OFDM-CDMA기반의 광대역 무선접속시스템에서 공간-시간부호의 성능분석

Performance Analysis of Space-Time Codes on OFDM-CDMA based Broadband Wireless Access Networks

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요 약

본 논문에서는 OFDM-CDMA기반의 광대역 무선 접속시스템에서 다중 안테나를 적용한다. 이로서 시간영역에서 윈도우 기반의 채널추정 기법과 OFDM기반의 공간영역에서 다중 안테나 전송시스템에서 채널추정의 불완전성을 극복하기 위한 다채널 분리용 프리앰블을 적용함으로서 광대역 무선 접속시스템에서 사용자수를 최대로 확대하고 사용자 용량을 증대하는 광대역 무선접속시스템의 성능을 분석하였다.

Abstract

In this paper, a channel estimation based on the time-domain windowing and its imperfectness in OFDM-based multiple-antenna transmission systems are analyzed with an emphasis on a preamble design for multi-channel separation. From the computer simulation results, the OFDM-CDMA system applying a space-time-frequency diversity with a full-rate full diversity code can give the diversity of $D=4$ and $D=8$ for both multi-user cases of maximum user and half user capacities, respectively

☞ Keyword : Broadband wireless access network, OFDM-CDMA, Multi-channel separation

1. INTRODUCTION

The orthogonal frequency division multiplexing (OFDM) has been commonly used for high data rate wireless communications due to its inherent error susceptibility in a multipath environment and has been chosen for several broadband network standards(IEEE802.11, and IEEE802.16) [1,2].

A multicarrier (MC) modulation in combination with spread-spectrum technique offers promising multiple access schemes for 4G broadband radio applications, known as OFDM-CDMA [3-5].

The performance of these OFDM-based systems can be improved by applying several diversity techniques. Especially, the OFDM based transmission system can be extended to a multiple input multiple output (MIMO) architecture using a space-time and Bell laboratories layered space-time (BLAST) concepts, which provides significant capacity gain in wireless channels [6].

This paper is concerned with a design of OFDM-CDMA physical (PHY) layer for high-rate and high-capacity broadband wireless access network.

The proposed preamble architecture provides a feasible solution of the channel estimation without restoring channel samples corresponding to the number of substantial subcarriers used in data transmission by interpolation.

Numerical and simulation results provide the

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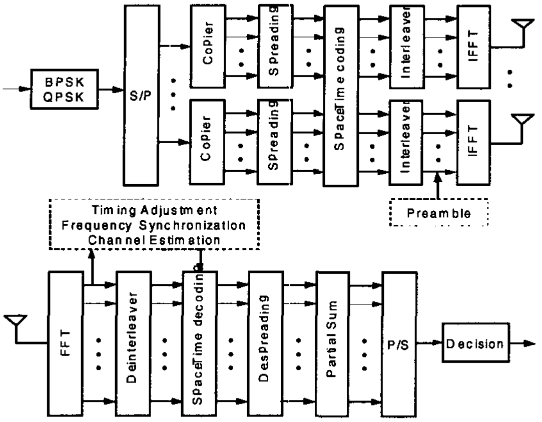

Fig 1. Transceiver for OFDM-CDMA broadband PHY.

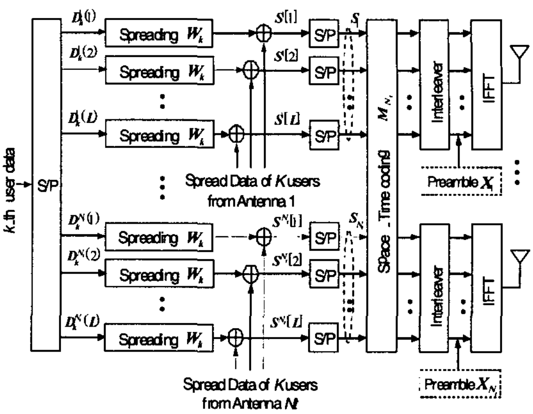

Fig 2. Data channel for the OFDM-CDMA broadband PHY.

channel estimation performance and the effect of imperfect windowing in term of the mean square error (MSE) performance of both the least square (LS) and linear minimum mean square error (LMMSE) estimators.

Furthermore, it is shown that a diversity of about $D=4$ and $D=8$ can be achievable by applying the space-time-frequency diversity scheme even if the worst two-path Rayleigh fading channel is encountered, maintaining the maximum user capacity and half user capacity, respectively. The presented results show that the OFDM-CDMA system can be a possible candidate for broadband wireless access network as well as 4G cellular network systems.

