A HYBRID M-ARY MODULATION SCHEME FOR TIME HOPPING UWB COMMUNICATION SYSTEMS

*Sudhan Majhi, A. S. Madhukumar, and A. B. Premkumar, and Francois Chin**

Centre for Multimedia and Network Technology, School of Computer Engineering
Nanyang Technological University, Singapore 639798
*Institute for Infocomm Research, A*STAR, Singapore 119613

ABSTRACT

This paper describes a combined modulation scheme for time hopping ultra wideband (TH-UWB) radio systems based on biphase shift keying (BPSK), orthogonal pulse position modulation (OPPM) and pulse shape modulation (BPSM). A set of $M = 2^k$ symbols are constructed by using $L = 2^l$ orthogonal pulse positions and $N = 2^{k-l-1}$ biorthogonal pulses, where k and l are nonnegative integers such that $0 \leq l \leq k-1$. The selection of number of pulse positions and pulses depend on the system performance and the availability of orthogonal pulses with estimable auto-correlation properties. The proposed scheme achieves higher data rate by introducing more number of orthogonal pulses in the same pulse repetition interval. It also reduces the system complexity by half by introducing antipodal version of orthogonal pulses. The proposed transmission scheme is analyzed through computer simulations in the presence of multipath channel.

Index Terms— Pulse shape modulation, orthogonal pulse position modulation, M-ary signaling, ultra wideband communication.

1. INTRODUCTION

UWB radio is a promising technology for short range wireless communication. The information is conveyed by short-duration pulses, and modulation scheme determines how the data stream is to be transmitted over these pulses. Various modulation schemes have been proposed to improve the performance of TH-UWB systems by giving low complexity system design. Due to robustness against inter symbol interference (ISI) and multiple access interference (MAI), PSM is becoming an interesting research topic in TH-UWB systems [1]. However, due to limited autocorrelation properties of higher order orthogonal pulses, PSM cannot be used for higher level modulation schemes. Also, it increases system complexity due to more number of correlators in the receiver.

To deal with these challenges, combined modulation schemes such as biorthogonal PSM, combined 2PPM-PSM, and combined BPSK-PSM have been proposed [1][2][3]. However, biorthogonal PSM still requires $M/2$ orthogonal pulses to achieve M-ary scheme. 2PPM-PSM requires coded modulation to maintain orthogonality of the constellation vectors and memory in the receiver to improve the system performance. Since pulses are transmitted simultaneously within the same time slot and pulses are not properly orthogonal in the presence of multipath channel, BPSK-PSM scheme is not suitable for higher level modulation scheme.

In order to address these problems and to achieve higher level modulation, this paper proposes a combined modulation scheme for TH-UWB systems. The proposed scheme is a combined form of orthogonal PPM and biorthogonal PSM. M-ary biorthogonal PPM (BPPM) or M-ary biorthogonal PSM (BPSM) can be inherited from this proposed scheme by introducing only one pulse or only one position, respectively [4]. The BER performance and data rate of the system depends on the number of pulse positions and orthogonal pulses used for fixed value of M. Therefore, this multivariate modulation scheme can be used adaptively for various TH-UWB system in multipath and multiuser environment [5].

2. SYSTEM MODEL OF OPPM-BPSM SCHEME

2.1. The Modulation Scheme

The proposed scheme is a combination of orthogonal PPM and biorthogonal PSM (OPPM-BPSM). In order to transmit M symbols, using the proposed scheme, one has to use L orthogonal time shift positions and N biorthogonal pulses where $M = 2^k$, $L = 2^l$, $N = 2^{k-l-1}$, $k > 1$ and $0 \leq l \leq k-1$. Antipodal pulses are chosen because it smoothes power spectral density of UWB signal and its ability to coexist with overlaid narrowband systems without considerable performance degradation. These biphase pulses also reduce the number of correlators and the system complexity by half as compared to the combination scheme of L pulse positions and N orthogonal pulses. By changing the number of pulse positions and orthogonal pulses, one can construct a wide variety of symbols. For example, M-ary BPPM scheme can be constructed by using $M/2$ pulse positions and one biphase pulse [4], and M-ary BPSM scheme can be constructed by using one pulse position and $M/2$ biorthogonal pulses. 8-ary alphabets of proposed OPPM-BPSM scheme can be created by combining 2 pulse positions and 2 biorthogonal pulses. The proposed scheme ensures relatively constant power envelope for transmitted symbol irrespective of number of positions and pulses. By introducing N biorthogonal pulses in N pulse positions, data rate can be increased to $(2+1/k)$ times of N-ary orthogonal PPM scheme where $N = 2^k$.

