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MULTIPLE ANTENNA TRANSMISSION TECHNIQUE FOR UWB SYSTEM

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Abstract—In this paper, the channel estimation in multi-band OFDM (MB-OFDM) ultra-wideband (UWB) based multiple- antenna transmission systems is studied. For multiple antennas, each preamble designed by the Zadoff-Chu sequence satisfies the orthogonal property in the time domain. Therefore, the proposed preambles can improve the system performance and be applied to MB-OFDM specification in the case of more than two transmit antennas.

1. INTRODUCTION

Ultra-wideband (UWB) technology is selected as a solution for low cost and high performance wireless entertainment network able to support streaming multimedia content and full motion video. The UWB has attracted considerable interest in the research and standardization communities, due to its promising ability to provide high data rate at low cost with relatively low power consumption [1–6]. In the UWB communication, the data rate must be high enough (greater than 110 Mb/s) to satisfy a set of multimedia industry needs for wireless personal area networks (WPAN) communication, and the quality of service (QoS) capabilities are required to support multimedia data types. Therefore, higher rate and reliable transmission are required to satisfy the condition.

Conventionally, more bandwidth is required for higher data-rate transmission. However, due to spectral limitations, it is often impractical or sometimes very expensive to increase bandwidth. In this case, the scheme using the multiple transmit and receive antennas for spectrally efficient transmission is alternative solution [7], and moreover multi-input multi-output (MIMO) systems provide significant capacity gain in proportion to the number of antennas [8–11]. Therefore, we apply MIMO architectures using space-time block code (STBC) [13, 14] to MB-OFDM UWB system. In the wireless communication environment, the channel modeling and channel estimation are important [15, 16]. As an application of the MIMO architecture, a preamble structure for employing STBC with more than 2 transmit antennas is designed to be orthogonal in the time domain, and the channel estimation performance based on an investigated preamble structure is highlighted. The 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. The proposed preamble can be applied to preamble of the MB-OFDM specification.

The outline of the paper is as follows. Section 2 describes the MB-OFDM system and the multi-antenna MB-OFDM system model. Section 3 describes a preamble design for multi-channel estimation. The performance of the multi-antenna MB-OFDM receiver based on numerical and simulation results is discussed in Section 4. Lastly, the concluding remarks are given in Section 5.

2. SYSTEM MODEL

2.1. MB-OFDM System

In the WPAN system based on MB-OFDM, the whole available UWB spectrum between 3.1–10.6 GHz is divided into 14 sub-bands with 528 MHz bandwidth [12]. The transmission rate of the MB-OFDM is between 53.3–480 Mbps. In Data rate 53.3 and 80 Mbps, time and frequency spreading are used, and only time spreading is used between 106.7–200 Mbps. In each sub-band, a normal OFDM modulated signal with 128 subcarriers is used. For rates up to 200 Mbps, the QPSK scheme is employed in the constellation mapping, and over 200 Mbps rates use dual carrier modulation (DCM). The main difference between the MB-OFDM system and other narrowband OFDM systems is the way that different sub-bands are used in the transmission with several hopping patterns.

The transmitted signals can be described using a complex baseband signal notation. The actual RF transmitted signal is related to the complex baseband signal as follows

$$x_{RF}(t) = \sum_{s=1}^{S-1} x^s(t - ST_I)e^{j2\pi f_s t} \tag{1}$$

where $x^s(t)$ is the complex baseband signal of the s-th OFDM symbol and is nonzero over the interval from 0 to T_I, S is the number of OFDM symbols, T_I is the symbol interval, and f_s is the center frequency for the s-th band.

2.2. Space-Time Coded MB-OFDM System

The STBC is a representative diversity transmission technique. Space-time block codes from complex orthogonal design obtain gain of transmitting diversity by transmission of the same data for multiple transmit antennas. Therefore STBC technique brings the improvement of error performance of the communication systems.

We adopt 2 and 4 transmit antennas and 1 receive antenna. For 2 transmit antennas, 2×2 code, as proposed by Alamouti, can be used as follows [13]:

$$C_2 = \begin{pmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{pmatrix} \tag{2}$$

where s_1 and s_2 are transmitted signals, and the superscript $(\cdot)^*$ denotes the conjugate of signal. Modulated data through constellation mapper are coded by (2), and transmitted through 2 transmit antennas and time slots. The receiver performs the channel estimation and combines data to obtain diversity gain. The combined data can be obtained as follows:

$$\begin{aligned} \widetilde{s}_1 &= \widehat{h}_1^* r_1 + \widehat{h}_2 r_2^* \\ \widetilde{s}_2 &= \widehat{h}_2^* r_1 - \widehat{h}_1 r_2^* \end{aligned} \tag{3}$$

