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Performance of a TH-PPM UWB system in different scenario environments

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1. Introduction

Ultra Wideband (UWB) communication technology has attracted considerable attention by researchers in recent years because of its appealing features and its several applications it offers in many areas (Win & Scholtz, 1998; Fontana, 2007; Ghavami et al, 2007). An UWB system is characterised by very short-duration pulses (usually on the order of a nanosecond) with a low duty cycle. It offers low power transmission, a fine path resolution and it easily supports multi-user communication (Di Benedetto, 2004). These properties make UWB technology an attractive candidate for short-range, high-speed wireless multiple access communication and ad hoc networking, with simple baseband and the capability to overlay legacy wireless systems. All this gives us many features such as wireless radar, communications, networking, imaging and positioning systems (Yang & Giannakis, 2004).
Historically, UWB systems are based on impulse radio (IR) concepts. In an IR UWB system, a number of pulses are transmitted per information symbol and information is usually conveyed by the positions or the polarities of the pulses. In order that impulse radios, operating in the highly frequency range below a few GHz, do not interfere with narrowband radio systems operating in the same frequency band, the use of spread-spectrum techniques is necessary. A simple mean to spread the spectrum of these UWB pulse trains is Time Hopping (TH), with data modulation achieved in the rate of many pulses per data symbol (Win & Scholtz, 1998, a). In UWB systems, there are several basic methods of modulation but the most common impulse radio based UWB concepts are based on Pulse Position Modulation combined with Time Hopping (TH-PPM) where each pulse is delayed in advance of a regular time scale. Thereafter, we will describe this concept with further details. The study of digital communications system performance over the AWGN (Additive White Gaussian Noise) channels starts generally with statistically independent zero-mean Gaussian noise samples. Due to the Gaussian statistics of the noise samples, the probability of error can therefore be written in terms of a Q-function.
There exists a set of efficient techniques for performance analysis when the system is distorted by AWGN and Rayleigh fading. We shall focus on the analytical methods that are useful in addressing the characteristics unique to UWB systems, such as the different modulation schemes and the large number of resolvable paths available to the receiver. In a UWB system rather realistic, the received pulses may overlap others causing inter-pulse

interference (IPI). Performance analysis taking into account IPI is commonly very complex and will not be developed in this chapter. This topic is studied and evaluated in (Zhao & Liu, 2005). A method to estimate the Bit Error Rate (BER) of UWB TH-PPM in the presence of multi-user interference (MUI) and AWGN channel is proposed by using Gaussian quadrature rules (GQR). Applied to UWB system performance analysis, its major improvement is to surmount the problem of exactly evaluating the MUI (Durisi & Benedetto, 2003). Studies of multiple-access system for the TH-PPM modulation were conducted in (Scholtz, 1993; Zhao & Haimovich, 2002), using a Gaussian approximation (GA) to statically model the multiple access interference (MAI). However, it was shown in (Durisi & Romano, 2002) that the GA significantly underestimates the BER of practical TH-PPM systems. A method is proposed for precisely calculating the BER of a TH-BPPM UWB system with MAI. The analytical expression is validated by simulation and used to assess the inaccuracy of the GA (Hu & Beaulieu, 2003). An analytical method based on exact statistical modeling of MAI is proposed for exact BER computation of TH-PPM UWB systems. The proposed modeling considers full asynchronism (Niranjayan et al, 2004). The system robustness and real indoor channel measurements in dense multipath environments have been studied. The results show that the UWB signal does not suffer from multipath fading. Therefore, little fading margin is necessary to undertaking reliable communications (Win & Scholtz, 1998, b).

In this chapter, however, we focus on an ideal multiple-access channel, i.e., an additive white Gaussian noise (AWGN) channel. An exact BER calculation for UWB systems is usually unwieldy. Our purpose is to provide an accurate approach for the evaluation of the ultra wideband system performance in a TH-BPPM scheme in the presence of an AWGN channel. This performance was illustrated using an analytical method based on the evaluation of the exact bit error rate (BER) probability versus signal to noise ratio (SNR). This is based on the decision that enables to decode the information transmitted over our UWB system model. This decision is then developed by equations in order to precisely compute the performance in terms of errors rate by bit. In order to emphasize the fundamental analysis techniques, we will firstly focus on a single-user and single-path system (no co-channel interference) that utilizes binary signaling, and suppose that there is no narrowband interference or inter-symbol interference (ISI). We will extend the used method in different scenario environments and a comparison is made between them.

The rest of this chapter is organized as follows. We present a detailed description of the TH-PPM UWB system in Section.2, and then we develop an error performance analysis for only one user and one path environment in Section.3. In Section.4, this analytical analysis is extended for multi-user TH-PPM UWB systems. The performance of multipath TH-PPM UWB systems is developed in Section.5 from the same method used previously. Section.6 presents the performance of simultaneously multipath and multi-user TH-PPM UWB systems always with this same analysis and a comparison between different scenario environments performance. This comparison is illustrated by simulation results. And finally, we conclude this chapter in Section.7.

2. TH-PPM UWB System Model

Common multiple access techniques implemented for pulse based UWB systems are Time Hopping (TH) and Direct Sequence (DS). Appropriate modulation techniques include OOK

(Foerster et al, 2001) and particularly PPM and PAM (Hämäläinen et al, 2002). A given UWB communication system will be a mixture of these techniques, leading to signals based on, for example, TH-PPM, TH-BPAM or DS-BPAM. TH-PPM is almost certainly the most frequently adopted scheme and will be applied in the following as an example for determining the resources existing in a UWB system.

2.1 Pulse Position Modulation (PPM)

With pulse position modulation (PPM), the selected bit to be transmitted influences the position of the UWB pulse. That denotes that while bit '0' is represented by a pulse originating at the time instant 0, bit '1' is shifted in time by the amount of δ from 0.
Analytically, the signal PPM x(t) can be represented as

$$x(t) = w_{tr}(t - \delta d_j) \tag{1}$$

Where $w_{tr}(t)$ is the transmitted pulse waveform and d_j assumes the following values, depending on the bit chosen to be transmitted,

$$d_j = \begin{cases} 0, & j = 0 \\ 1, & j = 1 \end{cases}$$

The advantages of PPM mainly arise from its simplicity and the ease with which the delay may be controlled. On the other hand, for the UWB system extremely fine time control is necessary to modulate pulses to sub-nanosecond accuracy.

