The BER performance optimization of ultra wideband TH-PPM in a multi-path environment

Abstract This paper is focuses on the unbalanced bit error rate (BER) for different transmitted data symbols of ultra wideband (UWB) impulse radio time-hopping pulse-position-modulation (TH-PPM) in a deterministic multi-path environment for unreasonable parameter selection. Two solutions are presented here. The first is that the decision threshold of RAKE is dynamic for different channel environments; the other is that we can improve the traditional TH-PPM modulation, which is, encoding the transmitted data symbol with balance code. It is shown by theoretical analysis and computer simulation that these two methods can solve the unbalanced BER of traditional TH-PPM. Compared with the dynamic threshold method, the balance encoding scheme can be implemented more easily, and is more robust to the channel time variant characteristics, the channel estimation of RAKE receiver and the combination techniques.

Keywords ultra wideband radio, performance optimization, dynamic threshold, balance encoding

1 Introduction

UWB communication techniques have attracted a great interest in both academia and industry in the past few years. Following the re-definition of UWB signal given by the FCC [1], communication techniques of UWB radio developed from impulse radio (IR) to the co-existence of three techniques, IR, MB-OFDM and DS-CDMA, two of which, MB-OFDM and DS-CDMA, were included in the main proposal for IEEE 802.3a standard. IR has received significant attention during the establishment of the IEEE 802.3a standard due to its potential advantages such as simple system structure, low cost and low power. This technique plays an important part in future short distance, high rate wireless communication of especially for extending the Internet, WPAN, mobile wire-less network and wireless multimedia, which has a tremendous wide foreground for applications.

IR-UWB is a non-sine system that conveys information with pulses of very short duration, whose characteristics through multi-path propagation have great differences from the conventional radio. Thus, special attention should be paid, for example, on its penetrating characteristics. Experiments were performed in Refs. [2, 3] to measure the characteristics of UWB signal through multi-path propagation both indoor and outdoor. At present, the channel model for indoor UWB communication has been defined basically [4]; The methods to select UWB signal in indoor environment are given in Ref. [5], while the problem about capturing energy from the received signal in a multi-path environment for UWB signal was analyzed in Ref. [6].

As the most classical modulation of IR-UWB communication, TH-PPM has been researched in many papers. In Refs. [7, 8] we mainly discussed about the BER performance of signal modulated by TH-PPM, and pointed out that under the condition of deterministic multi-path channel, the BER would become imbalance between ‘0’ and ‘1’ while adopting TH-PPM receiver with zero-cross detection. Different performances of multi-path combination methods while adjudging symbols with the RAKE receiver adopting zero-cross detection were discussed in Ref. [9]. Because the IR signal consists of tremendous numbers of multi-path components, multi-finger RAKE receiver will improve the system complexity, so we propose two methods to improve the performance of TH-PPM modulation based on
2 Signal model and structure of receiver

2.1 Classical modulated signal by TH-PPM

Transmitted waveform modulated by TH-PPM [9] is

\[ S_m(t) = \frac{1}{N_k} \sum_{j=0}^{N_k-1} w(t - j t_f - C_j t_c - \delta) \]  

(1)

where superscript \( k \) represents the \( k \)th user of the system; \( w(t) \) is the transmitted monocycle pulse, and the pulse duration time is \( w_0 \); \( t_f \) is the pulse repetition time, and \( w_0 << t_f \); \( C_j = C^{(i)}_{j} \) is the \( j \)th code of the \( j \)th user’s PN code, where \( m = 0,1,2, \cdots, N_k \) represents the PN code cycle period, and \( 0 < C_j \leq N_k \); \( N_k \) is maximum of \( C^{(i)}_{j} \), and \( N_k t_c < t_f \); \( t_c \) is the unit delay of the transmitted pulse constrained by the PN code; \( \delta \) is the unit delay of the transmitted pulse constrained by the binary code (also noted as modulation index), \( d \in \{0,1\} \), and a binary code is transmitted every \( N_k \) monocycle pulses. The bandwidth of the monocycle pulse is \( B_c = 1/w_0 \), the duration time of every bit symbol is \( T_m = N_k t_f \), and the information transmitting speed is \( R_s = 1/T_m \). The modulation index \( \delta \), the unit delay of the transmitted pulse \( t_c \) constrained by the PN code and the pulse duration time \( w_0 \) are at the same level quantitatively. The normalized self-correlation function of \( w(t) \) is:

\[ R(\tau) = \frac{\int_{-\infty}^{\infty} w(t) w(t - \tau) dt}{\int_{-\infty}^{\infty} w^2(t) dt} \]  

