공간-시간부호화를 이용한 OFDM-CDMA의 성능분석

강민구*

Performance Analysis of OFDM-CDMA Systems using Space-Time Coding

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요 약

본 논문에서는 무선 광대역 통신망을 위한 OFDM-CDMA 광대역시스템을 설계하였다. 다중채널에서 프리앰블 설계기법을 활용함으로서, OFDM 기반의 다중안테나 전송시스템에서 시간영역의 윈도우기법의 활용에 의한 채널추정이 가능하다. 시간영역에서 직교하는 다중 안테나를 위한 각각의 프리앰블을 설계함으로서 ETSI HIPERLAN/2과 IEEE~802.11a 표준에 적용가능한 채널 추정기법을 제안한다. 또한, OFDM-CDMA 기반의 광대역망에서 성능개선을 위한 다이버시티 효과를 분석하였으며, 두개의 레일레이 페이딩 채널에서 얻을 수 있는 최대의 다이버시티 이득을 계산하였다. 본 논문의 시뮬레이션 결과로 완전한 속도와 완전한 다이버시티를 가진 시공간-주파수 다이버시티기법을 적용한 OFDM-CDMA시스템에서 D=4, D=8 다이버시티의 최대 사용자수 및 절반의 사용자인 경우의 대한 다중 사용자 용량에 대한 성능을 분석하였다.

ABSTRACT

In this paper, an OFDM-CDMA broadband system is considered for a possible candidate of fixed wireless broadband access network applications. With an emphasis on a preamble design for multi-channel separation, we address a channel estimation based on the time-domain windowing and its imperfectness in OFDM-based multiple-antenna transmission systems. By properly designing each preamble for multiple antennas to be orthogonal in the time domain, the channel estimation can be applied to the ETSI HIPERLAN/2 and IEEE~802.11a standards in the case of more than two transmit antennas. Also, an effect of diversity techniques on the performance of OFDM-CDMA based broadband wireless access networks is investigated and the maximum achievable diversity gain for a two-path Rayleigh fading environment is evaluated. Simulation results show that 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.*

키워드

Broadband wireless access network, OFDM-CDMA, Diversity, Multi-channel separation, IEEE 802.11a.

I. INTRODUCTION

Recently, 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 wireless local area network (LAN) and broadband wireless access network standards like IEEE802.11a, European HIPERLAN/2 and Japanese MMAC, IEEE802.16 [1][2]. Especially, IEEE802.16 wirelessMAN has been

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developed to link homes and businesses to core telecommunications networks worldwide, as illustrated in Fig. 1. The current tendency towards broadband communications implies a big effort on research in improved and flexible multiple access methods to cope with the increasing number of subscribers. A multicarrier (MC) modulation in combination with well-known spread-spectrum technique offers promising multiple access schemes for 4G broadband radio applications, known as MC-CDMA and OFDM-CDMA [3]-[5].

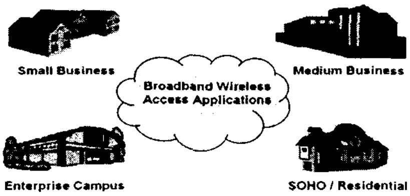

Fig. 1. Broadband wireless access target applications.

This paper is concerned with a design of OFDM-CDMA physical (PHY) layer for high-rate and high-capacity broadband wireless access network. As an application of the MIMO architecture, a new preamble structure for the OFDM-CDMA systems with more than two transmit antennas is designed to be orthogonal in the time domain, and the channel estimation performance based on a new preamble structure and its imperfectness by using time-domain widowing are investigated. 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.

Also, this paper evaluates an application of diversity techniques to an OFDM-CDMA based multiple access system for typical radio environments. Numerical and simulation results provide the 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 channelis 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.

II. OFDM-CDMA Broadband Physical Layer

We consider a K-user OFDM-CDMA forward link with N subcarriers 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. Figure 2 provides the general block diagram of the transmitter and receiver 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, as depicted in Fig. 3.

