Impact of Time PPM Shift on TH-UWB Under SGA model

Abdelaziz Maaref
University of Djillali Liabes SBA
TTNS laboratory
Bordj Bou Arreridj Algeria
e-mail: maarefbba@yahoo.fr

Sid Ahmed Elahmar
University of Djillali Liabes SBA
TTNS laboratory
Sidi Bel abbes Algeria
e-mail: silahmar@yahoo.fr

Ali Djebbari
University of Djillali Liabes SBA
TTNS laboratory
Sidi Bel abbes Algeria
e-mail: alidjebbari@yahoo.com

***Abstract*— In this paper the effect of the time shift PPM to TH-UWB system performance is analyzed in multiple user interference based Standard Gaussian Approximation (SGA). We used a first and second derivative of Gaussian pulses and modified Hermite pulse, each with its specific optimal time shift PPM to use a Bit Error Rate (BER) to obtain a pulse wave form with better performance.**

Keywords- UWB; MUI; impulse radio; PPM; Time hopping

I. INTRODUCTION

UWB (Ultra-Wide-Band) wireless transmission is based on impulse radio and can provide very high data rates over short distances. Its traditional application was in non-cooperative radar. UWB device by definition has a bandwith equal or greater than 20% of the center frequency or a bandwidth equal or more than 500MHz. Since FCC (Federal Communications Commission) authorized in 2002 the unlicensed use in the domain 3.1– 10. 6 GHz, UWB became very interesting for commercial development. High data rate UWB can enable wireless monitors, efficient transfer of data between computer in a Personal Wireless Area Network, from digital camcorders, transfer of files among cell phone and home multimedia devices, and other radio data communication over short distances [3].

Depending upon modulation scheme TH UWB signal is known as TH-PAM UWB, or TH-PPM UWB [1]. Also Direct Sequence UWB. In all TH-UWB method single bit duration (Tb) is divided into Nf number of frames, each with equal duration of (Tf) such that, Tb = NfTf . Further each frame duration (Tf) is divided into Nc number of chips of duration (Tc). During each hip period (Tc) UWB radio signal is transmitted. This UWB pulse is Gaussian pulse or its derivative, which is transmitted depending upon TH code. UWB radio signal comprised of a sequence of sub-nano second duration pulses. In TH-PAM, antipodal signal is used for representing data bit "1" and "0". In TH-PPM, UWB pulse will take additional delay at the beginning of chip duration when data bit 010 is transmitted.

II. PULSE CONSTRUCTION FOR UWB TRANSMITTERS

A. Gaussian pulse

By far the most popular pulse shapes discussed in UWB communication literature are the Gaussian pulse and its derivatives, We have the definition of a so-called "Gaussian pulse zero order" [4].

$$P^{(0)}(t) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(t)^2}{2\sigma^2}} \tag{1}$$

The first and second order Gaussian pulses can be obtained by differentiating $P^{(0)}(t)$ against t as:

$$P^{(n)}(t) = \frac{d^n}{d^n(t)} P^{(0)}(t) \tag{2}$$

Figure 1 show the Gaussian pulses from first and second order in time domain

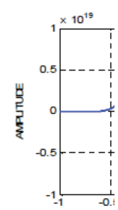

Figure 1. First and second order Gaussian pulse in time domain.

B. Modified Hermite Polynomial

MHPF [1],[5] are derived from Hermite polynomials. Hermite polynomials themselves do not possess orthogonality, however this is achieved by modifying them which leads to the term modified Hermite polynomial functions and are defined as follows:

$$\begin{cases} H_{e0}(t) = e^{t^2/4} h_{en}(t) \\ H_{en} = (-1)^n e^{t^2/4} \dfrac{d^n}{dt^n}\left(e^{-t^2/2}\right) \end{cases} \tag{3}$$

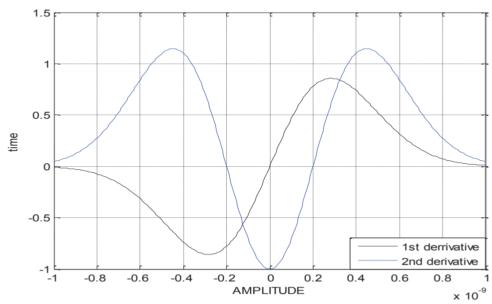

Figure 2. Modified Hermite wave functions in time domain.

