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Performance of orthogonal based modulation schemes for TH-UWB communication systems

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Abstract: This paper describes a combined modulation scheme for TH-UWB radio systems using on-off keying (OOK) and pulse shape modulation (PSM). For this scheme, a set of orthogonal pulses is used to represent bits in a symbol. These orthogonal pulses are transmitted simultaneously in the same time slot resulting in a composite pulse. The proposed transmission scheme can achieve higher data rate by using fewer number of pulses and receiver correlators than PSM. Due to the presence of OOK, the proposed scheme requires minimum energy and is applicable for energy constrained TH-UWB systems.

Keywords: combined modulation scheme, multi-user interference, on-off keying and pulse shape modulation

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

The successful deployment of time-hopping Ultra Wideband (TH-UWB) radio systems strongly depends on the development of pulses, modulation techniques and low complexity receivers. The major challenge is in the selection of appropriate modulation scheme for the system design. Due to the robustness against multi-user interference (MUI) and inter-symbol interference (ISI), pulse shape modulation (PSM) can be considered as a suitable choice for TH-UWB radio systems [1]. However, due to speculative autocorrelation property of higher order orthogonal pulses, PSM cannot be used for higher-level modulation schemes. This is because PSM requires more number of correlators in the receiver, and this increases the system complexity.

To address this problem, combined forms of PSM scheme such as bi-orthogonal [2], 2PPM-PSM and BPSK-PSM have been proposed to transmit the same amount of data by using few number of orthogonal pulses [3, 4]. It is noted that BPSK-PSM uses multipulse within one time frame, whereas bi-orthogonal uses single pulse. The other objective for combined modulation schemes is that they are able to reduce the number of spectral spikes in TH-UWB signal, which helps the TH-UWB system to coexist with narrowband systems without significant interference [3]. Due to polarity dependent property of bi-orthogonal modulation and BPSK-PSM, it is difficult to design of antipodal signal for orthogonal pulses [5]. Due to the presence PPM, the ISI and MUI issues resurface in the 2PPM-PSM modulation scheme, which can severely affect the system performance in multi-path environments [6]. Since this modulation uses 2PPM with PAM, recovering of signals at the receiver is complicated in the presence of multipath, since signals are at different amplitude levels and at different time position (simple PPM) [3, 6]. 2PPM-PSM and BPSK-PSM require coded modulations and guard time interval that increase the complexity of system design [3]. Most of the PSM and its combined schemes have been analyzed in AWGN channel model [2, 3].

To deal with these challenges, a new combined modulation scheme based on OOK and PSM for M-ary modulation scheme is proposed to reduce system complexity. The paper also discusses the usefulness of orthogonal pulses in a multi-user environment. It is also known that orthogonal pulses are more susceptible in multi-path channel. Therefore, BER performance of proposed scheme is analyzed through computer simulation in modified IEEE 802.15.3a S-V UWB multi-path channel model [7]. To compare it with other schemes,

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Table I. Transmitted pulses for 2-bit symbol.

4-ary	T_f		Transmitted pulses
	$h_0(t)$	$h_1(t)$	
00	Off	Off	None
01	Off	On	$h_1(t)$
10	On	Off	$h_0(t)$
11	On	On	$h_0(t) + h_1(t)$

existing PSM and its combined modulation schemes are also analyzed in multipath channel model.

2 Proposed combined modulation scheme

The proposed method maps a set of message bits or a symbol into one or more orthogonal pulses by on-off keying. The number of pulses in each symbol depends on the number of non-zero bits. This method transmits the same number of symbols using fewer pulses and requires fewer correlators than those used in conventional PSM and its combined schemes [1, 2]. Table I shows an example of 2-bit symbol transmission and the corresponding transmitted pulses. From the table, it can be seen that in general, N orthogonal pulses are required for N-bits (number of symbols=2^N) transmission. These N independent bits can be sent at the same time by assigning different orthogonal pulses. Each pulse can be recovered from the composite pulses by exploiting its correlation properties. The proposed scheme provides low design complexity due to fewer number of pulses and receiver correlators than those use in PSM. Moreover, it does not require a large number of orthogonal pulses for higher-level modulation scheme. Another advantage is that it can coexists with overlapping NB systems without significant interference due to the presence of fewer spectral spikes [3, 8].