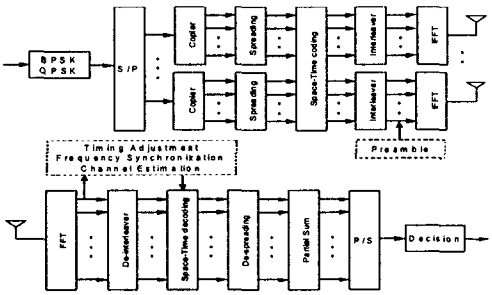

Fig. 2. Transmitter and receiver block diagram for the OFDM-CDMA broadband PHY layer

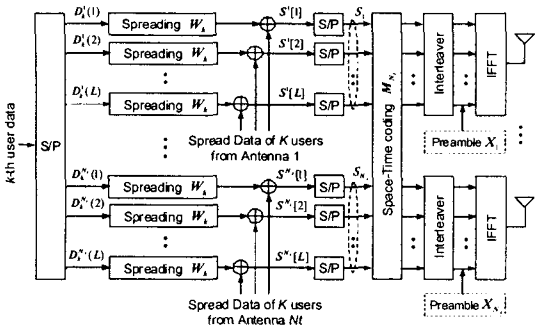

Fig. 3. Data channel structure for the OFDM-CDMA broadband PHY layer

A. Preamble Pattern

For the notational convenience, in the following, we define an N_t N-dimensional vector of time-domain transmitted signal as $x = [x_1\ x_2 \cdots x_{N_t}]^T$ with each element of $x_i = [x_i(0)\ x_i(1) \cdots x_i(K-1)]^T$. If we denote X_1as 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 X_i for $1 < i \le N_t$ is formulated as following rule:

$$X_i = e_i X_1 = F x_i \tag{1}$$

where e_i denotes an $N \times N$ diagonal matrix with each component of $\exp\{j2\pi k n_i / N\}$ 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 $X_i = diag(Fx_i)$.

For a given number ofsubstantial 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.

B. Spreading Code

Orthogonal Walsh spreading codes with period M are used for the user identification. A stream of QPSK symbols of the k-th system user from antenna i is first serial-to-parallel converted, where every L symbols are groped into a vector as $D_k^i = [D_k^i(1)\ D_k^i(2) \cdots D_k^i(L)]^T$ and each symbol of the k-th user is spread by a same Walsh spreading sequence with a length of M, which is denoted as $W_k = [W_{k1}\ W_{k2} \cdots W_{kM}]$.

For all serial-to-parallel converted data and transmit antennas of the k-th user, a same Walsh spreading code $\overline{W}_k$ is used to increase the system capacity.

C. Transmitted Signal

After spreading, an M-dimensional spread vector of the l-th sub-data of the k-th user from antenna i 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

$$\bar{S}_k^i[l] = [S_k^i(1)\ S_k^{i*}(2)] \tag{3}$$

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

$$S^i[l] = \sum_{k=1}^{K} \bar{S}_k^i[l] \tag{4}$$

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

$$S_i = diag[S^i[1]\ S^i[2] \cdots S^i[L]] \tag{5}$$

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, which will be validated by simulation in the section V-C.

D. Space-Time Code

As an application of a full-rate full-diversity real space-time code to the OFDM-CDMA broadband system, which corresponds to BPSK transmission, we consider two and four transmit antennas. 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

$$M_2 = \begin{bmatrix} S_1 & S_2 \\ -S_2 & S_1 \end{bmatrix} \tag{6}$$

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:

$$M_4 = \begin{bmatrix} S_1 & S_2 & S_3 & S_4 \\ -S_2 & S_1 & -S_4 & S_3 \\ -S_3 & S_4 & S_1 & S_2 \\ S_4 & -S_3 & -S_2 & S_1 \end{bmatrix} \tag{7}$$

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

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

and

$$M_4 = \begin{bmatrix} S_1 & S_2 & \frac{S_3}{\sqrt{2}} & \frac{S_3}{\sqrt{2}} \\ -S_2^H & S_1^H & \frac{S_3}{\sqrt{2}} & -\frac{S_3}{\sqrt{2}} \\ \frac{S_3^H}{\sqrt{2}} & \frac{S_3^H}{\sqrt{2}} & \frac{-S_1-S_1^H+S_2-S_2^H}{2} & \frac{-S_2-S_2^H+S_1-S_1^H}{2} \\ \frac{S_3^H}{\sqrt{2}} & -\frac{S_3^H}{\sqrt{2}} & \frac{S_2+S_2^H+S_1-S_1^H}{2} & \frac{S_1+S_1^H+S_2-S_2^H}{2} \end{bmatrix} \tag{9}$$

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.

