Performance Analysis and Evaluation of TH-PPM and TH-BPSK under Dynamic Channel Environment

Safa Saad Hussein, Aliaa youssif, and Ghouz H. H. M.

***Abstract*—This paper presents analysis and evaluation of ultra-wideband time-hopping communication system with either pulse position modulation (TH-PPM) or binary phase shift keying (TH-BPSK). The channel model has been assumed as CM1 (line-of-sight) and/or CM3 (Non-line-of-sight) along with AWGN (IEEE 802.15.3a). In addition, the impact of all system parameters on its performance have been investigated and evaluated. This includes the number of pulses per each data frame, receiver model, single user and multiple users.**

***Index Terms*—UWB wireless communication systems, multiple access techniques, and modulation schemes.**

I. Introduction

Ultra wideband impulse-radio communication systems are upstanding technology with the potential for robust communication in multipath and multiuser environments. In addition, they also have the advantages of low cost, low power, less system complexity, and high speed in short-range. In UWB communication systems, the data is transmitted in a train of very short pulse duration in order of nanosecond resulting in an extremely wide spectrum from near zero to a few gigahertz. However, the UWB system performance is highly dependent upon the multiple access techniques as well as the modulation types. Thus, several multiple access techniques and modulation types have been developed and used for the UWB communication systems. This includes direct sequence speared spectrum (DSSS), frequency hopping (FH), time hopping (TH), and orthogonal frequency division multiplexing (OFDM) as a multiple access technique. On the other hand, pulse position modulation (PPM), binary phase shift keying (BPSK), pulse amplitude modulation (PAM), and on-off keying (OOK) as modulation types. Nowadays, TH combined with either PPM or BPSK is the most common multiple access technique and modulation type used for UWB communication systems. Also, TH-multiple access along with spread spectrum technique is commonly used for an impulse radio system [1]. The distinguishing process between different users is based upon the arrival time of each user respective pulse sequences. In this paper, a complete UWB wireless communication system with time hopping technique and two different modulation types is considered. These modulation schemes are PPM and BPSK. The assumed UWB systems have been analyzed and their performances have been evaluated for dynamic channel environment as well single and multiple users. Also, different receiver types have been assumed to have a global view of the main system parameters effects on its overall performance. UWB system model is discussed in detail in Section II. The assumed system parameters and the simulation results are investigated and presented in Section III. Performance comparison between ideal and real channel models for either single user or multiple users is also presented. Performances of three UWB receiver models are evaluated, compared and presented in Section III. Finally, Section IV concludes the present paper.

Manuscript received April 18, 2012; revised June 5, 2012.

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II. System Models

The asynchronous TH-PPM and TH-BPSK UWB systems are described in [1], [2], and [3]. A typical TH-PPM UWB signal takes the form

$$S_{PPM}^{(k)}(t,i) = \sqrt{\frac{E_b}{N_s}} \sum_{j=iNs}^{(i+1)Ns-1} p(t-jTf - C_j^{(k)}Tc - d_i^{(k)}\delta) \quad (1)$$

And a TH-BPSK UWB signal with antipodal data modulation is written as:

$$S_{BPSK}^{(k)}(t,i) = \sqrt{\frac{E_b}{N_s}} \sum_{j=iNs}^{(i+1)Ns-1} d_i^{(k)} p(t-jT_f - C_j^{(k)}Tc) \quad (2)$$

where ***t*** is time, $s^{(k)}(t, i)$ is the K^{th} user's signal conveying the i^{th} data bit, and $p(t)$ is the signal pulse with pulse width Tp. The parameters employed in these UWB models are described as follows [1-3]:

E_b is the bit energy common to all signals

N_s is the number of pulses required to transmit a single data bit, called the length of the repetition code [4].

T_f is the time duration of a frame, and thus, the bit duration $T_b = N_s \times T_f$

$\{C_j^{(k)}\}$ Represents the TH code for the k^{th} source

$d_i^{(k)}$ Represents the i^{th} binary data bit transmitted by the k^{th} source, and different bits are assumed to be equiprobable. In antipodal TH-BPSK UWB systems, $d_i^{(k)} \in \{1,-1\}$

δ is the time shift associated with binary PPM.

