논문 2006-43TC-7-14

고속 전송률 UWB 시공간 부호화 OFDM

(High Data Rate Ultra Wideband Space Time Coded OFDM)

이 광 재*, Hsiao-Hwa Chen**, 이 문 호***

(Kwang-Jae Lee, Hsiao-Hwa Chen, and Moon-Ho Lee)

요 약

본 논문에서는 단거리 개인 네트워킹을 위한 고속 전송률 UWB 시공간 부호화 OFDM 시스템을 제시한다. 본 시스템은 UWB 펄스를 토대로 하는 혼성 OFDM 신호와 함께 복소 시공간 부호화 신호를 송신한다. 송신 신호는 적절히 설계된 주파수 집합으로부터 선별된 주파수에 의해 변조된 희소 펄스열이다. 부수적으로 WL(widely linear) 수신 여파기와 시간-주파수 공간 전송은 단순한 병렬 선형 검파기를 이용하여 설계한다. 또한, 전파 시스템에서 깊은 페이딩을 극복하기 위해 시공간 블록 부호와 결합한 빔성형을 간략히 고찰한다.

Abstract

In this paper, we present a candidate high data rate space time coded OFDM system for short range personal networking. The system transmits the complex space time coded signals with a hybrid orthogonal frequency division multiplexing (OFDM) based on ultra wideband (UWB) pulses. The transmitted signals are sparse pulse trains modulated by a frequency selected from a properly designed set of frequencies. Additionally, a widely linear (WL) receive filter and a space time frequency transmission are designed by using two simple parallel linear detectors. To overcome the deeply fade in the propagation system, a beamforming combined with space time block codes also are briefly discussed.

Keywords : UWB, Space Time Codes, OFDM, Space Time Frequency, Widely Linear Filter

I. Introduction

Recently the UWB communication systems have been described in the literature for this application, e.g.[1,2] They offer several potential advantages, such as robustness to multipath interference[1,3], high rate transmission and capacity increasing almost linearly with power. It is demonstrated as an efficient transmission for personal area networking (PAN) and a design of high data rate, short range (10m-20m) communication network for high performance clusters. UWB communication systems use signals with a fractional bandwidth that is larger than 25% of the center frequency, or more than 1.5 GHz[6]. Prior research indicates that the wide bandwidth of such systems makes them more robust to multipath interference[1]. As an overlay system, UWB will necessarily be required to operate in the presence of potentially strong inter symbol interferences (ISI), perhaps multiple interferes and multipath fading. Several works proposed the OFDM and diversity techniques combined with UWB transmitter to achieve very good performance[12,13]. In [14], the

* 정회원, 한려대학교
(Hanlyo University)
** 정회원, 순얏센대학교
(National Sun Yat-Sen University, Taiwan)
*** 정회원, 전북대학교
(Chonbuk National University)
※ This work was supported by The International Cooperation Research Program of the Ministry of Science & Technology, KOTEF and Chonbuk National University.
접수일자: 2005년7월19일, 수정완료일: 2006년7월14일

authors also show that the UWB-OFDM system has the potential capacity in the short range networking. A direct application of the Shannon's channel capacity theorem to an additive white Gaussian noise channel shows that such systems also offer a potentially high data rate transmission capability with capacity increasing almost linearly with power. In the equivalent space time channel, we can write

$$C = W\sum_{i=1}^{r}\log_2(1+\frac{P_{ri}}{\sigma^2}) = W\sum_{i=1}^{r}\log_2(1+\frac{\lambda_i P}{n_T\sigma^2})$$

$$= W\log_2\prod_{i=1}^{r}(1+\frac{\lambda_i P}{n_T\sigma^2}) \qquad (1)$$

where W is the bandwidth of each sub-channel from r channels, $\frac{P}{n_T}$ is the transmit power from each transmit antenna and P_{ri} is the received signal power in the ith sub-channel, it has $P_{ri} = \frac{\lambda_i P}{n_T}$, with singular value $\sqrt{\lambda_i}$ of channel matrix H, and the number of transmit antennas n_T. In (1), it clearly shows that UWB space time systems has huge bandwidth Wto increase the capacity, and that the channel capacity is also related to the value of $P_{ri} = \frac{\lambda_i P}{n_T}$ based on transmit diversity. Therefore, space time codes applied for UWB system were reported in [15, 16], the authors show that they can achieve large capacity and better performance than single antenna UWB system. Different from the previous work, the UWB space time coded OFDM system is considered in this paper[11]. The space time coded OFDM systems were reported to obtain much capacity improvement without additional energy. It is shown as a simple but efficient algorithm to combat fading for wireless high data rate communications[9]. In this paper, we describe a high data rate UWB system based on space time block code (STBC) and OFDM with proper frequency interval selection. The transmitted signals are sparse pulse trains modulated by a frequency selected from a properly designed set of frequencies. The train itself consists of frequency

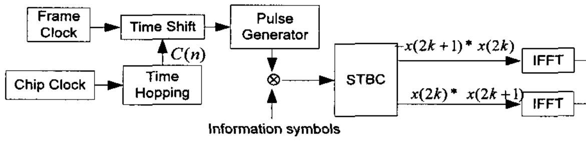


그림 1. UWB 시공간 부호화 OFDM 송신기
Fig. 1. UWB space time coded OFDM transmitter.

modulated ultra wide pulses. Unlike the traditional orthogonal frequency division multiplexing (OFDM) systems, a given tone is transmitted only during parts of the transmission interval. It achieves potential capacity and antennas diversity without additional power increasing. Moreover, different from the conventional space time OFDM designs, a space time frequency scheme is presented to improve the performance on frequency sensitive channels, and the scheme simply groupsseveral space time block codes to different basic frequencies with the widely frequency diversity. In addition, a widely linear filter is exploited to optimize the receiver information from generalized space time symbols in complex domain. In some special cases, the UWB signals are propagated by a deeply fade channel where the orthogonalilty of space time coded OFDM will be destroyed. Therefore, a beamforming combined with STBC are also briefly discussed.

