Performance Improvement of OFDM System Using Transmit Diversity with Space-Time Block Coding

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Abstract: Orthogonal frequency division multiplexing (OFDM) is a special technique for communication systems which can support the high data rate transmission with sufficient robustness to fading channels. Transmitter diversity with space-time block coding (STBC) is an attractive transmission scheme to improve the performance of systems. In this paper, we compare the performance of space-time block coded OFDM systems with that of conventional OFDM systems over fast fading channels. The block-interleaved (BI) STBC and frequency hopping (FH) OFDM are proposed in the study to provide the maximum achievable diversity gains. As the simulation results, the STBC OFDM, BI-STBC OFDM and BI-STBC FH-OFDM provide the much improved performance over the conventional OFDM. And the BI-STBC FH-OFDM also provide the better performance than the STBC OFDM and BI-STBC OFDM, especially, in the case of the two transmit antennas are employed while BI-STBC FH-OFDM can maintain the same data rate of 12 Mbps.

1. Introduction

Currently, wireless communication systems are designed for some specific applications, such as speech on mobile telephone or high bit rate data in a wireless local area network (LAN) and large mobility. Supporting such large data rates with sufficient robustness to radio channel impairments, requires careful choosing of transmission technique. One of the most suitable transmission choices seem to be Orthogonal Frequency Division Multiplexing (OFDM). It can combat intersymbol interference (ISI) of channels that handle the multipath propagation and increase the robustness against frequency selective fading or narrowband interference [1]. The disadvantage of OFDM, however are the sensitivity to phase noise and frequency offset causing to destroy the orthogonality of the individual signal, thereby causing intercarrier interference (ICI) in an OFDM receiver. Consequently, it has to assists that additional some processing into systems to prevent ICI and improve performance of the system.

The major impairments of the wireless communication, however are noise, interference, and multipath fading. Generally, several diversity techniques such as temporal, frequency, polarization, and space have been used to combat the multipath fading or to suppress the interference signal. Spatial diversity is a well-known technique for improving the performance and reliability of wireless communications over fading channels. Traditionally, spatial diversity has been implemented at the receiver side with multiple antennas but the important constraints of the receiver are cost, size and current drain. In recently years, transmitter diversity has been introduced by Alamouti [2] to combat fading in wireless environments and improve the performance of the wireless system without significantly increasing the size or complexity of the receiver. Space-time coding (STC) techniques have been proposed for transmitter diversity [3]-[4] and then employed in the OFDM system to further reduce fading and obtain the better signal quality from the diversity gain [5]-[7]. Space-time block coded OFDM presented in [8] can only exploit space diversity. In [5] and [9], the space-time trellis coded OFDM is considered to exploit both space and time diversity. Some works tried to combine bit-interleaved space-time trellis codes to increase the maximum achievable diversity provided by the channels [10]-[12]. Although several research works have been conducted on the space-time (block) coded OFDM, but few studies have reported on the performance of these transmission schemes based on the combination between block-interleaved and frequency hopping.

In this paper, we focus on the improved performance of the OFDM system using transmit diversity with space-time block coding. The block-interleaved space-time block coding (BI-STBC) and frequency hopping OFDM (FH-OFDM) are proposed in the study to provide the maximum achievable diversity gain. The performance comparisons of the bit error probability for conventional OFDM, STBC OFDM, BI-STBC OFDM and BI-STBC FH-OFDM have been presented. As the simulation results, the STBC OFDM, BI-STBC OFDM and BI-STBC FH-OFDM provide the much improved performance over conventional OFDM. And the BI-STBC FH-OFDM also provides the better performance than the STBC OFDM and BI-STBC OFDM, especially, in the case of the two transmit antennas ($\mathcal{G}_2$) are employed at the transmitter.

2. The System Model

Consider a wireless communication system with n transmit antennas and one receive antenna as shown in Fig. 1. At each time slot t, the output signal of one OFDM modulated symbol can be written as

$$X^t_{i,k} = X^t_{1,0} \cdots X^t_{n,0} X^t_{1,1} \cdots X^t_{n,1} \cdots X^t_{1,N_s-1} \cdots X^t_{n,N_s-1} \tag{1}$$