In TH-PPM UWB systems, the data bits can conveniently be {0, 1} or {1,-1}, as explained in the following.

DOI: 10.7763/IJFCC.2012.V1.94

Many pulse shapes have been proposed for UWB impulse radio systems. This includes the Gaussian pulse, Gaussian monocycles, and Gaussian doublet. [5]. The Gaussian pulse has the form

$$p_o(t)=\exp\left[-2\pi\left(\frac{t}{\tau_p}\right)^2\right] \quad (3)$$

And its *n*th derivative, named the *n*th-order Gaussian monocycle, is [6]

$$p_n(t)=\varepsilon_n\frac{d^n}{dt^n}\exp\left[-2\pi\left(\frac{t}{\tau_p}\right)^2\right] \quad (4)$$

where, τ_p represents time normalization factor. The most widely reported pulse in UWB systems is the second-order Gaussian monocycle [1]:

$$p(t)=\left[1-4\pi\left(\frac{t}{\tau_p}\right)^2\right]\exp\left[-2\pi\left(\frac{t}{\tau_p}\right)^2\right] \quad (5)$$

The autocorrelation $\boldsymbol{R(x)}$ of the Gaussian monocycle is:

$$R(x)=\left[1-4\pi\left(\frac{x}{\tau_p}\right)^2+\frac{4\pi^2}{3}\left(\frac{x}{\tau_p}\right)^4\right]\exp\left[-\pi\left(\frac{x}{\tau_p}\right)^2\right] \quad (6)$$

Assuming $\boldsymbol{N_u}$ users are transmitting asynchronously over an AWGN channel, thus

$$r(t)=\sum_{k=1}^{Nu}A_k s^{(k)}p(t-\tau_k)+n(t) \quad (7)$$

where, $n(t)$ the additive noise, and $\{\tau k\}$ represent time shifts. Consider $\boldsymbol{S^{(1)}(t)}$ to be the desired signal and $\mathbf{d}_0^{(k)}$ to be transmitted. We further assume $C_j(1)=0$ for all j [4]. All the other $\boldsymbol{N_u}$ -1 signals are interference signals. Assuming perfect synchronization with the reference signal, the single-user correlation receiver computes the following decision statistic:

$$r=\sqrt{\frac{N_s}{E_b}}\sum_{j=0}^{N_s-1}\int_{jT_f}^{(j+1)T_f} r(t)v(t-\tau_1-jT_f)dt \quad (8)$$

where, v (t) is the correlation template waveform, which takes different forms in the TH-PPM and TH-BPSK UWB systems correspondingly [7].

III. Simulation Assumptions and Results

Time hopping multiple-access with two different modulation types (TH-PPM and TH-BPSK) has been employed to evaluate and investigate the performance of UWB communication system. The channel has been modeled as AWGN along with fading to include the effects of multipath signals propagation. The following subsections present performance evaluation of the assumed UWB system. First, the system performance has been evaluated in presence of an ideal channel for a single user and multi-users. Second, a real channel is assumed to include the effects of the multipath on the system's performance for single user. Finally, the system performance in the presence of AWGN with the multi-user interference (MUI) has been evaluated and presented.

A. Propagation over AWGN Channel

In the present simulation, the data length is assumed to be ten thousand bits each one with a different number of pulses Ns. This data is transmitted and propagated over an ideal channel (AWGN). The performance of the UWB systems (TH-PPM and TH-BPSK) for different number of pulses (one, three and five) is illustrated in Fig.1. As it is clear from the figure, the three carves with dashed lines represent TH-PPM performance with N_s=1, 3 and 5 respectively. Performance of TH-BPSK is represented by the other solid carves. Moreover, it can be observed form this figure that the average BER is dramatically decreased with increasing the length of the repetition code. This due to the fact that increasing the number of pulses lead to higher detection probability of the transmitted bit at the receiver output. In addition, UWB system with BPSK has a superior performance over the TH-PPM system. Furthermore, for higher number of pulses (e.g. N_s=5), the performance of UWB system with PPM is relatively the same as TH-BPSK with less number of pulses (e.g. N_s=3).