where $\widetilde{s}_1$ and $\widetilde{s}_2$ are combined signals, and $\widehat{h}_1$ and $\widehat{h}_2$ are channel state information (CSI) estimated. r_1 and r_2 are received signals at time t and time $t + T$. In the case of 4 transmit antennas, C_4 of 4×4 code is used as follows:

$$C_4 = \begin{pmatrix} s_1 & s_2 & s_3 & 0 \\ -s_2^* & s_1^* & 0 & -s_3 \\ -s_3^* & 0 & s_1^* & s_2 \\ 0 & s_3^* & -s_2^* & s_1 \end{pmatrix}. \tag{4}$$

C_4 has a code rate of 3/4, because three symbols are transmitted through four time slots. The combining process is similar to 2 transmit antennas, and combined signals are as follows:

$$\begin{aligned}\widetilde{s}_1 &= \widehat{h}_1^* r_1 + \widehat{h}_2 r_2^* + \widehat{h}_3 r_3^* + \widehat{h}_4^* r_4 \\ \widetilde{s}_2 &= \widehat{h}_2^* r_1 - \widehat{h}_1 r_2^* + \widehat{h}_4^* r_3 - \widehat{h}_3 r_4^* \\ \widetilde{s}_3 &= \widehat{h}_3^* r_1 - \widehat{h}_4^* r_2 - \widehat{h}_1 r_3^* + \widehat{h}_2 r_4^*.\end{aligned} \tag{5}$$

3. PREAMBLE DESIGN FOR MULTIPLE ANTENNAS OF MB-OFDM

In the MB-OFDM system, the channel estimation is executed at the all sub-band, and in the STBC MB-OFDM system, the channel estimation is carried out for every transmit antenna of the all sub-band. For the channel estimation of each antenna, we design preambles using the Zadoff-Chu sequence, one of the constant-amplitude zero-autocorrelation (CAZAC) sequence, [17]. The sequence C_k is as follows:

$$C_k = \exp\left[j\frac{M\pi k^2}{N}\right] \tag{6}$$

where N is a length of preamble, and $k = [0, 1, \ldots, N-1]$. M is an integer relatively prime to N, and we consider the case of M is 1.

C_k has the property of a periodic autocorrelation function that is zero everywhere except at a single maximum per period. In the MB-OFDM system, the channel estimation sequence is transmitted twice at each band, and the length of sequence is 128 except zero-padded suffix and guard interval. By using C_k of 64-symbol length ($N = 64$), we design the extended 128-length Zadoff-Chu sequence with zero-padding. Therefore the proposed sequence can be adopted to the MB-OFDM specification. The extended Zadoff-Chu sequence is as follows:

$$S_{8m+n+1} = \begin{cases} C_{4m+n} & \text{for } m: \text{ even including zero} \\ 0 & \text{for } m: \text{ odd} \end{cases} \tag{7}$$

where $m \in \{0, 1, 2, \ldots, 15\}$, $n \in \{0, 1, 2, \ldots, 7\}$. In order to apply 4 transmit antennas, 4 preambles can be designed by cyclic shift. For 2 transmit antennas, 2 preambles are used, and for 4 transmit antennas, all preambles are used.

From [18], we deduce generalized relation to determine the number of distinguishable paths D as follows:

$$1 \leq D \leq \frac{L}{N_t} \tag{8}$$

where L indicates the symbol-length of sequence, and N_t is the number of transmit antenna.

The orthogonality of preambles is broken and the preamble is not suitable for MB-OFDM specification, when the system just uses 64-symbol length sequence. However, extended sequences will keep the property of the orthogonality at channel model (CM) 1 and 2 when the system uses 2 and 4 transmit antennas. It is noted that D is 64 for $N_t = 2$ and is 32 for $N_t = 4$ from (8). The orthogonality of extended sequences is broken at CM3 and CM4, because the number of channel paths exceeds D. However, because CM3 and CM4 almost never come into existence, the proposed preamble can be used in the WPAN. Using the orthogonality, the receiver can execute the channel estimation and separate channel impulse response (CIR) of each transmit antenna. There are two main methods to estimate the CSI which are the LS and MMSE method. First, we take into account the LS method that can be archived by following equation:

$$\widehat{h}_{LS}^{(p)}[i] = \frac{1}{L} \sum_{l=0}^{L-1} \frac{r[i+l]}{s^{(p)}[l]} \tag{9}$$

where $\widehat{h}_{LS}^{(p)}[i]$ is the estimated i-th CIR at the p-th channel branch, and r and s are respectively the received signal and transmitted preamble.