2.2 Data Modulation with Time Hopping

In TH-mode, the pulse transmission instant is defined by the pseudo-random code. One data bit is spread over the multiple pulses to achieve a processing gain due to the pulse repetition. The processing gain is also increased by the low transmission duty cycle.
The time hopping randomizes the signal in both time and frequency domains (Withington et al., 1999). Pseudo random time hopping also reduces collisions between users in multiple access systems, where each user has a distinct pulse shift pattern (Win & Scholtz, 1997a).

2.3 Description of TH-PPM UWB System Model

TH-UWB impulse radio is built upon position shift of pulses with a certain shape in the time domain. The studied system's model is based on Time Hopping (TH) combined with pulse position modulation (PPM) scheme applied in the context of UWB. The TH-PPM block diagram used in our case is shown in Fig. 1.

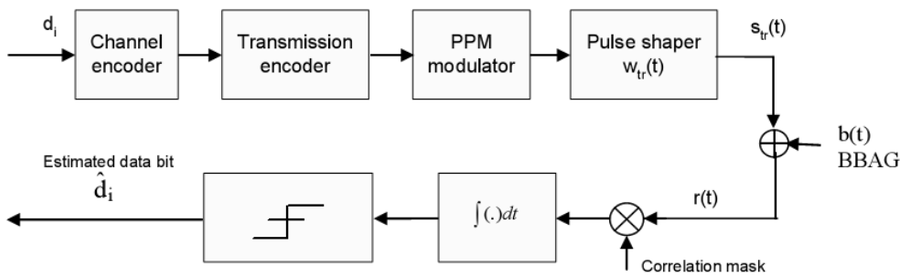

Fig. 1. Description of the used UWB TH-PPM scheme block diagram

The transmitted signal $S_{tr}(t)$ in the UWB TH-PPM systems is described by the following model (Durisi & Benedetto, 2003):

$$S_{tr}(t) = \sum_{k=1}^{+\infty} a_k \sum_{i=-\infty}^{+\infty} \sum_{j=0}^{N_h-1} w_{tr}\left(t - iT_s - jT_f - c_j^{(k)}T_s - d_i^{(k)}\delta\right) \quad (2)$$

Where $w_{tr}(t)$ is the transmitted pulse waveform, which is usually referred to monocycle. T_s is the symbol (or bit) duration, K is the number of users and a_k is the amplitude of different users. In order to allow the channel to be shared by many users and eliminate catastrophic collision, each user is assigned a distinctive time-shift pattern $c_j^{(k)}$ called as TH sequence, which takes values in $\{0,1,...,N_h-1\}$. The frame time T_f and the chip time T_c are chosen to satisfy $N_hT_c \leq T_f$. The binary information stream $\{d_i^{(k)}\}$ is transmitted employing a PPM modulation format and introducing an additional shift δ to distinguish between pulses carrying the bit 0 and the bit 1.

In binary PPM modulation scheme, the information is transmitted with time lags between the nominal and real moments of transmission of impulse. If the impulsion is sent during the real time of transmission which is defined by the pseudo-random code specific to the user, the bit is '0'. If the moment of transmission is delayed of a certain time which is connected to the index of modulation of the system, the bit transmitted is '1'. This is described by the Fig. 2 which represents two cases of transmission ('0' and '1') for $N_f = 4$ (bit represented on 4 impulses), $N_h = 3$ (3 chips).The TH code is given by [1 *0 0 2*], which means that the pulse in the first frame is shifted by $1T_c$ seconds, the ones in the second and the third frame are not shifted and the one in the fourth frame is shifted by $2T_c$ seconds.

We suppose that the model of the TH-PPM system is synchronized. This enables us to avoid dealing with the problems involved in synchronization.

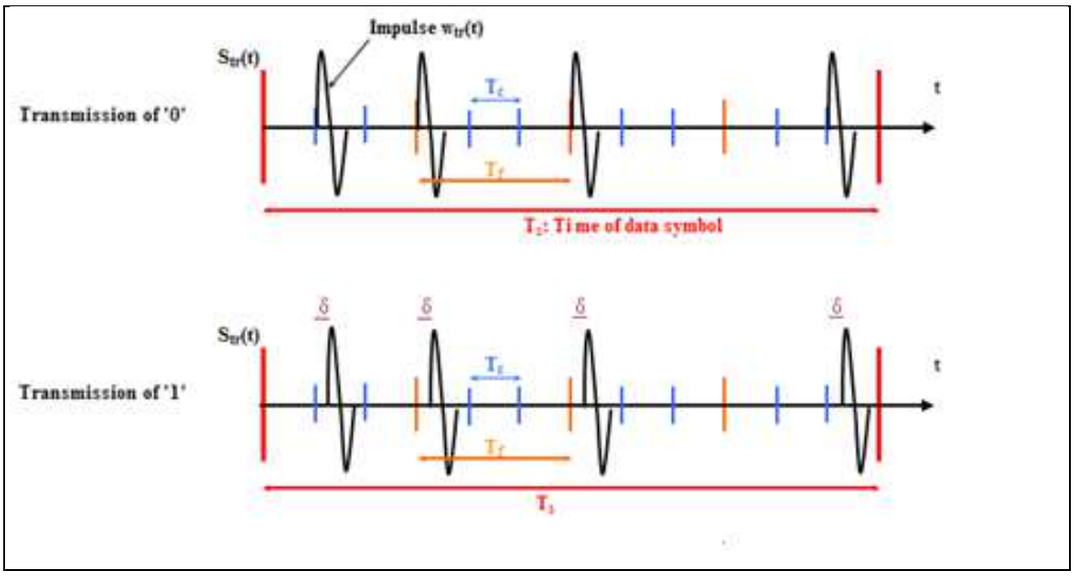

Fig. 2. Transmission of a TH-PPM signal

3. Analytical Analysis of BER in the UWB TH-PPM System Model

In order to determine the probability of error, we will first of all start by studying the reception of the UWB TH-PPM system model for only one user and one path (Hizem & Bouallegue, 2008).

