An Acquisition Method Using a Code-Orthogonalizing Filter in UWB-IR Multiple Access

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Abstract - This paper proposes an acquisition method using a code-orthogonalizing filter (COF) in an ultra wideband -impulse radio (UWB-IR) multiple access communication system with time hopping / spread spectrum (TH/SS). In the COF of this system, the particular template signal of the TH system is adopted. By using a COF, multiple access interferences are suppressed, and orthogonalization of an own-sequence is achieved. Then, calculating the correlation between the coefficients of a COF and the own-sequence of in-phase, the synchronous phase can be obtained. It is shown that the proposed method can be superior to the conventional sliding correlator when the number of users increases.

Key words- UWB-IR, TH/SS, acquisition method, code-orthogonalizing filter, multiple access interference, average acquisition time

I. INTRODUCTION

In recent years, the various demands for radio communication systems have increased rapidly. Ultra wideband –impulse radio (UWB-IR) systems can realize high date rate communications using nano-second pulse of base-band. In one of UWB-IR systems, spread spectrum (SS) technique using time hopping (TH) is adopted. It is modulated by position of pulse and can be avoidable for influence of amplitude fluctuation [1][2].

In UWB/spread spectrum systems, signal acquisition is important [3][4]. A sliding correlator is well known as a conventional acquisition method in SS techniques, however, in a large multiple access interference (MAI) environment (e.g., near-far problem), synchronous acquisition using the sliding correlator will be difficult to achieve because large peaks of cross-correlation functions will appear periodically. To overcome this problem, an acquisition method with a code-orthogonalizing filter (COF) in direct sequence/ code division multiple access (DS/CDMA) system has been proposed previously [5][6]. In this method, the tap coefficients are adaptively controlled to orthogonalize to all user’s sequences including the desired user’s spreading sequence for each phase. By this method, the PN sequence acquisition can be achieved in a large MAI environment. However, it is necessary to modify for application of the UWB-IR (TH/SS) system.

In this paper, we propose a modified acquisition method using COF in an UWB-IR (TH/SS) system and compare the average acquisition time of the proposed method with that of a conventional method. In Sect. 2, we present a brief introduction to the system model of UWB-IR (TH/SS type) system. In Sect. 3, we explain the basic construction of a COF in UWB-IR, and, in Sect. 4, we propose an acquisition method using a COF for UWB-IR. Simulation results are discussed in Sect. 5. Finally, conclusion remarks are made in Sect. 6.

II. SYSTEM MODEL

An UWB-IR (TH/SS type) system is used nano-second pulse of base-band, and adopted pulse position modulation (PPM), and its own TH pattern for each user. The typical transmitter out put signal $s^{(k)}(t)$ is given by

$$s^{(k)}(t) = \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_s-1} w(t - iT_s - jT_t - b_j^{(k)}T_c - T_e) (a_i^{(k)} \oplus u_i^{(k)})$$

(1)
where

\[ w(t) = \begin{cases} 1 & \text{for } 0 < t < T_c / 2 \\ 0 & \text{otherwise,} \end{cases} \]  

\[ \text{otherwise} \]

where \( t \) is the transmitter clock time, \( w(t) \) represents the transmitted monocycle waveform (see Fig. 1), \( T_s \) is symbol duration, \( T_f \) is frame duration, \( T_c \) is chip duration of waveform, \( T_c = T_f / N_f \) (\( N_f \) : the number of chips per frame), \( N_s \) is the number of frame per data, data symbol duration is \( T_s = N_s T_f \), the whole code length is \( N_s N_f \), \( b_j^{(k)} \) is the j-th pulse position of k-th user (TH pattern), \( a_j^{(k)} \in (0,1) \) is the PN sequence of the j-th pulse position of k-th user. \( u_j^{(k)} \in (0,1) \) is the i-th data of k-th user. \( + \) means addition of modulo 2.

When the number of users is \( N_u \), the received signal \( r(t) \) is given by

\[ r(t) = N_u \sum_{k=1}^{N_u} \sum_{i=0}^{N_s-1} w(t - T_{pk}) - w(t - T_{pk} - T_c) + n(t) \]  

\[ \text{where} \]

\[ T_{pk} = T_c \left( \frac{j}{N_f} \right) \]

\[ T_{pk} + \frac{T_c}{2} \]

\[ \text{where } \tau^{(k)} \text{ is delay time (phase), and } n(t) \text{ is an additive white Gaussian noise.} \]

The template waveform in a pulse \( v(t) \) (see Fig. 2) at the receiver is given by

\[ v(t) = w(t) - w(t - T_c / 2) \]  

\[ \text{As a summation for duration } T_c, \text{ the k-th user’s template signal in a symbol } v_j^{(k)}(t) \text{ is given by} \]

\[ v_j^{(k)}(t) = N_s \sum_{j=0}^{N_s-1} v(t - \tau^{(k)} - jT_f - c_j^{(k)}T_c) \]  

