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Throughput Enhancement for Multiband-OFDM UWB System Based on Extensive Preamble Utilization

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Abstract: In this paper, we propose a method to improve the performance of initial channel estimation (CE) for the multiband-OFDM (MB-OFDM) UWB. The performance of the initial CE can be generally improved as increasing the number of the used preamble symbols. The MB-OFDM specification presents two CE symbols per band in preamble format. The performance of CE estimation with two CE symbols may be satisfied in relatively high sensitivity -77.5 and -72.5 dBm for 200 Mbps and 480 Mbps data rate, respectively, but can not be enough in the degraded 55 Mbps and 110 Mbps sensitivities such as -83.5 and -80.5 dBm, respectively. A method proposed in this paper achieves the performance improvement by extending CE estimation region to packet synchronization (PS) symbols and frame synchronization (FS) symbols including two CE symbols. This can improve the CE performance in the degraded SNR and increase the link-margin by reducing the error rate in physical-layer header. The link-margin improvement obtained by the proposed CE preamble can induce the decrease of error-rate in physical-layer header and increase of communication throughput. Simulation results for the proposed initial method show that the performance is improved by about 0.6 dB at 10^{-4} bit-error-rate using '3' symbols than initial method using only two CE symbols.

1. Introduction

The ultra wide-band (UWB) technique has attracted attention more and more in its broad applicability in the wireless communication systems. The multi-band OFDM (MB-OFDM) is one of systems under consideration to international UWB standard and it is also based on the OFDM system using ultra wide-band as in [1] and [2]. In OFDM systems, the initial channel estimation obtained during the preamble period is used repeatedly to equalize the received signals. Then, the inaccurate initialization for channel estimation increases the error-rate in physical-layer header which follows the preamble symbols and includes the primitive information for physical-layer communication. The precise initial estimation can decrease error-rate in physical-layer header and enhance the communication throughput by reducing the requests for re-transmission caused by error of physical-layer header.

This paper proposes a method to obtain the performance improvement of the initial channel estimation for MB-OFDM UWB systems by reducing the effect of random noise. The proposed method extends the channel estimation (CE) preamble to the packet synchronization (PS) and the frame synchronization (FS) preamble presented in the MB-OFDM specification. In addition, this paper suggests an architecture to perform the extended CE preamble. The performance improvement of CE can reduce the error rate in physical-layer header in the degraded -83.5 and -80.5 dBm sensitivities at the 55 and 110 Mbsp, respectively And the enhanced throughput can be induced by the performance improvement like that (throughput) even in case of -77.5 and -72.5 dBm sensitivities at 200 and 480 Mbps, respectively, as in [1] and [2].

2. Initial Channel Estimation on Symbol Averaging

This paper is proposing a method to estimate the effect of bandpass channel taking an assumption that the OFDM receiver has the perfect frequency synchronization since the frequency-offset estimation can be obtained with the algorithm described in [4] or [5]. After the n-th OFDM preamble symbol passed through a bandpass channel, the frequency-domain signal at k-th subcarrier receiving without frequency-offset can be expressed in the equation (1) by [4].

$$\mathbf{R}_{n,k} = \mathbf{P}_{n,k}\mathbf{H}_{n,k} + \mathbf{W}_{n,k} \tag{1}$$

In the equation (1), the received signal Rn,k at k-th subcarrier of n-th OFDM preamble symbol is composed of the transmitted preamble-signal Pn,k, the channel transfer signal Hn,k and the Gaussian random noise signal Wn,k in the frequency-domain. The received signal Rn,k contains the preamble-signal Pn,k which is previously known between the transmitter and the receiver. For the initial channel estimation with the preamble symbols, a general and simple method is the symbol averaging method using arithmetic average in the time-domain windowing.