II. Description of UWB Space Time Coded OFDM Transmitter

The UWB OFDM signal is a modulated sparse train $p(t)$ of modulated short pulse $s(t)$ uniformly spaced in time. In particular, we exploit a hybrid ultra wideband (UWB) orthogonal frequency division multiplexing scheme for this application. Assuming the UWB signal is a modulated train $p(t)$ of modulated short rectangular or Gaussian pulses $s(t)$ spaced in time, we have

$$p(t) = \sum_{n=0}^{N_T-1} s(t-nT)e^{-j\frac{2\pi C(n)t}{T_c}} \qquad (2)$$

where T is the repetition period of the pulse train $p(t)$, $c(n)$ is a permutation of integers $\{0,1,\cdots,N_T-1\}$

for time hopping, and $T_c = \frac{T}{N_T}$. In this paper, the Gaussian pulse $s(t)$ is defined by

$$s(t) = \exp(-t^2/T_s^2)/\sqrt[4]{\pi T_s^2} \quad (3)$$

where T_s denotes the pulse period. Next, the UWB BPSK modulated signals are denoted as

$$x(k) = b_k p(t) \quad (4)$$

where b_k is k-th transmitted BPSK symbol chosen from $\{\pm 1\}$. Now the space time coded signals B[4] can be written by

$$B = \begin{bmatrix} x(2k) & x(2k+1) \\ -x(2k+1)^* & x(2k)^* \end{bmatrix} \quad (5)$$

We design the UWB space time coded OFDM system as shown in Fig. 1, and present the orthogonal frequency signals as

$$f_k(t) = b_k p(t) e^{j2\pi k f_0 t} \quad (6)$$

where f_0 is a fundamental frequency that is determined by UWB pulse train $p(t)$. Further, we write the space time coded OFDM signals for two transmit antennas as

Antenna 1:

$$X_1(t) = \sum_{k=0}^{N-1} x(2k) e^{j2\pi k f_0 t},$$

$$X_1(t+T_p) = \sum_{k=1}^{N} -x(2k+1)^* e^{j2\pi k f_0 t}$$

$$t = 0,1,2 \ldots N-1 \quad (7)$$

Antenna 2:

$$X_2(t) = \sum_{k=0}^{N-1} x(2k+1) e^{j2\pi k f_0 t},$$

$$X_2(t+T_p) = \sum_{k=0}^{N-1} x(2k)^* e^{j2\pi k f_0 t}$$

$$t = 0,1,2 \ldots N-1 \quad (8)$$

where the N-point IFFT (Inverse Fast Fourier Transform) is exploited and T_p is the transmission period of OFDM signals. However, the orthogonality of transmission carriers should be considered. It means that we have to select a suitable carrier to substitute the FFT (Fast Fourier Transform) units. Specifically, for the UWB OFDM system, the inner product between $f_{k1}(t-\tau)$ and $f_{k2}(t-\tau)$is approximately equal to the ambiguity function of $p(t)$ from decorrelator of the UWB system[5]. Assuming that the time hopping $c(n)$ is properly selected, we can simplify the receive function X_p as

$$X_p[(k2-k1)f_0],$$

$$= \int_{-\infty}^{\infty} p(t-\tau) p^*(t-\tau) e^{j2\pi(k2-k1)f_0 t} dt$$

$$\approx \frac{\sin(N\pi(k1-k2)f_0 T)}{\sin(\pi(k1-k2)f_0 T)} \times X_s(0,(k2-k1)f_0) \quad (9)$$

where $X_s(\tau, f) = s(t)s^*(t-\tau)e^{j2\pi(k2-k1)f_0 t}$ is the ambiguity function of $s(t)$ which presents the decorrelation results of the Gaussian pulses. Therefore, if $f_0 = \frac{1}{NT}$, then $f_{k1}(t-\tau)$ and $f_{k2}(t-\tau)$will be approximately orthogonal provided that $k1-k2$ is an integer not equal to a multiple of N, or if $k1-k2$ is multiple of N, that either $X_s(0,(k1-k2)f_0) \approx 0$. To select the modulating frequencies kf_0 simply, let $f_0 = p/NT$, for some integers p, we can achieve the orthogonality for all $k1 \neq k2$, in the synchronous UWB space time coded OFDM transmitter.

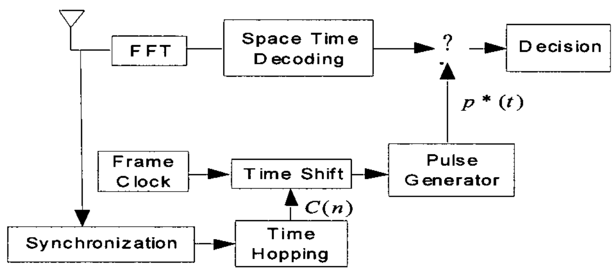


그림 2. UWB 시공간 부호화 OFDM 검파기
Fig. 2. UWB space time coded OFDM Detector.