E. Frequency Interleaving

In order to avoid the strong correlation among the L subcarriers occupied by a particular symbol, the L chips of each symbol are transmitted using subcarriers at equally spaced frequency [5], which gives an additional frequency diversity. The M chips for index $l = 1,2,\cdots,M$ of each bit $m(1,2,\cdots,L)$ are transmitted at equally spaced frequency as follows:

$$f_{m,l} = [(m-l)L + (l-1)]/T_s \tag{10}$$

where T_s is the OFDM symbol period.

F. Frequency Interleaving

The OFDM-CDMA broadband frame consists of the preamble, the header, and the user payload. The common preamble denoted as X_c and the long preamble denoted as X_i for $i = 1,2,\cdots,N_t$ shall be provided before the user payload to help receiver algorithms related to symbol timing adjustment, frequency synchronization, and channel estimation. As described earlier, the preambles X_i of two and four transmit antennas are derived according to eqns. (3) and (4), respectively, and provide a reliable multi-channel separation and estimation. The structure of the common preamble X_c is similar to the short OFDM training symbol used in IEEE802.11a standard.

III. Channel Model

Suppose the channel has a discrete-time impulse response from transmitter i to receiver j defined as $\mathbf{h}_{ji} = [h_{ji}(0)\, h_{ji}(1) \cdots h_{ji}(\lambda - 1)]^T$ and its frequency-domain response is $\mathbf{H}_{ji} = \mathbf{F}\mathbf{h}_{ji} = [H_{ji}(l,0)\, H_{ji}(l,1) \cdots H_{ji}(l, N-1)]^T$ whose elements are independent identically distributed (i.i.d.) complex Gaussian with zero mean and unit variance at the l-th symbol period.

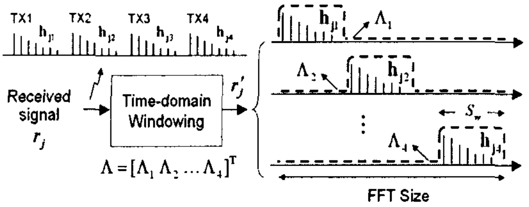

Fig. 4. Example of the window operation for the received signal from four transmit antennas in the j-th receiver

Also, $H_{ji}(l,n)$ are statistically independent for different i 's, the cross-correlation function between $H_{ji_1}(l,n)$ and $H_{ji_2}(l,n)$ can be expressed as

$$R_{H_{ji_1}H_{ji_2}}(l,n) = \begin{cases} R_H(l,n), & if\ i_1 = i_2 \\ 0, & if\ i_1 \neq i_2 \end{cases} \tag{11}$$

For wide-sense stationary uncorrelated scattering (WSSUS) channels, $R_H(l,n)$ can be rewritten by using the separation property as

$$R_H(l,n) = J_o(2\pi l T_s f_D) \sum_n \sigma_n^2 e^{-j2\pi k \Delta f \tau_n}. \tag{12}$$

where $J_0(\cdot)$ is the zeroth-order Bessel function of the first kind, and T_s and f_D are the OFDM symbol period and maximum Doppler frequency, respectively.

Also, σ_n^2, Δf, and τ_n represent the average power, subchannel spacing, and delay time of the n-th multipath component, respectively. In the following, the index l for symbol period will be omitted for notational convenience.

IV. OFDM-CDMA Receiver Consideration

The OFDM-CDMA system has a high performance characteristic (i.e., multipath immunity and interference rejection capability) of both

OFDM and CDMA. The coarse time and frequency synchronization can be adjusted by using the periodic common preamble. Under the assumption of slow varying channels, a simple channel estimation and a carrier frequency estimation are used for carrier and frequency synchronizations. In this paper, it is assumed that perfect symbol, frequency, and carrier synchronization are performed.

