channel codewords are of equal length, and we look for a source packetization scheme to maximize the average quality at receiver. This approach is more suitable for OFDM block data transmission and RS block code.

If the average number of source bits received before errors occur is used to find the packetization scheme $\mathcal{A}$ for given L, the optimal $\mathcal{A}^*$ should maximize

$$\begin{aligned} \overline{BITS_{\mathcal{A}}} &= \sum_{i=1}^{L-1}\left(\sum_{j=1}^{i} K_j m\right) P_e(b_{i+1}) \prod_{j=1}^{i}(1 - P_e(b_j)) \\ &\quad + \left(\sum_{j=1}^{L} K_j m\right) \prod_{j=1}^{L}(1 - P_e(b_j)). \end{aligned} \quad (6)$$

This optimization problem can be solved by dynamic programming as proposed in [6].

The decoding failure probability of a OFDM block $RS(N, K)$ over $GF(2^m)$ under the assumption of Gaussian noisy subchannels is

$$P_e(b) = 1 - \sum_{v=0}^{(N-K)/2} \binom{N}{v} P_s^v (1 - P_s)^{N-v} \quad (7)$$

where P_s is the error probability of RS code symbol, which is $P_s = 1 - (1 - P_{ce})^{m/b}$, b is the number of bits for each subchannel symbol, m/b is the number of subchannel symbols in a RS code symbol, p_{ce} is the subchannel symbol error rate.

The computation in (7) is based on the assumption that the subchannels in OFDM with (N, M) STBC are mutually independent Gaussian noisy channels with the same SNR, which is true when NM goes to infinity. For finite NM, the assumption doesn't hold. Since the instantaneous SNR at receiver, denoted as γ_c, is time-varying and not known by the transmitter, the JSCC scheme has to be designed for a specified SNR, which is called *target SNR* and denoted as γ_T. The *target SNR* γ_T is computed for a given probability P_B such that $P(\gamma_c \leq \gamma_T) = P_B$. By specifying a relatively small P_B, the γ_c is larger than γ_T with high probability and the system performance can be guaranteed. We call this scheme *worst-case JSCC design.* The advantage of using STBC or spatial diversity is that the *target SNR* γ_T approaches the average SNR as the NM increases. As a result, the system performance can be improved.

Table 1: The *target SNR* for average receiver $SNR = 1$ at different P_B under different (N, M) STBC.

	$(1,1)$	$(2,1)$	$(2,2)$	$(2,4)$	$(2,8)$
$P_B = 0.01$	0.0101	0.0743	0.2058	0.3633	0.5113
$P_B = 0.05$	0.0513	0.1777	0.3416	0.4976	0.6272
$P_B = 0.10$	0.1054	0.2659	0.4362	0.5820	0.6960

For a OFDM system using (N, M) STBC, the instant SNR γ_c at subchannels with a known average receiver SNR $\bar{\gamma_c}$ is [12]

$$\gamma_c = \frac{\bar{\gamma_c}}{NM} \sum_{i=1}^{NM} C_i^2 \tag{8}$$

where C_i is the amplitude of complex zero-mean Gaussian random variable with variance $\sigma^2 = 0.5$ at each dimension. Let $x = \sum_{i=1}^{NM} C_i^2$, then x is a χ^2 random variable with $2NM$-degree freedom. To find the *target SNR* γ_T such that $p(\gamma_c \leq \gamma_T) = P_B$ for a given P_B, we only need to find a real value y such that $p(x \leq y) = P_B$, then using (8) we have $\gamma_T = \frac{\bar{\gamma_c} y}{NM}$. The cumulative distribution function (CDF) of $x = \sum_{i=1}^{NM} C_i^2$ is [12]

$$p(x \leq y) = 1 - e^{-y/2\sigma^2} \sum_{k=0}^{NM-1} \frac{1}{k!}\left(\frac{y}{2\sigma^2}\right)^k, \; y \geq 0 \tag{9}$$

To show the advantage of using diversity, the γ_T for different (N, M) STBC at same average receiver SNR $\bar{\gamma_c} = 1$ is listed in Table 1 for several P_B's. Indeed, as $NM \to \infty, p(\gamma_c = \bar{\gamma_c}) \to 1$. After the *target SNR* γ_T is obtained, the *worst-case* subchannel symbol error probability of Gray-mapped QPSK is $P_{ce} = 2P_b = 2Q(\sqrt{\gamma_T})$. For other MPSK symbols except BPSK and QPSK, P_{ce} has to be obtained by simulations.