The symbol averaging method at k-th subcarrier using D preamble symbols is described as follows :

$$\mathbf{SA}_{k,D} = \frac{1}{D}\sum_{n=1}^{D}\left(\frac{\mathbf{R}_{n,k}}{\mathbf{P}_{n,k}}\right) = \frac{1}{D}\sum_{n=1}^{D}\left(\mathbf{H}_{n,k} + \frac{\mathbf{W}_{n,k}}{\mathbf{P}_{n,k}}\right) \tag{2}$$

With assumption that the channel transfer signal Hn,k is hardly changed during the preamble symbols, the variance of the initial channel estimation on symbol averaging can be expressed in the equation (3) by [6]. This assumption is reasonable because about 3 MHz symbol-rate of the MB-OFDM UWB is relatively high compared to the change of the indoor channel.

$$
\begin{aligned}
var\left(SA_{k,D}\right) &= var\left(\frac{1}{D}\sum_{n=1}^{D}\mathbf{H}_{n,k}\right) + var\left(\frac{1}{D}\sum_{n=1}^{D}\frac{\mathbf{W}_{n,k}}{\mathbf{P}_{n,k}}\right) \\
&\quad + \frac{2}{D^2}E\left[\sum_{n=1}^{D}\mathbf{H}_{n,k}\sum_{n=1}^{D}\frac{\mathbf{W}_{n,k}}{\mathbf{P}_{n,k}}\right] \\
&\simeq var\left(\frac{1}{D}\sum_{n=1}^{D}\frac{\mathbf{W}_{n,k}}{\mathbf{P}_{n,k}}\right) = \frac{1}{D^2}var\left(\sum_{n=1}^{D}\frac{\mathbf{W}_{n,k}}{\mathbf{P}_{n,k}}\right) \\
&= \frac{1}{D}var\left(\frac{\mathbf{W}_{n,k}}{\mathbf{P}_{n,k}}\right)
\end{aligned}
\qquad (3)
$$

where var( ) is operation for the variance and E[ ] is operation for the expectation.

The preamble of the MB-OFDM UWB has the normalized power, and the amplitude of the frequency-domain preamble-signal equals to one, as in [1]. Then, the equation (3) can be derived as :

$$
var\left(SA_{k,D}\right) = \frac{1}{D}var\left(\mathbf{W}_{n,k}\right) = \frac{\sigma^2}{D} \qquad (4)
$$

where σ^2 is noise power.

The equation (4) represents that the performance of initial channel estimation using the symbol averaging method with 'D' preamble symbols is 'D' times better than that of the channel estimation with one preamble symbol. And the standard deviation of initial channel estimation is reduced by $\sqrt{D}$ based on the averaging initialization with 'D' preamble.

3. Preamble Format of MB-OFDM

Figure 1 shows the standard preamble format of MB-OFDM. A standard preamble shall be added prior to the physical layer convergence procedure (PLCP) header to aid receiver algorithms related to synchronization, carrier-offset recovery, and channel estimation. The standard PLCP preamble consists of three distinct portions: packet synchronization sequence composed of the PS symbols, frame synchronization sequence consisting of the FS symbols, and the channel estimation sequence as CE preamble. The packet synchronization sequence shall be constructed by successively appending 21 periods, denoted as {PS0, PS1, … , PS20}, of a time-domain sequence. Each time-domain sequence is associated with a particular time-frequency code. These time-domain sequences are defined in MB-OFDM specification [1]. In MB-OFDM specification, it is described that this packet preamble portion can be used for packet detection and acquisition, coarse carrier frequency estimation, and coarse symbol timing. Similarly, the frame synchronization sequence shall be constructed by successively appending 3 periods, denoted as {FS0, FS1, FS2}, of an 180 degree rotated version of the time-domain sequence. The MB-OFDM specification describes that this portion of the preamble can be used to synchronize the receiver algorithm within the preamble. Finally, the channel estimation sequence shall be constructed by successively appending 6 periods, denoted as {CE0, CE1, …, CE5}, of the OFDM training symbol. In the MB-OFDM specification, it is also expressed that this portion of the preamble can be used to estimate the channel frequency response, for fine carrier frequency estimation, and fine symbol timing.