III. Detector Structure and Performance

In this section we introduce the detector structure and the performance evaluation. First, the structure of UWB space time coded OFDM detector is described as Fig. 2 and the received signals of two transmit antennas are given by

$$r(t)=H_1(t)X_1(t)+H_2(t)X_2(t)+n(t),$$
$$r(t+T_p)=H_1(t+T_p)X_1(t+T_p)+H_2(t+T_p)X_2(t+T_p)+n(t+T_p) \quad (10)$$

where $H_n(t)$ and $n(t)$ are from nth antenna and AWGN respectively. Next, after FFT operation, we have

$$\hat{r}(k)=h_{2k}x(2k)+h_{2k+1}x(2k+1)+n(k)$$
$$\hat{r}_{T_p}(k)=h_{2k}(-x^*(2k+1))+h_{2k+1}(x^*(2k))+n_{T_p}(k) \quad (11)$$

where $\hat{r}(k)$ and $\widehat{r_{T_p}}(k)$ denote the received values corresponding to time t and t+T_p after FFT calculation; n(k), and $n_{T_p}(k)$ are independent zero mean complex Gaussian noise corresponding to $n(t)$ and $n(t+T_p)$ respectively, and h is the channel gain from $H_n(t)$ based on nth transmit antenna. Furthermore, we estimate the UWB transmit signals using space time maximum ratio combing decoding scheme as shown in [4] and [10]

$$\hat{x}(2k)=(|h_{2k}|^2+|h_{2k+1}|^2)x(2k)+N,$$
$$\hat{x}(2k+1)=(|h_{2k}|^2+|h_{2k+1}|^2)x(2k+1)+N' \quad (12)$$

where N and N′ are independent zero mean complex Gaussian noise. The UWB signals are obtained by

$$\hat{b}_{(2k)}=\hat{x}(2k)p^*(t).$$
$$=(|h_{2k}|^2+|h_{2k+1}|^2)b_{2k}p(t)p^*(t)+Np^*(t)$$
$$\hat{b}_{(2k+1)}=\hat{x}(2k+1)p^*(t)$$
$$=(|h_{2k}|^2+|h_{2k+1}|^2)b_{2k+1}p(t)p^*(t)+N'p^*(t) \quad (13)$$

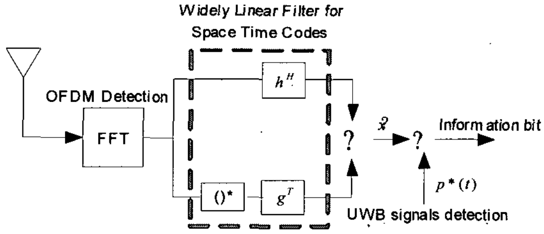


그림 3. UWB 시공간 부호화 OFDM 시스템을 위한 WL 여파기

Fig. 3. The widely linear filter for UWB space time coded OFDM system.

The decision of the UWB BPSK decorrelator in the receiver is

$$Z=\begin{cases}\int_{-\infty}^{-\infty} b_k p(t-\delta)p^*(t)dt>0, \text{if } b_k=+1\\ \int_{-\infty}^{-\infty} b_k p(t-\delta)p^*(t)dt<0, \text{if } b_k=-1\end{cases} \quad (14)$$

However, as mentioned in [7], the traditional linear filter does not remain linear for generalized complex data such as space time UWB symbols. Therefore, the widely linear filter is designed by using two parallel linear filter to estimate x and x* simultaneously. The general scalar detection function can be written as

$$\hat{x}=h^H y+g^T y^* \quad (15)$$

where h^H and g^T are the proposed parallel linear filters with matrix hermitian H and matrix transpose T , y and y* are the received data and its conjugate. In the proposed space time coded OFDM using two transmit antennas, we can write (11) as two parts after FFT operation

$$y=H_1X+H_2X^*+N,$$
$$=\left(\begin{bmatrix}h_{2k} & h_{2k+1}\\ 0 & 0\end{bmatrix}\begin{bmatrix}x(2k)\\ x(2k+1)\end{bmatrix}+\begin{bmatrix}0 & 0\\ h_{2k+1} & -h_{2k}\end{bmatrix}\begin{bmatrix}x^*(2k)\\ x^*(2k+1)\end{bmatrix}\right)+N' \quad (16)$$

where H_1 and H_2 denote the rewritten channel matrices with elements h_{2k} and h_{2k+1}. Clearly, the received data is divided into two parts, one only includes the original symbols, the other has their conjugates. As shown in Fig. 3 the widely linear filter with full diversity is given by

$$\hat{x} = h^H y + g^T y^* = \begin{bmatrix} h_{2k} & h_{2k+1} \\ 0 & 0 \end{bmatrix}^H y + \begin{bmatrix} 0 & 0 \\ h_{2k+1} & -h_{2k} \end{bmatrix}^T y^*$$

$$= \begin{bmatrix} |h_{2k}|^2 & h_{2k} * h_{2k+1} \\ h_{2k+1} * h_{2k} & |h_{2k+1}|^2 \end{bmatrix} \begin{bmatrix} x(2k) \\ x(2k+1) \end{bmatrix}$$

$$+ \begin{bmatrix} |h_{2k+1}|^2 & -h_{2k+1} h_{2k} * \\ -h_{2k} h_{2k+1} * & |h_{2k}|^2 \end{bmatrix} \begin{bmatrix} x(2k) \\ x(2k+1) \end{bmatrix} + N'$$

$$= \begin{bmatrix} |h_{2k}|^2 + |h_{2k+1}|^2 & 0 \\ 0 & |h_{2k}|^2 + |h_{2k+1}|^2 \end{bmatrix} \begin{bmatrix} x(2k) \\ x(2k+1) \end{bmatrix} + N' \quad (17)$$