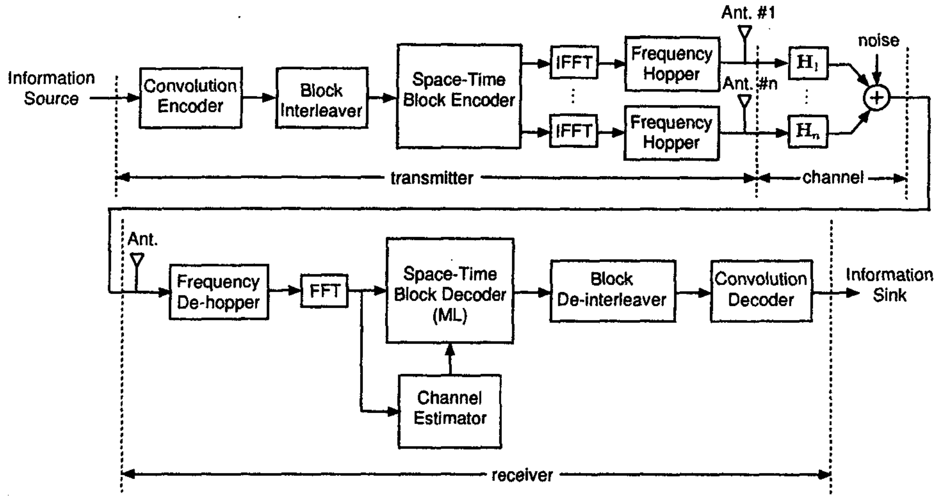

Figure 1. Baseband modeling of the BI-STBC FH-OFDM system.

for $i = 1, 2, \ldots, n$ and $k = 1, 2, \ldots, N_s - 1$ where N_s represents number of overlapping subchannels and signals are transmitted simultaneously from the n transmit antennas at the time slot t.

In our simulation, we assume that the OFDM transformed a frequency selective fading channel into N_s perfectly flat fading subchannels. Therefore, the wireless channel is assumed to be quasi-static so that the path gains are constant over one OFDM frame of length l and it changes from one frame to others.

At the time slot t, the received signal is given by

$$r_k^t = \sum_{i=1}^{n} H_{i,k} X_{i,k}^t + N_k^t \tag{2}$$

where $H_{i,k}$ is the frequency response of the channel from the i^{th} transmit antennas to one receive antenna, at k^{th} multicarrier frequency. N_k^t is independent sample of a zero-mean complex Gaussian random variable with variance 0.5 per real dimension. Suppose the synchronization between the transmitter and the receiver is perfectly synchronized and channel state information (CSI) is available at the receiver. The maximum likelihood (ML) decision matrix at the receiver can be expressed as

$$\hat{X}_k = \arg\min \sum_{t=1}^{l} \left| r_k^t - \sum_{i=1}^{n} H_{i,k} X_{i,k}^t \right|^2 \tag{3}$$

where the minimum of the summation is over all possible codewords.

To mitigate the channel memory, the BI-STBC FH-OFDM is proposed as shown in Fig. 1. For block interleaver, input bits are written in a matrix column by column and read out row by row which defined as subchannels (N_s) and can be expressed as

$$\begin{bmatrix} 0 & N_s & 2N_s & \cdots & (m-1)N_s \\ 1 & N_s+1 & 2N_s+1 & \cdots & (m-1)N_s+1 \\ 2 & N_s+2 & 2N_s+2 & \cdots & (m-1)N_s+2 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ N_s-1 & 2N_s-1 & 3N_s-1 & \cdots & N_b-1 \end{bmatrix} \tag{4}$$

We define a block size of N_b bits and m columns, the c^{th} interleaved bit is equal to the r^{th} encoded input bit, where r is given by [1]

$$r = cm - (N_b - 1)\ \text{floor}\left(\frac{cm}{N_b}\right). \tag{5}$$

Frequency hopper is defined as subchannels (N_s) that same block interleaver and can be expressed as

$$\begin{bmatrix} 0 & N_s+1 & 2N_s+2 & \cdots & N_b-1 \\ 1 & N_s+2 & 2N_s+3 & \cdots & (m-1)N_s \\ 2 & N_s+3 & 2N_s+4 & \cdots & (m-1)N_s+1 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ N_s-1 & N_s & 2N_s+1 & \cdots & N_b-2 \end{bmatrix} \tag{6}$$

We define a block size of (N_b) bits and d^{th} columns, where q^{th} and p^{th} represent input bits and hopping bits, respectively, and the relation is given by

$$p = q + N_s\ \text{floor}\left(\frac{N_s(d-1)}{q-d+1}\right) - \text{rem}\,(d-1, N_s). \tag{7}$$

Convolution code is used as the outer code for all transmission schemes, namely, conventional OFDM, STBC OFDM, BI-STBC OFDM and BI-STBC FH-OFDM. For the inner code, the STBC with the coded schemes $\mathcal{G}_2, \mathcal{G}_3, \mathcal{H}_3, \mathcal{G}_4$, and $\mathcal{H}_4$ [4] are used for 2, 3, and 4 transmit antennas, respectively.

Table 1. Simulation parameters.

