Performance Investigation of Space-Time Block Coded Multicarrier DS-CDMA in Time-Varying Channels

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ABSTRACT—In this letter, we evaluate the system performance of a space-time block coded (STBC) multicarrier (MC) DS-CDMA system over a time selective fading channel, with imperfect channel knowledge. The average bit error rate impairment due to imperfect channel information is investigated by taking into account the effect of the STBC position. We consider two schemes: STBC after spreading and STBC before spreading in the MC DS-CDMA system. In the scheme with STBC after spreading, STBC is performed at the chip level; in the scheme with STBC before spreading, STBC is performed at the symbol level. We found that these two schemes have various channel estimation errors, and that the system with STBC before spreading is more sensitive to channel estimation than the system with STBC after spreading. Furthermore, derived results prove that a high spreading factor (SF) in the MC DS-CDMA system with STBC before spreading leads to high channel estimation error, whereas for a system with STBC after spreading this statement is not true.

Keywords—Space-time block coding, MC DS-CDMA, channel estimation error.

I. Introduction

Multicarrier technologies are considered very promising for future broadband data services in fading environments. In particular, MC DS-CDMA has emerged as the predominant candidate technique for 4G systems because it increases capacity and facilitates network planning in a cellular network.

Since, there is a growing demand for high-speed, spectrally efficient and reliable communication; systems using multiple transmit and receive antennas have been proposed as an efficient solution for future mobile systems. In particular, STBC systems have received much attention since they can greatly improve the system performance with a reasonable level of complexity [1].

The combination of STBC techniques and MC DS-CDMA systems has the potential to increase the performance of multiple users in a cellular network, hence such systems have been discussed by many researchers [2], [3]. Nevertheless the effect of STBC block placement on BER performance has not been investigated, due to the perfect channel estimation [2], [3]. In practice, channel information is never perfect and accurate estimation of channel parameters is an important issue in the decoding of the space-time codes. STBC block placement can affect the channel estimation error value; hence we investigate the STBC MC DS-CDMA system's average BER impairment due to imperfect channel information, by taking into account the effect of the STBC position.

We consider two variations of the STBC MC DS-CDMA system: STBC *before* spreading and STBC *after* spreading. Our results show that in a real channel environment with imperfect channel information these schemes have different channel estimation error values, and result in different levels of BER performance.

This letter is organized as follows. Section II describes the MC DS-CDMA system model with STBC before and after spreading. In section III system analysis and mathematical computation results are given. Simulation parameters and results are discussed in section IV. Finally, concluding remarks are given in section V.

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II. STBC MC DS-CDMA System Model

In this letter we analyze two schemes: MC DS-CDMA with STBC before and after spreading. For a simple description, we assume the BPSK modulated downlink system with two transmit and one receive antennas.

1. MC DS-CDMA with STBC after Spreading

The MC DS-CDMA with STBC after spreading system model is shown in Fig. 1. A stream of information symbols s_i after BPSK modulation is first serial-to-parallel (S/P) converted into $\{b_a[n, k], n=0,1,\cdots, L; k=0,1,\cdots, N-1\}$, where n indicates the time index, k denotes different OFDM subcarriers, and N is the number of OFDM subcarriers. Next, S/P converted data is spread by the same spreading sequence $C=[c_0, c_1, c_2,\cdots, c_{SF-1}]$, with a spreading factor of SF. As a result, each symbol of the above vector is changed into chipstream $d[i, k]$, where $i=0,1,\cdots,L\times(SF-1)$. Then, a STBC encoder codes the $d[i, k]$ into two different signals $\{t_m[i, k], m=1,2\}$, transmitted simultaneously from two different transmit antennas. The transmission matrix after STBC encoding is represented by

$$\begin{bmatrix} t_1[i+1,k]=-d^*[i+1,k] & t_1[i,k]=d[i,k] \\ t_2[i+1,k]=d^*[i,k] & t_2[i,k]=d[i+1,k] \end{bmatrix}, \quad (1)$$

where $i=0, 2, 4,\cdots$; $k=0, 1, 2,\cdots, N-1$ and $(.)^*$ denotes the complex conjugate. For simplicity, the guard interval and pilot symbols insertion are used but not expressed here.

