Exploitation of Extra Diversity in UWB MB-OFDM System

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Abstract: **This paper describes and analyzes the performance of MB-OFDM (Multi-Band OFDM) UWB (Ultra-WideBand) system that is suggested as one of standards in IEEE 802.15 TG3a for UWB application. UWB channel model that has been contributed in IEEE 802.15 SG3a is a wideband channel model of 6GHz bandwidth, so we modify it to have 3 subband channels that are obtained by filtering conventional UWB channel considering center frequency and bandwidth of each subband. We demonstrate performances of MB-OFDM system under the UWB channel by simulation and verify the frequency and time domain diversity gains. We also compare the performance of a proposed SFBC (Space-Frequency Block Code) MB-OFDM system with that of conventional MB-OFDM system and manifest the extra spatial diversity gain of MB-OFDM UWB system. Simulation results show SFBC MB-OFDM system outperforms conventional MB-OFDM system about 1.5 dB of Eb/No at target BER of 10^{-4}.**

Keyword **: UWB, MB-OFDM, SFBC, Frequency Diversity, Time Diversity, Spatial Diversity**

Extended Abstract

UWB (Ultra-Wideband) has been used as a military technology over 40 years. It has an advantage of providing several Mbps data rate just using 1/10 power consumption compared with that of wireless LAN or mobile communication. However, UWB system uses very wide bandwidth so that it can cause the interference to the other communication systems sharing same spectrum. By the results, the UWB technology could not be actively applied to the commercial area.

However, FCC (Federal Communication Commissions) allows commercialization of UWB technology on condition that the bandwidth limit of 3.1GHz ~ 10.6GHz and maximum radiation intensity limit of -41.25dBm per 1MHz. Consequently, the standardization process has been in progress actively to define UWB physical layer that utilizes conventional IEEE 802.15.3 MAC. Among many standards of IEEE 802.15 TG3a for UWB application, MB-OFDM that is suggested from MBOA (Multi-Band OFDM Alliance) has been discussed as a prime standardization candidate.

IEEE 802.15.SG3a suggested an UWB channel model to validate the performance

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analysis of IEEE 802.15 TG3a MB-OFDM physical layer in February 2003. The UWB channel model is a kind of S-V (Saleh-Valenzuela) channel, but requires some modifications in that due to clustering effects of multipath discovered through channel measurements. The CM1-CM4 are provided for UWB channel [1]. CM1-CM3 are models based on channel measurements and CM4 is the worst case channel model, of which RMS delay spread is 25ns. Each Channel Model consists of 100 realization channels.

Basically, MB-OFDM system provides time-domain diversity by time-domain symbol spreading technique and frequency-domain diversity by transmitting OFDM symbols in different sub-bands. However, MB-OFDM system does not provide spatial-domain diversity yet. So, we apply SFBC (Space Frequency Block Code), that is a kind of spatial diversity scheme [2], to conventional MB-OFDM UWB system for improving link performance further.

Fig. 1 depicts the structure of SFBC MB-OFDM transmitter and receiver suggested in this paper. In transmitter side, there are two antennas for data transmission. And SFBC encoder is located behind time/frequency spreading block to obtain a spatial diversity gain. In receiver side, SFBC decoder is located in front of the time/frequency spreading block to decode SFBC encoded OFDM symbols.

The data symbol vector $\mathbf{X}(n)$ is coded two vectors $\mathbf{X}_1(n)$ and $\mathbf{X}_2(n)$ by the space-frequency encoder block as

$$\begin{aligned} \mathbf{X}_1(n) &= [\mathbf{X}_0(n)\ \ -\mathbf{X}_1^*(n)\ \ ....\ \mathbf{X}_{N\text{-}2}(n) - \mathbf{X}_{N\text{-}1}^{\ *}(n)]^T \\ \mathbf{X}_2(n) &= [\mathbf{X}_1(n)\ \ \mathbf{X}_0^{\ *}(n)\ \ ....\ \mathbf{X}_{N\text{-}1}(n)\, \mathbf{X}_{N\text{-}2}^{\ *}(n)]^T \end{aligned} \tag{1}$$

Let $\mathbf{X}_e(n)$ and $\mathbf{X}_o(n)$ be two length N/2 vectors denoting the even and odd component vectors of $\mathbf{X}(n)$ as below.

$$\begin{aligned} \mathbf{X}_e(n) &= [\mathbf{X}_0(n)\ \ \mathbf{X}_2(n)\ \ ....\ \mathbf{X}_{N-4}(n)\ \mathbf{X}_{N-2}(n)]^T \\ \mathbf{X}_o(n) &= [\mathbf{X}_1(n)\ \ \mathbf{X}_3(n)\ \ ....\ \mathbf{X}_{N-3}(n)\ \mathbf{X}_{N-1}(n)]^T \end{aligned} \tag{2}$$