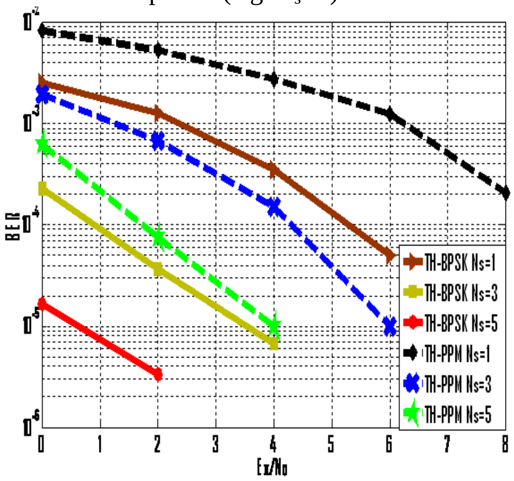

Fig. 1. Performance of TH-PPM and TH-BPSK.

B. Propagation over the Multipath Channel

The useful user data is transmitted and propagated over the multipath environment using IEEE 802.15.3a (CM1) channel model. In fact, this channel model represents line of sight propagation. Three receiver models have been assumed to investigate the effects of multipath signals on the system performance. These models are the all-rake, the partial-rake, and the selective-rake receivers. Fig. 2 and Fig. 3, illustrate the average bit error rate for the assumed UWB systems. These Figs present a performance comparison between the different receiver types. As it is clear from the Figs, the dotted-line and solid-square line represent the ideal rake, the dashed-lines represent the S-Rake receiver either with 7 fingers or 5 fingers, and the solid-lines represent P-Rake either with 7 fingers or 5 fingers. The ideal rake collects all the multipath contributions, and it has better performance than the partial and the selective rake receivers. On the other hand, this receiver is extremely complex, and it is difficult to implement in practice. This is due to the large number of the rake fingers used to compensate all multipath components. Furthermore, performance of P-Rake with 7 branches is relatively the same as the S-Rake with 5 branches. The main reason is due to the difference in the collected energy of branches captured by the receiver. Finally, from Fig. 4, the BPSK has better performance than the PPM, where the solid-lines corresponding to the PPM modulation and the other dashed-lines represent the BPSK modulation.

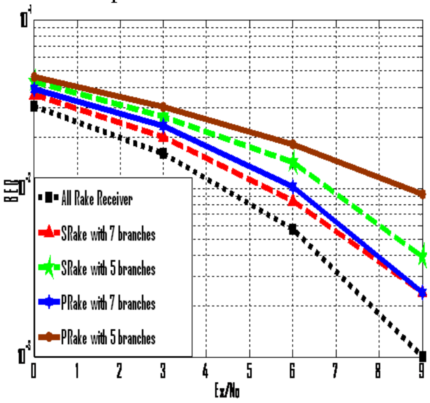

Fig. 2. PPM performance for different rake receivers.

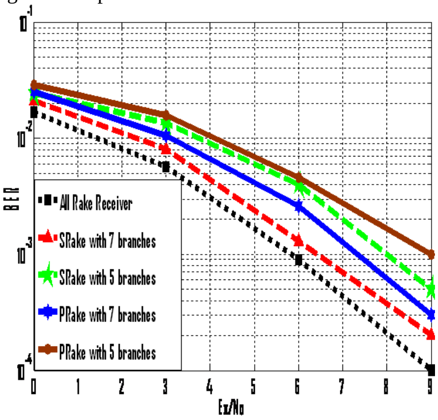

Fig. 3. BPSK performance for different rake receivers.