In summary, the MB-OFDM specification suggests that the two frequency-domain preamble symbols per a sub-band of time-frequency hopping 3-bands, described as 'Mode 1' [1], are assigned to estimate channel frequency response. Thus, the initial channel estimation based on the preamble format with only two symbols per sub-band has limitation in performance shown in equation (4).

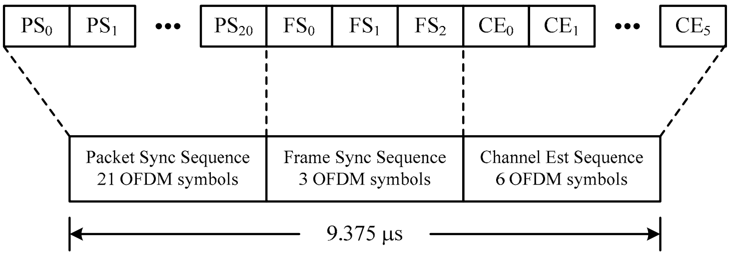
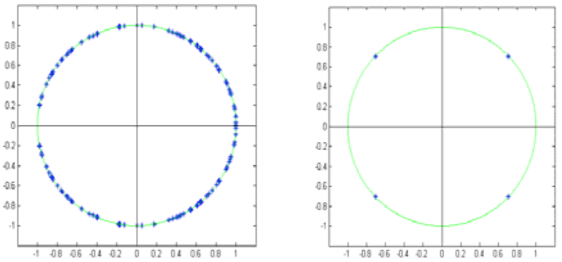


Figure 1. Standard Preamble Format of MB-OFDM

4. Proposed Initial Channel Estimation for MB-OFDM UWB

The equation (4) shows that the number of preamble symbols to estimate the channel frequency response depends on the performance of initial channel estimation. However, the number of symbols as frequency references for initial CE is represented as two. In this case, the desired throughput may not be satisfied in the degraded channel since the initial CE with two preamble symbols has the degraded error rate in physical header.

In figure 2, the type of PS and FS symbols is the time-domain reference associated with a particular time-frequency code. This means that PS and FS symbols are not directly applicable to the CE to enhance the CE performance with the extensive use of the preamble. The figure 1 shows that the frequency-domain references with uniform-random distribution for PS and FS symbols and the references for CE symbols with quadrature distribution are different.