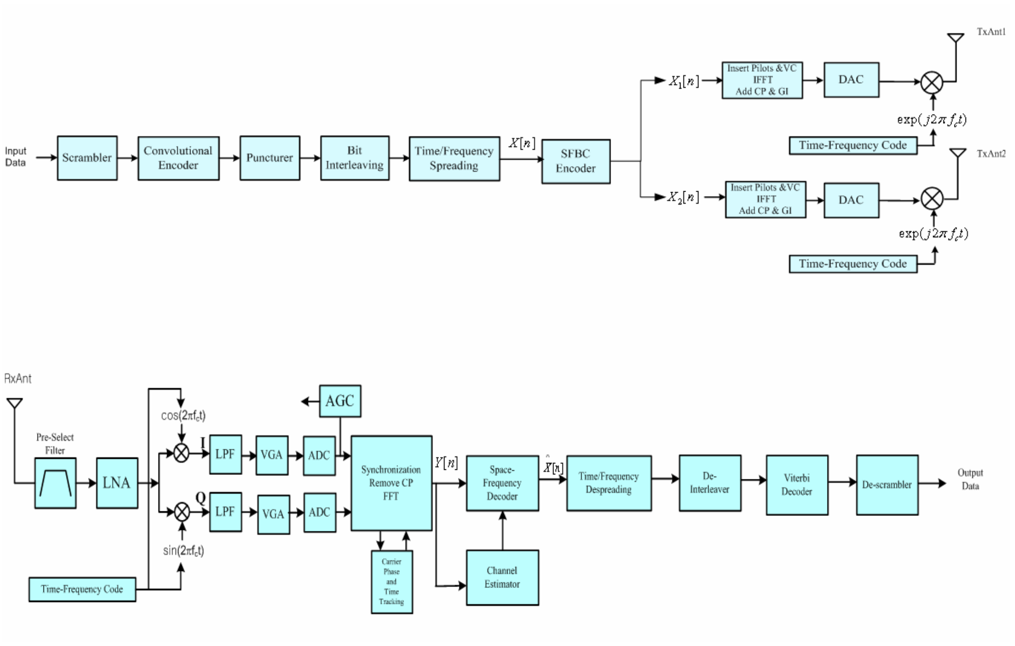

Fig. 1. The structure of the proposed SFBC MB-OFDM modem.

Equation (1) can then be expressed in terms of the even and odd component vectors as

$$\begin{aligned} \mathbf{X}_{1,e}(n) &= \mathbf{X}_e(n) \ , \mathbf{X}_{1,o}(n) = -\mathbf{X}_o^*(n) \\ \mathbf{X}_{2,e}(n) &= \mathbf{X}_o(n) \ , \mathbf{X}_{2,o}(n) = \mathbf{X}_e^*(n) \end{aligned} \tag{3}$$

Let $\mathbf{\Lambda}_1(n)$ and $\mathbf{\Lambda}_2(n)$ be two diagonal matrices whose elements are the DFTs of the respective channel impulse responses, $\mathbf{h}_1(n)$ and $\mathbf{h}_2(n)$. The demodulated signal at the receiver is given by

$$\mathbf{Y}(n) = \mathbf{\Lambda}_1(n)\mathbf{X}_1(n) + \mathbf{\Lambda}_2(n)\mathbf{X}_2(n) + \mathbf{Z}(n) \tag{4}$$

Assuming the channel responses are known or can be estimated accurately at the receiver, the space-frequency decoder block constructs the decision estimate vector $\hat{\mathbf{X}}(n)$ as belows.

$$\begin{aligned} \hat{\mathbf{X}}_e(n) &= \mathbf{\Lambda}_{1,e}^*(n)\mathbf{Y}_e(n) + \mathbf{\Lambda}_{2,o}(n)\mathbf{Y}_o^*(n) \\ \hat{\mathbf{X}}_o(n) &= \mathbf{\Lambda}_{2,e}^*(n)\mathbf{Y}_e(n) - \mathbf{\Lambda}_{1,o}(n)\mathbf{Y}_o^*(n) \end{aligned} \tag{5}$$

SFBC transmitter diversity scheme is similar in form to that of the optimal two branch maximal ratio combing (MRC) receiver diversity system. So, SFBC MB-OFDM system can outperforms conventional MB-OFDM system due to additional spatial diversity gain.

The performance of conventional MB-OFDM system and time and frequency diversity effects of MB-OFDM system will be demonstrated. Also we compare the performance between conventional MB-OFDM system and SFBC MB-OFDM system that utilize additional spatial diversity and manifest spatial diversity gain. For performance evaluation, we simulate with the modified S-V UWB channel model that is filtered according to RF center frequency and bandwidth of subbands that MB-OFDM utilizes. The system parameters and pattern of changing RF center frequency of MB-OFDM can be referenced in [3].