The receiver performs the same computation as above to get the source packetization shame $\mathcal{A}^*$ for the given parameters.

4. SIMULATION RESULTS

In our simulation, a two-ray channel model with delay spread from 0 to 40 μs and Doppler frequency from 10Hz to 200Hz is used. STBC $(2,2)$ and $(2,4)$ are used for comparison. The 800 kHz channel bandwidth is divided into 128 subchannels. Four subchannels on each end are used as guard tones and the rest 120 tones are used. To make the tones orthogonal to each other, the symbol duration is 160 μs. An additional 40 μs guard interval is used to provide protection from ISI due to multipath delay. QPSK and coherent estimation is used with the assumption of perfect channel information at receivers. The punctured and/or shortened RS code over $GF(2^8)$ is used such that each OFDM block has $120 \times 2/8 = 30$ RS code symbols, and the number of information symbols in each OFDM block is in the range $\{3, 4, \cdots, 26\}$. In all the simulations, 300 times image transmission are simulated under each case. The transmit rate used for all the simulations is 0.5 bpp, which is approximately equivalent to $L = 576$ OFDM blocks.

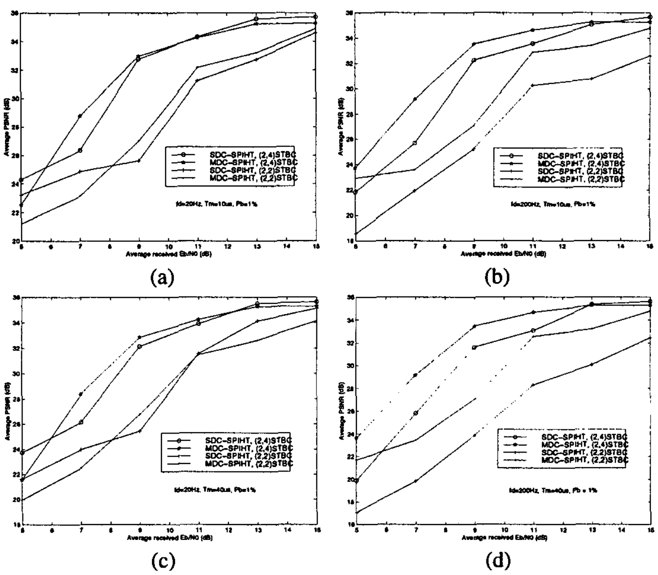
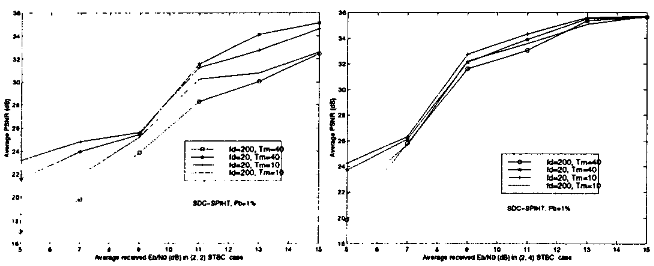


Figure 2: Performance comparison between S-SPIHT and M-SPIHT using STBC $(2,4)$ and $(2,2)$: (a) f_d = 20Hz, $\tau_m = 10\mu s$, (b)f_d = 200Hz, $\tau_m = 10\mu s$, (c) f_d = 20Hz, $\tau_m = 40\mu s$, and (d) f_d = 200Hz, $\tau_m = 40\mu s$.

The discrete wavelet transform of 512×512 gray image *Lena* is obtained first, then two schemes are compared: (a)*Single stream transmission (S-SPIHT):* The DWT coefficients is encoded into a SPIHT bitstream, and is packetized into L packets. The packetization scheme is obtained through the JSCC scheme described above. (b)*Multiple substream transmission (M-SPIHT):* The DWT coefficients are partitioned into M_s sub-images, each sub-image keeps the Zero-tree structure across scales and is SPIHT coded [14]. Each SPIHT substream is packetized into L/M_s packets using the JSCC scheme for L/M_s blocks. The OFDM blocks is transmitted across the substreams such that the progressive transmission is still maintained with a delay of M_s OFDM blocks. In the simulation the number of subimage used is 16.