2.2. Transmitted Signal in TH-UWB Systems

In TH-UWB transmission, the combined orthogonal PPM and biorthogonal PSM signal of the k^{th} user for i^{th} symbol can be defined as

$$s_i^{(k)}(t) = \sum_j \sqrt{E_{tx}^{(k)}}\, d_{2(i\%2)-1}^{(k)} w_{\lfloor i/2 \rfloor \% N}^{(k)}(t - jT_f - c_j^{(k)} T_c - \delta_{\lfloor i/2N \rfloor}^{(k)}) \quad (1)$$

where $i = 0, 1, \cdots, M-1$, $d_{2(i\%2)-1}^{(k)} \in \{\pm 1\}$ is the sign of amplitude of the pulse $w_{\lfloor i/2 \rfloor \% N}^{(k)}(t)$ at position $\delta_{\lfloor i/2N \rfloor}^{(k)}$ of the k^{th} user, T_p is the pulse duration, the pulses have finite energy and are normalized so as to ensure equal energy per transmission, that is: $\int_{-\infty}^{+\infty} |w_l(t)|^2 dt = 1$ where $0 \le l \le N-1$. $E_{tx}^{(k)}$ is the energy of k^{th} user. $\lfloor i/2 \rfloor \% N$ and $\lfloor i/2N \rfloor$ indicate order of the pulse and pulse position for i^{th} symbol,respectively. The pulse repetition interval, T_f, of a user is divided into N_h time slots of length T_c where $N_h T_c \le T_f$, $\{c_j^{(k)}\}$ is a pseudo-random TH code sequence, where $0 \le c_j^{(k)} < N_h - 1$. Index j is used for representing number of pulse repetition intervals for each symbol. For simplicity it is assumed that $\delta_q^{(k)} = \delta_q$ and $\delta_q = q\delta$ for all users where $0 \le q \le L-1$. A guard time (g_1) is inserted to reduce ISI from the strongest paths from the previous pulse positions. The resulting time shift can be written as $\delta = T_p + g_1$. Although the guard time concept reduces the data rate, it provides a low duty cycle of T_f/T_p with a pulse-processing gain of β. The bit rate of the system is $R_b = \log_2(N \times L \times 2)/(N_s T_f)$.

3. PROPOSED SCHEME IN MULTIPATH CHANNEL MODEL

In this section, the proposed scheme is analyzed in the presence of multipath channel model proposed by the IEEE 802.15 study group 3a [6]. This multipath model can be written as of the following discrete time impulse response:

$$h^{(k)}(t) = \sum_{l=1}^{L_P} \alpha_l^{(k)} \delta(t - \tau_l^{(k)}) \quad (2)$$

where $\tau_l^{(k)}$ is the delays of k^{th} user which takes values in the continuous time-invariant model, $\alpha_l^{(k)}$ is the l^{th} path gain of k^{th} user, L_P is the total number of paths and is assumed same for all the users.

Without loss of generality, it is assumed that orthogonality of the pulses is maintained despite the differentiating effect of the transmitter and receiver antennas. For simplicity, it is assumed that the signal is transmitted by using i^{th} $(0 \le i \le N-1)$ order pulse in the q^{th} $(0 \le q \le L-1)$ pulse position, therefore the signal in (1) can be rewritten as

$$s_{iq}^{(k)}(t) = \sum_j \sqrt{E_{tx}^{(k)}}\, d_m^{(k)} w_i^{(k)}(t - jT_f - c_j^{(k)} T_c - \delta_q^{(k)}) \quad (3)$$

where $m \in \{-1, 1\}$. If there are N_u number of users and each experiences a different channel model (2), the received signal can be expressed as

$$r(t) = \sum_{k=1}^{N_u} \sum_{l=1}^{L_p} \alpha_l^{(k)} s_{iq}^{(k)}(t - \tau_l^{(k)}) + n(t) \quad (4)$$

where the additive white Gaussian noise (AWGN) $n(t)$, is assumed to have a two sided power spectral density of $N_0/2$.