At the receiver, output of the FFT can be expressed as

$$r_a[1,k]=\sum_{m=1}^{2}(t_m[1,k]h_m[i,k]+w_m[i,k]), \quad (2)$$

where $h_m[i, k]$ denotes the channel response of the k-th subchannel between the m-th transmit and receive antenna during the i-th chip period and $w[i, k]$ represents the AWGN.

Assuming that the channel is quasi-static and satisfies $h_m[i, k]=h_m[i+1, k]$, the STBC decoder with optimum combining builds the following two combined signals that are sent to the maximum likelihood detector:

$$\begin{aligned}\tilde{d}[i,k]&=\left(|h_1[i,k]|^2+|h_2[i,k]|^2\right)d[i,k]\\&\quad+h_1^*[i,k]w_1[i,k]+h_2[i,k]w_2^*[i,k],\\ \tilde{d}[i+1,k]&=\left(|h_1[i,k]|^2+|h_2[i,k]|^2\right)d[i+1,k]\\&\quad+h_2^*[i,k]w_1[i,k]-h_1[i,k]w_2^*[i,k].\end{aligned} \quad (3)$$

The output of the STB decoder is despread by spreading sequence C. Despread data is then parallel-to-serial converted and after BPSK demodulation we get the desired stream of information symbols, $\tilde{s}_i\,(i=0, 1, \cdots)$.

2. MC DS-CDMA with STBC before Spreading

The MC DS-CDMA with STBC before spreading system model is shown in Fig. 2. The serial transmit symbols, s_i, after modulation are first parameterized to $\{b_b[n, k], n=0,1,\cdots, L; k=0,1,\cdots,N-1\}$. Each two consecutive symbols of this vector are then sent into the space-time block encoder that has the transmission matrix given below:

$$\begin{bmatrix} -b_b^*[n+1,k] & b_b[n,k] \\ b_b^*[n,k] & b_b[n+1,k] \end{bmatrix}, \quad (4)$$

where $n=0, 2, 4,\cdots$; and $(.)^*$ denotes the complex conjugate [1].

Next each encoded symbol is spread by the same spreading sequence $C=[c_0,c_1,\cdots,c_f,\cdots]$, $(f=0,1,\cdots, SF-1)$, so the transmitter matrix can be expressed as

$$\begin{bmatrix} t_1[n+1,k]=-b_b^*[n+1,k]\times C & t_1[n,k]=b_b[n,k]\times C \\ t_2[n+1,k]=b_b^*[n,k]\times C & t_2[n,k]=b_b[n+1,k]\times C \end{bmatrix}. \quad (5)$$

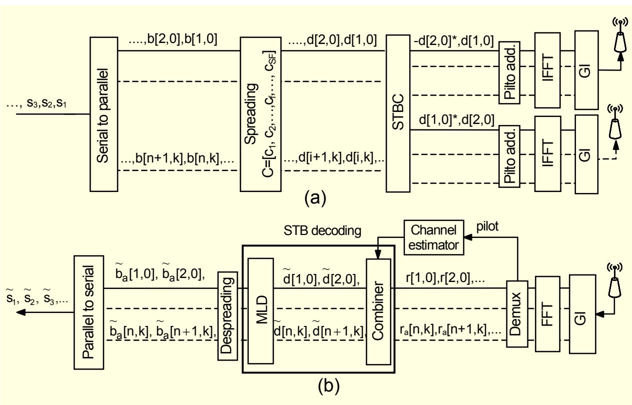

Fig. 1. MC DS-CDMA with STBC after spreading, (a) transmitter and (b) receiver.