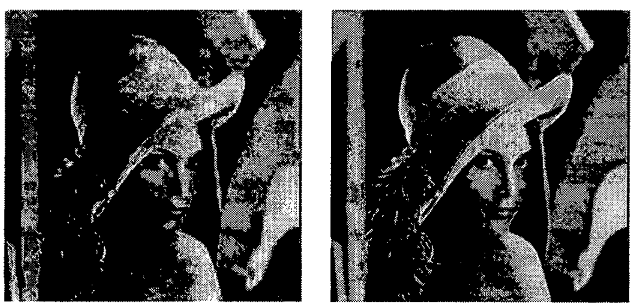
In Fig.2, the average PSNR of the received images is compared with $P_B = 0.01$ using STBC $(2,4)$ and $(2,2)$, under different delay spread and Doppler spread parameters. It can be observed that at the same average receiver SNR, the image quality using STBC $(2,4)$ is always better than using STBC $(2,2)$ because the *target SNR* of STBC $(2,4)$ is larger than that of STBC $(2,2)$, as a result, the JSCC scheme has larger throughput for STBC $(2,4)$ than that of STBC $(2,2)$.

We also observed that the performance of M-SPIHT is better than that of S-SPIHT at moderate SNR, this is because of the following two reasons: (1) In S-SPIHT, when one source-packet is error-detected, then all the source-packets followed can not be used; In M-SPIHT, however, the error of one source-packet only



(a) (b)

Figure 3: Performance sensitivity to different multipath delay spread and Doppler frequency: (a) S-SPIHT with STBC(2, 2), (b) S-SPIHT with STBC(2, 4).



(a) PSNR=25.72dB (b) PSNR=31.24dB

Figure 4: Received images of "Lena" when $E_b/N_0 = 9$dB at (a) S-SPIHT with STBC(2, 2), (b) S-SPIHT with STBC(2, 4).

affect the source-packets followed in that single substream. The interpolation from the neighbor coefficients at LL Subband from other substreams can be used to conceal the error effects. (2) The effective source-rate of M-SPIHT is larger than the source-rate of S-SPIHT in most cases. For a given transmission rate R_t, The corresponding source rate for M-SPIHT is $R_M = R_t \frac{M_s \sum_{i=1}^{L/M_s}(K_i-2)}{LN}$ and for S-SPIHT is $R_S = R_t \frac{\sum_{i=1}^{L}(K_i-2)}{LN}$. Because of the progressive property of SPIHT bitstream, we know that $K_j \leq K_i$ for $j \leq i$, then we have $M_s \sum_{i=1}^{L/M_s}(K_i - 2) > \sum_{i=1}^{L}(K_i - 2)$, as a result, $R_S \leq R_M$.

The performance under different multipath delay spread and Doppler frequency for same STBC configuration are also compared in Fig. 3. The multipath delay spread and Doppler spread have less effects to the performance when the diversity gain NM increases. Actually, when $NM \geq 8$, the system performances are almost same under different multipath delay and Doppler spread because the OFDM subchannels approach Gaussian noisy channels.

The received images is also shown in Fig. 4 when $E_b/N_0 =$ 9dB, where the delay spread $\tau_m = 40\mu s$, Doppler frequency $f_d =$ 200Hz. The probability for *target SNR* $P_b = 1\%$ is used in JSCC algorithm. The image quality of STBC (2, 4) as shown in Fig. 4(b) is much better than the image quality of STBC (2, 2) in Fig.4(a).

5. CONCLUSIONS

A JSCC scheme is proposed for SPIHT encoded image transmission over OFDM systems over multiple antennas using concatenation of RS channel code and space-time block code. By using space-time block code, the fading effect of wireless channels can be significantly decreased. We have shown that the OFDM subchannels are indeed parallel independent Gaussian noisy channel in a frequency-selective, time-dispersive Rayleigh fading environment when diversity gain goes to infinity. To further decrease the channel impairment, we divide the image into several subimage where the proposed joint source channel coding scheme can be applied directly. The simulation results show that this scheme is robust to different Doppler and multipath delay spread and the throughput is optimized. The proposed scheme is suitable for real-time image transmission over high bit-rate wireless channels where no feedback channel is available such as in broadcasting services.

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