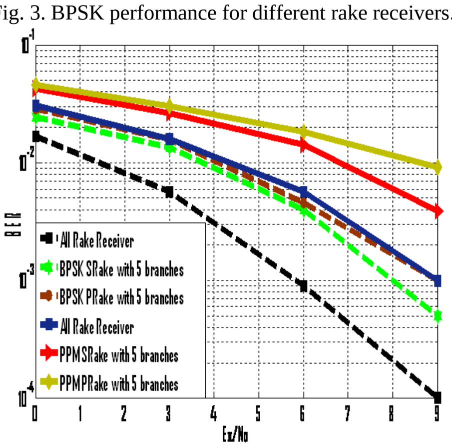

Fig. 4. Performance of PPM and BPSK modulations.

Another channel model has been used to investigate the performance of UWB systems (IEEE 802.15.3a (CM3) channel model). This channel model represents non-line of sight propagation. The separating distance between the transmitter and the receiver has been assumed 7m with higher reference attenuation than the case the first channel model (CM1). The performance results are presented in Fig. 5 and Fig.6. Again, these figures show that S-Rake performs better than P-Rake (the same as in case of the previous channel model CM1). The dotted-line represents the ideal rake, the dashed-lines represent the S-Rake for 7 and 5 fingers, and the solid-lines represent P-Rake for 7 and 5 fingers. Furthermore, less performance has been obtained in this case as compared to CM1 channel model. This is due to the obstacles and the larger distance between the transmitter and the receiver.

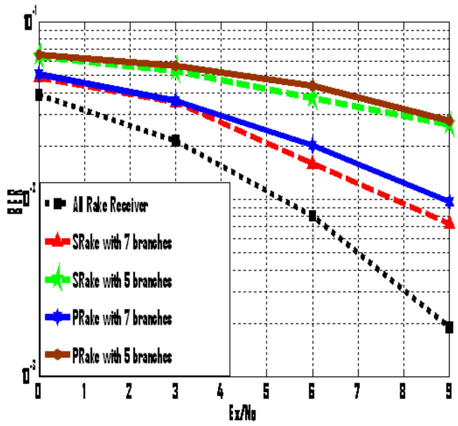

Fig. 5. PPM performance for different rake receivers.

Performances of the assumed receiver models in case of TH-PPM has been investigated and evaluated for different number of pulses. These results are compared and presented in Fig. 7. In this case a fixed number of pulses for All-Rake model is assumed (*Ns*=1, solid line-data 1). As it is clear from the figure, the performance of the others receiver models (S-Rake and P-Rake) became comparable to All-Rake for higher number of pulses (*Ns*=11, S-Rake-data 2 and P-Rake-data 3). The higher number of pulses leads to an additional system complexity as well as processing time.

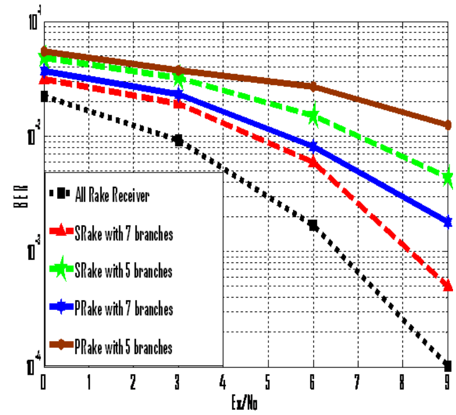

Fig. 6. BPSK performance for different rake receivers.

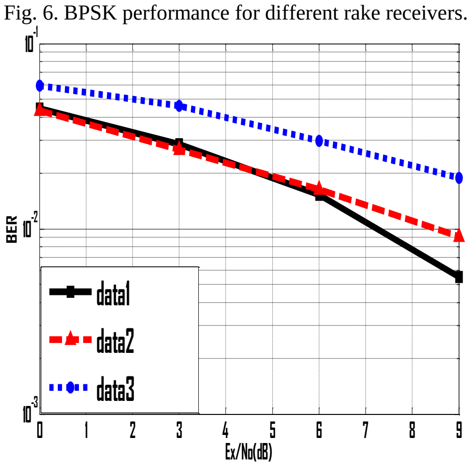

Fig. 7. Performance of all-rake, s-rake and p-rake.