A. Multi-Channel Separation and Channel Estimation

If the preamble is carefully designed to satisfy the criteria of eqns. (1) and (2), the convolution terms received at the j-th receiver antenna $\{x_i \otimes h_{ji}\}$ are orthogonal in the time domain. Therefore, the N-dimensional received signal vector at the j-th receiver antenna is

$$r_j = \sum_{i=1}^{N_t} c_{ji} + n_j \tag{13}$$

where $c_{ji} = x_i \otimes h_{ji}$ is the N-dimensional vector.

Then, as shown in Fig. 4, by multiplying the received signal vector r_j with a vector of a rectangular window function Λ with a size of $S_w = \lceil N/N_t \rceil$, the received signal r_j is resolved into an N_t N-dimensional received vector with the elements of each shifted channel impulse response from N_t transmit antennas plus additive white Gaussian noise (AWGN) samples

$$r'_j = \Lambda r_j = c_j + n'_j \tag{14}$$

where $c_j = [c_{j1}\ c_{j2} \cdots c_{jN_t}]^T$, $\Lambda = [\Lambda_1\ \Lambda_2 \cdots \Lambda_{N_t}]^T$ is a vector of a rectangular window function.

If N_t is an odd number, the size of the last window Λ_{N_t} is extended to $N-(N_t-1)S_w$. For the illustrative convenience of the receiver model, we assume that N_t is an even number.

Defining $\Im$ being a vector of FFT matrix with the elements of F on its diagonal and assuming perfect synchronization, the FFT output of frequency-domain subcarrier can be expressed as

$$R_j = \Im r'_j = XH_j + N_j \tag{15}$$

where X isa vector with each element of an $N \times N$ diagonal matrix X_i on its diagonal, $H_j = [H_{j1}\ H_{j2} \cdots H_{jN_t}]^T$ with each component of $H_{ji} = Fh_{ji}$, and $N_j = [N_{j1}\ N_{j2} \cdots N_{jN_t}]^T$ with the elements of $N_{ji} = Fn'_{ji}$ which has a zero mean and variance of $N\sigma_t^2 / N_t$.

Then, the estimates of H_j based on the LS estimation can be obtained by multiplying X^{-1} with R_j as

$$\tilde{H}_j = H_j + N_j X^{-1} \tag{16}$$

Therefore, using a simple LS method, the LS estimation of the channel impulse response is $\hat{H}_{LS} = \hat{H}_j$. Furthermore, this can be easily extended to the LMMSE estimator. In order to have minimum information quantity, the estimator assumes a priori knowledge of noise variance and channel covariance, and is expressed as

$$\hat{H}_{LMMSE} = R_H \left[R_H + \frac{1}{SNR} I_{N \times N} \right]^{-1} \hat{H}_{LS} \tag{17}$$

where $\boldsymbol{R}_H = \boldsymbol{E}[\boldsymbol{H}_j \boldsymbol{H}_j^H]$ are the auto-covariance matrix of $\boldsymbol{H}_j$ and $\boldsymbol{I}_{N\times N}$ is an $N \times N$ identity matrix. This channel estimation is called LS estimate and since an preamble length can be designed to be equal to the FFT size for data modulation regardless of the number of transmit antennas, there is no need to restore channel impulse response samples corresponding to the number of substantial subcarriers used in data transmission by interpolation.

As described earlier, the number of transmit antennas is selected according to the criterion of for given system and channel parameters of N and λ. Unfortunately, if a propagation length of λ exceeds the window size of S_w due to incorrectly designing preamble architectures, the estimator results in an additional estimation error. The effect of imperfect windowing on the estimation performance will be discussed by using simulations.