Assuming practical channel estimation that performs zero forcing channel estimation using channel estimation sequence provided in MB-OFDM system in UWB channel model 3 and 110Mbps data rate, Fig. 2 shows the diversity gains that MB-OFDM system provides. 110Mbps with TFI (Time-Frequency Interleaved) means the general BER performance of MB-OFDM system that utilizes the time and frequency diversity by applying MRC diversity combining with two time spreading symbols which are transmitted in different subbands. 110Mbps without FH (Frequency Hopping) means the BER performance of MB-OFDM system that only provides time diversity by performing MRC diversity combining with two time spreading symbols which are transmitted in same subband. Note that if MB-OFDM system does not change RF center frequency 4dB performance degradation at BER 10^{-4} occurs compared with the case of 110Mbps with TFI and that corresponds to the frequency diversity gain by changing RF center frequency. 110Mbps with average means the BER performance of MB-OFDM system that equalizes the two time spreading symbols that are transmitted in different subbands and averages two symbols. Because of equalization process that deletes the channel gains, the case of 110Mbps with average cannot obtain time-domain MRC diversity combining gain. Simulation results show that the case of 110Mbps with average is worse than the case of 110Mbps with TFI about 13dB at BER 10^{-4} which corresponds to time diversity gain. Assuming that practical channel estimation in UWB channel model 3 and 110Mbps data rate, Fig. 3 shows the BER performance of conventional MB-OFDM system and proposed SFBC MB-OFDM system. SFBC MB-OFDM system outperforms conventional MB-OFDM system about 1.5dB of Eb/No at target BER 10^{-4} due to spatial diversity gain. That is, spatial diversity gain is achieved as the extra gain of MB-OFDM system using SFBC.

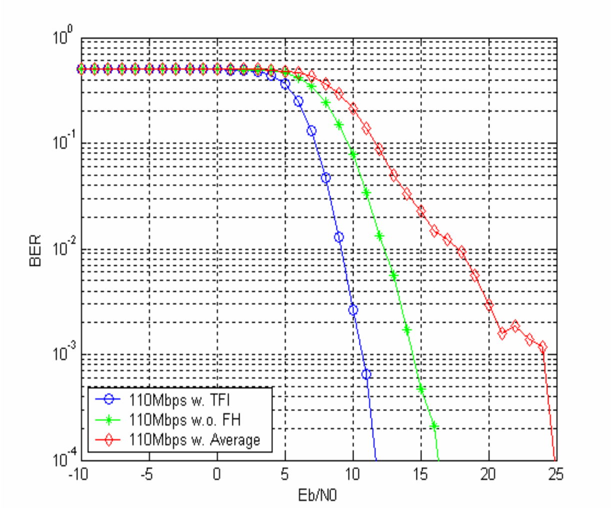

Fig. 2. Frequency and time diversity effect of MB-OFDM system in UWB channel model 3.
(110Mbps, practical channel estimation)

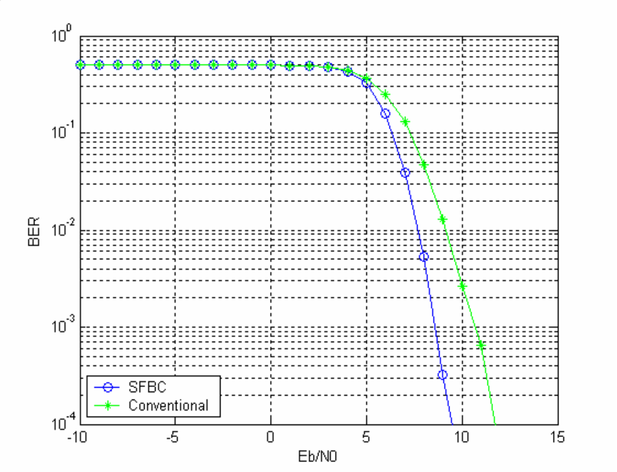

Fig. 3. Spatial diversity effect of SFBC MB-OFDM system in UWB channel model 3.
(110Mbps, practical channel estimation)

REFERENCES

[1] Jeff Foerster, Sub-committee Chair, Channel Modeling Sub-commiter Report, IEEE P802.15-02/490r1-SG3a, Feb. 2003.

[2] J. Heo and K. H. Chang, “Performance analysis of SFBC MB-OFDM UWB system”, Proceedings of IEEK Summer Conference, Jun. 2004, vol. 27, no. 1, pp. 67-70.

[3] Anuj Batra et al., Texas Instruments et al., Multi-band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a, IEEE P802. 15-03/268r3, Mar. 2004.