Int. J. Communications, Network and System Sciences, **2009, 7, 664-668**
doi:10.4236/ijcns.2009.27076 Published Online October 2009 (http://www.SciRP.org/journal/ijcns/).

Space-Time-Frequency Coded for Multiband-OFDM Based on IEEE 802.15.3a WPAN

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Received September 9, 2008; *revised February* 23, 2009; *accepted April* 15, 2009

ABSTRACT

In this paper, Multiband-OFDM UWB system based on IEEE 802.15.3a standard is studied and simulated with spatial, time and frequency (STF)coding scheme. The using of STF coding method can guarantee both full symbol rate and full diversity advantages. The simulation results show that the STF code uses multi-path-rich and random-clustering characteristics of UWB channel environment on the performance of MB-OFDM system.

Keywords: IEEE 802.15.3a, UWB, MB-OFDM, MIMO, Space-Time-Frequency Coding

1. Introduction

Ultra wideband (UWB) systems are the first nomination for future wireless personal area networks (WPANs). The enormous band with availability provides the potential for very high data rates. The ultra wide bandwidth of UWB enables various WPAN applications such as high-speed wireless universal serial bus (WUSB) connectivity for personal computers and their accessories, high-quality real-time video and audio transmission, and cable replacement for home entertainment systems.

Currently, the multi-band orthogonal frequency division multiplexing (MB-OFDM) [1] is an important candidate for the physical layer within IEEE 802.15.3a standard.

On the other hand, the rich scattering multipath channel in UWB indoor environment provides an ideal transmission scenario for multiple antenna configurations. In this paper, we use a space-time-frequency coding (STFC) method [2] that can guarantee both full symbol rate and full diversity for performance improvement of MB-OFDM UWB systems over CM 1-CM 4 environment with 2ISO and 2I2O MIMO configurations.

The paper is organized as follows: In Section 2, an overview of STFC MB-OFDM UWB system is given. Section 3 gives the simulation results, and finally Section 4 concludes the paper.

2. STFC MB-OFDM UWB System

2.1. UWB Channel Model

The channel model is based on Saleh-Valenzuela model [3] according to IEEE 802.15.3a standard. The channel impulse response can be expressed as

$$h_i(t) = X_i \sum_{l=0}^{L_c-1} \sum_{k=0}^{K_c-1} \alpha_{k,l}^i \delta\left(t - T_l^i - \tau_{k,l}^i\right) \quad \textbf{(1)}$$

where i represents the realization of the i-th impulse response, $\alpha_{k,l}^i$ is the multipath gain coefficients, T_l^i is the delay of the l-th cluster, $\tau_{k,l}^i$ is the delay of k-th ray, and X_i represents the log-normal shadowing. The cluster arrivals and the path arrivals within each cluster are modeled by Poisson processes

$$\begin{aligned} p\left(T_l \mid T_{l-1}\right) &= \Lambda \exp\left[-\Lambda\left(T_l - T_{l-1}\right)\right], \quad l > 0 \\ p\left(\tau_{k,l} \mid \tau_{(k-1),l}\right) &= \lambda \exp\left[-\lambda\left(\tau_{k,l} - \tau_{(k-1),l}\right)\right], \quad k > 0 \end{aligned} \quad \textbf{(2)}$$

where Λ and λ (where λ >Λ) are the cluster arrival rate and ray arrival rate, respectively. Four set of channel model (CM) parameters for different measurement environments were defined, namely CM 1, CM 2, CM 3, and CM 4. Table 1 provides the model parameters of CM 1-CM 4 [4].

2.2. STFC MB-OFDM Structure

We consider a UWB multiband OFDM system with fast band-hopping rate that signal is transmitted on a frequency-band during one OFDM symbol interval, and then

Table 1. The IEEE UWB channel parameters.