It is assumed that the reference receiver is synchronized i.e. $\tau_l^{(1)} = 0$ for l^{th} RAKE finger of user 1. N number of orthogonal pulses are required at each pulse position for detecting a desired symbol. Therefore, $N \times L$ number of correlators or matched filters are required in the receiver to detect $N \times L \times 2$ symbols. The largest magnitude of the correlators and the sign of this magnitude are used to detect a possible transmitted symbol. The corresponding receiver structure is shown in Fig.1. The reference signal of correlator for i^{th} order pulse and in the q^{th} pulse position of user 1 can be expressed as

$$\phi_{iq}^{(1)}(t) = \sum_{j=0}^{N_s-1} v_i^{(1)}(t - jT_f - c_j^{(1)} T_c - \delta_q^{(1)}) \quad (5)$$

where N_s is the number of pulse repetition interval for a symbol and

$$v_i^{(1)}(t) = \sum_{p=1}^{L_p} \alpha_p^{(1)} w_i^{(1)}(t - \tau_p^{(1)}) \quad (6)$$

The combined output of first L_p paths of the correlator for i^{th} order pulse and for q^{th} pulse position can be written as [5]

$$\begin{aligned} z_{iq}^{(1)} &= \int_{jT_f}^{(j+1)T_f} r(t)\phi_{iq}^{(1)}(t)dt \\ &= S_{iq}^{(1)} + ISI_{iq}^{(1)} + MAI_{iq}^{(1)} + N_{iq}^{(1)} \end{aligned} \quad (7)$$

where $S_{iq}^{(1)}$ is the useful signal component ,$ISI_{iq}^{(1)}$ is the inter-symbol-interference, $MAI_{iq}^{(1)}$ is the multiple-access interference, and $N_{iq}^{(1)}$ is the additive white Gaussian noise (AWGN)

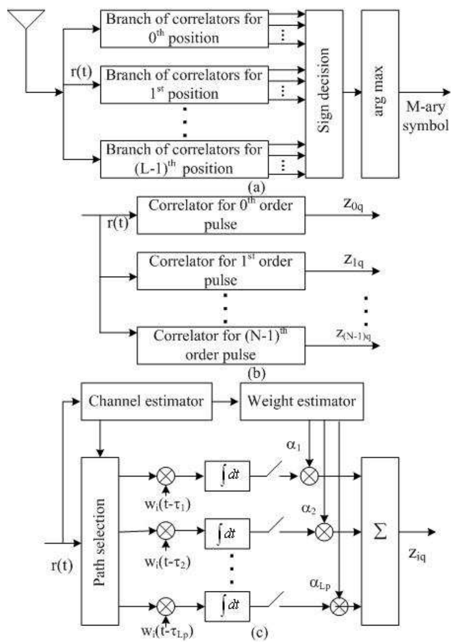

Fig. 1. (a) Receiver structure for branch of correlators in the different pulse positions.(b) Diagram of correlators for $q^{th}(q = 0, 1, \ldots, L-1)$ position, which contain N number of correlators for N different orthogonal pulses.(c) RAKE receiver for each correlator.

of the correlator for i^{th} order pulse and for q^{th} pulse position, and can be written as

$$S_{iq}^{(1)} = \sqrt{E_{tr}^{(1)}} d_m^{(1)} N_s \sum_{p=1}^{L_p} \left(\alpha_p^{(1)}\right)^2 \tag{8}$$

$$ISI_{iq}^{(1)} = \sqrt{E_{tr}^{(1)}} d_m^{(1)} N_s \sum_{p=1}^{L_p} \sum_{\substack{l=1 \\ l \neq p}}^{L_p} \alpha_p^{(1)} \alpha_l^{(1)} R_{ii}(\Delta) \tag{9}$$

$$MAI_{iq}^{(1)} = d_m^{(1)} \sum_{k=2}^{N_u - 1} \sqrt{E_{tr}^{(k)}} \sum_{j=0}^{N_s-1} \sum_{p=1}^{L_p} \sum_{l=1}^{L_p} \alpha_l^{(k)} \alpha_p^{(1)} R_{ii'}(\Delta') \tag{10}$$

and

$$N_{iq}^{(1)} = \sum_{j=0}^{N_s-1} \sum_{p=1}^{L_p} \alpha_p^{(1)} \int_0^{T_f} n(t) \times w_i^{(1)}\left(t - c_j^{(1)} T_c - \delta_q^{(1)} - \tau_p^{(1)}\right) dt \tag{11}$$

where in general $R_{ii'}(\Delta) = \int_0^{T_f} w_i(t) w_{i'}(t - \Delta) dt,\ i, i' \in \{0, 1, \cdots, N-1\}$, $\Delta = (\tau_l^{(1)} - \tau_p^{(1)})$, $\Delta' = (c_j^{(1)} - c_j^{(k)}) T_c - (\delta_q^{(1)} - \delta_{q'}^{(k)}) - (\tau_p^{(1)} - \tau_l^{(k)})$, and, i' and q' denote order of the pulse waveform and pulse position of user k, respectively.

