SUMMARY In this paper, a novel UWB system called pulse position controlled UWB is proposed. One of the problems in UWB systems is the restriction of data rates due to multipath. The proposed UWB system shorten the pulse interval adaptively depending on channel characteristics. It has been shown that the proposed UWB system can increase the data rate with about 30% and improve the BER at the same time.

key words: DS-UWB, pulse position control, TDD

1. Introduction

Recently, a new kind of spread spectrum communication systems called ultra wideband (UWB) has been paid large attention among researchers in the wireless communication area [1], [2]. The UWB employs a pulse called monocycle for data transmission, which has very short time duration. The main focus of the UWB systems is short range, very high rate wireless communications. It is possible to replace the cables between PCs and displays or HDDs with UWB. The one of the problems of UWB is the restriction of data rate due to intersymbol interference. The pulse can not be transmitted while the delayed pulses are still arriving to the receiver.

In this paper, a novel UWB system called pulse position controlled (PPC) DS-UWB is proposed. This UWB system employs DS spreading. Different from the conventional DS systems, the chip pulses are transmitted with unequal time intervals depending on the channel characteristics. The proposed system can increase the transmission data rate with about 30% and also reduce the BER at the same time.

This paper is organized as follows. In Sect. 2 the conventional and proposed systems are presented and their performances are derived. Section 3 shows numerical results. Our conclusions are presented in Sect. 4.

2. System Model

2.1 Conventional System

The conventional system spreads the spectrum of the data signal with M sequence. The transmitted signal is then given by

\[ s(t) = \sum_{n=-\infty}^{\infty} \sum_{i=0}^{N-1} \sqrt{P} b_i c_n z(t - iT_b - nT_c) \]  

where \( N \) is the period of the spreading sequence, \( b_i \in \{ \pm 1 \} \) is the data bit, \( c_n \in \{ \pm 1 \} \) is the spreading sequence, \( z(t) \) is the impulse waveform, \( T_b \) is the bit period, and \( T_c \) is the chip period. The received signal is expressed as

\[ r(t) = \sum_{l=0}^{L-1} a_l s(t - lT_m) + n(t) \]  

where \( L \) is the number of multipath, \( a_l \) is the amplitude of the \( l \)-th path, \( T_m \) is the pulse duration, and \( n(t) \) is the noise. In order to avoid the intersymbol interference it is assumed that \( T_c \geq LT_m \). Assuming that the channel characteristics are quasi-static, the output of the correlator to the first path of the \( m \)-th chip is then given by

\[ d_m = \int_0^{T_m} z(u)r(u + mT_c)du. \]  

The outputs of the correlator for one spreading sequence period is

\[ d = [d_0, d_1, \ldots, d_{N-1}]^T \]
\[ = a_0 \sqrt{P} b_1 [c_0, c_1, \ldots, c_{N-1}]^T + [n_0, n_1, \ldots, n_{N-1}]^T \]  

where \( B_s \sim 1/T_m \) is the frequency bandwidth of the pulse. The noise component, \( n_m \), is

\[ n_m = \int_0^{T_m} z(u)n(u + mT_c)du \]  

and its variance is given as \( \sigma^2 = N_0/B_s \). The BER is given by

\[ P_b = \frac{1}{2} \text{erfc}\left( \sqrt{c^T c \frac{a_0^2 P T_m}{N_0}} \right) = \frac{1}{2} \text{erfc}\left( \sqrt{E_b \frac{N_0}{N_0}} \right) \]  

where \( c^T = [c_0, c_1, \ldots, c_{N-1}] \), and \( E_b = a_0^2 N P T_m \).

2.2 Proposed System

It is assumed in the proposed system that the channel response of the specific delay is known or can be measured at the transmitter side. This can be achieved as UWB may be
used as the replacement of cables between PCs and peripheral devices such as displays or printers. At the beginning of the data transmission, these devices transmit the packets to make connections. Through the procedure, the transmitters can measure the channel responses.

Suppose that \( a_L \) is known to the transmitter, where \( L/2 < L' < L \). The interval between the pulsed can be then shortened as follows.

- \( a_0 a_L \leq 0 \):
  - if \( c_n c_{n+1} > 0 \), the pulse interval between \( c_n \) and \( c_{n+1} \) is set to \( T_c \).
  - if \( c_n c_{n+1} < 0 \), the pulse interval between \( c_m \) and \( c_{m+1} \) is set to \( L'T_m \).

- \( a_0 a_L > 0 \):
  - if \( c_n c_{n+1} > 0 \), the pulse interval between \( c_n \) and \( c_{n+1} \) is set to \( T_c \).
  - if \( c_n c_{n+1} < 0 \), the pulse interval between \( c_n \) and \( c_{n+1} \) is set to \( L'T_m \).

Therefore, it is possible to increase the maximum data rate. It is also possible to improve the SNR at the output of the correlator as the amplitude of the first pulse is enhanced with the delayed pulse from \( a_0 \) to \( a_0 + a_L \).

An example of the pulse intervals of the conventional and proposed systems are shown in Fig. 1. Here, it is assumed that \( T_c = 4T_m \). In the conventional system the pulse interval is always \( T_c \), which is set as \( 4T_m \) in this example. On the other hand, in the proposed system, as \( a_0 a_L > 0 \), the pulse interval between \( c_0 \) and \( c_1 \) is set to the conventional one between \( a_0 \) and \( a_L \) since the multipath component increases the received pulse amplitude. Thus, it is also possible to improve the BER performance.

The amount of data rate increase depends on the spreading sequence and the channel condition. If \( M \) sequences with the length of \( 2^k - 1 \) are used for spreading, the amount of data rate increase is \( N/(N - N_g(L - L'))/L \) when \( N_g \) is the number of shortened intervals that is given as

\[
\text{Fig. 2 BER vs. } E_b/N_0 \text{ of the 1st path.}
\]

\[
\text{when } a_0 a_L \geq 0, N_g = \sum_{k=1}^{L'} 2^{k-2} - i + (k - 1),
\]

\[
\text{when } a_0 a_L < 0, N_g = 2^{(k-1)} - 1.
\]

For example, if the length of spreading is 31, \( N_g \) is 15. Thus, the data rate increases with 1.32 times where \( L = 4 \) and \( L' = L/2 \).

If the received amplitude of \( N_g \) pulses are enhanced by the \( L' \)-th path component, the BER is improved as

\[
P_{\text{im}} = \frac{1}{2} \text{erfc} \left( \sqrt{\frac{1 + N_g a_L}{N a_0}} \right) \left( \frac{E_b}{N_0} \right). \tag{7}
\]

3. Numerical Results

The following conditions are assumed. The period of the spreading sequence, \( N = 31 \), the chip period, \( T_c = LT_m = 20 [\text{ns}] \). Exponential delay profile is assumed and the delay spread is 10 [\text{ns}] . \( N_g \) is then 15, \( L' \) is set to \( L/2 \), and then \( a_L = \sqrt{L'} \). The BER is given as

\[
P_{\text{im}} = \frac{1}{2} \text{erfc} \left( \sqrt{\frac{1 + \sqrt{15}/31}{N_0}} \right) \left( \frac{E_b}{N_0} \right). \tag{8}
\]

Figure 2 shows the BER performance of the conventional and the proposed DS-UWB systems. It is clear that the proposed system can improve \( E_b/N_0 \) by 2.2 [dB].

4. Conclusions

In this paper, a novel UWB system called pulse position controlled UWB is proposed. It has been shown that the proposed UWB system can increase the data rate with about 30% and improves the BER at the same time.

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