B. Space-Time Coded OFDM-CDMA Receiver Model

In the case of two transmit antennas, based on the assumption of constant fading across two consecutive OFDM symbols, the received vector of an OFDM symbol at the i-th symbol period newly denoted as $\boldsymbol{R}_i$ is given by

$$\begin{bmatrix} \boldsymbol{R}_1 \\ \boldsymbol{R}_2 \end{bmatrix} = \begin{bmatrix} \boldsymbol{S}_1 & \boldsymbol{S}_2 \\ -\boldsymbol{S}_2^H & \boldsymbol{S}_1^H \end{bmatrix} \begin{bmatrix} \boldsymbol{H}_1 \\ \boldsymbol{H}_2 \end{bmatrix} + \begin{bmatrix} \boldsymbol{N}_1 \\ \boldsymbol{N}_2 \end{bmatrix} \tag{18}$$

where N_i is a vector of i.i.d. AWGN samples at the i-th symbol period. For the notational convenience, the subscript j for the receiver antenna will be omitted. The two transmitter antennas simultaneously transmit the OFDM signals modulated by S_1 and S_2 at the first symbol period. Hence, the combiner builds the following combined signals:

$$\hat{\boldsymbol{S}}_i = \boldsymbol{S}_i \boldsymbol{H}_G + \hat{\boldsymbol{N}}_i \tag{19}$$

where $\hat{\boldsymbol{N}}_1 = \boldsymbol{diag}(\boldsymbol{N}_1 \boldsymbol{H}_1^H + \boldsymbol{N}_2 \boldsymbol{H}_2^H)\boldsymbol{I}_{N\times 1}$, and $\hat{\boldsymbol{N}}_2 = \boldsymbol{diag}(\boldsymbol{N}_1 \boldsymbol{H}_2^H \quad - \boldsymbol{N}_1 \boldsymbol{H}_2^H)\boldsymbol{I}_{N\times 1}$, and

$$\begin{aligned} \boldsymbol{H}_G &= [|H_1(0)|^2 + |H_2(0)|^2 \; |H_1(1)|^2 + |H_2(1)|^2 \cdots \\ &\quad |H_1(N-1)|^2 + |H_2(N-1)|^2]^T \\ &= [H_G[1] \, H_G[2] \cdots H_G[L]]^T \end{aligned} \tag{20}$$

with each component of

$$\begin{aligned} \boldsymbol{H}_G[\boldsymbol{l}] = [&|H_1((l-1)M)|^2 + |H_2((l-1)M)|^2 \\ &|H_1((l-1)M+1)|^2 + |H_2((l-1)M+1)|^2 \\ &\cdots |H_1(lM-1)|^2 + |H_2(lM-1)|^2]^T \end{aligned} \tag{21}$$

Then, by multiplying the corresponding k-th Walsh sequence to the combined signal, the demodulated symbol vector of the transmitted signals of the k-th user from antenna i denoted as $\boldsymbol{D}_k^i$ can be expressed as

$$\hat{\boldsymbol{D}}_k^i = [\boldsymbol{H}_C[1]\boldsymbol{W}_k \hat{\boldsymbol{S}}^i[1] \; \boldsymbol{H}_C[2]\boldsymbol{W}_k \hat{\boldsymbol{S}}^i[2] \cdots \boldsymbol{H}_C[\boldsymbol{L}]\boldsymbol{W}_k \hat{\boldsymbol{S}}^i[\boldsymbol{L}]]^T \tag{22}$$

where $\boldsymbol{H}_C[\boldsymbol{l}]$ is the combining vector, which can be determined according to corresponding combining strategies. The gains of the orthogonality restoring combining (ORC) and the equal gain combining (EGC) are given by $\boldsymbol{H}_C[\boldsymbol{l}] = \boldsymbol{H}_G[\boldsymbol{l}]^{-1}$ and $\boldsymbol{H}_C[\boldsymbol{l}] = \boldsymbol{H}_G[\boldsymbol{l}]^{-1/2}$, respectively. Furthermore, in the case of the maximum ratio combining (MRC), $\boldsymbol{H}_C[\boldsymbol{l}]$ is an $1 \times \boldsymbol{M}$ identity vector $\boldsymbol{I}_{1\times M}$. Especially, in the case of the multi-user OFDM-CDMA forward link, the EGC results in better bit error rate (BER) performance [4] and therefore this paper considers only EGC scheme.

