A Novel M-ary Code-Selected Direct Sequence BPAM UWB Communication System

Zhiquan Bai and Kyungsup Kwak

ABSTRACT—In this letter, a novel M-ary code-selected direct sequence (DS) ultra-wideband (UWB) communication system is presented. Our purpose is to achieve a high data rate by an M-ary code-selected direct sequence bipolar pulse amplitude modulation (MCSDS-BPAM) scheme. In this system, a particular DS code sequence is selected by the $\log_2 M/2$ bits from the DS gold code set. This scheme can accomplish both a high data rate without increasing the system bandwidth or changing the pulse shape and improve the BER with an increase of modulation level M even at a lower signal-to-noise ratio (SNR). The receiver signal processing algorithm is given for an MCSDS-BPAM UWB system over an ideal AWGN channel and correlation receivers.

Keywords—Direct sequence spread spectrum (DSSS), ultra wideband (UWB), bipolar pulse amplitude modulation (BPAM).

I. Introduction

Ultra-wideband (UWB) communication systems were proposed in [1] and [2] and have attracted a lot of attention for indoor high-rate communications due to their advantageous characteristics. Because of a large bandwidth, UWB technology can achieve high throughput, is robust to co-channel interference and narrowband jammers, and has a greater ability in realizing spectrum sharing. High capacity can be achieved with much lower transmission power levels. In a UWB system, a data bit is transmitted using sub-nanosecond baseband pulses without the need for mixers, and the occupied frequency band is from near DC to several GHz.

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In wireless communications, a high data rate and high transmission quality are the two key system requirements. The common M-ary modulation scheme in a UWB system is M-ary pulse position modulation PPM, which is proposed in [3]. In this scheme, the data rate is improved at the expense of bandwidth expansion, and the receiver is composed of M correlators. Biorthogonal pulse shape modulation (BPSM) in [4] can be seen as another M-ary modulation UWB system. These two schemes increase system complexity or bandwidth expansion.

In this letter, without changing the pulse shape and the transmission bandwidth, a new M-ary modulation method is proposed based on direct sequence (DS) codes and bipolar pulse amplitude modulation (BPAM). Compared with the conventional DS-BPAM UWB system, the proposed scheme transmits extra $\log_2 M/2$ data bits by selecting one of the $M/2$ DS codes. In the receiver end, the transmitted signal is detected by using $M/2$ correlators in which the processing complexity is moderate and acceptable.

II. System Description

In this section, we present an MCSDS-BPAM modulation scheme as shown in Fig. 1. We consider a DS code set composed of $\{C_0, C_1, \ldots, C_{M/2-1}\}$, where $C_k=\{c_{k,0}, c_{k,1}, \ldots, c_{k,(N_c-1)}\}$ and N_c is the length of the spread code ship. While one bit is transmitted using BPAM, a particular DS code sequence from the DS code set is selected with the length of $\log_2 M/2$ bits. Assuming that the data rate of the conventional DS-BPAM UWB system [5] is R_b, then the proposed scheme can achieve the rate by $R=(1+\log_2 M/2)R_b$, which is improved by a factor of $(1+\log_2 M/2)$.

The transmitted signal processing diagram can be seen in Fig.1. We assume that the transmitted bits are grouped by $\{m_j,$