The LS method only uses the information of training sequences to estimate the CSI. However, the MMSE method utilizes the information of channel characteristics and SNR. In order to have minimum information quantity, the estimator assumes a priori knowledge of noise variance and channel covariance, and is expressed as

$$\widehat{H}_{MMSE} = R_H \left(R_H + \frac{1}{SNR} I \right)^{-1} \widehat{H}_{LS} \tag{10}$$

where $R_H = E[HH^H]$ is the auto-covariance matrix of H, the superscript $(\cdot)^H$ denotes Hermitian transpose, and I is the identity matrix.

4. PERFORMANCE EVALUATION AND DISCUSSION

The performance of the proposed preamble is evaluated in terms of MSE in this section. The MSE that shows the error-variance is one of the most common measures to evaluate the quality of estimator. It can be calculated as follows:

$$MSE = E\left[\left(h - \widehat{h} \right) \left(h - \widehat{h} \right)^H \right]. \tag{11}$$

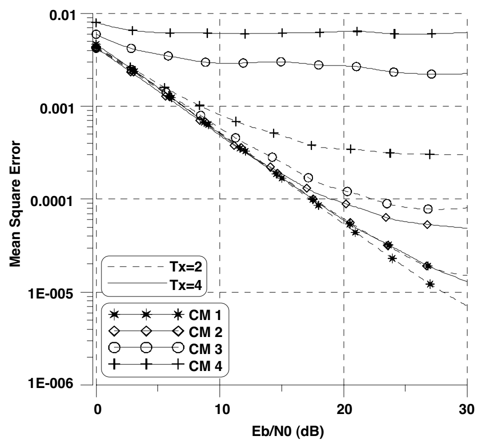

Figure 1. The MSE performance of proposed preambles applied to 2 and 4 transmit antennas with MMSE estimator.

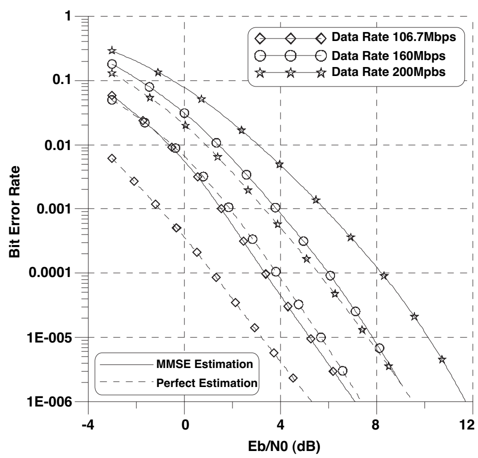

Figure 2. The BER performance of perfect channel estimation and MMSE method at the 2-transmit-antenna system.

Figure 1 shows the MSE performance of 2 and 4 transmit antennas at CM 1–4 [19]. In the case of 2 and 4 transmit antennas of CM 1 and 2 transmit antennas of CM2, the system can keep the orthogonality of preambles. However, in the other cases, MSE performances are very poor because the orthogonality of preamble is broken because of the reason that mentioned through (8) in Section 3.

To evaluate the performance of the STBC MB-OFDM system, in Fig. 2, we plot the BER performance of MMSE and perfect

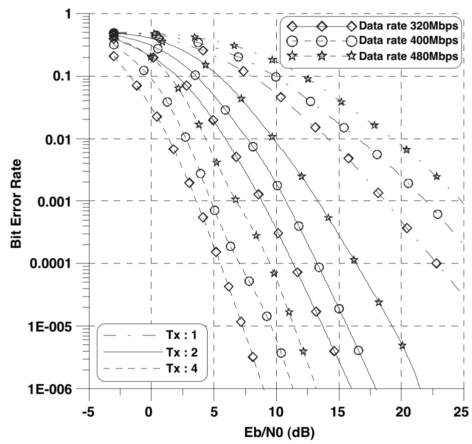

Figure 3. The BER performance of 1, 2 and 4 transmit antennas at data rate 320, 400 and 480 Mbps.

channel estimations of 2 transmit antennas at data rate 106.7, 160 and 200 Mbps. The channel model of the BER performance simulation is 1 (CM1). Simulation results show that there is a gap between perfect channel estimation and MMSE estimation. However, the system has the better BER performance than single antenna.

Figure 3 shows the effect of the number of transmit antennas on the BER performance. Simulations are executed in conditions which are 1, 2 and 4 transmit antennas at data rate 320, 400 and 480 Mbps. In the case of 4 transmit antenna, data rate is 3/4 that is confirmed from (4). Simulation results show that multi-antenna systems have the better performance than single antenna system and also as the number of antennas increases, the system has the better BER performance.