3 Transmission and detection procedure

The combined OOK and PSM modulated signal of the k^{th} user for the i^{th} symbol can be defined as

$$s_i^{(k)}(t) = \sqrt{E_{tx}^{(k)}} \sum_{j=0}^{Ns-1} \mathbf{a}_i \mathbf{h}_N(t - jT_f - c_j^{(k)} T_c) \tag{1}$$

where $E_{tx}^{(k)}$ is the transmitted power of k^{th} user, $i = 0, 1, \ldots, 2^N$., and

$$\mathbf{h}_N(t) = [h_0(t)\ h_1(t) \cdots h_{N-1}(t)]^T \tag{2}$$

is N dimensional column vector contains N orthogonal pulses for N-bit symbol transmission, $\mathbf{a}_i$ is the N-bit row data vector for the i^{th} symbol. The received signal for any symbol can be written as

$$r(t) = \sum_{k=1}^{N_u} \sqrt{E_{rx}^{(k)}} \sum_{j=0}^{Ns-1} \mathbf{a}_i \mathbf{h}_N(t - jT_f - c_j^{(k)} T_c - \tau^{(k)}) + n(t) \tag{3}$$

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where N_u is the total number of users, $E_{rx}^{(k)}$ is the received power of the k^{th} user, τ^k is the time delay for k^{th} user, and $n(t)$ is the AWGN. The decision statistics of the desired user (say, user one) can be written as

$$\begin{aligned}\mathbf{y_1} &= \sum_{k=1}^{N_u}\sum_{j=0}^{N_s-1}\int_{jT_f}^{(j+1)T_f}\left(\sqrt{E_{rx}^{(k)}}\mathbf{a}_i\mathbf{h}_N(t-jT_f-c_j^{(k)}T_c-\tau^{(k)})+n(t)\right)\\ &\qquad\qquad\qquad\qquad \times \mathbf{h}_N(t-jT_f-c_j^{(1)}T_c)dt \qquad (4)\\ &= [Z_0\ Z_1\cdots Z_{N-1}]^T\end{aligned}$$

where N_s is the number of pulse repetitions for each symbol, $\mathbf{h_N(t)}$ is the vector of template signal, Z_l is the independent test statistic of l^{th} correlator. The value of Z_l can be expressed as the sum of the desired signal, MUI and noise as

$$Z_l = Z_{l,s} + Z_{l,mui} + Z_{l,n} \qquad (5)$$

For analysis, it is assumed that perfect synchronization exists between transmitter and reference receiver. For user 1 assuming $1\tau^1 = 0$ and l^{th} bit is non zero element. The desired $Z_{l,s}$, $Z_{l,mui}$ and $Z_{l,n}$ can be expressed as

$$Z_{l,s} = \sum_{j=0}^{N_s-1}\int_{jT_f}^{(j+1)T_f}\sqrt{E_{rx}^{(1)}}h_l(t-jT_f-c_j^{(1)}T_c))h_l(t-jT_f-c_j^{(1)}T_c)dt \qquad (6)$$

$$\begin{aligned}Z_{l,mui} &= \sum_{k=2}^{N_u}\sum_{j=0}^{N_s-1}\int_{jT_f}^{(j+1)T_f}\sqrt{E_{rx}^{(k)}}h_n^{(k)}(t-jT_f-c_j^{(k)}T_c-\tau^{(k)}-\epsilon)\\ &\quad \times h_l(t-jT_f-c_j^{(1)}T_c)dt \qquad (7)\end{aligned}$$

$$Z_{l,n} = \sum_{j=0}^{N_s-1}\int_{jT_f}^{(j+1)T_f} n(t)h_l(t-jT_f-c_j^{(1)}T_c)dt \qquad (8)$$

where $h_l(t)$ is the template signal of the l^{th} correlator.