Parameters	CM 1	CM 2	CM 3	CM 4
Condition	LOS 0-4m	NLOS 0-4m	NLOS 4-10m	NLOS 4-10m
Λ (1/nsec)	0.0233	0.4	0.0667	0.0667
λ (1/nsec)	2.5	0.5	2.1	2.1
cluster decay factor	7.1	5.5	14	24
ray decay factor	4.3	6.7	7.9	12
N_{path} (10 dB)	12.5	15.3	24.9	41.2
N_{path} (85%)	20.8	33.9	64.7	123.3

moved to a different frequency-band at the next interval. In Table 2 you can see the simulation parameters of MB-OFDM UWB system. The data is encoded by STF code words across M_t transmit antennas, N OFDM subcarriers, and K OFDM blocks. We suppose a frequency-selective fading channels based on S-V model, between any pair of transmit and receive antennas. Figure 1 represents the structure of system. Because of small wavelength in UWB environment and fast frequency hopping, consideration of independency between MIMO channel elements is reasonable. In this case, according to [2,5] the maximum achievable diversity is at most min $\{ M_tM_r, rank(R_T), KNM_r\}$, where L is the number of delay path and R_T is the temporal correlation matrix.

We use repetition coded STF code [2] that is a full diversity code as follows:

$$D_{STF} = \mathbf{1}_{K\times 1} \otimes D_{SF} \tag{3}$$

where $1_{K\times 1}$ is an all one matrix, $\otimes$ is tensor product, and D_{SF} is a full diversity SF code of size $N\times M_t$ which have been proposed in [6]. At the transmitter, the information is jointly encoded across M_t transmit antennas, M OFDM subcarriers, and K OFDM blocks. Each STF codeword is a $KN\times M_t$ matrix that can be expressed as a

$$\boldsymbol{D}_k = \begin{bmatrix} \boldsymbol{G}_{k,1}^T & \boldsymbol{G}_{k,2}^T & \dots & \boldsymbol{G}_{k,P}^T & \mathbf{0}_{(N-P\Upsilon M_t)\times M_t}^T \end{bmatrix} \tag{4}$$

where $P = \left\lfloor N / \Upsilon M_t \right\rfloor$ and Υ is an integer smaller than N, which determines the number of jointly encoded subcarriers. Also

$$\boldsymbol{G}_{k,P} = \left(\boldsymbol{I}_{KM_t} \otimes 1_{\Upsilon\times 1} \right) \begin{pmatrix} x_{p,1} & x_{p,2} \\ -x_{p,2}^* & x_{p,1}^* \end{pmatrix} \tag{5}$$

where $x_{p,k}s$ are selected from QPSK or BPSK constellations. As mentioned earlier, we use repetition STFC which is based on Alamouti's structure. After STFC encoder, we add some preambles and headers for channel estimation and frame and packet synchronization. The baseband OFDM signal to be transmitted by i-th transmit antenna at the k-th OFDM block can be expressed as [7]

$$x_i^k(t) = \sqrt{\frac{E}{M_t}} \sum_{n=0}^{N-1} d_i^k(n) \exp\left\{ \left(j2\pi n\Delta f \right) \left(t - T_{CP} \right) \right\} \tag{6}$$

where $d_i^k(n)$ represents the complex symbol to be transmitted over n-th subcarrier by i-th transmit antenna during the k-th OFDM symbol period. Finally, after filtering, up conversion and band hopping, the trans-mitted signal over i-th antenna is

$$s_i(t) = \sum_{k=0}^{K-1} \mathrm{Re}\left\{ x_i^k(t - kT_{SYM}) \exp(j2\pi f_c^k t) \right\} \tag{7}$$

In the receiver, after frequency dehopping, down converting and filtering, we have received signal at in matrix form as [2]

$$\boldsymbol{Y} = \sqrt{\frac{E}{M_t}} \boldsymbol{DH} + \boldsymbol{Z} \tag{8}$$

where $\boldsymbol{D}$ is the STF coded data, $\boldsymbol{H}$ is the MIMO channel matrix, and $\boldsymbol{Z}$ is complex baseband noise. Because of channel estimation pilots, we can determine $\boldsymbol{H}$, so we have

$$\boldsymbol{W} \times \boldsymbol{Y} = \sqrt{\frac{E}{M_t}} \boldsymbol{WDH} + \boldsymbol{WZ} = \sqrt{\frac{E}{M_t}} \boldsymbol{D} + \boldsymbol{WZ} \tag{9}$$

where $\boldsymbol{W} = \left(\boldsymbol{H}^H \boldsymbol{H} \right)^{-1} \boldsymbol{H}^H$. The receiver exploits a maximum likelihood detector over received signal matrix.