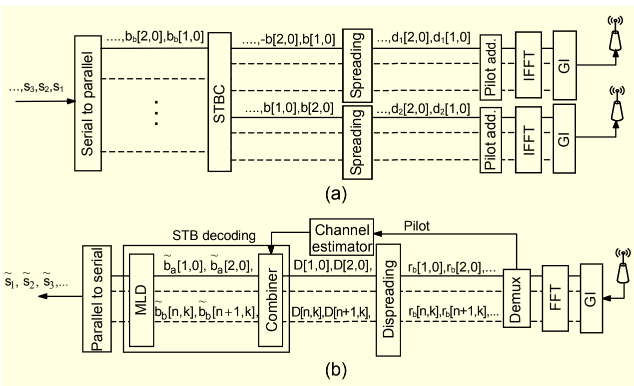

Fig. 2. MC DS-CDMA with STBC before spreading, (a) transmitter and (b) receiver.

Then two different symbols given above $\{t_m[n, k], m=1,2\}$ are transmitted simultaneously from two different transmit antennas after an N-length IFFT operation.

At the receiver side the output of the FFT can be expressed as

$$r_b[n,k] = \sum_{m=1}^{2} (t_m[n,k]H_m[n,k] + w_m[n,k]) , \qquad (6)$$

where $H_m[n, k]$ denotes the channel response of k-th subchannel between the m-th transmit and receive antenna during the n-th symbol period. Signal from the output of the FFT is then despread:

$$D[n,k] = r_b[n,k] \times C^T , \qquad (7)$$

where C^T is the transform of the spreading sequence C.

Once despreading is performed, optimal combining of $D[n, k]$ gives

$$\begin{aligned}\tilde{b}_b[n,k] &= \left(|H_1[n,k]|^2 + |H_2[n,k]|^2\right) b_b[n,k] \\ &\quad + H_1^*[n,k]w_1[n,k] + H_2[n,k]w_2^*[n,k], \\ \tilde{b}_b[n+1,k] &= \left(|H_1[n,k]|^2 + |H_2[n,k]|^2\right) b_b[n+1,k] \\ &\quad + H_2^*[n,k]w_i[n,k] - H_1[n,k]w_2^*[n,k], \qquad (8)\end{aligned}$$

where $H_m[n, k]$ is the estimated channel value, assuming that channel is quasi-static and satisfies $H_m[n, k]=H_m[n+1, k]$.

Decoded data is then parallel-to-serial converted and demodulated and finally we get the desired stream of informational symbols $\tilde{s}_i (i = 0, 1, \cdots)$.

III. System Analysis

Since, accurate estimation of channel parameters is an important issue in decoding of the space-time codes, the remaining part of this letter gives attention to channel estimation error.

To account for channel estimation errors, in contrast to [1], we consider the channel matrices as

$$\begin{bmatrix} h_1[i,k] + \varepsilon_1[i,k] & h_2[i,k] + \varepsilon_2[i,k] \\ h_1[i,k] + \varepsilon_1[i+1,k] & h_2[i,k] + \varepsilon_2[i+1,k] \end{bmatrix} \qquad (9)$$

for the system with STBC after spreading, and

$$\begin{bmatrix} H_1[n,k] + \xi_1[n,k] & H_2[n,k] + \xi_2[n,k] \\ H_1[n,k] + \xi_1[n+1,k] & H_2[n,k] + \xi_2[n+1,k] \end{bmatrix} \qquad (10)$$

for the system with STBC before spreading. The columns of (9) and (10) correspond to channels seen by different antennas, and the rows correspond to channel conditions at different time instances. The channel estimation error of the k-th subcarrier of antenna m during the i-th chip and n-th symbol period are denoted by $\varepsilon_m[i, k]$ and $\xi_m[n, k]$, respectively.

