MUD Based on Hidden Training Sequence for UWB Communication System

Sung-Yoon Jung and Dong-jo Park
Department of Electrical Engineering and Computer Science
Korea Advanced Institute of Science and Technology (KAIST)
373-1 Guseong-dong, Yuseong-gu, Daejeon, Republic of Korea 305-701
E-mail: syjung@kaist.ac.kr and dpark@ee.kaist.ac.kr

Abstract— In this paper, we propose a multi-user detection scheme using a hidden training sequence. The hidden training sequence, which uses a fraction of the informative sequence’s transmitting power as a training sequence, was utilized for the receiver adaptation. The proposed detection scheme is applied to the DS-CDMA UWB system considered strongly as a physical solution for the IEEE 802.15.3a standard and we analyzed the performance of the proposed scheme in the view point of output signal-to-interference and noise-ratio (SINR). From simulation results using the IEEE 802.15.3a NLOS UWB channel model, we verify that the proposed scheme shows reasonably good BER performance and near-far resistance in single and multiuser environment.

I. INTRODUCTION

The ultra-wideband (UWB) technology has recently attracted considerable interest. Especially, it is thought as a candidate solution for High Data Rate Wireless Personal Area Networks (HDR W-PAN). In early days, most existing approaches are based on impulse radio (IR) systems with time-hopping multiple access (TH-MA) employing correlators to correlate received signals with a template signal [4]. This technique is simple and powerful, but not so satisfactory in a multipath and multiple access channel. Therefore, both unknown multiple access interference (MAI) and multipath distortion need to be mitigated. Recently, the multi-user detection schemes for the UWB system based on time-hopping or direct-sequence (DS) multiple-access (MA) are proposed [5]-[7]. As an early work, the multi-user detection scheme with a perfect channel is investigated just for performance evaluation [5]. The adaptive multi-user detection scheme based on a training sequence with unknown channel information is also suggested in home environment [6]. As a next step, to make up for the inefficient bandwidth utilization of the trained detection scheme, the blind multi-user detection scheme which does not need channel information is also considered [7].

In this paper, we propose an adaptive multi-user detection scheme using a hidden training sequence. The hidden training sequence, which uses a fraction of the informative sequence’s transmitting power as a training sequence, was utilized for the receiver adaptation [1]-[3]. By sacrificing a portion of the transmitting power for training, the proposed scheme offered increased bandwidth efficiency (no period just for training) and showed performance similar to the perfectly trained multi-user detection scheme, for example, the trained minimum mean square error (MMSE) scheme. The proposed detection scheme is applied to the DS-CDMA UWB system considered strongly as a physical solution for the IEEE 802.15.3a standard and we analyzed the performance of the proposed scheme in the view point of output signal-to-interference and noise-ratio (SINR). From simulation results with the IEEE 802.15.3a NLOS channel model [10], we verify that the proposed scheme shows reasonably good BER performance and near-far resistance in single and multiuser environment.

II. SYSTEM DESCRIPTION

We consider detecting user 1’s symbols in a K-user asynchronous DS-CDMA system through multipath UWB channels, where each user employs BPSK direct-sequence spread-spectrum (DS-SS) modulation. The overall block diagram of the proposed system is illustrated in Fig. 1.

The transmitter side is shown in Fig. 1(a). As seen in [1]-[3], the mth transmitting symbol can be generated as follows:

\[ b_k(m) = \sqrt{\alpha_k} b_{I_k}(m) + \sqrt{\beta_k} b_{P_k}(m) \] (1)

where \( b_{I_k} \) is the kth user’s informative sequence to be marked; \( b_{P_k} \) is the kth user’s marking sequence that, for our purpose, we indicate it as the hidden training sequence. Here \( \alpha_k \) and \( \beta_k \) are the transmitting power of the informative sequence and that of the hidden training sequence, respectively. If the system’s total transmitting power is restricted to be \( E_k \), \( \alpha_k + \beta_k \) should be \( E_k \). It is assumed that \( b_{I_k} \) and \( b_{P_k} \) are i.i.d., random binary sequences with zero mean and unit variance. Then, it is spreaded by the spreading waveform, \( c_k(t) \). After the UWB pulse shaping, the transmitted signal generated by the kth user is given by

\[ x_k(t) = \sum_{m=-\infty}^{\infty} b_k(m) \cdot c_k(t - mT_s) \] (2)

where \( T_s \) is symbol duration. The spreading waveform \( c_k(t) \)
is given by