$$\hat{\boldsymbol{D}} = arg\ min \left\{ \left\| \boldsymbol{Y} - \sqrt{\frac{E}{M_t}} \boldsymbol{DH} \right\|^2 \right\} \tag{10}$$

Therefore, the error probability will be as

$$P_e \,|_{\boldsymbol{H}} = Q\left(\sqrt{\frac{\rho}{2M_t} \sum_{j=1}^{M_r} \left\| \left(\mathrm{D} - \hat{\mathrm{D}} \right) \boldsymbol{H} \right\|^2} \right) \tag{11}$$

Table 2. The MB-OFDM UWB parameters.

Information rate	200 Mbps
Number of Subcarriers	128
Channel coding	5/8 rate convolutional
Constellation	QPSK/BPSK
Data tones	100
T_{FFT}	242.4 nsec
T_{CP}	60.6 nsec
T_{GI}	9.5 nsec
T_{SYM}	312.5 nsec
Decoder	Hard viterbi

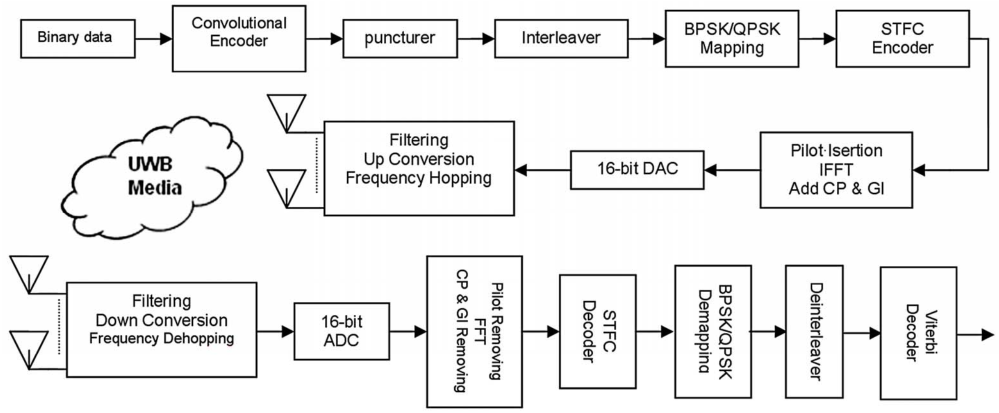

Figure 1. STFC MB-OFDM UWB system.