Due to the imperfect channel estimation, (3) and (8) become

$$\begin{aligned}\tilde{d}[i,k] &= \left(|h_1[i,k]|^2 + |h_2[i,k]|^2\right) d[i,k] \\ &\quad + h_1^*[i,k]w_1[i,k] + h_2[i,k]w_2^*[i,k] + I_a[i,k], \\ \tilde{d}[i+1,k] &= \left(|h_1[i,k]|^2 + |h_2[i,k]|^2\right) d[i+1,k] \\ &\quad + h_2^*[i,k]w_1[i,k] - h_1[i,k]w_2^*[i,k] + I_a[i+1,k] \qquad (11)\end{aligned}$$

and

$$\begin{aligned}\tilde{b}_b[i,k] &= \left(|H_1[i,k]|^2 + |H_2[i,k]|^2\right) b_b[n,k] \\ &\quad + H_1^*[i,k]w_1[i,k] + H_2[i,k]w_2^*[i,k] + I_b[n,k], \\ \tilde{b}_b[n+1,k] &= \left(|H_1[i,k]|^2 + |H_2[i,k]|^2\right) b_b[n+1,k] \\ &\quad + H_2^*[i,k]w_i[i,k] - H_1[i,k]w_2^*[i,k] + I_b[n+1,k], \qquad (12)\end{aligned}$$

respectively.

The interference terms $I_a[i, k]$ and $I_a[i+1, k]$ in (11) and $I_b[i, k]$ and $I_b[i+1, k]$ in (12) are

$$\begin{aligned}I_a[i,k] &= h_2^*[i,k](\varepsilon_1[i,k]d[i,k] + \varepsilon_1[i+1,k]d[i+1,k]) \\ &\quad + h_1[i,k](\varepsilon_2^*[i,k]d[i+1,k] + \varepsilon_2^*[i+1,k]d[i,k]), \\ I_a[i+1,k] &= h_2[i,k](\varepsilon_2^*[i,k]d[i,k] + \varepsilon_2^*[i+1,k]d[i+1,k]) \\ &\quad + h_1^*[i,k](\varepsilon_1^*[i+1,k]d[i+1,k] - \varepsilon_1^*[i,k]d[i,k]), \qquad (13)\end{aligned}$$

$$\begin{aligned}I_b[n,k] &= H_2^*[i,k](\xi_1[n,k]b[n,k] + \xi_1[n+1,k]b[n+1,k]) \\ &\quad + H_1[n,k](\xi_2^*[n,k]d[n+1,k] + \xi_2^*[n+1,k]b[n,k]), \\ I_b[n+1,k] &= H_2[n,k](\xi_2^*[n,k]b[n,k] + \xi_2^*[n+1,k]b[n+1,k]) \\ &\quad + H_1^*[n,k](\xi_1^*[n+1,k]b[n+1,k] - \xi_1^*[n,k]b[n,k]). \qquad (14)\end{aligned}$$

For a high SNR, the interference terms in (11) and (12) are performance limiting factors, rather than noise components [4].

Since, in the MC DS-CDMA system with STBC before spreading, after STBC encoding, each two consecutive symbols are spread with spreading sequence length of SF, the channel frequency response $H_m[n, k]$ in (14) is equal to

$$H_m[n,k] = \sum_{f=0}^{SF-1} h_m[(n \times SF + f), k], \qquad (15)$$

and the channel estimation error is

$$\xi_m[n,k] = \sum_{f=0}^{SF-1} \varepsilon_m[(n \times SF + f), k]. \qquad (16)$$

From (16) we can see that the channel estimation error value in the MC DS-CDMA system with STBC before spreading is considerably larger than that in the system with STBC after spreading. Also, increasing the *SF* in the MC DS-CDMA with STBC before spreading leads to higher channel estimation error. In the case of ideal channel estimation $\xi_m[n,k] = \varepsilon_m[i,k]$, in which the interference terms defined in (13) and (14) also go to zero, both systems will have the same performance.

IV. Simulation Results

Simulations were performed under a 6-path time selective Rayleigh fading channel. The total number of carriers was 64. As a spreading sequence we used the Walsh codes with *SF*=4, 8, 16, 32, and 64. The numbers of transmit and receive antennas were 2 and 1, respectively.

As shown in Fig. 3, in the case of ideal channel estimation, both MC DS-CDMA schemes with STBC before and after spreading have almost the same level of performance.