To generalize the performance of UWB space time coded system which uses the full diversity and widely linear filter, we sample the received signals $y(t)$ at $t = iT_c/N$ for $i = 0, \ldots, L-1$, if the multipath is known and the receiver are synchronized, we have

$$y_i = y(iT_c/N)$$

$$= 2\sqrt{\frac{E_b}{N}} \sum_{l=0}^{(L-1)/2} \sum_{k=1}^{K} (|h_{2l}|^2 + |h_{2l+1}|^2)$$

$$\cdot b_k^0 X_p(\frac{(i-l)T_c}{N}, (m-k)f_0) + n_i \quad (18)$$

conditioned on the diversity gain $|h_{2k}|^2 + |h_{2k+1}|^2$, the bit error rate (BER) of the optimal BPSK UWB space time coded OFDM receiver corresponding to (18) is equal to:

$$Pe = Q\left(\sqrt{\frac{N_T E_b}{E_b \gamma + No}} \left\| (|h_{2k}|^2 + |h_{2k+1}|^2) \right\| \right) \quad (19)$$

since the received SNR is given by

$$SNR_{received} = \frac{\sum_{i=0}^{N_T-1} (|h_{2k}|^2 + |h_{2k+1}|^2) \|X_p\|^2}{\|X_{\text{interference}}\|^2 + No},$$

$$= \frac{N_T \left\| |h_{2k}|^2 + |h_{2k+1}|^2 \right\| \left\| \sqrt{E_b} \right|^2}{\left| \sqrt{E_{iterference}} \right|^2 + No}$$

$$= \frac{N_T E_b}{E_b \gamma + No} \left\| (|h_{2k}|^2 + |h_{2k+1}|^2) \right\|$$

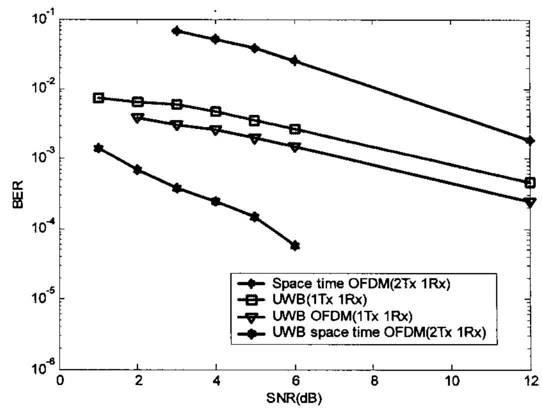


그림 4. UWB BPSK 시공간 부호화 OFDM의 성능
Fig. 4. Performances of UWB BPSK space time coded OFDM ($N_T = 4$, 4-point IFFT).

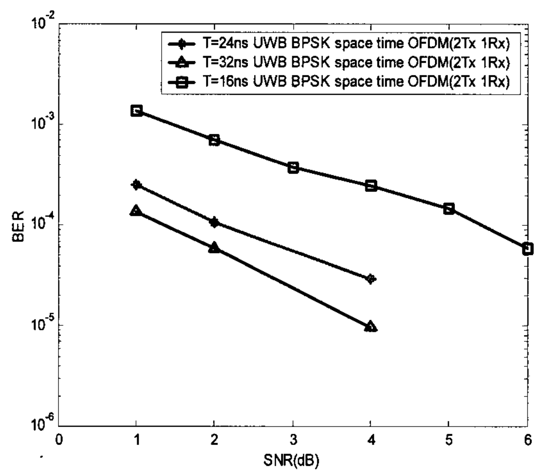


그림 5. 서로 다른 Gaussian 펄스 수의 UWB 트레인
Fig. 5. The UWB trains with different number of Gaussian pulses (BPSK modulation, 4-point IFFT).

where N_T is the number of the pulses in one UWB train, $X_{interference}$ are interference symbols and their energy is defined by $|X_{\text{interference}}|^2 = E_{\text{interference}} = E_b \gamma$, γ denotes the gain from correlations of $s(t)$ in UWB space time coded OFDM system, E_b and N_0 present the bit energy and noise power density respectively.

Simulations

In this paper the simulations are in 4-IFFT (N-IFFT) OFDM system; the Gaussian pulse has $T_s = 2ns$ the time hopping period $T_c = 4ns$ time hopping parameter $N_T = 4$, the period of UWB train $T = N_T T_c$ $f_0 = 1/NT = 1/4T$ BPSK modulation; Rayleigh fading channel; Alamouti space time block codes; and coherent decoding. As shown in Fig. 4, the numerical results demonstrate that the UWB space time coded OFDM system improve about 6dB in the simulation environment, and almost maximum diversity may be achieved under perfect synchronization. Otherwise, as shown in Fig. 4, the UWB has better performance than space time OFDM on fading channel, and the space time processing may help it to get the potential capacity and diversity without additional power increasing. Moreover, as shown in Fig. 5, following the increase of the number of the pulses in one UWB train, the performances also can be enhanced. In the Fig. 5, T=24ns, T=32ns, and T=16ns are corresponding to the number of Gaussian pulses $N_T = 6$, $N_T = 8$ and $N_T = 4$, respectively.