This translates into the following equation which is basically the decision at the reception (Multiplication of the emitted symbol expression by the difference between the received symbols expression '0' and '1'),

$$D_i = \int_{[T_s]} \left[\sum_{j=0}^{N_h-1} w_{tr}\left(t - jT_f - c_jT_c - d_i\delta\right) + b(t) \right] \times \left[\sum_{j=0}^{N_h-1} \left(w_{tr}\left(t - jT_f - c_jT_c\right) - w_{tr}\left(t - jT_f - c_jT_c - \delta\right) \right) \right] dt \tag{3}$$

We will suppose that the temporal support in this case is disjoins. After calculation, we obtain the equation (4) derived from (3):

$$D_i = N_h R_w(d_i\delta) - N_h\left((1 - d_i)\delta\right) + \tilde{b} \tag{4}$$

With $R_w(d_i\delta) = \int_{[T_s]} w_{tr}(t) w_{tr}(t - d_i\delta)dt$, $\tilde{b}$ determines the noise power and R_w represents the autocorrelation function of the transmitted signal. In the noise less case (b(t) = 0), we obtain:

$$d_i = 0; \qquad D_i = N_h[R_w(0) - R_w(\delta)] > 0$$
$$d_i = 1; \qquad D_i = N_h[R_w(\delta) - R_w(0)] < 0$$

By definition, the probability of error represents the percentage of error of the received sequences $\widehat{d_i}$ compared to the emitted sequences d_i. This is given by:

$$P_e = \mathrm{Prob}\left(\widehat{d_i} \neq d_i\right) \tag{5}$$

Since the d_i are equiprobable, the equation (5) becomes:

$$P_e = \mathrm{Prob}\left(\widehat{d_i} \neq d_i \,/\, d_i = 0\right) = \mathrm{Prob}(D_i < 0 \,/\, d_i = 0) \tag{6}$$

After calculation, we find the expression of the probability of error:

$$P_e = \mathrm{Prob}\left(\frac{\tilde{b}}{\sigma_b^2} > \frac{N_h[R_w(0) - R_w(\delta)]}{\sigma_b^2}\right) \tag{7}$$

To be able to calculate the autocorrelation functions $R_w(0)$ and $R_w(\delta)$, we consider the expression of Gaussian monocycle which can be defined as the first derivative of the Gaussian function. The Gaussian monocycle in time domain $w_{tr}(t)$ can be mathematically defined using the formula (Win & Scholtz, 2000):

$$w_{tr}(t) = \left(\frac{t}{\tau}\right)\exp\left(-\left(\frac{t}{\tau}\right)^2\right) \tag{8}$$

Thus, we obtain the expressions of $R_w(0)$ and $R_w(\delta)$,

$$R_w(0) = \frac{\sqrt{2\pi}}{8}\tau$$

$$R_w(\delta) = \frac{\sqrt{2\pi}}{8}(\tau^2 - \delta^2)\exp\left(-\frac{\delta^2}{2\tau^2}\right)$$

After having made calculation of $R_w(0)$ and $R_w(\delta)$, the equation (7) will become:

$$P_e = \mathrm{Prob}\left(\frac{\tilde{b}}{\sigma_b^2} > \frac{\sqrt{2\pi}N_h\left[\tau - (\tau^2 - \delta^2)\exp\left(-\frac{\delta^2}{2\tau^2}\right)\right]}{8\sigma_b^2}\right) \tag{9}$$

Since the signal power is given by:

$$P_s = N_h \int w_{tr}^2(t)dt = N_h\tau\frac{\sqrt{2\pi}}{8} \tag{10}$$

We can rewrite the equation (9) in another way:

$$P_e = \mathrm{Prob}\left(\frac{\tilde{b}}{\sigma_b^2} > \frac{P_s}{\sigma_b^2} - \frac{\sqrt{2\pi}}{8}N_h\left(\frac{\tau^2 - \delta^2}{\sigma_b^2}\right)\exp\left(-\frac{\delta^2}{2\tau^2}\right)\right)$$

$$= \text{Prob}\left(\frac{\tilde{b}}{\sigma_b^2} > SNR - \frac{\sqrt{2\pi}}{8} N_h \left(\frac{\tau^2 - \delta^2}{\sigma_b^2}\right) \exp\left(-\frac{\delta^2}{2\tau^2}\right)\right)$$

After having developed the expression of P_e, we obtain the equation (11):

$$P_e = \int_{\beta}^{+\infty} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) dx \tag{11}$$

With $\beta = \text{SNR} - \frac{\sqrt{2\pi}}{8} N_h \left(\frac{\tau^2 - \delta^2}{\sigma_b^2}\right) \exp\left(-\frac{\delta^2}{2\tau^2}\right)$

Knowing that σ_b^2 is the noise power and the signal power is equal to $R_w(0)$, we find the equation (12) derived from (11):

$$P_e = Q\left(\text{SNR}\left(1 - \tau\left(1 - \frac{\delta^2}{\tau^2}\right) \exp\left(-\frac{\delta^2}{2\tau^2}\right)\right)\right) \tag{12}$$

The above equation represents the performance of an UWB TH-PPM system for the case of one user and one path, where Q characterizes the Marcum function and, by definition, is the complementary error function.

The Fig. 3 gives us an outline of the comparison, point of view probability of error, between the analytical approach and simulation by the Matlab tool. According to the figure, we can see that the probability of error in the analytical case and the simulation case are almost the same.

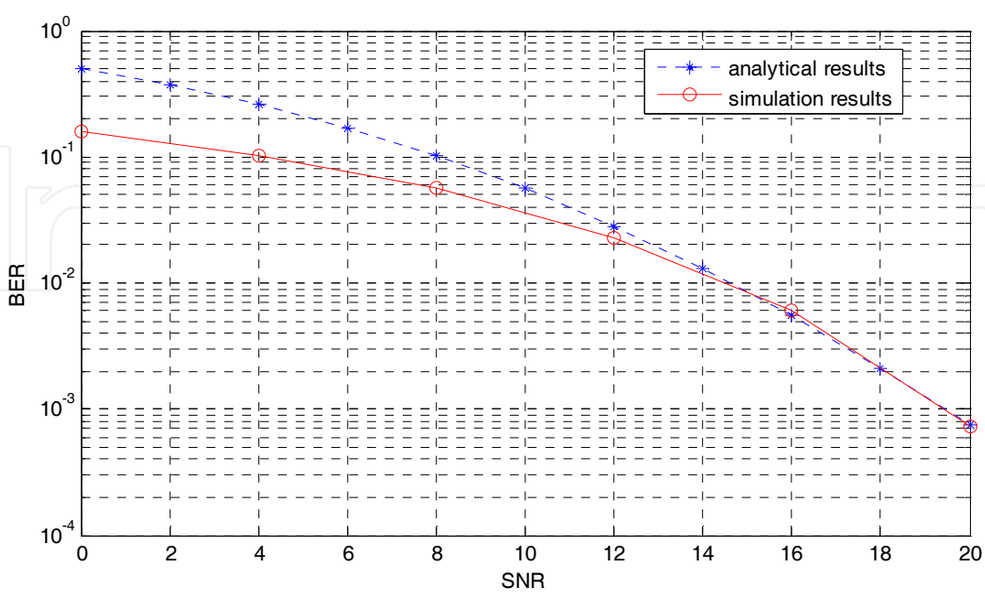

Fig. 3. Comparison between analytical and simulation results

4. Analytical Analysis of BER in the UWB TH-PPM System Model in Multi-user environments

In this section, we are interested in performance of UWB TH-PPM system model in multi-user environments. We assume that the amplitudes a_k of different users are known (assuming that we use later in our analytical analysis). The Fig. 4 shows a particular case of emission of three users. These emitters have some TH different codes and each sends a symbol (either '0' or '1') according to its own TH code.