Parameters	Value
Data Rates	6, 9, 12 Mbps
Modulations	QPSK
Convolution code rate	1/2
STBC schemes	$\mathcal{G}_2$, $\mathcal{G}_3$, $\mathcal{G}_4$, $\mathcal{H}_3$, $\mathcal{H}_4$
STBC rates	1, 1/2, 3/4
Number of subcarriers	52
Number of pilots	4
OFDM symbol duration	4 μs
Guard interval	800 ns

3. Simulation Results

In this section, we provide the simulation results of the conventional OFDM, STBC OFDM, BI-STBC OFDM and BI-STBC FH-OFDM over fast fading channels with maximum Doppler frequency $f_d = 200$ Hz. The simulation parameters are given in Table 1. For our simplification, the proposed systems are defined to support only the single user (no multiuser interference: MUI). Furthermore, we assume that the received signals must have equal average power and impulse response of the channel is known at the receiver.

For STBC OFDM, BI-STBC OFDM and BI-STBC FH-OFDM, the number of the transmit antennas depends on the STBC schemes such as $\mathcal{G}_2$ for two transmit antennas and $\mathcal{G}_3$ for three transmit antennas etc. All transmission schemes perform standard of the conventional OFDM system that has convolution coding rate 1/2 and constraint length 7 code with generator polynomial (133,171) and these schemes employ QPSK modulation and one receive antenna [1].

In the case of one transmit antenna (conventional OFDM), it can support data rate at 12 Mbps as same as the two transmit antennas employ the $\mathcal{G}_2$ (code rate is one). In the case of 3 and 4 transmit antennas, the code $\mathcal{G}_3$, $\mathcal{H}_3$, $\mathcal{G}_4$ and $\mathcal{H}_4$ are used, respectively. Consequently, the code rate of $\mathcal{G}_3$ and $\mathcal{G}_4$ are 1/2 then the data rate in each case is 6 Mbps and the code rate of $\mathcal{H}_3$ and $\mathcal{H}_4$ are 3/4 then the data rate in each is 9 Mbps. Fig. 2 provides the simulation results for the transmission using one, two, three and four transmit antennas and the various of code rate. It is found that at the BER of 10^{-5} the code $\mathcal{H}_3$, $\mathcal{H}_4$, $\mathcal{G}_3$ and $\mathcal{G}_4$ improve the diversity gains of about 8.25 dB, 11.25 dB, 12.5 dB and 15.75 dB over the code $\mathcal{G}_2$, respectively, which they provide the performance better than the conventional OFDM. In Fig. 3, we provide the BER for the transmission using two transmit antennas with $\mathcal{G}_2$. It is seen that at the BER of 10^{-5} the BI-STBC OFDM and BI-STBC FH-OFDM can be improved the diversity gain of about 1.25 dB and 2 dB, respectively.

Fig. 4 and Fig. 5 provide the simulation result for the transmission using three and four transmit antennas which employ the $\mathcal{H}_3$, $\mathcal{G}_3$, $\mathcal{H}_4$ and the $\mathcal{G}_4$, respectively. It is found that at BER of 10^{-5} the code $\mathcal{G}_3$ and $\mathcal{G}_4$ give about 4.5 dB gain over the $\mathcal{H}_3$ and $\mathcal{H}_4$ while data rate is decreased about 3 Mbps and the improved diversity gain of these code rate about 0.4 dB and 1 dB can be obtained from BI-STBC OFDM and BI-STBC FH-OFDM, respectively.

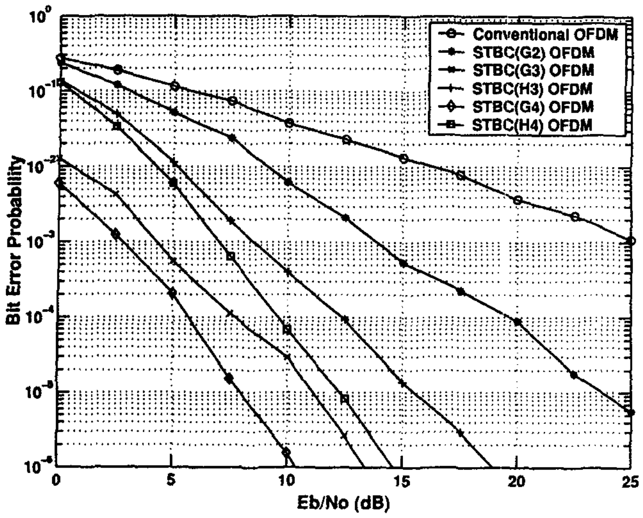

Figure 2. Performance comparisons of bit error probability for conventional OFDM and STBC OFDM employ the various code rate of STBC schemes.