4 Performance in multi-user environment in AWGN channel

Under the standard Gaussian approximation, $Z_{l,mui}$ are zero-mean Gaussian random processes as characterized by variances σ_{mui}^2. As the timing jitter error, ϵ, is very small as compared to $\tau^{(k)} \in [0, N_sT_f]$, one can assume that $\tau^{(k)} + \epsilon \approx \tau$ is uniformly distributed over the interval $[0, N_sT_f]$. Therefore total interference energy from other users can be written as

$$\sigma_{l,mui}^2 = \frac{N_s}{T_f}\sum_{k=2}^{N_u}\int_0^{T_f}\left(\sqrt{E_{rx}^{(k)}}\int_0^{T_p} h_n^{(k)}(t-\tau)h_l(t)dt\right)^2 d\tau \qquad (9)$$

where T_p is the width of the pulse, $h_n^{(k)}$ is the n^{th} order pulses from the k^{th} user. If all users use the same set of orthogonal pulses, n and l take any value from the set $\{0, 1, \cdots, N-1\}$ and if all users use different subsets of orthogonal pulses from the same set then n is not equal to l. If perfect power control is available then it can be assumed that $E_{rx}^{(1)} = \cdots = E_{rx}^{(N_u)} =$

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E_{rx}. Since correlation value depends on the width of the pulses, (9) can be expressed as

$$\begin{aligned}\sigma^2_{l,mui} &= \frac{N_s}{T_f} E_{rx} \sum_{k=2}^{N_u} \int_0^{T_p} \left(\int_0^{T_p} h_n^{(k)}(t-\tau) h_l(t) dt \right) \\ &= \frac{N_s}{T_f} E_{rx} \sum_{k=2}^{N_u} \int_0^{T_p} \left(R_{l,n}^{(k)}(\tau) \right) d\tau \end{aligned} \tag{10}$$

where $R_{l,n}^{(k)}(\tau)$ denotes the correlation between l^{th} and n^{th} pulses. The term $R_{l,n}^{(k)}(\tau)$ becomes $R_{l,l}^{(k)}(\tau)$ or $R_l^{(k)}(\tau)$ if k^{th} user uses l^{th} order pulses in the given time $[0, N_s T_f]$. Due to the correlation properties of orthogonal pulses, the term $R_{l,n}^{(k)}(\tau)$ is always less than or equal to $R_{l,l}^{(k)}(\tau)$. In conventional single pulse systems, this correlation is always between the same pulses for different users, which gives significant amount of MUI which can be reduced considerably by using orthogonal pulses. The correlation values can be improved further by sharing mutually exclusive subsets of orthogonal pulses from the same set among different users. This naturally leads to a much better performance than the conventional TH-UWB radio systems using single pulse.

5 Simulation results in AWGN and multipath channel

In this section, simulation results of 2-bit symbol for PSM and its combined schemes are presented. The simulation studies are conducted in AWGN and IEEE 802.15.3a S-V UWB multi-path channel model under the assumption of perfect synchronization between transmitter and reference receiver. In multipath scenario, number of significant path is decided by taking path within 10 dB of the strongest path where number of Rake finger is 17. Since threshold value is insensitive to the number of users, a fixed threshold value $\theta_{th} = \gamma\sqrt{E_{tx}}$ has been chosen rather than adaptive optimum threshold, where γ is normalized threshold value. For multipath channel, a standard method based on [9] is used to obtain γ. The present simulation studies used $\gamma = 0.5$ for AWGN channel and $\gamma = 0.75$ for CM1 channels. All simulations have been done by using the modified Hermite pulses without any coding and guard time interval [1, 3, 4].

From Fig. 1, it can be seen that all the combined modulation schemes outperform PSM scheme. Comparing with bi-orthogonal scheme, the proposed scheme requires fewer number of pulses and receiver correlators for the same data rate. Bi-orthogonal scheme is totaly different form the proposed scheme and the differentiation of these schemes is more visible for higher level modulation scheme. It is noticed that BPSK-PSM also gives a comparable performance over the proposed method. But as the number of bits/symbol increases, the performance difference is decreasing. It is because of the increase in average number of pulses required for the BPSK-PSM modulation when compared against OOK-PSM. For example, in 2-bit BPSK-PSM scheme, each symbol requires two orthogonal pulses, whereas for