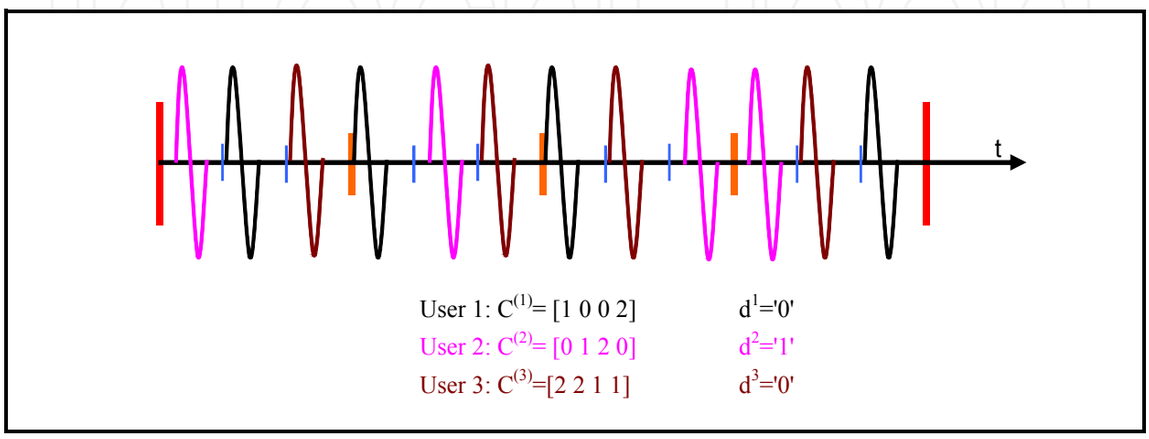

Fig. 4. Transmission of an UWB TH-PPM signal in multi-user environments

As before, we begin by studying the reception of this system translated by the following equation which is the decision making at the reception (Hizem & Bouallegue, 2009a; Hizem & Bouallegue, 2009b),

$$D_i = \int_{[T_s]} \left[\sum_{k=1}^{K} a_k \sum_{j=0}^{N_h-1} w_{tr}\left(t - jT_f - c_j^{(k)}T_c - d_i^{(k)}\delta\right) + b(t) \right] \times \left[\sum_{j=0}^{N_h-1} \left(w_{tr}(t - jT_f - c_jT_c) - w_{tr}(t - jT_f - c_jT_c - \delta) \right) \right] dt \tag{13}$$

Considering the same assumptions as for the previous section and developing the above equation,

$$D_i = \int_{[T_s]} \left[\sum_{k=1}^{K} a_k \left(\sum_{j=0}^{N_h-1} w_{tr}\left(t - jT_f - c_j^{(k)}T_c - d_i^{(k)}\delta\right) w_{tr}(t - jT_f - c_jT_c) - w_{tr}\left(t - jT_f - c_j^{(k)}T_c - d_i^{(k)}\delta\right) w_{tr}(t - jT_f - c_jT_c - \delta) \right) \right] dt + \tilde{b} \tag{14}$$

To simplify our calculation, we take first the case of 2 users and then try to generalize the found results for K users. After developing the equation (14) and made an appropriate change of variable, we obtain the following equation:

$$D_i = \int_{[T_s]} \left[\left(a_1 \sum_{j=0}^{N_h-1} w_{tr}\left(t - d_i^{(1)}\delta\right) w_{tr}(t) + a_2 \sum_{j=0}^{N_h-1} w_{tr}\left(t - d_i^{(2)}\delta\right) w_{tr}(t) \right) - \left(a_1 \sum_{j=0}^{N_h-1} w_{tr}\left(t - d_i^{(1)}\delta\right) w_{tr}(t-\delta) + a_2 \sum_{j=0}^{N_h-1} w_{tr}\left(t - d_i^{(2)}\delta\right) w_{tr}(t-\delta) \right) \right] dt + \tilde{b} \tag{15}$$

By replacing the integral in the above equation with N_h, we obtain:

$$D_i = \int_{[T_s]} \left[N_h a_1 \left(w_{tr}\left(t - d_i^{(1)}\delta\right) w_{tr}(t) - w_{tr}\left(t - d_i^{(1)}\delta\right) w_{tr}(t-\delta) \right) + N_h a_2 \left(w_{tr}\left(t - d_i^{(2)}\delta\right) w_{tr}(t) - w_{tr}\left(t - d_i^{(2)}\delta\right) w_{tr}(t-\delta) \right) \right] dt + \tag{16}$$

To simplify our calculation, we can rewrite the equation (16) in another way,

$$D_i = N_h a_1 \left[R_w\left(d_i^{(1)}\delta\right) - R_w\left((1 - d_i^{(1)})\delta\right) \right] + N_h a_2 \left[R_w\left(d_i^{(2)}\delta\right) - R_w\left((1 - d_i^{(2)})\delta\right) \right] + \tag{17}$$

With

$$R_w\left(d_i^{(1)}\delta\right) = \int_{[T_s]} w_{tr}(t)\, w_{tr}\left(t - d_i^{(1)}\delta\right) dt$$
$$R_w\left(d_i^{(2)}\delta\right) = \int_{[T_s]} w_{tr}(t)\, w_{tr}\left(t - d_i^{(2)}\delta\right) dt$$

The performance will be determined in relation to the user 1. Obviously, it will be the same as for the user 2. In the noise less case (b(t) = 0), we obtain:

$$d_i^{(1)} = 0; \quad D_i = N_h a_1 [R_w(0) - R_w(\delta)] + N_h a_2 \left[R_w\left(d_i^{(2)}\delta\right) - R_w\left((1 - d_i^{(2)})\delta\right) \right] > 0$$
$$d_i^{(1)} = 1; \quad D_i = N_h a_1 [R_w(0) - R_w(\delta)] + N_h a_2 \left[R_w\left((1 - d_i^{(2)})\delta\right) - R_w\left(d_i^{(2)}\delta\right) \right] < 0$$