The variance of ISI, MAI and AWGN are σ_{ISI}^2, σ_{MAI}^2, and σ_N^2, respectively, and can be expressed as

$$\sigma_{ISI}^2 = E_{tr}^{(1)} N_s T_f^{-1} \sum_{p=1}^{L_p} \sum_{l=1}^{L_p} \sum_{\substack{p'=1 \\ p' \neq p}}^{L_p} \sum_{\substack{l'=1 \\ l' \neq l}}^{L_p} \alpha_p^{(1)} \alpha_l^{(1)} \alpha_{p'}^{(1)} \alpha_{l'}^{(1)} Q(\Delta'') \tag{12}$$

$$\sigma_{MAI}^2 = N_s T_f^{-1} \sum_{k=2}^{N_u} E_{tr}^{(k)} \sum_{p=1}^{L_p} \sum_{l=1}^{L_p} \sum_{p'=1}^{L_p} \sum_{l'=1}^{L_p} \alpha_p^{(1)} \alpha_l^{(k)} \alpha_{p'}^{(1)} \alpha_{l'}^{(k)} Q(\Delta''') \tag{13}$$

and

$$\sigma_N^2 = \frac{N_0 N_s \left(\sum_{p=1}^{L_p} \alpha_p^{(1)}\right)^2}{2} \tag{14}$$

where $Q(.)$ is the correlation function of $R_{ii'}(.)$, $\Delta'' = \left(\tau_l^{(1)} - \tau_p^{(1)} - \tau_{l'}^{(1)} + \tau_{p'}^{(1)}\right)$ and $\Delta''' = \left(\tau_l^{(1)} - \tau_p^{(k)} - \tau_{l'}^{(1)} + \tau_{p'}^{(k)}\right)$ [5].

Here it is assumed that z_{iq} is larger than each of the other $M/2 - 1$ correlator outputs, then the average probability of a correct decision in the presence of ISI and MAI is given by [4]

$$P_c = \int_0^{\infty} \left(\frac{1}{\sqrt{2\pi}} \int_{-z_{iq}/\sqrt{\sigma_{ISI}^2 + \sigma_{MAI}^2 + \sigma_N^2}}^{z_{iq}/\sqrt{\sigma_{ISI}^2 + \sigma_{MAI}^2 + \sigma_N^2}} \exp \frac{-x^2}{2} dx \right)^{\frac{M}{2} - 1} \times p(z_{iq}) dz_{iq} \tag{15}$$

where

$$p(z_{iq}) = \frac{1}{\sqrt{2\pi(\sigma_{ISI}^2 + \sigma_{MAI}^2 + \sigma_N^2)}} \times \exp\left(- \frac{\left(z_{iq} - N_s \sqrt{E_{tr}^{(1)}} \sum_{p=1}^{L_p} (\alpha_p^1)^2 \right)^2}{2(\sigma_{ISI}^2 + \sigma_{MAI}^2 + \sigma_N^2)} \right) \tag{16}$$

Finally, the probability of a symbol error for combined M-ary OPPM-BPSM is given by

$$P_N = 1 - P_c \tag{17}$$

4. SIMULATION RESULTS AND DISCUSSION

In this section, simulation results of an 8-ary scheme are presented by employing different number of pulse positions and orthogonal pulses in the presence of modified IEEE 802.15.3a S-V UWB multipath channel model. Channel model corresponding to line of sight (0-4m) environment (CM1) is used for this studies. The results of the simulation studies are given in Fig.2 and Fig.3. In figures, dashed lines represent the performance for Prolate spheroidal wave function (PSWF) pulses and solid lines represent for modified Hermite pulses.

The performance of an 8-ary scheme is given by employing 1 position and 4 pulses, 2 positions and 2 pulses, and, 4 positions and 1 pulse. In Fig.2, the number of significant paths is decided by selecting paths within 10 dB of the strongest paths. These performances are analyzed in multi data rate environment i.e. the length of pulse position is fixed but the pulse repetition interval is varied according to the number of positions. The data rate of 1 position, 2 positions and 4 positions for $\delta = 10$ ns and $N_s = 1$ are 75 mb/s, 37.5 mb/s, and 18.75 mb/s, respectively. Since, pulse repetition interval is increased with increase in the number of positions, the inter frame interference is reduced. Therefore, the system with more positions (4 positions 1 pulse) gives better performance than system with 1 position and 4 pulses. However, using multiple pulse positions will reduce the data rate correspondingly. On the other hand, 1 position and 4 pulses gives worse performance because of the speculative auto-correlation properties for higher order pulses. Therefore, number of positions and pulses can be selected adaptively based on the requirements of data rate and system performance.