In addition, the space time coded OFDM (ST-OFDM) has robustness in the case of large time delay with the constant path gains, however, it is difficult to improve the performance in the case of frequency offset and Doppler attenuation[8]. Therefore, we describe a simple space time frequency coded OFDM (STF-OFDM) to combat the frequency sensitivity. As shown in Fig. 6, the STF-OFDM is a class of three dimension scheme which may assign the different two dimension orthogonal blocks to different frequencies. It exploits the frequency sources to transmit the space time orthogonal block codes, and each two orthogonal blocks can use two different frequencies. Therefore, the orthogonality from the space time codes is remained and the interference of adjacent blocks is reduced by the frequency diversity. In thispaper, we propose a space time frequency coding scheme with two different frequencies for UWB-OFDM transmission, as shown in Fig. 7. Instead of the traditional UWB space time coded OFDM system (7)-(8), the mapping rule of the proposed scheme is denoted by

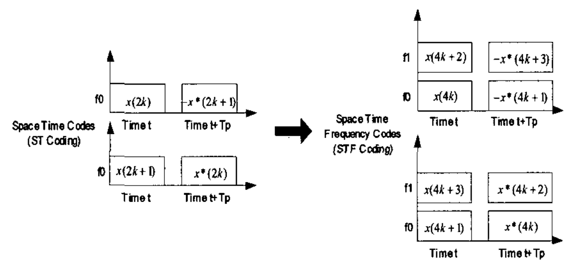


그림 6. ST 및 STF 구성의 부호화 기법

Fig. 6. Coding schemes of ST and STF constructions.

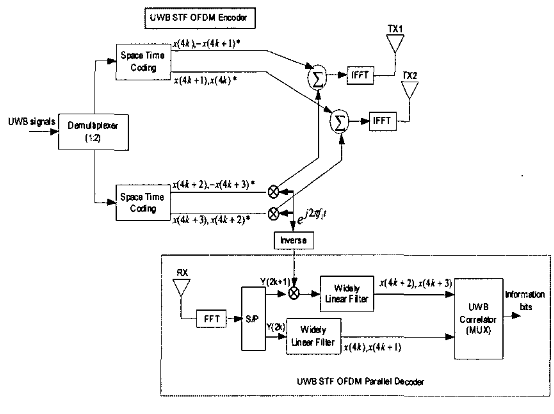


그림 7. UWB STF OFDM 부호화 구조

Fig. 7. UWB STF OFDM coding structure.

Antenna 1:

$$X_1(t) = \sum_{k=0}^{N/2-1}[x(4k)]e^{j2\pi(2k)f_0 t}$$

$$+ \sum_{k=0}^{N/2-1}[x(4k+2)e^{j2\pi f_1 t}]e^{j2\pi(2k+1)f_0 t}$$

$$= \sum_{k=0}^{N/2-1}[x(4k)]e^{j2\pi(2k)f_0 t}$$

$$+ e^{j2\pi f_1 t}e^{j2\pi f_0 t}\sum_{k=0}^{N/2-1}[x(4k+2)]e^{j2\pi(2k)f_0 t}$$

$$= \sum_{k=0}^{N/2-1}[x(4k)]e^{j4\pi k f_0 t},$$

$$+ e^{j2\pi f_1 t}e^{j2\pi f_0 t}\sum_{k=0}^{N/2-1}[x(4k+2)]e^{j4\pi k f_0 t}$$

$$X_1(t+T_p) = \sum_{k=0}^{N/2-1}[-x(4k+1)^*]e^{j2\pi(2k)f_0 t}$$

$$+\sum_{k=0}^{N/2-1}[-x(4k+3)*e^{j2\pi f_1 t}]e^{j2\pi(2k+1)f_0 t}$$

$$=\sum_{k=0}^{N/2-1}[-x(4k+1)*]e^{j4\pi k f_0 t}$$

$$+e^{j2\pi f_1 t}e^{j2\pi f_0 t}\sum_{k=0}^{N/2-1}[-x(4k+3)*]e^{j4\pi k f_0 t},$$

$$t=0,1,2...N-1 \tag{20}$$

Antenna 2:

$$X_2(t)=\sum_{k=0}^{N/2-1}[x(4k+1)]e^{j2\pi(2k)f_0 t}$$

$$+\sum_{k=0}^{N/2-1}[x(4k+3)e^{j2\pi f_1 t}]e^{j2\pi(2k+1)f_0 t}$$

$$=\sum_{k=0}^{N/2-1}[x(4k+1)]e^{j4\pi k f_0 t}$$

$$+e^{j2\pi f_1 t}e^{j2\pi f_0 t}\sum_{k=0}^{N/2-1}[x(4k+3)]e^{j4\pi k f_0 t}$$

$$X_2(t+T_p)=\sum_{k=0}^{N/2-1}[x(4k)*]e^{j2\pi(2k)f_0 t}$$

$$+\sum_{k=0}^{N/2-1}[x(4k+2)*e^{j2\pi f_1 t}]e^{j2\pi(2k+1)f_0 t}$$

$$=\sum_{k=0}^{N/2-1}[x(4k)*]e^{j4\pi k f_0 t}$$

$$+e^{j2\pi f_1 t}e^{j2\pi f_0 t}\sum_{k=0}^{N/2-1}[x(4k+2)*]e^{j4\pi k f_0 t}$$

$$t=0,1,2...N-1 \tag{21}$$

The (20) and (21) can be seen as two N/2 FFT to construct N FFT, and each part supports one kind of orthogonal space time block. Therefore, the complexity of the computations for FFT in STF-OFDM will be reduced from the conventional ST-OFDM. If the $e^{j2\pi f_1 t}=1$, the above equations are the Decimation-in-Time (DIF) Fast Fourier Transform. However, it can not have the frequency diversity in the proposed STF-OFDM. Normally we set f_1 is not 0, and $f_1 \neq f_0$. After the FFT operation,the decoding of the UWB-STF OFDM system should be divided into two groups. One is the first orthogonal space time block, the other is next block. To design an efficient architecture, we now present a parallel decoding structure by using these two groups which is shown in Fig. 7. In this paper, the STF OFDM scheme uses two frequencies to transmit two groups of space time block codes. After the FFT operations, the output results will be two groups which are written by

$$Y(2k)=h_{4k}x(4k)+h_{4k+1}x(4k+1)+n(k)$$

$$Y'(2k)=h_{4k}(-x*(4k+1))+h_{4k+1}(x*(4k))+n'(k)$$

$$Y(2k+1)=[h_{4k+2}x(4k+2)$$

$$+h_{4k+3}x(4k+3)+n(k)]e^{j2\pi f_1 t}$$

$$Y'(2k+1)=[h_{4k+2}(-x*(4k+3))$$

$$+h_{4k+3}(x*(4k+2))+n'(k+1)]e^{j2\pi f_1 t}$$

$$k=0,1,2...,\frac{N}{2}-1 \tag{22}$$

By computing the inverse of the frequency, we can easily use two parallel decoders as introduced above