Then, from this expression, we can determine the probability of error for the user 1,

$$P_e^{U_1} = \text{Prob}\left(\frac{\tilde{b}}{\sigma_b^2} > \frac{N_h a_1 [R_w(0) - R_w(\delta)] + N_h a_2 \left[R_w\left(d_i^{(2)}\delta\right) - R_w\left((1 - d_i^{(2)})\delta\right) \right]}{\sigma_b^2} \right) \tag{18}$$

As in the previous section, we consider the expression of a Gaussian pulse. $R_w(0)$ and $R_w(\delta)$ already being calculated, remains to be determined the expressions of $R_w\left(d_i^{(2)}\delta\right)$ and $R_w\left((1-d_i^{(2)})\delta\right)$. Thus, we obtain:

$$R_w\left(d_i^{(2)}\delta\right) = \frac{\sqrt{2\pi}}{8}\left[\tau^2 - \left(d_i^{(2)}\delta\right)^2\right]\exp\left(-\frac{\left(d_i^{(2)}\delta\right)^2}{2\tau^2}\right)$$

$$R_w\left((1-d_i^{(2)})\delta\right) = K\frac{\sqrt{2\pi}}{8}\left[\tau^2 + \delta^2\left(1-d_i^{(2)}\right)\left(1-3d_i^{(2)}\right)\right]$$

With $$K = \exp\left(-\frac{3}{4}\delta^2\right)\exp\left(-\frac{\delta^2}{2}d_i^{(2)}\right)\exp\left(\frac{3}{4}\delta^2\left(d_i^{(2)}\right)^2\right)$$

Based on the foregoing, it is clear that the probability of error for the user 1 depends on $d_i^{(2)}$. Therefore, there are two cases following that $d_i^{(2)} = '0'$ or $d_i^{(2)} = 1$.

4.1 First Case: $d_i^{(2)} = '0'$

Therefore, $K = exp\left(-\frac{3}{4}\delta^2\right)$ and the probability of error for the user 1 will have as expression (knowing that $P_s = N_h\tau\frac{\sqrt{2\pi}}{8}$),

$$P_e^{U_1} = Q\left(a_1 SNR\left(1-\tau\left(1-\frac{\delta^2}{\tau^2}\right)\exp\left(-\frac{\delta^2}{2\tau^2}\right)\right) + a_2 SNR\left(\tau\left(1-\exp\left(-\frac{3}{4}\delta^2\right)\right) - \frac{\delta^2}{\tau^2}\exp\left(-\frac{3}{4}\delta^2\right)\right)\right) \quad (19)$$

4.2 Second Case: $d_i^{(2)} = '1'$

Therefore, $K = exp\left(-\frac{\delta^2}{2}\right)$ and the probability of error for the user 1 will have as expression,

$$P_e^{U_1} = Q\left(a_1 SNR\left(1-\tau\left(1-\frac{\delta^2}{\tau^2}\right)\exp\left(-\frac{\delta^2}{2\tau^2}\right)\right) + a_2 SNR\left(\left(\tau-\frac{\delta^2}{\tau}\right)\exp\left(-\frac{\delta^2}{2\tau^2}\right) - \tau\exp\left(-\frac{\delta^2}{2}\right)\right)\right) \quad (20)$$

The Fig. 5 compares the probability of error for the two cases $d_i^{(2)} = '0'$ and $d_i^{(2)} = 1$. We notice according to this figure that there is very little difference between the two performances. Therefore, we can conclude that the choice of the impulsion ('0'or '1') doesn't influence the performance of this arrangement of modulation.

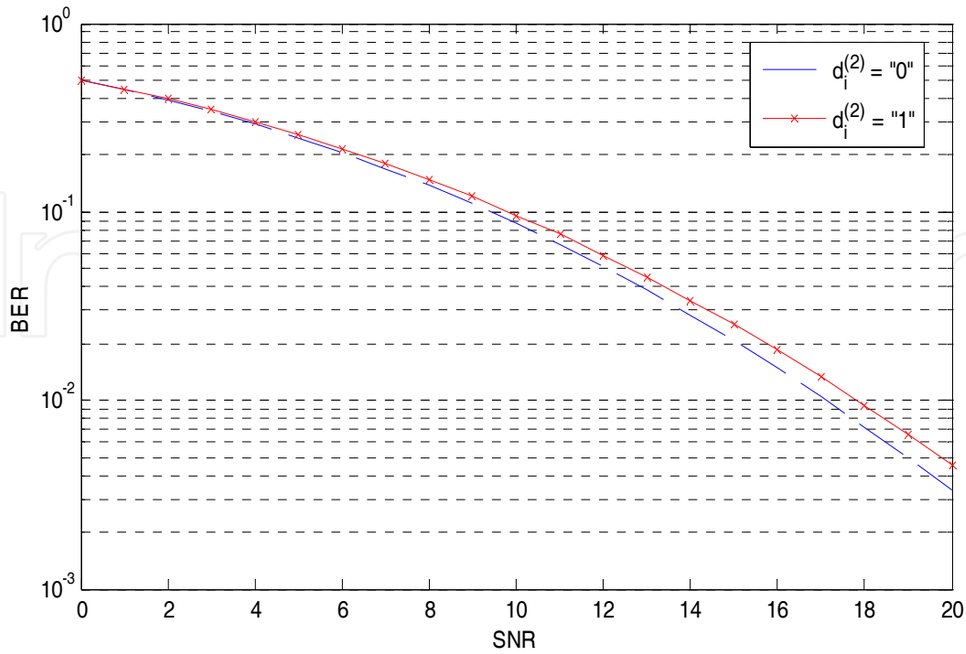

Fig. 5. Comparison of the error probability for $d_i^{(2)} = '0'$ and $d_i^{(2)} = '1'$

From this result for 2 users, we can deduce the expression of the error probability in an arrangement of UWB TH-PPM modulation in multi-user environments,

$$P_e^{U_1} = Q\left(\frac{N_h}{\sigma_b^2}\left[a_1[R_w(0) - R_w(\delta)] + \sum_{k=2}^{K} a_k\left[R_w\left(d_i^{(k)}\delta\right) - R_w\left(\left(1 - d_i^{(k)}\right)\delta\right)\right]\right]\right) \tag{21}$$

With
$$R_w\left(d_i^{(k)}\delta\right) = \frac{\sqrt{2\pi}}{8}\left[\tau^2 - \left(d_i^{(k)}\delta\right)^2\right]\exp\left(-\frac{\left(d_i^{(k)}\delta\right)^2}{2\tau^2}\right)$$
$$R_w\left(\left(1 - d_i^{(k)}\right)\delta\right) = K^{(k)}\frac{\sqrt{2\pi}}{8}\left[\tau^2 + +\delta^2\left(1 - d_i^{(k)}\right)\left(1 - 3d_i^{(k)}\right)\right]$$

Knowing that
$$K^{(k)} = exp\left(-\frac{3}{4}\delta^2\right) exp\left(-\frac{\delta^2}{2}d_i^{(k)}\right) exp\left(\frac{3}{4}\delta^2\left(d_i^{(k)}\right)^2\right)$$

The Fig. 6 represents the performance of a modulation arrangement UWB TH-PPM for 1, 2 and 3 users. According to this figure, it is clear that more the number of users increases more the performance deteriorates. This result confirms our forecasts and previous work.