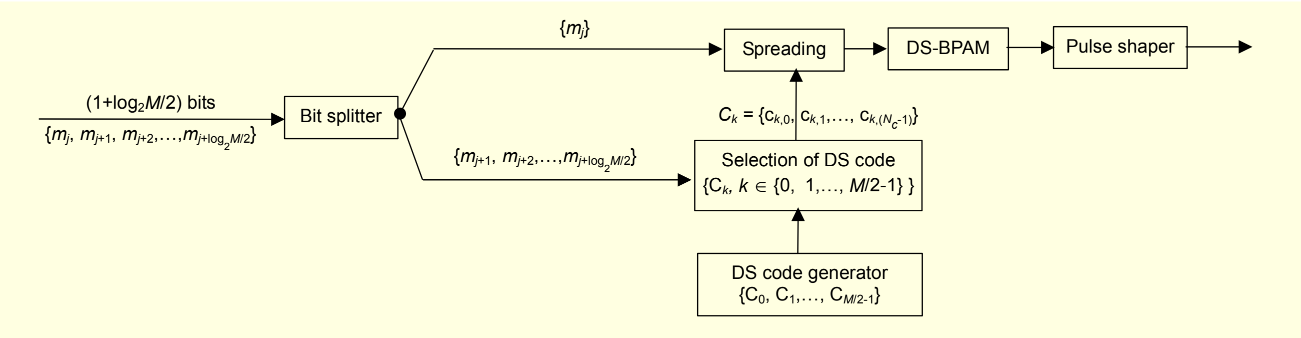

Fig. 1. Transmission diagram of an MCSDS-BPAM UWB system.

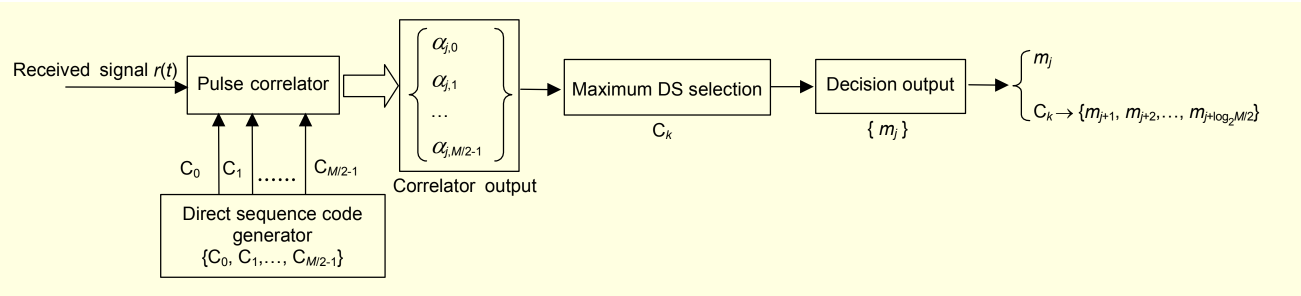

Fig. 2. Receiver diagram of an MCSDS-BPAM UWB system.

$m_{j+1}, m_{j+2},\ldots, m_{j+\log_2 M/2}\}$ with $m_j \in \{0, 1\}$, where m_j is the information bit that will be spread and modulated by BPAM, and $\{m_{j+1}, m_{j+2},\ldots, m_{j+\log_2 M/2}\}$ are used to select the code from the DS code set. We set

$$k = \sum_{i=1}^{b} m_{j+i} 2^{b-i} \text{ with } b=\log_2 M \tag{1}$$

The transmitted signal, based on information bit m_j and the selected code sequence C_k, is given by

$$s_{tr}(t) = \sum_{j=-\infty}^{\infty} \sum_{n=0}^{N_c-1} d_j c_{k,n} w_{tr}(t - jT_f - nT_c), \tag{2}$$

where $w_{tr}(t)$ is the transmitted monocycle waveform as in [1] and [2]. Symbol d_j is the modulated data symbol with d_j=2m_j−1, T_f is the frame time, and $\{c_{k,n}\}$ is the spread chips with duration T_c.

Since the ideal channel and receiving antenna system are known to modify the shape of transmitted monocycle $w_{tr}(t)$ to $w_{rec}(t)$ at the receiver antenna output, we assume that the true transformed pulse shape, $w_{rec}(t)$, is known at the receiver. Hence, the received signal $r(t)$ can be expressed as

$$r(t) = A_1 s_{rec}(t-\tau_1) + n(t), \tag{3}$$

where

$$s_{rec}(t) = \sum_{j=-\infty}^{\infty} \sum_{n=0}^{N_c-1} d_j c_{ln} w_{rec}(t - jT_f - nT_c), \tag{4}$$

A_1, τ_1, represents the channel attenuation and the channel delay corresponding to the transmitter, respectively, and $n(t)$ is the AWGN modeled as $N(0, \sigma_n^2)$. In this letter, we only consider the AWGN channel as the transmission impairment since we verify the feasibility of the propose scheme.