(a) Frequency references for PS and FS symbols

(b) Frequency references for CE symbols

Figure 2. Reference points of preamble symbols in signal constellation

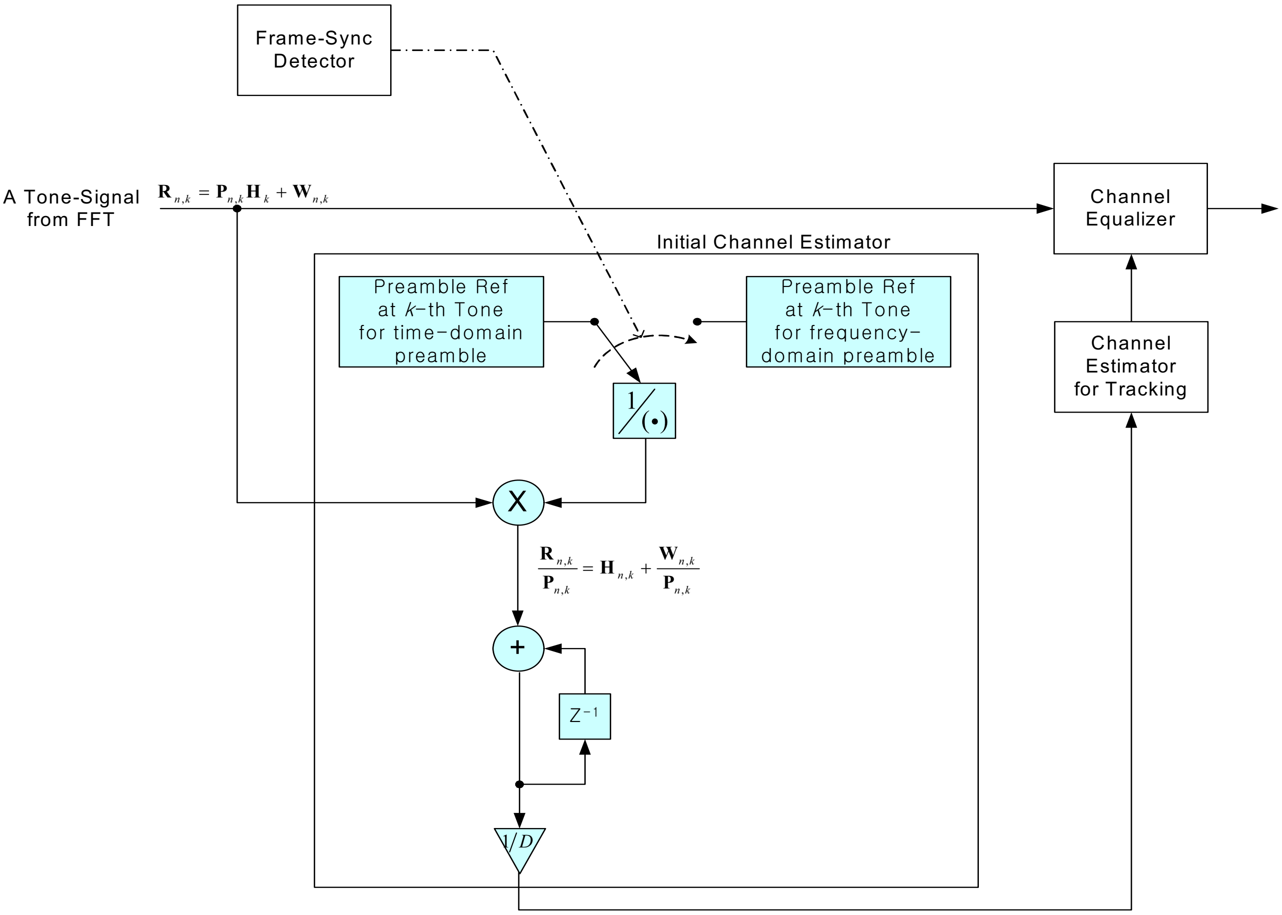


Figure 3. A proposed architecturefor the extensive utilization of MB-OFDM preamble

For the extensive use of the preamble, the transformation of PS and FS symbols which are directly applied to initial CE is needed for channel estimation in frequency domain. Considering this transformation, a proposed architecture is shown in figure 3. The architecture in figure 3 has the table for frequency-domain references transformed from the time-domain sequence composed of PS and FS symbols. And it also has the switching module from the references for time-domain sequence to the references for frequency-domain sequence with frame synchronization indicator.

5. Simulation Results

Figure 4 shows the simulation results for the proposed method. In the simulation environment, QPSK mapping and convolutional coding are performed as in [1]. The simulation results for the proposed initial method show that the performance is improved by about 0.7 dB at 10̃4 bit-error-rate (BER) when using four symbols as compared with using only two CE symbols.

6. Conclusion

This paper proposed the method to improve the performance of initial channel estimation (CE) by the extensive use of preamble format in multiband OFDM (MB-OFDM). The initialization method proposed in this paper can obtain the performance improvement by the use of symbol averaging which is based on not only two CE symbols but also PS and FS symbols. And this paper also suggested the architecture that PS and FS symbols are used for CE initialization. The simulation results for the proposed initial method show that the performance is improved by about 0.7 dB at dB at 10̃4 bit-error-rate (BER) when using four symbols as compared with using only two CE symbols.