III. ANALYZING MULTIPLE-USER INTERFERENCE

The multiple-user system model which uses 2PPM-THMA can be seen in Figure. 3 and the transmitted 2PPM-THMA signal can be expressed as [1],[2]:

$$s_{TX}^{(n)} = \sum_{j=-\infty}^{\infty} \sqrt{E_{TX}^{(n)}}\, p_0\left(t - jT_s - c_j^{(n)}T_c - a_j^{(n)}\varepsilon\right). \qquad (4)$$

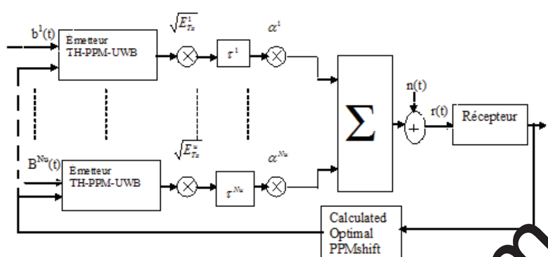

Figure 3. TH-PPM-UWB multi-users Model

where $p_0(t)$ is the energy normalized pulse waveform with duration T_M and $E_{TX}^{(n)}$ is the energy transmitted over each single pulse for the n^{Th} device; $C_j^{(n)}T_c$ is the time shift introduced by the TH code with $C_j^{(n)}$ being the j-th pseudo-random code of device n, Tc the chip duration and Ts is the average pulse repetition time. The TH sequence is considered to be a set of independent and identically distributed random variables. The term $a_j^{(n)}\varepsilon$ represents the time Shift introduced by the modulation accounting with the number of pulses per bit (Ns). For the binary PPM modulation, $a_j^{(n)}$ can assume the binary values (0 or 1) and e is the time shift introduced by modulation, in this case, the PPM shift. With the use of a repetition coder, the correct detection in the receiver may be easily obtained. The output (Ns, 1) of the code repetition coder receives as input the binary source sequence. With the use of the repetition coder, the average pulse repetition period is considered to be: $T_S = T_b / Ns$ Where Tb is the bit time.

Assume that we use IEEE 802.15.3a channel model, and the channel is impacted by thermal noise (Gaussian White Noise), the received signal is the sum of the transmitted signal which from transmitters and the Gaussian White Noise, it can be expressed as [1]:

$$r(t) = \sum_{n=1}^{Nu}\sum_{j-\infty}^{\infty} \sqrt{E_{RX}^{(n)}}\, p_0\left(t - jT_s - C_j^{(n)}T_c - a_j^{(n)}\varepsilon - \tau^{(n)}\right) + n(t) \qquad (5)$$

The received signal can be defined as [1],[2]:

$$r(t) = r_u(t) + r_{mui}(t) + n(t). \qquad (6)$$

Where received signal contributions are independent $r_u(t)$ and $r_{mui}(t)$ are the useful signal and multiple access interference gathered at the receiver, respectively.

$E_{RX}^{(n)}$ is the energy received over each single pulse and n(t) is the AWGN noise with double sided spectral density N0/2. The useful received signal is expressed by

$$r(t)_U = \sum_{j=0}^{Ns-1} \sqrt{E_{RX}^{(1)}}\, p_0\left(t - jT_s - C_j^{(1)}T_c - a_j^{(1)}\varepsilon - \tau^{(1)}\right). \qquad (7)$$

Where $E_{RX}^{(1)}$ is the energy received from a single pulse from the reference transmitter. The multiple access interference signals are expressed by:

$$r(t) = \sum_{n=2}^{Nu}\sum_{j-\infty}^{\infty} \sqrt{E_{RX}^{(n)}}\, p_0\left(t - jT_s - C_j^{(n)}T_c - a_j^{(n)}\varepsilon - \tau^{(n)}\right) + n(t). \qquad (8)$$

$\tau^{(n)}$ represents the time delay of the pulse of the n-th device. We assume that reference transmitter and receiver are perfectly synchronized, i.e., $\tau^{(1)} = 0$.

Delays $\tau^{(n)}$ with $n \neq 0$ are assumed independent and uniformly distributed random variables between 0 and Ts.