2. OFDM-CDMA Broadband Phy. Layer

We consider a K-user OFDM-CDMA forward link with N sub-carriers that uses N_t transmit antennas.

The OFDM-CDMA physical (PHY) layer operates in the 5.25GHz, and is designed to achieve data rates of up to 20Mbps under multi-user environments for cellular network as well as broadband wireless access applications. Fig.1 provides the general block diagram of the transceiver for the OFDM-CDMA PHY layer.

All data transmitted on the data link are first serial-to-parallel converted, orthogonally spread, space-timed coded, and frequency-interleaved prior to transmission.

The considered OFDM- CDMA system is an extension of the existing MC-CDMA system to be specialized for the broadband access applications.

A. Preamble Pattern

We define an N_t N-dimensional vector of time-domain transmitted signal as $x=[x_1 x_2 \cdots x_N]^T$ with each element.

If we denote as a preamble for the 1-st transmit antenna, which is an N-dimensional vector with each component of all 1's, the preamble for the i-th transmit antenna denoted as for $1<i\leq N_t$ is formulated as following rule:

$$X_i = e_i X_1 = Fx_i \tag{1}$$

where e_i denotes an $N\times N$ diagonal matrix with each component of $\exp\{j2\pi kn_i/N\}$ for the frequency-domain index $0 \le k < N$, F denotes $N \times N$ FFT matrix, and x_i is the n_i-th cyclic shifted version of a time-domain OFDM symbol of the 1-st transmit antenna denoted as x_1. For the notational convenience, in the following, we define X_i as an $N \times N$ diagonal matrix given by $X_i = \boldsymbol{diag}(Fx_i)$.

For a given number of substantial subcarriers used in data modulation denoted by N, the maximum number of transmit antennas N_t can be given by

$$N_t = \lceil N / \lambda \rceil \tag{2}$$

where $\lceil m/n \rceil =$ first integer $< m/n$ and λ is the total number of channel paths. Considering eqn. (2), the time shift index n_i for each of N_t multiple transmit antennas can be designed as $n_i = (i-1)\lceil N/N_t \rceil$ for $1 \le I \le N_t$, which guarantees each channel impulse response to be orthogonal in the time domain. In the case of two and four transmit antennas, the preamble pattern can be expressed as

$$\begin{aligned} X_1 &= \boldsymbol{diag}[\underbrace{1111 \cdots 1111 \cdots 1111}_{N}] \\ X_2 &= \boldsymbol{diag}[\underbrace{1-11-1 \cdots 1-11-1}_{N}] \end{aligned} \tag{3}$$

for N_t = 2 and

$$\begin{aligned} X_1 &= \boldsymbol{diag}[\underbrace{1111 \cdots 1111 \cdots 1111}_{N}] \\ X_2 &= \boldsymbol{diag}[\underbrace{1-11-1 \cdots 1-11-1}_{N}] \\ X_3 &= \boldsymbol{diag}[\underbrace{11-1-1 \cdots 11-1-1}_{N}] \\ X_4 &= \boldsymbol{diag}[\underbrace{1111 \cdots -1-1-1-1}_{N}] \end{aligned} \tag{4}$$

for N_t = 4.

B. Transmitted Signal

After spreading, an M-dimensional spread vector of the l-th sub-data of the k-th user from antenna l is $S_k^i[l] = D_k^i(l)\, W_k$, which is divided into two consecutive $M/2$-dimensional vectors as $S_k^i[l] = [S_k^i(1)\; S_k^i(2)]$. Using a simple symbol formatting, the spread vector of the l-th sub-data of the k-th user can be formulated as

$$\bar{S}_k^i[l] = [S_k^i(1)\; S_k^{i*}(2)] \tag{5}$$

where $(\cdot)^*$ denotes complex conjugation. Then, the signal including all K users is given by

$$S^i[l] = \sum_{k=1}^{K} \bar{S}_k^i[l] \tag{6}$$

Finally, the transmitted signal of K users from antenna i through all N subcarriers used in data modulation is

$$S_i = \boldsymbol{diag}[S^i[1]\, S^i[2] \cdots S^i[L]] \tag{7}$$

The transmitted vector S_i is a multilevel signal with levels varying from $-K$ to K. Above described symbol formatting gives the peak-to-average power ratio (PAPR) reduction.

C. Space-Time Codes

As an application of a full-rate full-diversity real space-time code to the OFDM-CDMA broadband system, which corresponds to BPSK transmission. In the case of two transmit antennas, the N-dimensional OFDM symbol transmitted from antenna 1 is denoted by $S_1$and from antenna 2 by S_2.