C. Multiple User Interference in AWGN

The effects of the number of multi-user interferences on the UWB system Performance have been investigated and evaluated. A perfect power control, and time synchronous between the transmitter and the receiver ($\tau = 0$) are assumed in system simulation. The simulation parameters and their values of the transmitted binary data stream of useful users are presented in Table I. The simulation results are presented in Fig. 8 and Fig. 9. It is clear that the average BER has been increases as the number of the interfering users increase. In addition, for small Eb/No (up to 3dB), the UWB system provided a weak performance as compared to the single user (subsection A). Dashed-dotted-line, dashed-line, dotted-line and the solid-line are for 5, 10, 20 and 30 users respectively. Performance results for the other modulation type (TH-PPM) are shown in Fig. 10. In this case, a less performance has been obtained as compared to the TH-BPSK. This due to that the BPSK is more efficient and robust than the PPM. Also, BPSK has a less susceptibility to distortion since the difference between any two successive pulse levels is twice the pulse amplitude.

TABLE I

Parameter	Symbol	Value
Bit duration	Tb	3ns
Code repetition	Ns	5
Multi-user interfering	MUI	5,10,20,30
PPM shift	δ_{shift}	0.5ns
Chip duration	Tc	1ns
Frame duration	Tf	3ns
Number of frame slots	Nh	3
Pulse duration	Tm	0.5ns

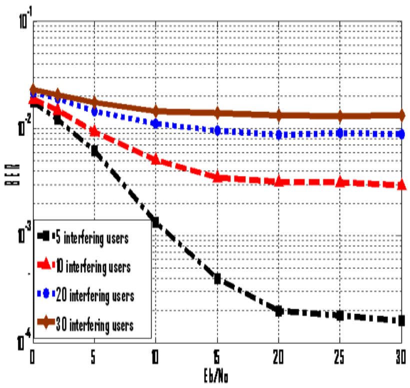

Fig. 8. PPM performance in the presence of MUI.

IV. Conclusion:

In this paper, performance of TH-PPM and TH-BPSK UWB systems has been investigated and evaluated. The obtained results indicate that increasing the number of pulses in each bit N_S enhances system performance. Also, a reduction in UWB system performance has been obtained in case of multipath model as compare to AWGN channel. It has been observed that the presence of the multi-user interference has a draw back on the system performance. In other words, less performance has been obtained with increasing the number of the MUI. Finally the UWB TH-BPSK achieves a better performance than the UWB TH-PPM for the same propagation environments. Future work will include performance investigation and evaluation of UWB wireless communication system for multi user under multipath channel models.

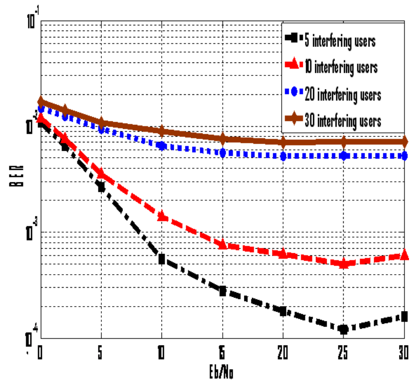

Fig. 9. BPSK performance in the presence of MUI.

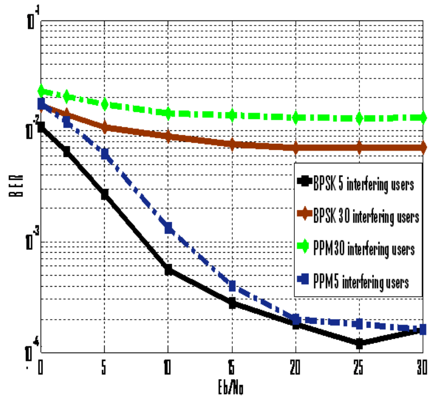

Fig. 10. PPM and BPSK performance in the presence of MUI.

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