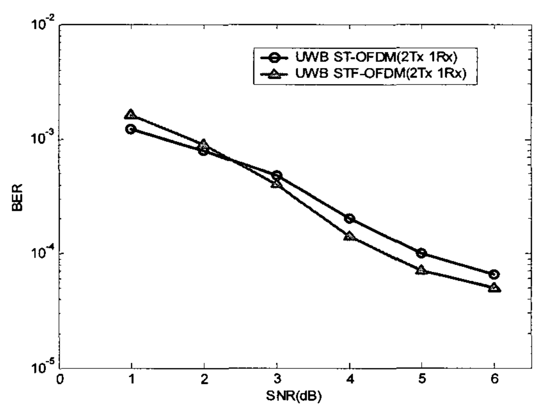


그림 8. UWB BPSK STF OFDM 시스템의 성능
Fig. 8. Performance of UWB BPSK STF OFDM system ($N_T=4$ 4-IFFT OFDM $f_0=1/4T$ and $f_1=3/4T$).

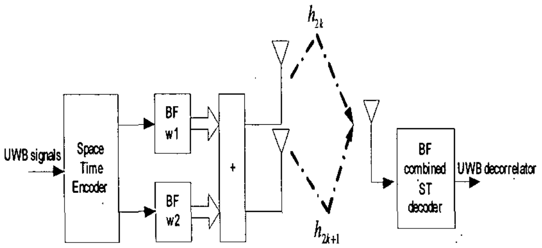


그림 9. 시공간 블록 부호와 결합된 UWB 빔성형 블록도

Fig. 9. Block diagram of UWB beamforming combined with space time block codes.

to estimate the UWB signals. Generally, the n groups can be assigned for STF-OFDM system, which is conditioned on n<(N-1)/2. In this paper, two groups are considered, and for each group the frequency $f_0 \neq f_1$. Since the basic frequency $f_0 = p/NT$ for proper UWB signals, the f_1 should have $f_1 = p'/NT$, with $p \neq p' \geq 2p$. As shown in Fig. 8, the numerical result demonstrates that UWB STF OFDM has robust performance to combat the frequency attenuation in UWB system. We obtain about 0.7dB improvement from UWB ST OFDM when the delay sample is smaller.

IV. Combined Beamforming with Space Time Coding for UWB System

In UWB system, the fading environment sometimes will be into deeply fade, and the orthogonallity of the space time codes will be destroyed[17]. To combat this situation, in this section, we combine beamforming with space time coding for UWB system. Beamforming technology can provide beamforming gain to increase SNR of the downlink channel. The beamforming antenna needs to achieve spatial directivity and the signals transmitted from all antennas must be correlated or coherent. Therefore, the antenna spacing should be very small, e.g. half wavelength for uniform linear array (ULA). Because of this contradictive requirement for antenna spacing of diversity systems and beamforming systems, there is a prejudice that diversity gain and beamforming gain can not be achieved simultaneously. In order toimprove the performance of the system over deeply fade channel, we propose a combined beamforming with STBC[18]. Assuming the above space time coded UWB signals $x(2k)$, and $x(2k+1)$ are passed into two transmit beamformers w1 and w2 respectively, followed by a signal combiner which performs a simple summing function of two inputs to produce a vector signal $V(n)$ for transmission, as shown in Fig. 9. i.e.

$$
\begin{aligned}
V(n) &= w1^H x(2k) + w2^H x(2k+1), \\
V(n+1) &= w1^H(-x(2k+1)^*) + w2^H x(2k)^*
\end{aligned}
\tag{23}
$$

The received signals can be denoted by

$$
\begin{aligned}
r(n) &= h_{2k}(w1^H x(2k) + w2^H(2k+1)) \\
&+ h_{2k+1}(w1^H x(2k) + w2^H x(2k+1)) + n(k) \\
r(n+1) &= h_{2k}(w1^H(-x(2k+1)^*) + w2^H x(2k)^*)) \\
&+ h_{2k+1}(w1^H(-x(2k+1)^*) + w2^H x(2k)^*)) + n(k+1)
\end{aligned}
$$

Based on the decoding of the space time codes, easily we can write the estimated signals as

$$
\begin{aligned}
& w1 \times h_{2k}{}^* r(n) + (w2)^* \times h_{2k+1} r(n+1)^*, \\
&= w1(w1^H |h_{2k}|^2 x(2k) + w2^H |h_{2k}|^2 x(2k+1))) \\
&+ h_{2k}{}^* h_{2k+1}(w1 \cdot w1^H x(2k) + w1 \cdot w2^H x(2k+1)) \\
&+ w1 \cdot h_{2k}{}^* n(k) - h_{2k+1} h_{2k}{}^* (w2 \cdot w1^H)^* x(2k+1) \\
&+ h_{2k+1} h_{2k}{}^* (w2 \cdot w2^H)^* x(2k) \\
&- |h_{2k+1}|^2 (w2 \cdot w1^H)^* x(2k+1) \\
&+ |h_{2k+1}|^2 (w2 \cdot w2^H)^* x(2k) + (n(k+1) \cdot w2)^* h_{2k+1} \\
&= (|w1|^2 |h_{2k}|^2 + |w2|^2 |h_{2k+1}|^2) x(2k) \\
&+ w1 \cdot h_{2k}{}^* n(k) + (n(k+1) \cdot w2)^* h_{2k+1} \\
&+ (|w1|^2 + |w2|^2) x(2k) h_{2k}{}^* h_{2k+1} \\
&+ w1 \cdot w2^H |h_{2k}|^2 x(2k+1) + w1 \cdot w2^H x(2k+1) h_{2k}{}^* h_{2k+1}
\end{aligned}
$$