$$c_k(t) = \sum_{i=1}^{N_s} c_k(i) \cdot p(t - iT_c)$$  \hspace{1cm} (3)$$

which has unit energy and consists of $N_s$ UWB pulses, $p(t)$. $T_c = T_s/N_s$ denotes the chip duration which are equal or greater than the pulse duration and $c_k(i)$ is the spreading sequence of the $k$th user. If we assume a time-invariant, asynchronous multipath channel for each user, the total received signal is

$$r(t) = \sum_{k=1}^{K} x_k(t) \otimes g_k(t) + n(t),$$ \hspace{1cm} (4)

where $g_k(t)$ denotes the multipath channel of user $k$, $n(t)$ is a zero mean additive white gaussian noise (AWGN) with variance $\sigma_n^2$ and $\otimes$ denotes convolution.

The receiver side is shown in Fig. 1(b). The received signal (4) is chip-rate sampled ($f_s = 1/T_s$) after the UWB pulse matched filtering and stacked over one symbol duration. Considering the spreading gain $N_s$ and the maximum channel length $L$ related to maximum delay spread, the received baseband signal vector with length $N_s + L - 1$ is given by

$$r(m) = \sum_{k=1}^{K} b_k(m) h_k + n(m) = b_1(m) h_1 + u(m) \hspace{1cm} (5)$$

where

$$u(m) = \sum_{k=2}^{K} b_k(m) h_k + n(m).$$ \hspace{1cm} (6)

Here, $h_k$ is called as the ‘effective spreading code’ of the $k$th user

$$h_k = C_k g_k \hspace{1cm} (7)$$

where $C_k \in \mathbb{R}^{(N_s+L-1) \times L}$ is the code filtering matrix which is composed of the delayed version of the spreading code of user $k$

$$C_k = \begin{bmatrix}
    c_k(0) & 0 & \cdots & c_k(0) \\
    \vdots & \ddots & \vdots \\
    c_k(N-1) & \cdots & c_k(N-1) \\
    0 & \cdots & 0
\end{bmatrix} \hspace{1cm} (8)$$

and $g_k$ is the $k$th user’s channel response as

$$g_k = [g_{k,0} \ g_{k,1} \ \cdots \ \ g_{k,(L-1)}]^T \hspace{1cm} (9)$$

We consider an MMSE criterion to find out the receiver vector $w_h$, given by

$$J(w_h) = E\left\{\left(w_h^T(m) r_h(m) - \sqrt{\beta_1} \hat{b}_1(m)\right)^2\right\} \hspace{1cm} (10)$$

where $r_h(m) = r(m) - \sqrt{\alpha_1} \hat{b}_1(m) C_k g(m-1)$ is the signal that is obtained to minimize the interference caused by the user 1’s informative sequence during the adaptation using a hidden training sequence. By utilizing one step prediction method, we can estimate $\hat{b}_1(m)$. From here, $g(m)$ should be a user 1’s channel response, $g_1$ which can be obtained using the cost function below:

$$J(g) = E\left\{\left(r_h(m) - \sqrt{\beta_1} \hat{b}_1 P_1(m) C_1 g(m)\right)^2\right\}. \hspace{1cm} (11)$$

The solution of $g(m)$ can be represented as follows:

$$g(m) = \frac{1}{\beta_1} (C_1^T C_1)^{-1} E\left\{\sqrt{\beta_1} \hat{b}_1 P_1(m) C_1^T r_h(m)\right\}. \hspace{1cm} (12)$$

After $r_h(m)$ is obtained, the filter tap weight vector $w_h(m)$ which minimizes (10) is derived as

$$w_h(m) = \beta_1 R_{r_h}(m)^{-1} C_1 g(m) \hspace{1cm} (13)$$

where $R_{r_h}(m) = E\{r_h(m) r_h^T(m)\}$.

Then, the estimated symbol of the desired user is obtained by

$$\hat{b}_1(m) = \text{sign}\left\{w_h^T(m) \left[r(m) - \sqrt{\alpha_1} \hat{b}_1(m) \hat{h}_1(m-1)\right] \right\}. \hspace{1cm} (14)$$

III. ADAPTIVE IMPLEMENTATION

Using the standard RLS algorithm, we have the RLS implementation of the filter tap weight vector $w_h(m)$ as follows:

[Step 1]

$$\hat{z}(m) = r(m) - \sqrt{\beta_1} b_1 P_1(m) \hat{b}_1(m-1)$$

$$\hat{b}_1(m) = \text{sign}\left\{\hat{w}_h(m-1)^T \hat{z}(m)\right\}$$

$$\hat{r}_h(m) = r(m) - \sqrt{\alpha_1} \hat{b}_1(m) \hat{h}_1(m-1)$$

[Step 2]

$$k(m) = \frac{P(m-1) \hat{r}_h(m)}{\nu + \hat{r}_h^T(m) P(m-1) \hat{r}_h(m)}$$

$$\xi(m) = \sqrt{\beta_1} b_1 P_1(m) \hat{w}_h^T(m-1) \hat{r}_h(m)$$

$$\hat{w}_h(m) = \hat{w}_h(m-1) + k(m) \xi(m)$$

$$P(m) = \frac{1}{\nu} \left[P(m-1) - k(m) \hat{r}_h^T(m) P(m-1)\right]$$

where $0 < \nu < 1$ is the forgetting factor. The algorithm can be initialized by $\hat{w}_h(0) = 0$ and $P(0) = \delta^{-1} I$ where $\delta$ is a large positive number.

Based on (12), we can also derive the RLS implementation of the channel vector $g(m)$ can be derived as shown below:

$$\hat{z}_g(m) = \hat{z}_g(m-1) + \left[\sqrt{\beta_1} b_1 P_1(m) C_1^T \hat{r}_h(m)\right]$$

$$\hat{g}_1(m) = \frac{1}{m} \left[\frac{1}{\beta_1} (C_1^T C_1)^{-1} \hat{z}_g(m)\right]$$

$$\hat{g}(m) = \frac{\hat{g}_1(m)}{\|\hat{g}_1(m)\|}$$

$$\hat{h}_1(m) = C_1 \hat{g}(m).$$

The initialization will be given as $\hat{g}(0) = [1, 0, \cdots, 0]^T$ and $\hat{z}_h(0) = 0$. 
We present simulation results for the performance of a DS-CDMA system with i) ideal All-RAKE receiver with Maximum Ratio Combining (MRC), ii) perfectly trained MMSE receiver, iii) proposed MMSE receiver using the hidden training sequence, iv) blind Minimum Variance receiver. In the case of the proposed receiver, $\alpha_1 = 0.9$ and $\beta_1 = 0.1$. We simulate an asynchronous BPSK DS-SS system with length 31 spreading codes (Gold sequences are used). The pulse duration is 0.75 ns and sampling rate is 1.33 GHz (chip rate sampling). For each experiment, each user undergoes the multipath UWB channels that are randomly selected from 100 UWB channel realization reported in [10]. The channel is a non-line-of-sight (NLOS) channel which is channel model 2 in [10]. We examine the performance for the following cases: a) no multiple access interference (MAI), b) multiple DS-CDMA UWB signals. The multiple-access interference from other UWB users are operating in a DS-CDMA network with and without near-far effect. Simulations represent the BER after averaging over 50 realizations. BER is counted after receivers are converged.

The All-RAKE receiver with the MRC method captures all multipath energy and is not practically implementable, but is included as a bound to RAKE performance. We assume that the channel information needed for MRC is perfectly known. The receiver in ii), iv) are implemented adaptively using recursive least square (RLS) algorithms [9].

In Fig. 2(a), the All-RAKE receiver with MRC shows almost idealized performance in the single-user NLOS UWB channel environment. The blind MV receiver is a poor performer, while the perfectly trained MMSE shows the best possible performance which is very close to the performance of the All-RAKE receiver. The proposed receiver shows the performance close to the perfectly trained MMSE and much higher than the blind MV receiver. Figure 2(b) shows the BER curve according to the number of users with and without near-far effect (In the near-far case, the received power of the interfering signals is 5 dB larger than the desired signal) when $SNR = 10 \text{ dB}$. In the presence of MUI, the performance of the All-RAKE receiver is getting worse as the number of users increases. However, the perfectly trained MMSE and the proposed receivers show the best and relatively better performance than the others, respectively. The blind MV receiver shows the worst performance. We can also see that the multiuser detection schemes such as the MMSE, proposed and MV receivers show more near-far resistance than the All-RAKE receiver.

V. Conclusion

In this paper, we proposed a new type of the multi-user detection scheme using a hidden training sequence. And we analyzed and demonstrated the effectiveness of the proposed receiver. Simulations were run using the IEEE 802.15.3a UWB NLOS channel model in [10]. The proposed receiver shows the performance close to the All-RAKE and the perfectly trained MMSE in the single user channel and relatively higher performance than the All-RAKE and blind MV receiver in the presence of MUI.

References

Fig. 2. BER performance

(a) Single-user NLOS UWB channels

(b) Multi-user NLOS UWB channels