The demodulation is achieved by the correlation between the received signal and the template signal (see Fig. 3). In case that data is “0”, the cross-correlation function value is plus value, in case that data is “1”, that is minus value ((c) in Fig. 3).

\[ \text{Fig. 1. Received signal.} \]

\[ \text{Fig. 2. Template signal.} \]

\[ \text{Fig. 3. Demodulation by PPM.} \]

\[ \text{III. CODE-ORTHOLOGALIZING FILTER (COF) AND ITS ALGORITHM IN UWB-IR (TH/SS TYPE)} \]

Fig. 4 shows block diagram of COF in UWB-IR (TH/SS) for suppression of MAI. In this section, the desired user’s signal (k=1) is in-phase (\( \tau^{(1)} = 0 \)). The received signal vector \( \hat{r} \) is defined as

\[ \hat{r} = \left( r_{frame}(0), r_{frame}(1), \ldots, r_{frame}(N_a - 1) \right)^T \]  

\[ \text{where } \left( \ast \right)^T \text{ denotes transposition of matrix } \ast \text{, and } r_{frame}(j) \text{ is the } j \text{-th integral value of } T_f \text{ duration. The tap coefficient vector } c \text{ is defined as} \]

\[ c = \left( c_0, c_1, \ldots, c_{N_a-1} \right)^T \]  

\[ \text{In Fig. 4, using least mean square (LMS) algorithm by unit of delay time } T_e, \text{ the tap coefficients are usually controlled to minimize the error signal } e(i) \text{ which is the difference between the decided (desired) signal } d(i) \text{ and the transversal filter output } y(i). \text{ This algorithm means the approach of orthogonalizing to received all other user’s sequences. In this paper, “to approach to orthogonalize” is represented as “to orthogonalize” for convenience of engineering sense. The signals of the i-th symbol are given by} \]
\[ y(i) = e^T(i) \hat{r}(i) \]  
(10)

\[ e(i) = d(i) - y(i) \]  
(11)

where vector \( e(i) \) and vector \( \hat{r}(i) \) are represented as the tap coefficient vector and the received signal vector of the \( i \)-th symbol, respectively. As the initial value of \( e(i) \), desired user’s sequence is set. The received signal is correlated the template signal. In every \( T_i \) seconds, the tap coefficient vector of the \((i+1)\)-th symbol is obtained by

\[ e(i+1) = e(i) + \mu e(i) \hat{r}(i) \]  
(12)

where \( \mu \) is the step size for LMS algorithm. \( e(i) \) and \( \hat{r}(i) \) are represented as \( N \)-th order vectors, and the calculation of Eq. (12) is achieved by parallel operation for each tap coefficient.

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**IV. A PROPOSED SYNCHRONOUS ACQUISITION METHOD USING A CODE-ORTHOGONALIZING FILTER IN UWB-IR (TH/SS TYPE)**

To employ the COF for an acquisition method in UWB-IR (TH/SS), the decided signal \( d(i) = 0 \) is applied for the basic COF of Fig. 4. The principle of the proposed acquisition method is explained as follows. First, the \( k \)-th user’s sequence vector \( a^{(k)} \) is defined as

\[ a^{(k)} = (a^{(k)}(0), a^{(k)}(1), \ldots, a^{(k)}(N_s - 1))^T \]  
(13)

where \( a^{(k)} \in \{+1, -1\} \)  
(14)

As a desired user, \( k = 1 \) is adopted at the receiver, we consider the difference of the received signal between “in-phase reception (\( \tau^{(1)} = 0 \))” and “out-of-phase reception (\( \tau^{(1)} \neq 0 \))” with the desired signal. Fig. 5 shows the state of tap coefficient vector both “in-phase reception” and “out-of-phase reception”. In-phase reception is the condition that the phase of the desired user’s sequence in the received signal coincides with no phase offset of the desired user’s sequence prepared at the receiver ((a) in Fig. 5). Out-of-phase reception is otherwise ((b) in Fig. 5). In this system, the tap coefficients are orthogonalized to all user’s sequences including desired user’s sequence, i.e., \( d(i) = 0 \) of Fig. 4 is applied. Then, in the case of in-phase reception, the tap coefficient vector is orthogonalized to the desired user’s sequence vector \( a^{(1)} \) which has no phase offset (i.e., \( e^T a^{(1)} = 0 \)). While in the case of the out-of-phase reception, it can be considered that the desired user’s sequence which has no phase offset does not exist in the received signal. The tap coefficient vector is orthogonalized to the desired user’s sequence vectors, \( a^{(1)}(-1), a^{(1)}(0) \), which are partial sequences divided by phase offset [5]-[7] (i.e., \( e^T a^{(1)}(-1) = 0, e^T a^{(1)}(0) = 0 \)), however, in general, the sequence vector \( a^{(1)} \) is not orthogonalized to the tap coefficient vector (i.e., \( e^T a^{(1)} \to unknown \)). Then, a proposed synchronous acquisition method is shown as follows.