During the next symbol period, $-S_2$ and S_1 are transmitted from antennas 1 and 2, respectively, and transmission matrix is given by

$$M_2=\begin{bmatrix} S_1 & S_2 \\ -S_2 & S_1 \end{bmatrix} \tag{8}$$

In the case of two transmit antennas, we assume that fading is constant across two consecutive symbols. The case of four transmit antennas has a following matrix form:

$$M_4=\begin{bmatrix} S_1 & S_2 & S_3 & S_4 \\ -S_2 & S_1 & -S_4 & S_3 \\ -S_3 & S_4 & S_1 & S_2 \\ S_4 & -S_3 & -S_2 & S_1 \end{bmatrix} \tag{9}$$

On the other hand, the QPSK transmission of both two and four transmit antennas uses the following complex space-time code, respectively:

$$M_2=\begin{bmatrix} S_1 & S_2 \\ -S_2^H & S_1^H \end{bmatrix} \tag{10}$$

and

$$M_4=\begin{bmatrix} S_1 & S_2 & \frac{S_3}{\sqrt{2}} & \frac{S_3}{\sqrt{2}} \\ -S_2^H & S_1^H & \frac{S_3}{\sqrt{2}} & -\frac{S_3}{\sqrt{2}} \\ \frac{S_3^H}{\sqrt{2}} & \frac{S_3^H}{\sqrt{2}} & \frac{-S_1-S_1^H+S_2-S_2^H}{2} & \frac{-S_2-S_2^H+S_1-S_1^H}{2} \\ \frac{S_3^H}{\sqrt{2}} & -\frac{S_3^H}{\sqrt{2}} & \frac{S_2+S_2^H+S_1-S_1^H}{2} & \frac{S_1+S_1^H+S_2-S_2^H}{2} \end{bmatrix} \tag{11}$$

where $(\cdot)^H$ denotes Hermitian transpose. In both equations, M_2 exploits a full-rate full-diversity for two transmit antennas and M_4 constructs rate 3/4 complex orthogonal code for four transmit antennas

3. OFDM-CDMA Receiver Performance

To validate the effectiveness of the proposed OFDM-CDMA system, IEEE802.11a OFDM system with carrier frequency of 5.25GHz, FFT size of 64, and guard interval of 16 is considered in a Rayleigh fading channel with $f_D=50$Hz.

A. Channel Estimation Performance

This section presents the numerical results of channel estimation method applied to both LS and LMMSE estimators in the case of imperfect windowing. As an application of a new preamble structure to the STBC receiver, some BER examples are illustrated. The multipath model is assumed to be a Rayleigh fading with an exponentially decaying and equal power profiles.

Figure 3 shows the MSE performance of LMMSE estimator for various values of λ. The number of transmit antennas is selected to be 4

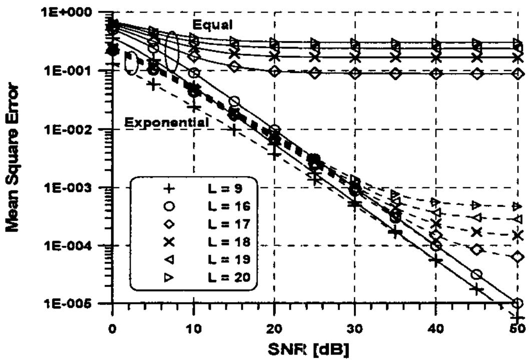

Fig 3. MSE performance of LMMSE estimator according to the length of channel impulse response with a selected value of Sw=16 according to N=64 and Nt=4

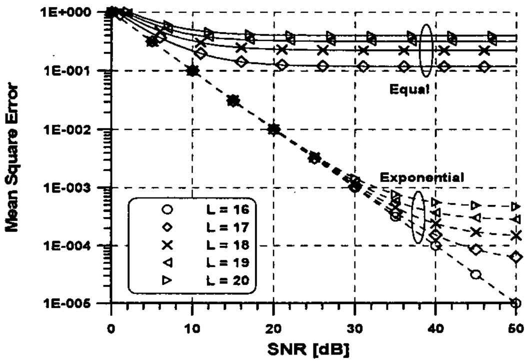

Fig 4. MSE performance of LS estimator according to the length of channel impulse response with a selected value of Sw=16 according to N=64 and Nt=4

according to the criterion of eq. (2) for given parameters of N=64 and $8<\lambda\le 16$, which corresponds to S_w=16, and the curves corresponding to the perfect windowing ($8<\lambda\le S_w$) and the imperfect windowing ($S_w<\lambda$) are provided in Fig. 3, respectively.