5. CONCLUSIONS

In this paper, we apply space-time architecture to MB-OFDM system based on WPAN for high capacity transmission and propose the new preamble structure for channel estimation which is required in MIMO architecture. Through the MSE performance, simulation results have shown that the proposed sequence can be adopted to multi-antenna MB-OFDM system. The BER performance shows that the reliability of STBC MB-OFDM system is improved efficiently by increasing the number of antennas. As the new preamble is applied, it has been shown that the MB-OFDM system with multi-antenna can achieve the high transmission capacity.

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REFERENCES

1. Naghshvarian-Jahromi, M., "Compact UWB bandnotch antenna with transmission-line-fed," *Progress In Electromagnetics Research B*, Vol. 3, 283–293, 2008.
2. El-Fishawy, N., M. Shokair, and W. Saad, "Proposed Mac protocol versus IEEE 802.15.3a for multimedia transmission over UWB networks," *Progress In Electromagnetics Research B*, Vol. 2, 189–206, 2008.
3. Xiao, S., J. Chen, X.-F. Liu, and B.-Z. Wang, "Spatial focusing characteristics of time reversal UWB pulse transmission with different antenna arrays," *Progress In Electromagnetics Research B*, Vol. 2, 223–232, 2008.
4. Yin, X.-C., C. Ruan, C.-Y. Ding, and J.-H. Chu, "A planar U type monopole antenna for UWB applications," *Progress In Electromagnetics Research Letters*, Vol. 2, 1–10, 2008.
5. Khan, S. N., J. Hu, J. Xiong, and S. He, "Circular fractal monopole antenna for low VSWR UWB applications," *Progress In Electromagnetics Research Letters*, Vol. 1, 19–25, 2008.
6. Li, Q. and L. A. Rusch, "Multiuser detection for DS-CDMA UWB in the home environment," *IEEE Trans. Wireless Communications*, Vol. 20, No. 9, 701–1711, December 2002.
7. Ye, L., J. H. Winters, and N. R. Sollenberger, "Signal detection for MIMO-OFDM wireless communications," *IEEE International Conference Communications*, Vol. 10, 3077–3081, June 2001.
8. Abouda, A. A. and S. G. Haggman, "Effect of mutual coupling on capacity of MIMO wireless channels in high SNR scenario," *Progress In Electromagnetics Research*, PIER 65, 27–40, 2006.
9. Abouda, A. A., H. M. El-Sallabi, and S. G. Haggman, "Effect of antenna array geometry and ULA azimuthal orientation on MIMO channel properties in urban city street grid," *Progress In Electromagnetics Research*, PIER 64, 257–278, 2006.

10. Abouda, A. A. and S. G. Haggman, "Effect of mutual coupling on capacity of MIMO wireless channels in high SNR scenario," *Progress In Electromagnetics Research*, PIER 65, 27–40, 2006.
11. Abouda, A. A., H. M. El-Sallabi, and S. G. Haggman, "Effect of antenna array geometry and ULA azimuthal orientation on MIMO channel properties in urban city street grid," *Progress In Electromagnetics Research*, PIER 64, 257–278, 2006.
12. MultiBand OFDM Alliance (MBOA) Special Interest Group (SIG), WiMedia Alliance, Inc. (WiMedia) "MultiBand OFDM physical layer specification," Release 1.1, July 2005.
13. Alamouti, S. M., "A simple transmit diversity technique for wireless communications," *IEEE Journal on Selected Areas in Communications*, Vol. 16, No. 8, 1451–1458, October 1998.
14. Dmitriev, V., "Space-time reversal symmetry properties of electromagnetic Green's tensors for complex and bianisotropic media," *Progress In Electromagnetics Research*, PIER 48, 145–184, 2004.
15. De Doncker, P., "Spatial correlation functions for fields in three-dimensional rayleigh channels," *Progress In Electromagnetics Research*, PIER 40, 55–69, 2003.
16. El-Sallabi, H. M. and P. Vainikainen, "Radio wave propagation in perpendicular streets of urban street grid for microcellular communications, Part I: Channel modeling," *Progress In Electromagnetics Research*, PIER 40, 229–254, 2003.
17. Chu, D. C., "Polyphase codes with good periodic correlation properties," *IEEE Transactions on Information Theory*, Vol. 18, No. 4, 531–532, July 1972.
18. Cho, D.-J., Y.-H. You, and H.-K. Song, "Channel estimation with transmitter diversity for high rate WPAN systems," *IEICE Trans. Commun.*, Vol. E87-B, No. 11, Nov. 2004.
19. IEEE P802.15-02/490rl-SG2a, "Channel modeling sub-committee report final," February 2003.