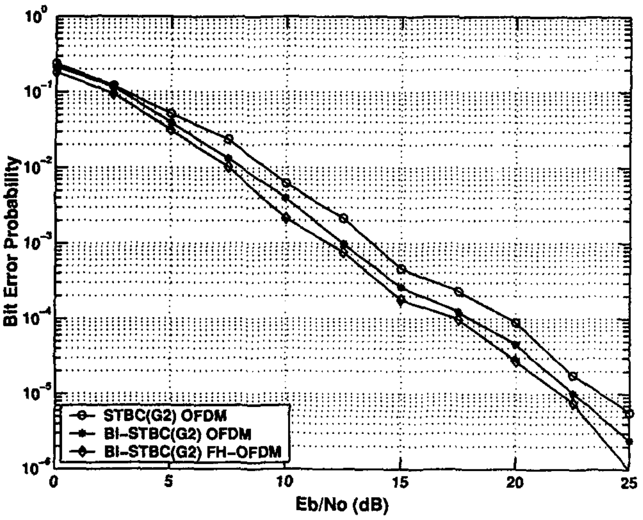

Figure 3. Performance comparisons of bit error probability using two transmit antennas for STBC OFDM, BI-STBC OFDM and BI-STBC FH-OFDM systems.

From these simulation results, they are demonstrated that the code $\mathcal{G}_2$ provides the better performance over the conventional OFDM because the data rate is not changed. Moreover, the usage of the block-interleaved with frequency hopping can be improved the performance rather than the unuse of either while it can maintain the same data rate of 12 Mbps.

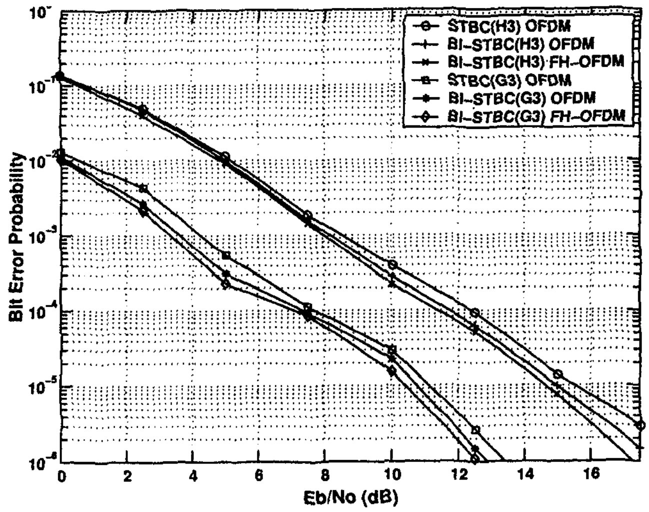

Figure 4. Performance comparisons of bit error probability using three transmit antennas for STBC OFDM, BI-STBC OFDM and BI-STBC FH-OFDM systems.

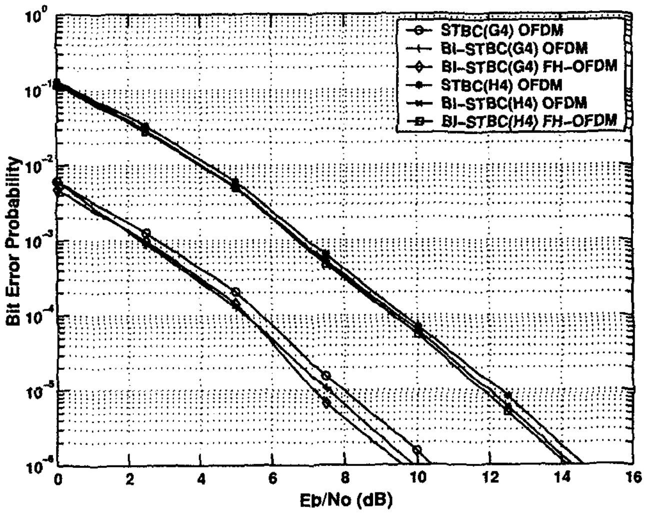

Figure 5. Performance comparisons of bit error probability using four transmit antennas for STBC OFDM, BI-STBC OFDM and BI-STBC FH-OFDM systems.

4. Conclusion

In this paper, we investigate the improved performance of the combined OFDM system using STBC schemes with multiple transmit antennas, block interleaver and frequency hopper. The performance comparisons of bit error probability for the conventional OFDM, STBC OFDM, BI-STBC OFDM and BI-STBC FH-OFDM have been presented. Simulation results were provided to demonstrate that significant gains can be achieved by introducing some combination technique (e.g. block interleaver, frequency hopper) and increase the number of transmit antennas with very little decoding complexity. Therefore, the STBC OFDM is a feasible way to reach the next generation of wireless communication for large data rates and applications.

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