The SNR gain of the best case of LMMSE estimator encountered with $\lambda=9$ is approximately 3dB, compared to the worst case of LMMSE estimator encountered with $\lambda=16$. Similar results can be obtained in the case of LS estimator as shown in Fig. 4. The only difference is observed at the low SNR.

Figure 5 illustrates the effect of maximum channel impulse response on the MSE performance of the LMMSE estimator with SNR as a parameter.

As a propagation length of λ increases, as expected, the number of transmit antennas decreases according to eqn. (2) and the MSE increases.

B. Space-Time Coded OFDM- CDMA Receiver

The OFDM-CDMA system is simulated especially for equal power two-path Rayleigh fading channel, and we assume that the OFDM-CDMA receiver has a perfect channel estimation and is perfectly synchronized.

Figure 6shows BER performance of OFDM-CDMA receiver with frequency diversity with BPSK transmission, $N_t = 1$, and $N = 64$. As expected, the performance of multi-user case is degraded, compared to that of single user case.

However, with the help of frequency diversity defined in eqn. (11), the performance of single user case for all values of M can come close to that of single user case with $M = 64$, which corresponds to a diversity of $D = 2$.

Fig. 7 illustrates the achievable diversity D of OFDM-CDMA systems with various diversity schemes versus E_b/N_0 with BPSK transmission, $N = 64$, and $M = 32$. In a single-user case, a diversity of $D = 2$, $D = 4$, and $D = 8$ can be obtained by employing a space-time-frequency (STF) diversity with two transmit antennas, and a STF diversity with four transmit antennas, respectively.

4. Conclusion

In this paper, the performance evaluation of

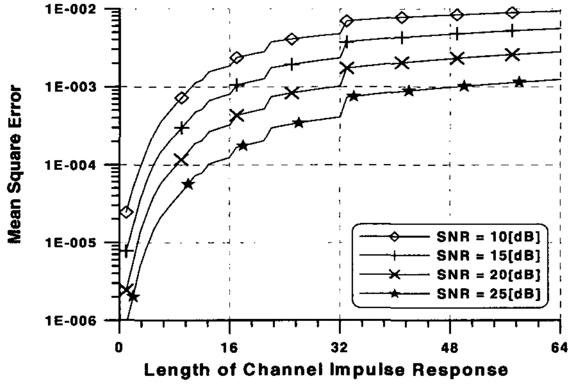

Fig 5. MSE performance of the LMMSE estimator according to the length of maximum channel impulse response for various values of SNR with N=64

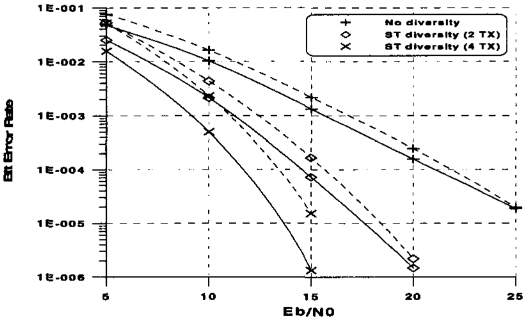

Fig 6. BER performance of STBC receiver for both perfect and LMMSE estimations according to the number of antennas with BPSK transmission, N=64, and M=32: (1) Solid lines-perfect estimation (2) Dotted lines-MMSE estimation

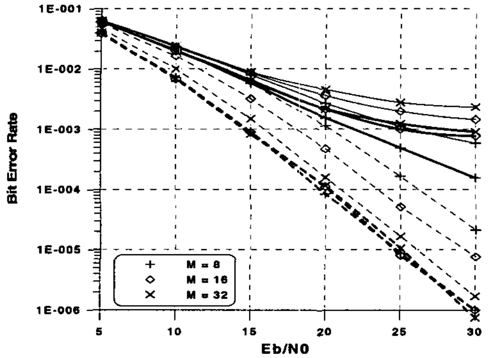

Fig 7. BER performance of OFDM-CDMA receiver with frequency diversity with QPSK transmission, Nt=1, and N=64: (1) Thin lines-no diversity (2) Bold lines-frequency diversity (3) Dotted lines - singleuser case (4) Solid lines-multiuser case with maximum user capacity

an OFDM-CDMA based broadband wireless access network employing diversity techniques is analyzed, and a preamble structure is proposed for the channel estimation performance. This preamble structure can estimate the multi-channel up to the 8 transmit antennas.

The OFDM- CDMA with various diversities is simulated especially for equal power two-path Rayleigh fading channel. Using real orthogonal space-time block code a diversity of $D = 4$ and $D = 8$ can be achieved for the multi-user with maximum user and half user capacities.

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