The soft decision receiver output can be express in the following [1]:

$$Z = \int_0^{Tb} r(t)m(t)\, dt \qquad (9)$$

where $m(t)$ is correlated mask, its expression as:

$$m(t) = \sum_{j=0}^{Ns-1} v\left(t - jT_s - C_j^{(1)}T_s\right) \qquad (10)$$

where $v(t) = P_0(t) - P_0(t-\varepsilon)$

The receiver estimates the bit according to all signals contribution:

$$Z = Z_u + Z_{mui} + Z_n . \quad (11)$$

where Z_u , Z_{mui} and Z_n represent the useful signal, the MUI noise and thermal noise, respectively.

For orthogonal and the best binary PPM modulation, we use ML decision rule

$$\begin{cases} Z > 0 \Rightarrow \hat{a} = 0 \\ Z < 0 \Rightarrow \hat{a} = 1 \end{cases} \quad (12)$$

According to the ML decision rule, we can get the BER expression as following:

$$\begin{aligned} BER &= \frac{1}{2}\Pr(\hat{a} = 1 \mid a = 0) + \frac{1}{2}\Pr(\hat{a} = 1 \mid a = 0) \\ &= \Pr(\hat{a} = 1 \mid a = 0) \\ &= \Pr(Z = 1 \mid a = 0). \end{aligned} \quad (13)$$

Assuming that Z_{mui} and Z_n are zero-mean Gaussian random processes characterized by variance σ_{mui}^2 and σ_n^2 , respectively. Based in that works, for the binary PPM modulation the bit error probability is written by [1], [2]

$$\Pr_b = \frac{1}{2} erfc\left(\sqrt{\frac{SINR}{2}}\right) \quad (14)$$

where SINR is the Signal-to-Interference and Noise Ratio and accounts for the useful, thermal and interference noise contributions. The useful signal contribution is the bit energy E_b over the time of the bit and within the SGA assumption the following expression is obtained:

$$SINR = \frac{E_b}{\sigma_n^2 + \sigma_{mui}^2} \quad (15)$$

$$SINR = \left((SNR)^{-1} + (SIR)^{-1}\right)^{-1} = \left(\left(\frac{E_b}{\sigma_n^2}\right)^{-1} + \left(\frac{E_b}{\sigma_{mui}^2}\right)^{-1}\right)^{-1} \quad (16)$$

where SNR and SIR represents the signal to thermal noise ratio, and the signal to MUI noise ratio respectively. If the signal energy can be looked as the sum of Ns pulses energy (per bit), the E_b can be defined as:

$$\begin{aligned} E_b &= \left(Z_u^2\right) \\ &= \left(\sqrt{E_{RX}^{(1)}} \sum_{j=0}^{Ns-1} \int_{jTs - C_j^{(1)}Tc}^{jTs - C_j^{(1)}Tc + Tc} p_0\left(t - jT_s - C_j^{(1)}T_c\right) v\left(t - jT_s - C_j^{(1)}T_c\right) dt\right)^2 \\ &= E_{RX}^{(1)}\left(N_s \int_0^{Tc} p_0(t)\left(p_0(t) - p_0(t-\varepsilon)\right) dt\right)^2 \\ &= E_{RX}^{(1)} N_s^2 \left(\int_0^{Tc} p_0(t) p_0(t) dt - \int_0^{Tc} \left(p_0(t) p_0(t-\varepsilon)\right) dt\right)^2 \end{aligned}$$

$$E_b = E_{RX}^{(1)} N_s^2 \left(1 - R_0(\varepsilon)\right)^2 . \quad (17)$$

Where $R_0(\varepsilon)$ is the Autocorrelation function of $P_0(t)$ At the binary PPM receiver output, the Variance of thermal noise is given bay[1]:

$$\sigma_n^2 = N_s N_0 \left(1 - R_0(\varepsilon)\right) \quad (18)$$

Expression for the SNR is then obtained:

$$SNR_n = \frac{N_s E_{RX}^{(1)}}{N_0}\left(1 - R_0(\varepsilon)\right) = \frac{E_b}{N_0}\left(1 - R_0(\varepsilon)\right) \quad (19)$$