III. Receiver Signal Processing and Analysis

The transmitted data bits can be recovered by the optimum receiver as shown in Fig. 2. The receiver first computes the output of the correlator using M/2 possible DS codes. In the receiver end, the templates can be set as

$$v_{bit}(t) = \sum_{n=0}^{N_c-1} c_{k,n} w_{rec}(t - jT_f - nT_c - \tau_1), \tag{5}$$

for $k = 0,1,\ldots, M/2-1$.

The correlator output for the j-th bit pair can be expressed as

$$\begin{aligned} \alpha_{j,k} &= \int_{\tau_1 + jT_f}^{\tau_1 + (j+1)T_f} r(t) v_{bit}(t) dt \\ &= \int_{\tau_1 + jT_f}^{\tau_1 + (j+1)T_f} r(t) \sum_{n=0}^{N_c-1} c_{k,n} w_{rec}(t - \tau_1 - jT_f - nT_c) dt \end{aligned} \tag{6}$$

for $k = 0,1,\ldots, M/2-1$.

For the first symbol received, $\{\alpha_{j,k}\}$ for k=0,1,…, M/2-1 is calculated as illustrated in Fig. 2. This results in M/2 correlator output values for each of the symbols received. To find the most possible outcomes of m_j and C_k, we select the maximum value of the correlator output. By maximizing $|\alpha_{j,k}|$, the corresponding selected code set C_k and also the correlator output $\alpha_{j,k}$ can be achieved, so that the decision variable for the j-th bit pair can be obtained according to C_k and $\alpha_{j,k}$. The process can be expressed as:

$$\max_k\left[|\alpha_{j,k}|\right] \Rightarrow C_k \Rightarrow \{m_{j+1}, m_{j+2},\ldots, m_{j+\log_2 M/2}\} \qquad (7)$$

$$\max_k\left[|\alpha_{j,k}|\right] \Rightarrow \alpha_{j,k} = \begin{cases} >0, \Rightarrow m_j = 1 \\ <0, \Rightarrow m_j = 0, \end{cases} \qquad (8)$$

for k = 0, …, M/2 -1.

Now, to investigate the average BER of the system, we assume that the transmitted bit pair $\{m_j, m_{j+1}, m_{j+2},\ldots, m_{j+\log_2 M/2}\}$ is to be $\{m_1, 0, 0,\ldots,0,1\}$, denoted by $\{m_1, C_1\}$. Then, the conditional average probability of error can be obtained as

$$P(error|m_1 = 1, C_1) = P\left\{\bigcup_{k=1}^{M/2} |\alpha_{j,k}| > \alpha_{j,1}\right\}. \qquad (9)$$

It is easily understood that $P(error|m_1 = 0, C_1)$ has the same result as $P(error|m_1 = 1, C_1)$ because of the symmetry of m_1. Therefore, the average probability on C_k is given by

$$P(error) = \frac{2}{M}\sum_{k=1}^{M/2} P\left\{\bigcup_{k=1}^{M/2} |\alpha_{j,k}| > \alpha_{j,1}\right\}. \qquad (10)$$

To avoid dependency among the interference, we employ the union bound. We can finally obtain the average BER by

$$P(error) \le \frac{2}{M}\sum_{k=1}^{M/2}\sum_{k'=1}^{M/2} P(|\alpha_{j,k}|_{k'} > \alpha_{j,1}). \qquad (11)$$