Fig.3 shows the performance of an 8-ary scheme for the same data rate (50 mb/s). Since pulse repetition interval is fixed for all the possibilities of position and pulses, length of pulse position is decreased for 4 pulse positions and 1 pulse. Therefore, multipath signals of the previous pulse positions affect the correlator outputs of the next pulse position, which leads to performance degradation for more number of pulse positions within fixed pulse repetition interval. It has been seen that moderate number of pulse positions and pulses (2 positions 2 pulses) is better choice for acceptable data rate and the system performance.

Since, auto-correlation property of 0^{th} order modified Hermite and 0^{th} order PSWF is the same, 4 positions and 1 pulse gives the same performance for both the pulses. However, difference of their auto-correlation properties is increased with the increase in the order of the pulses, resulting in their performance difference. Fig.2 and Fig.3 shown that the PSWF pulses give better performance than the modified Hermite pulses for more number of orthogonal pulses. Therefore, selection of orthogonal pulses also influences the system performance of pulse based modulation schemes.

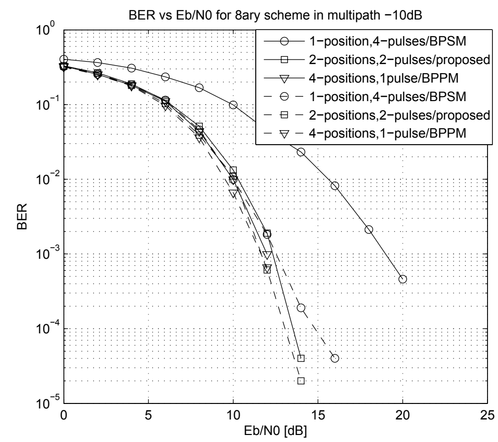

Fig. 2. Performance of 8-ary modulation scheme for different data rate where upto-10dB path is captured from peak point.

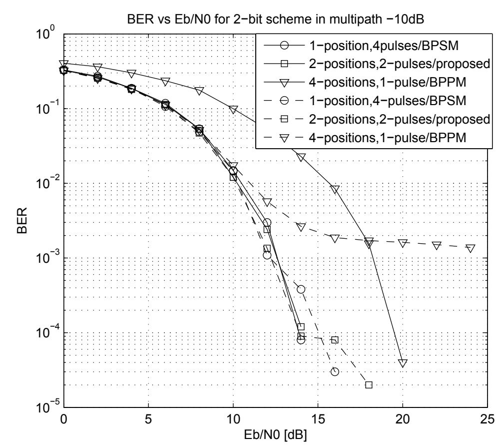

Fig. 3. Performance of 8-ary modulation scheme for the same data rate where upto-10dB path is captured from peak point.

5. REFERENCES

[1] H. Wen and Z. Guoxin, "Orthogonal hermite pulses used for UWB M-ary communication," in *Proceedings of the International Conference on Information Technology*, March 2005.

[2] C. Michell, G. T. F. de Abreu, and R. Kohno, "Combined pulse shape and pulse position modulation for high data rate transmission in ultra-wideband communication," in *International Journal of Wireless Information Networks*, Oct. 2003, pp. 167–178.

[3] K. Usuda, H. Zhang, and M. Nakagawa, "M-ary pulse shape modulation for PSWF-based UWB systems in multipath fading environment," in *IEEE Global Telecommunication Conference*, Nov. 2004, pp. 3498–3504.

[4] H. Zhang and T. A. Gulliver, "Biorthogonal pulse position modulation for time-hopping multiple access UWB communications," *Kluwer Transaction on Wireless Communication*, vol. 4, May 2005.

[5] T. Jia and D. I. Kim, "Analysis of average signal-to-interference-noise ratio for indoor uwb rake receiving system," in *in proceedings of IEEE 61st Vehicular Technology Conference*, June 2005, pp. 1396–1400.

[6] J. Foerster, "UWB channel modeling sub-committee report final," *IEEEP802.15 Working Group for Wireless Personal Area Networks (WPANs)*, Feb. 2003.