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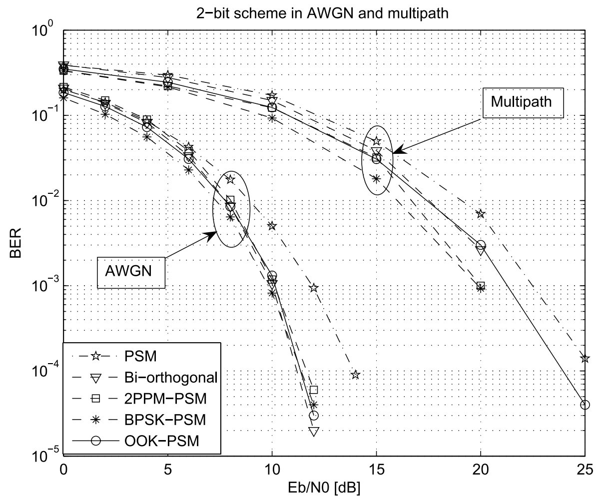

Fig. 1. Performance of 2-bit transmission scheme.

OOK-PSM requires one pulse except for the symbol 11 which requires two pulses. This difference in number of pulses is more visible when the number of bits/symbol is more. Though the pulses are said to be orthogonal, they are non-orthogonal in the finite interval. The correlation between two orthogonal pulses varies from 0.70 to 0.255 depending on the selection of orthogonal pulses and width of the pulses. For Hermite pulses of order 2 and 4 and 2-bit symbol transmission in the absence of noise, the correlator outputs of OOK-PSM scheme are $0(< 0.5)$ for the symbol 00, whereas BPSK-PSM scheme, outputs are $-0.3/\sqrt{2}$ and $0.3/\sqrt{2}$. It is clear that outputs of OOK-PSM correlators are much below than the OOK-PSM threshold level (=0.5) compared to the corresponding values of BPSK-PSM scheme. This leads to, performance degradation when the number of pulses are more with in the same time interval. From Fig. 1, it can be seen that 2PPM-PSM also has the same performance with proposed modulation scheme but it has some limitation which have been described in section 1. Since zero is represented by pulse off, OOK complexity is nearly half of that in any of the modulation scheme. Hence the combined form OOK-PSM has $(3/4)^{th}$ complexity of that of BPSK-PSM. Furthermore, OOK-PSM is polarity independent modulation scheme and needs minimum power when compared with that required in BPSK-PSM scheme. For higher-level modulation schemes, BPSK-PSM cannot be used for energy constrained TH-UWB system.

In Fig. 2, the simulation performance in multi-user environment are presented in the presence of AWGN channel. It is seen that the performance is decreasing with the increase in number of bits/symbol. It is largely because the increase in the number of orthogonal pulses used for the transmission. Since pulses are not properly orthogonal within the finite interval, the interferences among these pulses lead to performance degradation. However, across multiple users the performance degradation is very minimal. A slight performance degradation across the number of users is noticed for single pulse 2-bit transmission scheme. This performance difference is minimal as

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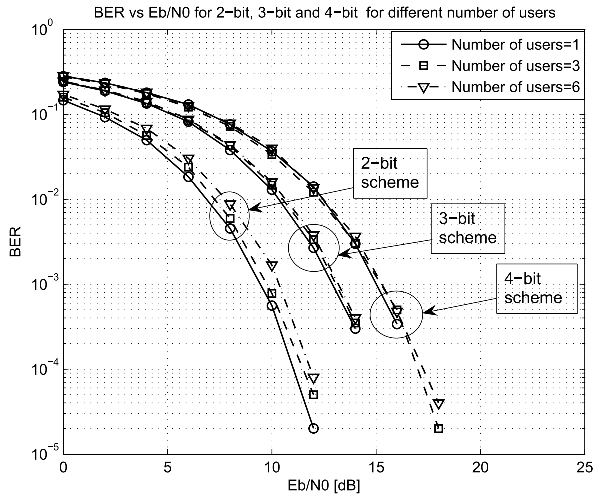

Fig. 2. Performance in the presence of multiuser in AWGN.

the number of bits/symbol increases due to the presence of multiple orthogonal pulses, which improve the correlation properties. Since time-hopping sequences take care of multiple access issues, the resulting performance of multiple users are very close to single user performance for AWGN environment. However, the performance degradation will be more prominent for multipath environment, which is currently under study. In short, it has been observed that the proposed scheme results in lower complexity while preserving the data rate and BER performance of existing combined schemes.

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