IV. Simulation Results

In this section, we present simulation results of the proposed system in a single user case. As in [1], the received pulse is modeled as the 2nd Gaussian pulse,

$$w_{\text{gaussian}}(t) = \left[1 - 4\pi\left(\frac{t}{\tau_m}\right)^2\right]\exp\left[-2\pi\left(\frac{t}{\tau_m}\right)^2\right],$$

shown in Fig. 3, where $\tau_m = 0.2$ ns and T_w=0.5 ns. The DS code we employed is a gold code sequence with the characteristics of N_c=15 and T_c = 1 ns. The information rate is R=$R_b\log_2 M$ Mbps with R_b=1/($N_c T_c$). The BER performance of the MCSDS-BPAM systems is shown in Fig. 4. In the simulation, the numbers of the modulation level are assumed to be M = 2, 4, 8, and 16. In the case of M = 2, the MCSDS-BPAM system becomes a conventional DS-BPAM system. When M=8, 16 with the required BER of 10^{-4}, the proposed scheme can achieve more than 1 and 2 dB gains, respectively, compared to DS-BPAM. From the analysis and simulation results, the performance of the proposed MCSDS-BPAM scheme outperforms the traditional DS-BPAM UWB scheme with the increase of M and moderate system complexity.

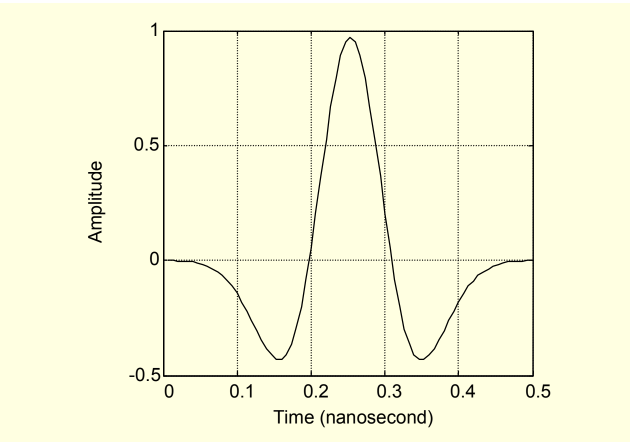

Fig. 3. Gaussian waveform.

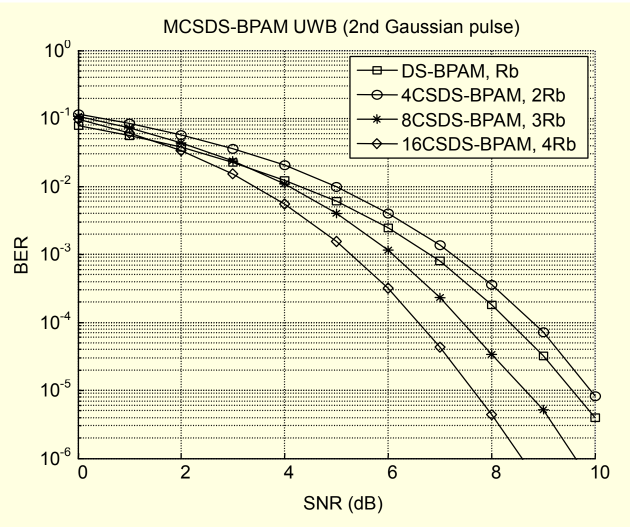

Fig. 4. BER performance of MCSDS-BPAM UWB with 2nd Gaussian pulse.

V. Conclusions

In this letter, a novel MCSDS-BPAM is presented. The simulation results show that our proposed system can achieve better performance in BER compared to the conventional M-ary modulation schemes. It is also shown that the information bit rate of the proposed system is equal to the product of $\log_2 M$ and the information rate of a DS-BPAM system. The proposed scheme is important in the sense that it can support both higher data transmission and improved BER performance with acceptable system complexity. For future analysis, the performance of the proposed method should be studied under a multi-path and multi-user environment.

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