C. Receiver Sensitivity

The OFDM-CDMA receiver sensitivity is defined as the minimum power level of the incoming signal, in dBm, present at the input of the receiver for which the BER performance of less than 10^{-5} in the presence of AWGN. The OFDM-CDMA receiver has a noise bandwidth of 20MHz, which determines the amount of AWGN power present in the receiver. A receiver noise figure of 12dB and a degradation due to the image noise of 3dB are assumed for sensitivity calculations. Using the above parameters, the receiver sensitivity can be expressed as

$$R_S = -174 + N_I + N_F + 10\log B_W + SNR_r \qquad (24)$$

where N_I is 3dBm degradation factor due to the image noise, N_F is the noise figure of 12dB, B_W is the noise equivalent detection bandwidth, and SNR_r is the system requirement corresponding to a 10^{-5} probability of error in a specific modulation scheme.

V. 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 5shows the MSE performance of LMMSE estimator for various values of λ. In this figure, the number of transmit antennas is selected to be 4 according to the criterion of eqn. (2) for given parameters of $N = 64$ and $8 < \lambda \leq 16$, which corresponds to $S_w = 16$, and the curves corresponding to the perfect windowing ($8 < \lambda \leq S_w$) and the imperfect windowing ($S_w < \lambda$) are provided in Fig. 5, 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. 6. The only difference is observed at the low SNR.

The proposed preamble appears to be a goodcandidate for extension of the ETSI HIPERLAN/2 and IEEE802.11a standards to the case of more than two transmit antennas with the assumption of $\lambda \leq 16$. Example of STBC applications : In Fig. 8, as an application of the investigated preamble to STBC applications

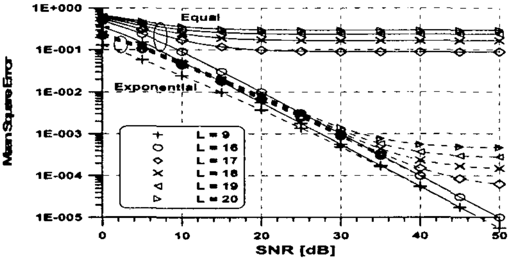

Fig. 5. MSE performance of LMMSE estimator according to the length of channel impulse response with a selected value of *Sw*=16 according to *N*=64 and *Nt*=4

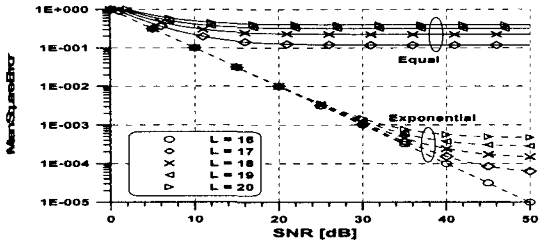

Fig. 6. MSE performance of LSestimator according to the length of channel impulse response with a selected value of *Sw*=16 according to *N*=64 and *Nt*=4

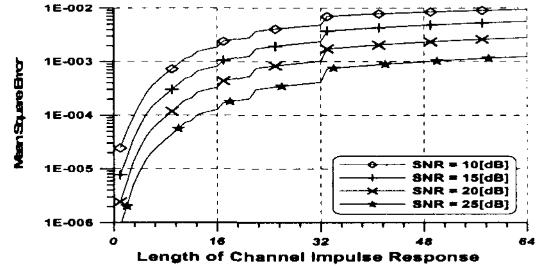

Fig. 7. MSE performance of the LMMSE estimator according to the length of maximum channel impulse response for various values of SN

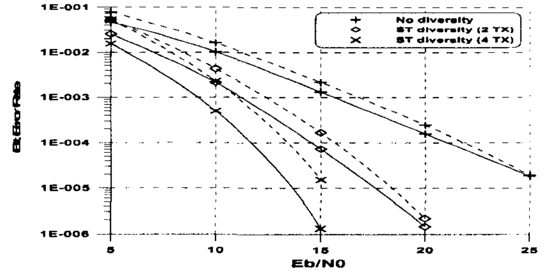

Fig. 8. BER performance of STBC receiver for both perfect and LMMSE estimations according to the number of antennas with BPSK transmission, *N*=64, and *M*=32: (1) Solid lines - perfect estimation (2) Dotted lines - MMSE estimation

we plot BER performances of STBC receiver for both perfect and LMMSE estimations according to the number of antennas with BPSK transmission, $\lambda = 2$, $N = 64$, and $M = 32$. In this figure, the single user case is assumed.