The features of MUI interference to the UWB receiver output can be defined as:

$$mui_p^{(n)}\left(\tau^{(n)}\right) = \sqrt{E_{RX}^{(n)}} \int_0^{2T_m} p_0\left(t - \tau^{(n)}\right) v(t)\, dt \quad (20)$$

where $2T_m$ represents the duration of the PPM mask. $E_{RX}^{(n)}$ is the energy received over each single pulse for the n-th interfering user. Assuming the delay τ^n is uniformly distributed over [0,Ts], the variance of the interfering noise is given by:

$$\begin{aligned} \sigma_{mui_p^n}^2 &= \frac{1}{T_s} \int_0^{T_s} \left(\sqrt{E_{RX}^{(n)}} \int_0^{2T_M} p_0\left(t - \tau^{(n)}\right) v(t) dt\right)^2 d\tau^{(n)} \\ &= \frac{E_{RX}^{(n)}}{T_s} \int_0^{T_s} \left(\int_0^{2T_M} p_0\left(t - \tau^{(n)}\right) v(t) dt\right)^2 d\tau^{(n)} \end{aligned} \quad (21)$$

If the time delay obeys the same distribution, can be written as:

$$E_{mui} = \frac{N_s}{T_s} \sigma_M^2 \sum_{n=2}^{Nu} E_{RX}^{(n)} . \quad (22)$$

Where once again τ obeys the uniform distribution from zero to Ts and the σ_M^2 expressed as:

$$\sigma_M^2 = \int_0^{T_s}\left(\int_0^{2T_M} p(t-\tau)v(t)dt\right)^2 d\tau$$

$$= \int_0^{T_s}\left(\int_0^{2T_M} p(t-\tau)(p(t)p(t-\varepsilon)dt)\right)^2 d\tau$$

$$= \int_0^{T_s}\left(\int_0^{2T_M} p(t-\tau)(p(t)dt) - \int_0^{T_M} p(t-\tau)(p(t-\varepsilon)dt)\right)^2 d\tau$$

$$= \int_{-2T_M}^{2T_M}\left(\int_0^{2T_M} p(t-\tau)p(t)dt - \int_{\varepsilon}^{T_M+\varepsilon} p(t-\tau)p(t-\varepsilon)dt\right) d\tau$$

$$\sigma_M^2 = \int_{-T_M}^{2T_M} (R_0(t)-(\tau+T_M))^2 d\tau \quad . \tag{23}$$

If we use approximations mathematics, we get the BER of 2PPM-THMA UWB system based on SGA model as [1], [2]:

$$BER = \frac{1}{2} erfc\left(\sqrt{\left(\left(\frac{E_b^{(1)}}{N_0}(1-R_0(\varepsilon))\right)^{-1} + \left(\frac{E_b^{(1)}}{N_0}\frac{N_0}{N_s^2\sigma_M^2\sum_{N=2}^{Nu} R_b^{(n)}E_{RX}^{(n)}}\right)^{-1}\right)^{-1}}\right) . \tag{24}$$

Equation (19) shows that SNRn is maximum (BER is minimum) when autocorrelation R_0 is minimum, and can be maximized by selecting an optimal shift PPM value. Not that for orthogonal waveform $(\varepsilon > T_M)$ $R_0(\varepsilon)=0$, than $1-R_0(\varepsilon)=1$.The optimum shift value, however, be smaller than T_m if $R_0(\varepsilon)$ takes on negative value, that is $1-R_0(\varepsilon)>1$.

In the simulation, we assume that the collision happens when the waveform overlapping in MUI system. Now we consider a common situation: this is Nu asynchronous user binary PPM Time-Hopping system which uses the common interface to send binary data. It is also assumed that 5 pulses are used to transmit one bit (Ns = 5) and the pulse repeat period Ts = 3 *ns* . Each period Ts is divided into three time slots (Tc =3 *ns*) the transmit rate *(Rb*) will be *Rb = 66.66Mb/*s . The basic waveform is first and second derivative of Gaussian pulse modified Hermite pulse.

After simulation, the optimum value for ε is used when PPM modulation is studied. The optimal ε for each pulse waveforms are presented in Table 1.