$$-|h_{2k+1}|^2(w2\cdot w1^H)*x(2k+1)$$
$$-h_{2k+1}h_{2k}*(w2\cdot w1^H)*x(2k+1) \quad (24)$$

and

$$w2\times h_{2k}*r(n)-(w1)*\times h_{2k+1}r(n+1)*,$$
$$=w2(w1^H|h_{2k}|^2x(2k)+w2^H|h_{2k}|^2x(2k+1))$$
$$+h_{2k}*h_{2k+1}(w2\cdot w1^Hx(2k)+w2\cdot w2^Hx(2k+1))$$
$$+w2\cdot h_{2k}*n(k)+h_{2k+1}h_{2k}*(w1\cdot w1^H)*x(2k+1)$$
$$-h_{2k+1}h_{2k}*(w1\cdot w2^H)*x(2k)$$
$$+|h_{2k+1}|^2(w1\cdot w1^H)*x(2k+1)$$
$$-|h_{2k+1}|^2(w1\cdot w2^H)*x(2k)+(n(k+1)\cdot w1)*h_{2k+1}$$
$$=(|w2|^2|h_{2k}|^2+|w1|^2|h_{2k+1}|^2)x(2k+1)$$
$$+w2\cdot h_{2k}*n(k)+(n(k+1)\cdot w1)*h_{2k+1}$$
$$+(|w1|^2+|w2|^2)x(2k+1)h_{2k}*h_{2k+1}$$
$$+w2\cdot w1^H|h_{2k}|^2x(2k)+w2\cdot w1^Hx(2k)h_{2k}*h_{2k+1}$$
$$-|h_{2k+1}|^2(w1\cdot w2^H)*x(2k)$$
$$-h_{2k+1}h_{2k}*(w1\cdot w2^H)*x(2k) \quad (25)$$

where the beamforming gain combined with transmit diversity are denoted as $(|w1|^2|h_{2k}|^2+|w2|^2|h_{2k+1}|^2)x(2k)$ and $(|w2|^2|h_{2k}|^2+|w1|^2|h_{2k+1}|^2)x(2k+1)$. In (24) and (25), obviously the interference parts are very complex. To optimize the beamforming factors, the interference parts should be a Gaussian like. That is to say the expectation function

$$E(w1\cdot w2^H)=E(w1\cdot w2^H)=0$$

specially,

$$|w1|^2+|w2|^2=(w1\cdot w1^H)+(w2\cdot w2^H)=1$$

In this paper we set $w1\cdot w1^H=w2\cdot w2^H=1/2$, and the angular spread is 10^0. As shown in Fig. 10,

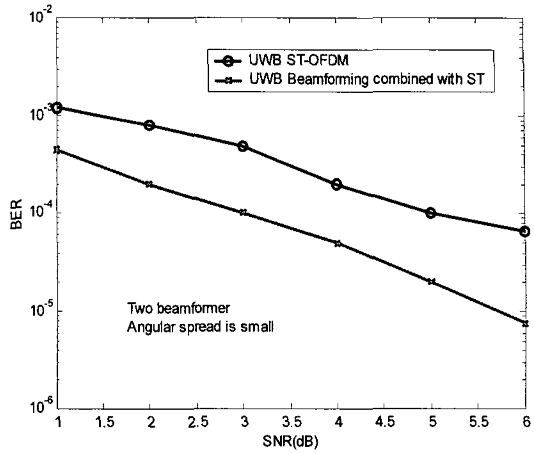


그림 10. 시공간 시스템과 결합된 UWB BPSK 빔성형
Fig. 10. UWB BPSK beamforming combined with space time system ($N_T=4$; 4-IFFT OFDM; $f_0=1/4T$, angular spread is 10^0).

the proposed scheme is 4 to 5 dB better than space time coded OFDM system in small angular spread.

V. Conclusions

Generally, by exploiting the UWB space time coded OFDM system, the maximum diversity gain and much performance enhancement are achieved, when the synchronization is perfectly in the receiver. In this paper, we investigate the OFDM and space time coding designs for proper UWB signals, and detailed present two systems for UWB transmission, one is UWB ST OFDM, and the other is UWB STF OFDM. Particularly, the UWB STF OFDM system has 0.7 dB over UWB ST OFDM system when the sample delay is small. Additionally, to properly detect the complex data from linear filter for space time decoder, a simple widely linear filter is studied. It has been applied for all simulation programs and shows a good result with full transmit diversity. Otherwise, for deeply fade channel, a combined beamforming with space time coding scheme are investigated. The superiority of the proposed scheme is confirmed by numerical simulation results.

참 고 문 헌

[1] M. Z .Win and R. A. Scholts, "Ultra-Wide Bandwidth Time-Hopping Spread-Spectrum Impulse Radio for Wireless Multiple-Access Communications," IEEE Trans. On Comm., vol.48, no.4, 2000, pp.679-689.