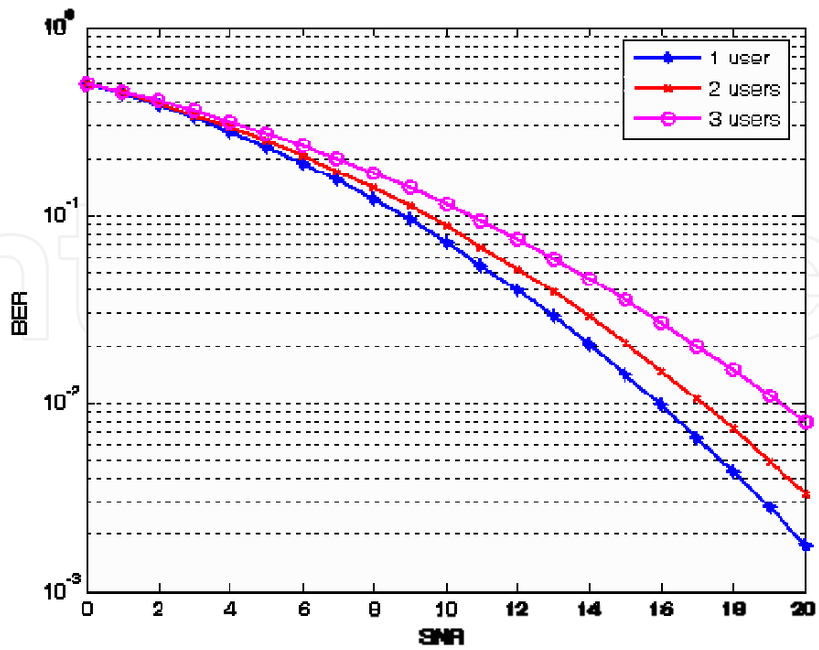

Fig. 6. Performance of TH-PPM UWB system in multi-user environments

5. Analytical Analysis of BER in the UWB TH-PPM System Model in Multipath Environments

In this section, we are interested in performance of UWB TH-PPM system model in multipath environments. In our case, we take as channel model a Rayleigh channel and we assume that their parameters are known (assuming that we use later in our analytical analysis).

The impulse response Rayleigh channel is given by:

$$h(t) = \sum_{l=1}^{L} \alpha_1 \delta(t - \tau_1) \tag{22}$$

Where is the (real) amplitude of the lth path, their delay and L is the paths number. A block diagram of a multipath channel is shown in Fig. 7.

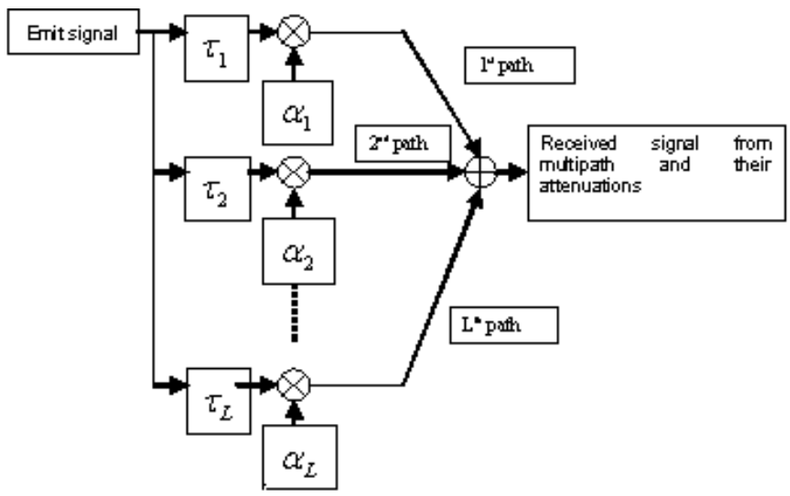

Fig. 7. Block diagram of a multipath channel

As before, we begin by studying the reception of this system translated by the following equation which is the decision making at the reception (Hizem & Bouallegue, 2009c),

$$D_i = \int_{[T_s]} \left[\sum_{j=0}^{N_h-1} \sum_{l=1}^{L} \alpha_l w_{tr}\left(t - jT_f - c_j T_c - \tau_l - d_i\delta\right) + b(t) \right] \times \left[\sum_{j=0}^{N_h-1} \sum_{l=1}^{L} \alpha_l \left(w_{tr}\left(t - jT_f - c_j T_c - \tau_l\right) - w_{tr}\left(t - jT_f - c_j T_c - \tau_l - \delta\right) \right) \right] dt \tag{23}$$

To simplify our calculation, we take first the case of 2 paths and then try to generalize the found results for L paths. After developing the equation (23), used the same hypothesis as for the preceding sections (disjoins temporal support, perfect synchronization) and made an appropriate change of variable, we obtain the following equation:

$$D_i = \int_{[T_s]} \left[\left((\alpha_1)^2 \sum_{j=0}^{N_h-1} w_{tr}(t - \tau_1 - d_i\delta)\, w_{tr}(t - \tau_1) + (\alpha_2)^2 \sum_{j=0}^{N_h-1} w_{tr}(t - \tau_2 - d_i\delta)\, w_{tr}(t - \tau_2) \right) - \left((\alpha_1)^2 \sum_{j=0}^{N_h-1} w_{tr}(t - \tau_1 - d_i\delta)\, w_{tr}(t - \tau_1 - \delta) + (\alpha_2)^2 \sum_{j=0}^{N_h-1} w_{tr}(t - \tau_2 - d_i\delta)\, w_{tr}(t - \tau_2 - \delta) \right) \right] dt + \tilde{b} \tag{24}$$

By replacing the integral in the equation (24) with N_h (consequence of assumptions made before), we obtain:

$$D_i = [N_h(\alpha_1)^2 + N_h(\alpha_2)^2][R_w(-d_i\delta) - R_w((1-d_i)\delta)] + \tilde{b} \tag{25}$$

With $R_w(-d_i\delta) = \int_{[T_s]} w_{tr}(t-\tau_1)\, w_{tr}(t-\tau_1-d_i\delta)dt$
$= \int_{[T_s]} w_{tr}(t-\tau_2)\, w_{tr}(t-\tau_2-d_i\delta)dt$