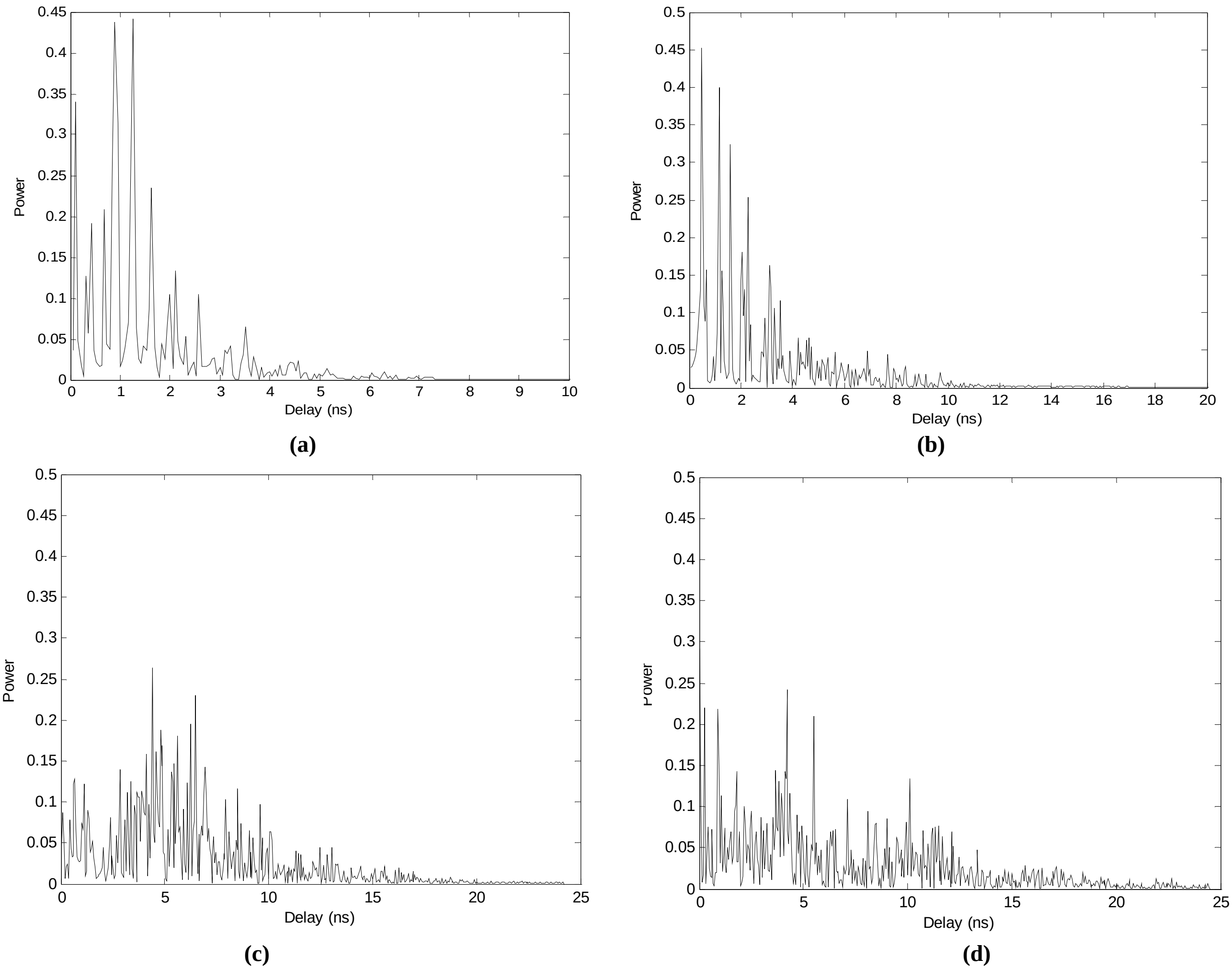

Figure 2. Simulated channel response; a) CM 1, b) CM 2, c) CM 3, d) CM 4.

3. Simulation Results

We performed simulations for a multiband UWB system with N = 128 subcarriers and the subband bandwidth of 528 MHz. Each OFDM symbol was of duration 242.42 *n*s. After adding the cyclic prefix of length 60.61 ns and the guard interval of length 9.47 ns, the symbol duration became 312.5 ns. Figure 2 gives the simulated channel impulse responses for CM 1-CM 4. We used a repetition STFC based on Alamouti's structure that can guarantee full diversity [2]. Also we used 5/8-rate convolutional coding for improving performance. So our pure data rate was 200 Mbps. We first simulated UWB channel based on IEEE 802.15.3a standard. CM 2 is 0-4 m, non line of sight channel, so it is reasonable to consider CM 2 for realistic application. Figure 3 gives the BER performance of MB-OFDM UWB as a function of SNR for CM 2 channel model, as frame length is 4200 QPSK symbols. In each frame, 600 symbols were preamble pilot for channel estimation. 100 channel realizations of IEEE 802.15.3a channel model (CM 1, 2, 3 and 4) were considered for the transmission of each symbol.

Figure 4 gives the BER performance of STFC coded MB-OFDM UWB as a function of SNR for CM 2 channel model without channel coding with the data jointly encoded across two subcarriers. The simulation results show that for CM 2 scenario, when K=1 the 2ISO and 2I2O configurations are almost 8.5dB and 16 dB better than MB-OFDM, respectively. For K=2, the 2ISO and 2I2O configurations are almost 11.5dB and 17.5 dB better than MB-OFDM, respectively.