[2] M. Z. Win and R. A. Scholts, "Impulse Radio: How It Works," IEEE Comm. Letters, vol.2, no.2, 1998, pp.36-38.

[3] F. R. Mireles, "On The Performance of Ultra Wideband Signals in Gaussian Noise and Dense Multipath," IEEE Trans. On Vehicular Technology, vol.50, no.1, 2001, pp.244-249.

[4] S. M. Alamouti, "A Simple Transmitter Diversity Scheme for Wireless Communications," IEEE J. Select. Areas Comm., vol.16, no.10, 1998, pp.1451-1458.

[5] H. L. Van Trees, Detection, Estimation and Modulation Theory, John Wiley and Sons, New York, 1991.

[6] FCC Notice of proposed rule making, "Revision of part 15 of the commission's rules regarding ultra wideband transmission systems," ET-Docket98-153.

[7] B. Picinbono and P. Chevalier, "Widely linear estimation with complex data," IEEE Trans. on Signal Processing, vol.43, no.8, August 1995, pp.2030-2033.

[8] Z. Liu, Y. Xin, and G.B. Giannakis, "Space time frequency coded OFDM over frequency selective fading channels," IEEE Trans. on Signal Processing, vol.50, no.10, October 2002, pp.2465-2467.

[9] D. Agrawal, V. Tarokh, A. Naguib, and N. Seshadri, "Space time coded OFDM high data rate wireless communication over wideband channels," in Proc. Veh. Technol. Conf., Ottawa, ON, Canada, May 18-21, 1998, pp.2232-2236.

[10] Jia Hou, Moon Ho Lee, and Ju Yong Park, "Matrices analysis of quasi orthogonal space time block codes," IEEE Communications Letters, vol.7, no.8, August 2003, pp.385-387.

[11] Jia Hou, and Moon Ho Lee, "High rate ultra wideband space time coded OFDM," in Proc. IEEE VTC Fall 2003, Orlando, Florida, USA, October 6-9, 2003, pp.3042-3045.

[12] Qinhua Li, and L. A. Rusch, "Multiuser detection for DS-CDMA UWB in the home environment," IEEE Journal on Selected Areas in Communications, vol.20, no.9, 2002, pp.1701-1711.

[13] D. Gerakoulis, and P. Salmi, "An interference suppressing OFDM system for ultra wideband width channels," in Proc. of 2002 IEEE conference on Ultra Wideband systems and technologies, 21-13 May, 2002, pp.259-264.

[14] R. Gupta, and A. H. Tewfik, "Capacity of ultra-wideband OFDM," in Proc. of the 57th IEEE vehicular technology conference, VTC2003-spring, vol.2, 22-25 April, 2003, pp.1420-1424.

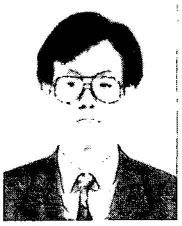
[15] N. A. Kumar, and R. M. Bueherer, "Application of layered space time processing to ultra wideband communication," in Proc. of the 2002 45th Midwest Symposium on Circuits and Systems, MWSCAS-002, Vol.3, 4-7 Aug. 2002, pp.597-600.

[16] Liuqing Yang, and G.B. Giannakis, "space time coding for impulse radio," in Proc. of the 2002 IEEE Conference on Ultra wideband Systems and Technologies, 2002, 21-23 May 2002, pp.235-239. The full paper will be appeared in 2004, IEEE Trans. on Communications.

[17] M. G. M. Hussain, "Principles of space time array processing for ultra wideband impulse radar and radio communications," IEEE Trans. on Vehicular Technology, vol.51, no.3, May 2002, pp.393-403.

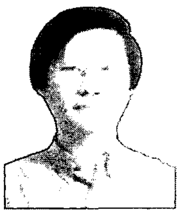
[18] Shengli Zhou, and G. B. Giannakis, "Optimal transmitter eigen-beamforming and space time block coding based on channel correlations," IEEE Trans. on Information Theory, vol.49, no.7, July 2003, pp.1673-1690.

저 자 소 개



이 광 재(정회원)

- He received the B.S. and M.S. degrees in electronic engineering from Chonbuk National University in 1986, 1990 respectively.
- He is currently a full time lecturer in Hanlyo University.
- His research interests include the areas of mobile communications, UWB, and channel coding.



Hsiao-Hwa Chen(정회원)

- He is currently a Full Professor in National Sun Yat-Sen University, Taiwan.
- He has authored or coauthored over 150 technical papers in major international journals and conferences, and four books, and three book chapters in the areas of communications. He served as a TPC Member and Symposium Chair of major international conferences, including IEEE VTC, IEEE ICC, IEEE Globecom, IEEE WCNC, and so forth.
- He served or is serving as an Editorial Broad Member or/and Guest Editor for IEEE Communications Magazine, IEEE Transactions on Wireless Communications, IEEE Vehicular Technology Magazine, Wireless Communications and Mobile Computing (WCMC) Journal and International Journal of Communication Systems, and so forth.
- He has been a Guest Professor of Zhejiang University, Shanghai Jiao Tung University, China.

이 문 호(정회원)

- He received the B.S. and M.S. degree both in Electrical Engineering from the Chonbuk National University, Korea, in 1967 and 1976, respectively, and the Ph.D degree in electronics engineering from the Chonnam National University in 1984 and the University of Tokyo, Japan, in 1990.
- From 1970 to 1980, he was a chief engineer with Namyang Moonhwa Broadcasting. Since 1980, he has been a professor with the Department of Information and Communication and a Director with the Institute of Information and Communication, both at Chonbuk National University. His research interests include the multidimensional source and channel coding, mobile communication, and image processing.