Waveform	Optimal PPMshift (ε_{opt})
1st derivative Gaussian	0.4ns
2nd derivative Gaussian	0.42ns
1st derivative modified hermite	0.1ns
2nd derivative modified hermite	0.07ns

Table 1. The optimal PPMshift for each pulse waveforms

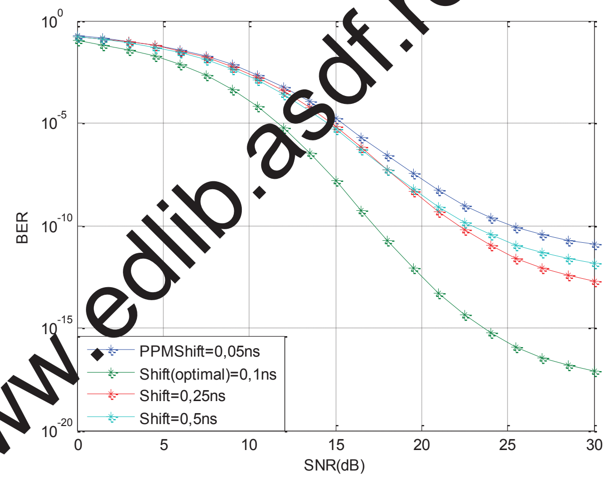

Figure 4. BER performance of different PPM Shift Using 1st derivative Gaussian pulse

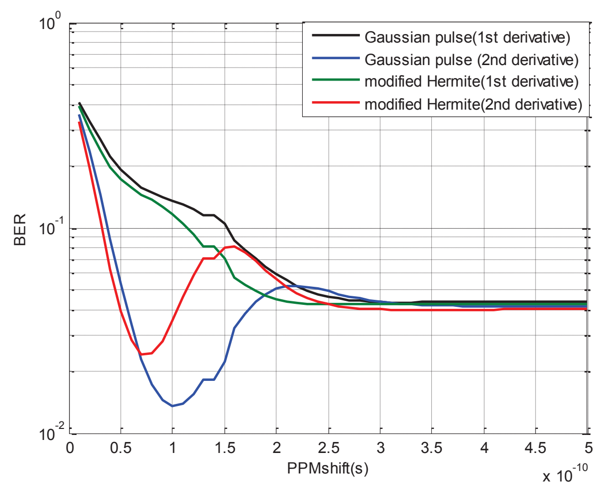

Figure 5. BER of different UWB pulses as a function of PPM shift.

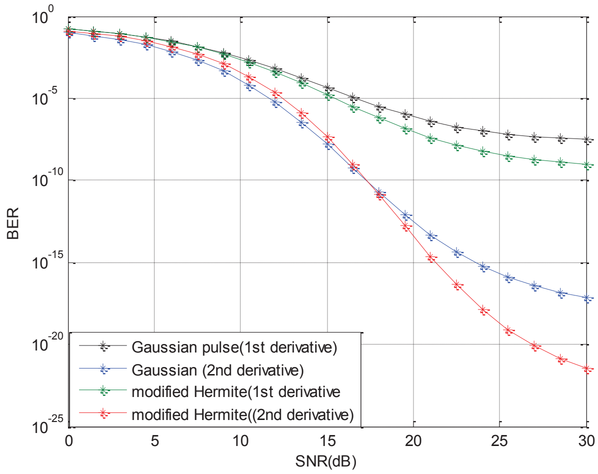

Figure 6. BER performance of different pulses with optimal PPMShift for each pulse.

The comparison between the different relative time shift used by Gaussian pulse in TH-PPM is shown in Figure 4. The Figure 5 represents the performance of TH-UWB-PPM under SGA model in terms of BER versus PPMshift for four pulse shape. Figure.6 illustrates the BER performance of the proposed pulses when the PPM shift is optimal.

We note according to these figures the following results:
- The minimum BER is reached for a lower value of PPMshift, and the BER itself gives better results.
- The performance of the model using 2^{nd} derivative is better than this of the model using the 1^{st} derivative Pulse.
- For the optimum value of shift PPM, The best results are obtained with the 2^{nd} derivative of Gaussian pulse, but the 2^{nd} derivative of modified Hermite gives low value of PPMshift, this justifies the possibility to creases the number of pulses per bit (Ns), which leads creases power energy per bit, therefore decreases the bit error rate BER

IV. CONCLUSION

The precedent results indicate that the time shift directly affects the performance of TH-PPM systems. It is clear that the TH-PPM-UWB systems will achieve the best performance when PPMshift is optimal, but this value is very small (0.1ns for the 2nd derivative modified Hermite), For this difficult to implement.

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