1. The correlation between the received signal and the template signal is calculated. And it is input to a COF.
2. Tap coefficients \( e \) of COF are converged for the incoming signal phase.
3. The cross-correlation function value between the tap coefficients \( e \) and the desired user’s sequence with no phase offset \( a^{(1)} \) is calculated and stored to the memory.
4. Tap coefficients \( e \) of COF are converged for 0.5 chip sliding of the incoming signal.
5. The cross-correlation function value between \( e \) and \( a^{(1)} \) is calculated and stored.
6. The similar manner is achieved for next 0.5 chip sliding in order. The number of cross-correlation function values becomes \( 2N_N \).
7. The synchronous phase is decided from the phase, which takes the minimum cross-correlation function value.
V. COMPUTER SIMULATION RESULTS

Table 1 and Table 2 show specifications of simulations in the proposed acquisition method and the sliding correlator, respectively. E_b is bit energy. Channel model is AWGN with the double-sided power spectral density N_0/2. E_b/N_0 is 9.8[dB]. Signal reception symbol timing and frame timing are asynchronous, and chip timing is synchronous, conveniently. The initial tap coefficients of COF is set the desired user’s PN sequence a_0. The interval of phase sliding of proposed acquisition method is 0.5T_c. Reliability of the phase by the acquisition is more than 90%. The total number of trials is 100. Tolerance level of in-phase detection is from in-phase to ± 0.5 chip. “The method of moving averages” [8] is adapted in the convergence decision of tap coefficients. In this method, the mean square error (MSE) is averaged during “average bits” and calculated at intervals of “shift bits”. The MSE value to the previous MSE value ratio, i.e., the convergence decision parameter α, becomes more than 0.7, the convergence decision is achieved. Step size µ is 10^{-3}. The number of users is 1 to 16. SIR is represented as power ratio of desired signal to interference per user.

In the sliding correlator (Table 2), threshold level is ±7.0. The synchronous phase is decided when the threshold level is exceeded n-times continuously. n is decided to satisfy the required reliability 90[%]. The number of users, interval of phase sliding, required reliability and SIR are the same values of Table 1.

<table>
<thead>
<tr>
<th>TABLE 1 SPECIFICATION OF SIMULATION (PROPOSED METHOD).</th>
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<tr>
<td><strong>Primary modulation</strong></td>
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<td><strong>Secondary modulation</strong></td>
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<tr>
<td><strong>Code length N_s,N_f</strong></td>
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<td><strong>E_b/N_0[dB]</strong></td>
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<tr>
<td><strong>Channel model</strong></td>
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<tr>
<td><strong>Initial of tap coefficients</strong></td>
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<tr>
<td><strong>Interval of phase sliding</strong></td>
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<tr>
<td><strong>Required reliability [%]</strong></td>
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<td><strong>Average time of moving average [bits]</strong></td>
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<td><strong>Shifted time of moving average [bits]</strong></td>
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<td><strong>Convergence decision parameter α</strong></td>
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<tr>
<td><strong>Step size parameter µ</strong></td>
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<tr>
<td><strong>Number of users</strong></td>
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<td><strong>SIR [dB]</strong></td>
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<tr>
<th>TABLE 2 SPECIFICATION OF SIMULATION (SLIDING CORRELATOR).</th>
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<tr>
<td><strong>E_b/N_0[dB]</strong></td>
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<tr>
<td><strong>Threshold level</strong></td>
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<td><strong>Decision of in-phase</strong></td>
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Fig. 6 shows the average acquisition time vs. the number of users for several SIR and the comparison of sliding correlator. In the proposed method, it can be achieved that the average acquisition time is almost constant in large multiple access interference environment, because it can be suppressed the multiple access interference by using a COF. Further, the acquisition time of proposed method of SIR=0 [dB] almost coincides with that of SIR=-3 [dB]. They overlap each other. While, in the sliding correlator, the acquisition cannot be achieved when the number of users increases and interference power increases, because the peak values of cross-correlation functions become large. For example, in case that SIR is 0[dB], the average acquisition time of the proposed method is shorter than that of the sliding correlator when the number of users is more than 8. In case that SIR is −3[dB], the superiority of proposed system appears when the number of users is more than 4.

VI. CONCLUSIONS

In this paper, we have proposed an acquisition method using a COF in UWB-IR (TH/SS type) multiple access. We have presented the principle and performance evaluation of the proposed method, compared with the sliding correlator by computer simulations. As a result, we have shown that it can be achieved the synchronous acquisition by using the proposed method even in large power multiple access interference environments. For further studies, discussions of a comparison the proposed techniques with similar MUD techniques in terms of performance and complexity, a method of fast convergence of the tap coefficients in COF and the applications for several channels will be necessary.

REFERENCES