B. Performance of Space-Time Coded OFDM -CDMA Receiver

To evaluate the effect of various diversity techniques on the performance of OFDM -CDMA systems, 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 9 shows 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. (12), 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 $D = 2$. As described earlier, further performance enhancement can be obtained by using a space-time coding, which will be illustrated in the following examples.

Figure 10illustrates 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 frequency diversity, a space-time-frequency (STF) diversity with two transmit antennas, and a STF diversity with four transmit antennas, respectively. On the other hand, the diversity of the multi-user cases with maximum user ($K = 32$) and half user ($K = 16$) capacities approach that of single-user cases corresponding to $D = 4$ and $D = 8$ by applying the STF diversity scheme with four transmit antennas, respectively. Against the worst channel case of

$\lambda = 2$, as the number of multipaths λ increases, the STF coded OFDM-CDMA can exploit the available frequency diversity and improve the BER performance.

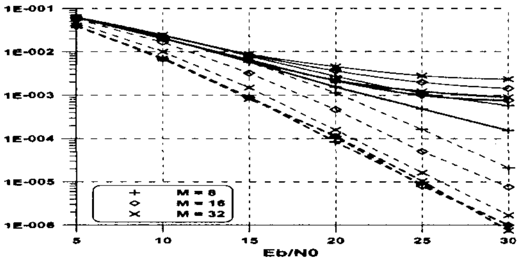

Fig. 9. BER performance of OFDM-CDMA receiver with frequencydiversity with QPSK transmission, Nt=1, and N=64: (1) Thin lines - no diversity (2) Bold lines - frequency diversity (3) Dotted lines - single-user case (4) Solid lines - multi-user case with maximum user capacity

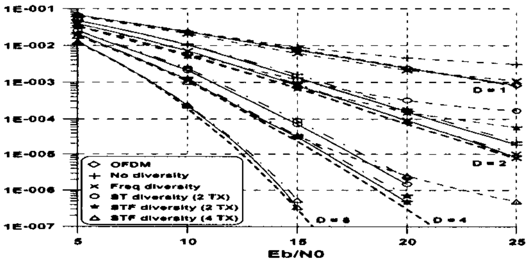

Fig. 10. Achievable diversity *D* of diversity schemes with BPSK, N=64, and M=32: (1) Bold dash lines - analysis of diversity order of single-user case (*D*=1~8) (2) Solid lines - simulation of single-user case (3) Dotted lines - simulation of multi-user case with maximum user capacity (4) Dashed lines - simulation of multi-user case with half user

VI. Conclusion

In this paper, we have highlighted the performance evaluation of an OFDM-CDMA based broadband wireless access network employing some diversity techniques. Especially, as an application of a space-time block code, we provide a preamble structure and evaluate the channel estimation performance. The preamble structure can estimate the multi-channel up to the 8 transmit antennas in the case of the HIPERLAN/2 and IEEE802.11a standards using two long preambles. Furthermore, this paper evaluates an achievable diversity of OFDM-CDMA based broadband wireless access networks under multi-user environments. The OFDM-CDMA system with various diversity schemes is simulated especially for equal power two-path Rayleigh fading channel. Using real orthogonal space-time block code in the case of four transmit antennas, a diversity of $D = 4$ and $D = 8$ can be achieved for the multi-user cases with maximum user and half user capacities compared to that of single-user cases, respectively.

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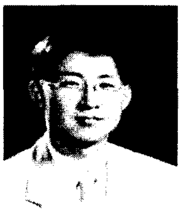

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