Acknowledgement

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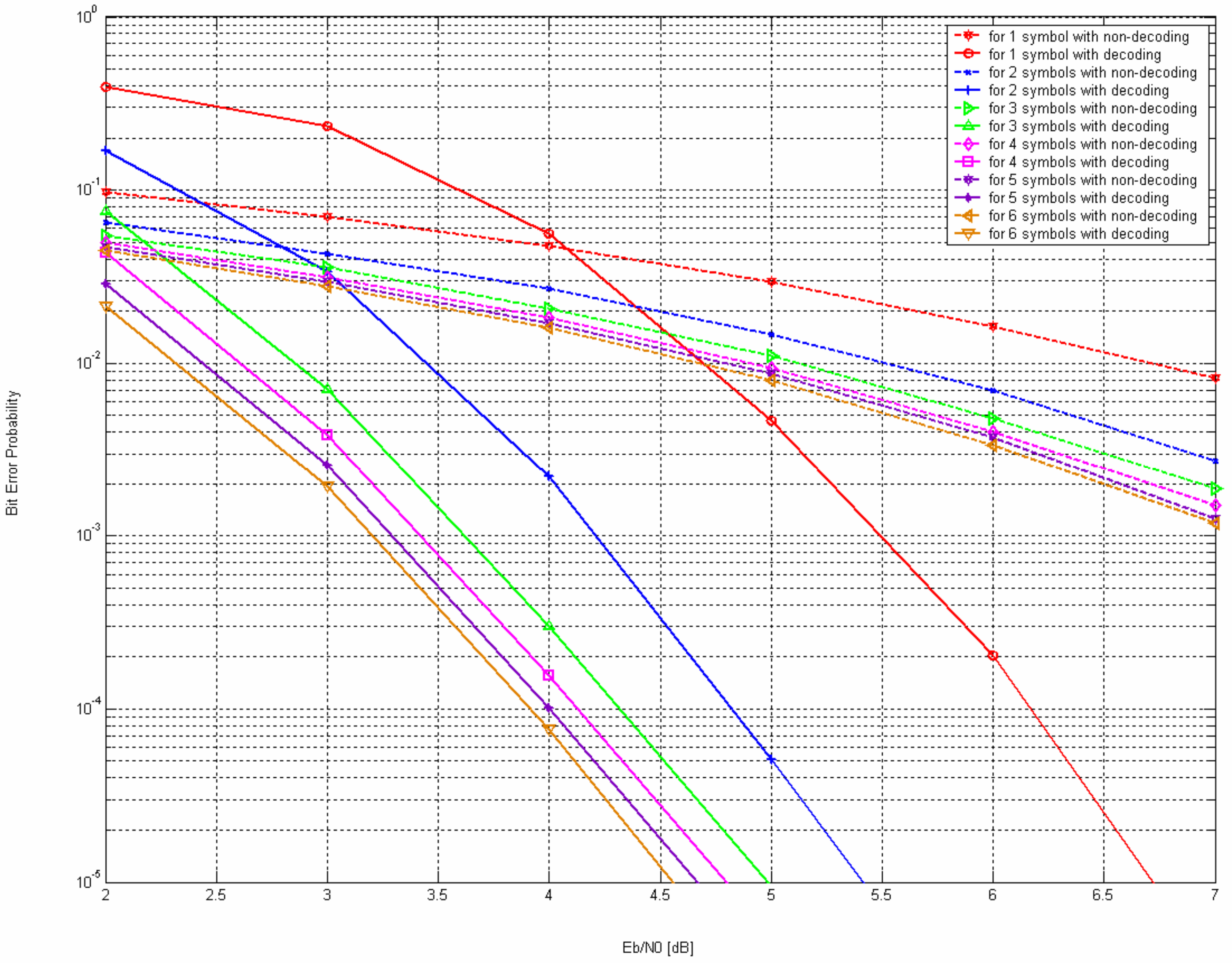

Figure 4. BER simulation results for the proposed method compared with conventional method in MB-OFDM specification