Where the noise is null (less noise case: b (t) = 0), we get:

$$d_i = 0; \quad D_i = N_h(\alpha_1)^2[R_w(0) - R_w(-\delta)] + N_h(\alpha_2)^2[R_w(0) - R_w(-\delta)] > 0$$
$$d_i = 1; \quad D_i = N_h(\alpha_1)^2[R_w(-\delta) - R_w(0)] + N_h(\alpha_2)^2[R_w(-\delta) - R_w(0)] < 0$$

From this expression, we can determine the probability of error,

$$P_e = \text{Prob}\left(\frac{\tilde{b}}{\sigma_b^2} > \frac{N_h[(\alpha_1)^2 + (\alpha_2)^2][R_w(0) - R_w(-\delta)]}{\sigma_b^2}\right) \tag{26}$$

As in the previous sections, we consider the expression of a Gaussian pulse. $R_w(0)$ already being calculated and $R_w(-\delta) = R_w(\delta)$. Thus, we obtain:

$$P_e = Q\left(\text{SNR}[(\alpha_1)^2 + (\alpha_2)^2]\left[1 - \tau\left(1 - \frac{\delta^2}{\tau^2}\right)\exp\left(-\frac{\delta^2}{2\tau^2}\right)\right]\right) \tag{27}$$

From this result for 2 paths, we can deduce the expression of the probability of error in an arrangement of TH-PPM modulation in multipath environments,

$$P_e = Q\left(\text{SNR}\left[\sum_{l=1}^{L}(\alpha_l)^2\right]\left[1 - \tau\left(1 - \frac{\delta^2}{\tau^2}\right)\exp\left(-\frac{\delta^2}{2\tau^2}\right)\right]\right) \tag{28}$$

The Fig. 8 represents the performance of an arrangement of modulation TH-PPM for 1, 2 and 3 paths. According to this figure, it is clear that more the number of paths increases more the performance deteriorates. Note that the system performance even in the presence of several paths remains correct. This is one of the characteristics of the ultra wideband technology. This result confirms our forecasts and previous work.

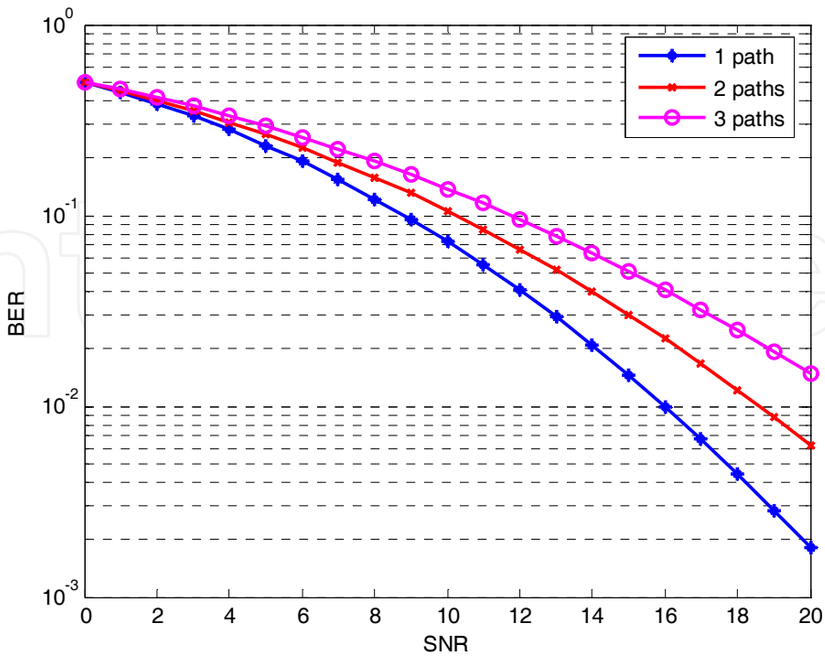

Fig. 8. Performance of TH-PPM UWB system in multipath environments

6. Analytical Analysis of BER in the UWB TH-PPM System Model in Simultaneously Multipath and Multi-user Environments

This final part is a combination of previous analytical approaches. In this section, we are interested in performance of UWB TH-PPM system model in simultaneously multipath and multi-user environments. In our case, we take a Rayleigh channel and we assume that their parameters are known. In the same way, we suppose that the amplitudes a_k of different users are known. These hypotheses are used later in our analytical analysis.

As before, we begin by studying the reception of this system translated by the following equation which is the decision making at the reception (Hizem & Bouallegue, 2009d),

$$D_i = \int_{[T_s]} \left[\sum_{k=1}^{K} \sum_{j=0}^{N_h-1} \sum_{l=1}^{L} a_k \alpha_l w_{tr}\left(t - jT_f - c_j^{(k)} T_c - \tau_l - d_i^{(k)}\delta\right) + b(t) \right] \times \left[\sum_{j=0}^{N_h-1} \sum_{l=1}^{L} \alpha_l \left(w_{tr}\left(t - jT_f - c_j^{(k)} T_c - \tau_l\right) - w_{tr}\left(t - jT_f - c_j^{(k)} T_c - \tau_l - \delta\right)\right)\right] dt \quad (29)$$

We will not repeat the same steps of calculation since it is the same as the previous sections. As in the previous section, we consider the expression of a Gaussian pulse. To simplify our calculation, we take first the case of 2 paths and 2 users and then try to generalize the found

results for L paths and K users. And after computation, we obtain the error probability expression with a UWB TH-PPM modulation arrangement in simultaneously multipath and multi-user environments,

$$P_e = Q\left(\mathrm{SNR}\left[1-\tau\left(1-\frac{\delta^2}{\tau^2}\right)\exp\left(-\frac{\delta^2}{2\tau^2}\right)\right]\left[\left(\sum_{k=1}^{K} a_k\right)^2\left(\sum_{l=1}^{L}(\alpha_l)^2\right)\right]\right.$$
$$+\tau\mathrm{SNR}\left[\sum_{i\neq j}\alpha_i\alpha_j\left(\sum_{k=1}^{K} a_k\right)^2\right]\left[\left(1-\sum_{i\neq j}(\tau_i-\tau_j)^2\right)\exp\left(-\frac{1}{2}\sum_{i\neq j}(\tau_i-\tau_j\right.\right.$$
$$\left.\left.\left.-\left(1-\sum_{i\neq j}(\tau_i-\tau_j+\delta)^2\right)\exp\left(-\frac{1}{2}\sum_{i\neq j}(\tau_i-\tau_j+\delta)\right)\right]\right) \tag{30}$$

The Fig. 9 represents the performance of a UWB TH-PPM modulation arrangement for simultaneously 2 users and 2 paths, 3 users and 3 paths. According to this figure, it is clear that more the number of paths and users increases more the performance deteriorates. This result confirms our forecasts and previous work. The Fig. 10 gives a comparison between different scenario environments performance and computer simulation results show the conformity of this method since we see that performance in the case of 2 users and 2 paths simultaneously is worse than other cases.