(2)

The energy of every bit is:

\[ E_b = \int_{-\infty}^{\infty} S^2_m(t) dt \]  

(3)

2.2 The receiver structure

We adopt the UWB indoor channel model proposed by the IEEE 802.15.3a working group [4] as our channel model, and the impulse response of the channel is:

\[ h(t) = \sum_{l=0}^{L-1} a_l \delta(t - \tau_l) \]  

(4)

where \( a_l \) represents the amplitude decline and \( \tau_l \) represents the time delay of the \( l \)th multi-paths component. They are all real. \( L \) is the multi-paths number, and the maximal multi-paths component time delay \( \tau_l \). Here we assume \( \tau_l \geq T_p \), \( \forall l \neq k \), where \( T_p \) is the width of \( w(t) \), because two paths with relative time delay less than a pulse width can not be resolved by the RAKE receiver. Thus, without consideration of pulse waveform distortion, the received signal is

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

(5)

where \( n(t) \) is the gauss white noise with bilateral power spectrum density \( N_0/2 \). The RAKE receiver structure is shown in Fig. 1. Where \( \beta_m \) and \( \tau_n \) represent the decline and time delay of the mth finger of the receiver, respectively.

![Fig. 1 Structure of UWB RAKE receiver](image)

3 The imbalance BER of TH-PPM

The conditional BER performance of the output data by the zero-cross detection is proposed in Ref. [8], when the ‘0’ is transmitted, the decision threshold is

\[ U_0 = E_b \sum_{m=0, \alpha}^{M-1} a_m \beta_m \{1 - R(\delta)\} \]

\[ - E_b \sum_{m=0, \alpha}^{M-1} \sum_{l=0, \alpha}^{L-1} a_m \beta_m R(t_c - \tau_n - \delta) + \xi \]  

(6)

where \( \xi \sim N \left( 0, N_b E_b (1 - R(\delta)) \sum_{m=0}^{M-1} \beta_m^2 \right) \)

The BER performance of the RAKE receiver is

\[ P(1/0) = \frac{K_0}{\sqrt{N_b E_b [1 - R(\delta)] \sum_{m=0}^{M-1} \beta_m^2}} \]  

(7)

\[ K_0 = E_b \sum_{m=0, \alpha}^{M-1} a_m \beta_m \{1 - R(\delta)\} \]

\[ - E_b \sum_{m=0, \alpha}^{M-1} \sum_{l=0, \alpha}^{L-1} a_m \beta_m R(t_c - \tau_n - \delta) \]  

(8)

When the ‘1’ is transmitted, the decision threshold is

\[ K_0 = E_b \sum_{m=0, \alpha}^{M-1} a_m \beta_m \]  

\[ - E_b \sum_{m=0, \alpha}^{M-1} \sum_{l=0, \alpha}^{L-1} a_m \beta_m R(t_c - \tau_n - \delta) \]  

\[ P(0/1) = \frac{K_0}{\sqrt{N_b E_b [1 - R(\delta)] \sum_{m=0}^{M-1} \beta_m^2}} \]  

(9)

\[ K_0 = E_b \sum_{m=0, \alpha}^{M-1} a_m \beta_m \{1 - R(\delta)\} \]

\[ - E_b \sum_{m=0, \alpha}^{M-1} \sum_{l=0, \alpha}^{L-1} a_m \beta_m R(t_c - \tau_n - \delta) \]  

(10)

When the ‘1’ is transmitted, the decision threshold is

\[ P(1/0) = \frac{K_0}{\sqrt{N_b E_b [1 - R(\delta)] \sum_{m=0}^{M-1} \beta_m^2}} \]  

(11)

\[ K_0 = E_b \sum_{m=0, \alpha}^{M-1} a_m \beta_m \]  

\[ - E_b \sum_{m=0, \alpha}^{M-1} \sum_{l=0, \alpha}^{L-1} a_m \beta_m R(t_c - \tau_n - \delta) \]  

(12)