Figure 5 gives the BER performance of STFC coded MB-OFDM UWB as a function of SNR for CM 2 and CM 4 for 2ISO and 2I2O configurations with the data jointly encoded across two subcarriers, when K=1. In conventional MB-OFDM, performance for CM 4 is worse than other scenarios, but it can be seen that the simulated performance for CM 4 is better than CM 2, when repetition STFC is employed. In coded system under CM 4 the coding gain is larger. It seems that space time frequency coding yields the MB-OFDM system can gain the multipath clustering property of UWB environments. In fact, when repetition STFC is employed, in comparison with other scenarios, CM 4 has the minimum correlation among OFDM subcarriers.

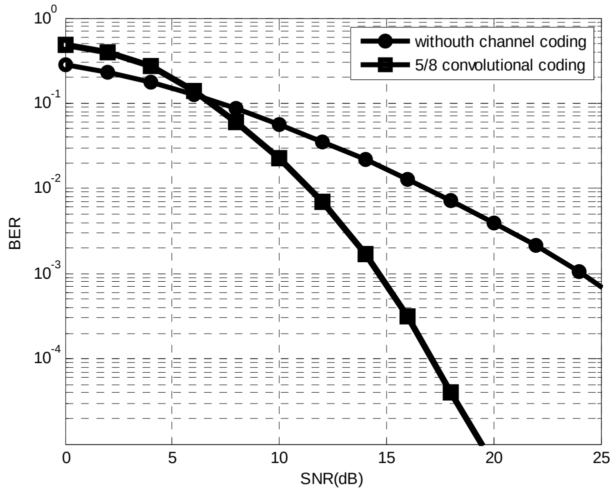

Figure 3. The performance of MB-OFDM UWB.

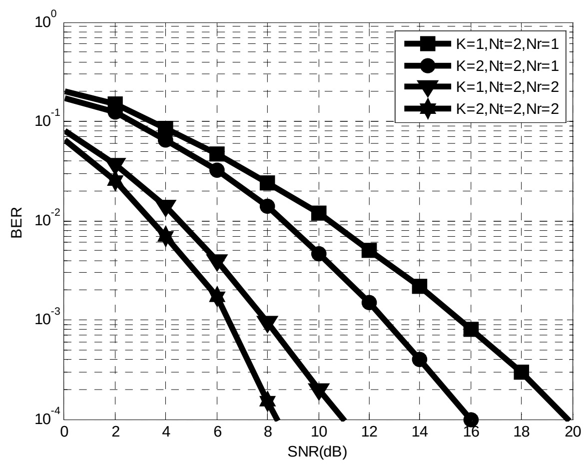

Figure 4. Performance of MB-OFDM for different MIMO configurations.

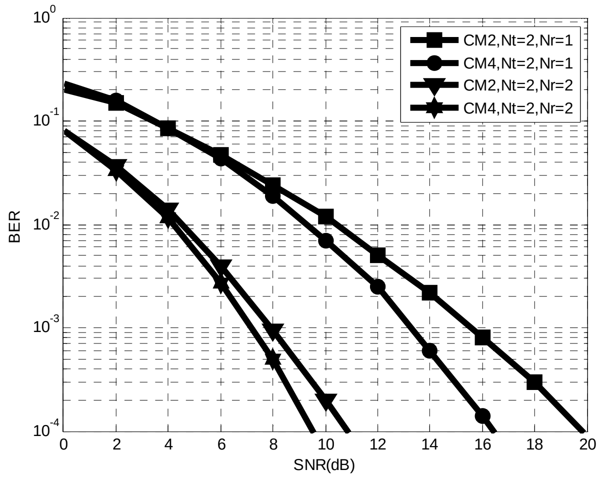

Figure 5. Performance comparison between CM 2 and CM 4.

4. Conclusions

In this paper, MIMO-MB-OFDM has been studied. The simulation results indicate that the 2I2O STFC-MB-OFDM scheme for UWB system shows much better performance compared with un-coded MB-OFDM. On the other hand, the performance of STF coded system can be improved by increasing the number of antenna, regardless of the random clustering behavior of UWB channels.

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