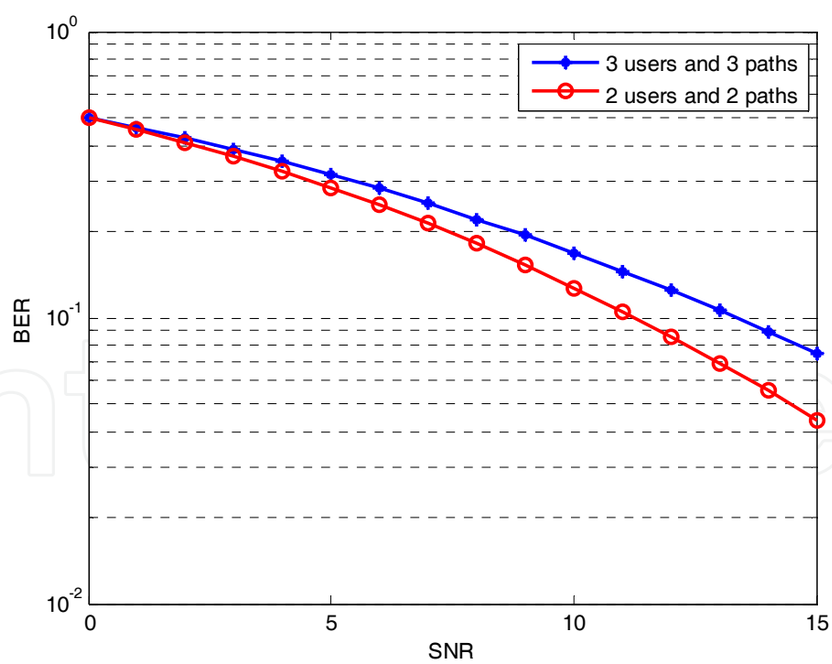

Fig. 9. Performance of TH-PPM UWB system in simultaneously multipath and multi-user environments

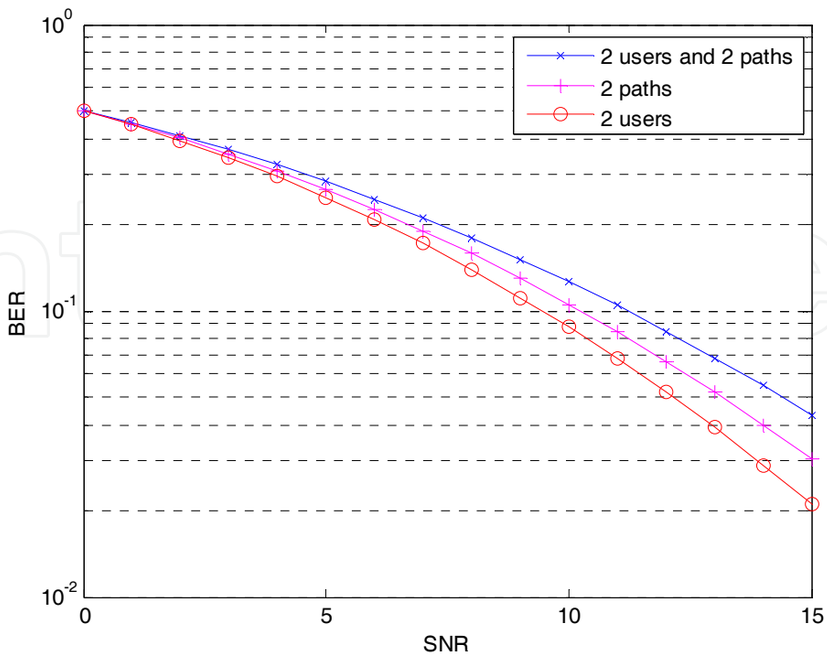

Fig. 10. Comparison between different scenario environments performance

7. Conclusion and Future Research

In this chapter, we have discussed the problem of TH-PPM UWB system performance in different environments. While there is a rich body of literature addressing this problem most of which has emerged recently, this topic is far from being mature. In this context, developing novel analytical methods with relatively low complexity still represents crucial task in meeting the challenges of UWB communications.

We first gave an outline of pulse position modulation and time hoping spectrum spreading and then describe the TH-PPM UWB system model. In the rest of this chapter, we have derived an accurate, analytical expression for the bit error rate of TH-PPM UWB systems. Compared with other methods employed in the performance analysis of UWB systems, our analysis provides a powerful tool for calculating BER's to any desired precision with very low complexity. It was verified by comparisons with simulation results the conformity of this method compared to previous work in this domain and therefore is usable in a UWB communication system.

Finally, we extend this method to multi-user, multipath and simultaneously multipath and multi-user environments. The results have confirmed our forecasts and demonstrated the ability to give simple expressions that allows us further to use them in more complexes cases and therefore benefit in computing time.

The presented analytical method has been only for scenarios with perfect synchronization. A natural extension will be to use dynamic and more realistic scenarios in order to fully describe the UWB radio channels. In future work, we shall try to study the other channel's models more close to the reality and other modulation's schemes to see which one gives us of better performances.

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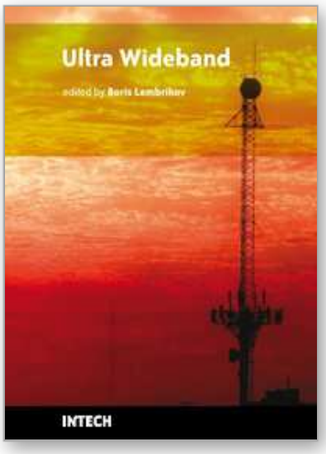

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Ultra wideband technology is one of the most promising directions in the rapidly developing modern communications. Ultra wideband communication system applications include radars, wireless personal area networks, sensor networks, imaging systems and high precision positioning systems. Ultra wideband transmission is characterized by high data rate, availability of low-cost transceivers, low transmit power and low interference. The proposed book consisting of 19 chapters presents both the state-of-the-art and the latest achievements in ultra wideband communication system performance, design and components. The book is addressed to engineers and researchers who are interested in the wide range of topics related to ultra wideband communications.

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