Figure 4 demonstrates the results of simulation with imperfect channel information. To obtain the channel state information we used the simple channel estimator proposed in [5]. As shown in Fig. 4, in the case of imperfect channel estimation, we have totally different results for the two schemes. At the same BER, the MC DS-CDMA system with STBC after spreading outperforms the system with STBC before spreading by about 4 dB in the required E_b/N_0. Moreover due to the errors in channel estimation, the MC DS-CDMA system with STBC before spreading has about 4 dB performance degradation at 10^{-3} BER; whereas, for the system with STBC after spreading, this effect is insignificant. This means that the system with

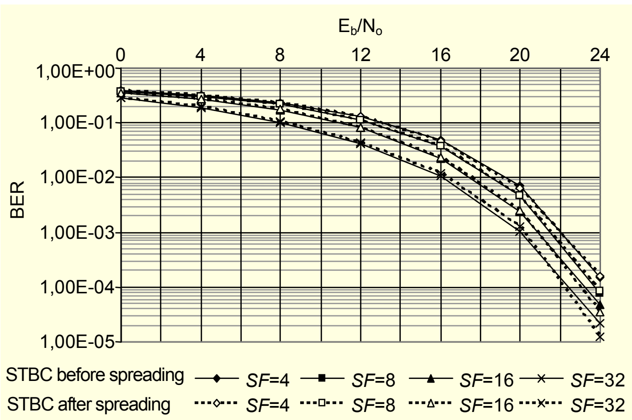

Fig. 3. MC DS-CDMA with STBC system simulation with ideal channel estimation.

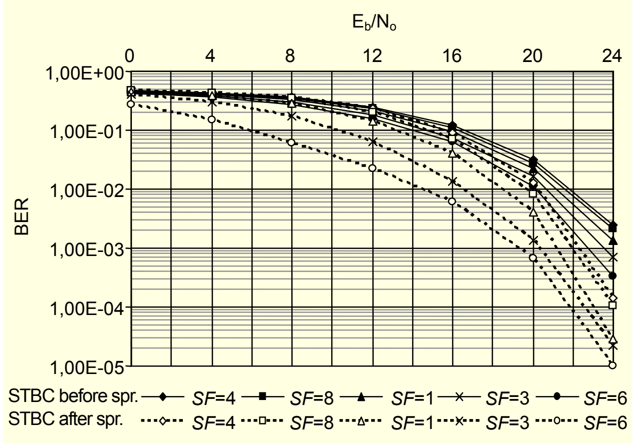

Fig. 4. MC DS-CDMA with STBC system simulation with non-ideal channel estimation.

STBC before spreading is more sensitive to channel estimation errors. Furthermore, in the MC DS-CDMA system with STBC before spreading, a high *SF* leads to less performance improvement than in the system with STBC after spreading.

V. Conclusion

In this letter, the BER performances of MC DS-CDMA systems with STBC before and STBC after spreading in a fast time-varying channel environment with imperfect channel estimation are investigated. In a real channel environment, with fast multipath fading, the MC DS-CDMA system with STBC after spreading has from 3 up to 6 dB performance gain, compared to the MC DS-CDMA system with STBC before spreading. Also, in the MC DS-CDMA with STBC before spreading results in a high channel estimation error.

References

[1] S.M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications," *IEEE J. Select. Areas Communications*, vol.16, no.8, Oct. 1998.

[2] L. Cai, Y. Xu, et. al., "Performance of SFH/MC DS-CDMA System Using Transmit Diversity with Space-Time Block Coding," *IEEE VTC2004*-Fall, vol. 7, Sept. 2004, pp. 4988-4990.

[3] X. Zhang and J, Tang, "Space-Time Diversity-Enhanced QoS Provisioning for Real-Time Service over MC-DS-CDMA Based Wireless Networks," *IEEE Globecom,* vol. 4, 2004.

[4] T. Kurt and H. Delic, "Transmitter Diversity for Robustness to Channel Estimation Errors," *IEE Electronics Letters*, vol. 41, no. 5, Mar. 2005, pp. 263 – 265.

[5] J. Guo, D. Wang, and C. Ran, "Simple Channel Estimator for STBC-Based OFDM Systems," *IEEE El. Letters Online,* no. 20030284, 2003.