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PERFORMANCE ASSESSMENT OF UWB MULTIPATH CHANNEL USING RAKE RECEIVER TYPES

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RESUME

La technologie de l'Ultra-Large Bande (ULB) consiste à transmettre des impulsions très fines de l'ordre de nanoseconde, ce qui implique dans le domaine fréquentiel une bande de fréquences très large. Le sujet principal à aborder dans ce travail est de confronter et faire face au phénomène des multi-trajets dans les communications ULB. Pour ce but, dans ce travail nous traiterons ce problème en utilisant les différents types du récepteur Rake (A-Rake, P-Rake, S-Rake). Les résultats prouvent que le récepteur A-Rake qui capte tous les composants multi-trajets est le préféré, mais ce type est difficile à mettre en œuvre. Pour cette raison, le A-Rake reste un récepteur idéal; où le S-Rake est le type le plus réaliste qui apporte un compromis entre la faisabilité et l'efficacité comme il est prouvé dans ce travail, où P-Rake peut etre vu comme une approximation simplifiée de S-Rake.

MOTS CLES: Multi-trajets, PPM, Rake, UWB.

ABSTRACT

Ultra-wide band (UWB) technology consists of transmitting very fine pulses of the order of nanosecond, which implies in the frequency domain a very wide frequency band. The main topic to be addressed in this work is to confront and face the phenomenon of multipath in UWB communications. For this purpose, in this work we will treat this problem using the different types of the Rake receiver (A-Rake, P-Rake, S-Rake). The results provides evidence that the A-Rake receiver that takes all the multipath components is the preferred one, but this type is difficult to be implemented. For that reason, the S-Rake remains the reasonable type that combines between the feasibility and the efficacy as proved in this work, where P-Rake is considered as a simplified approximation of S-Rake.

KEYWORDS: Multipath, PPM, Rake, UWB.

1 INTRODUCTION

In recent years, The Ultra-Wide Band (UWB) technology is used since the 1960s in radar applications. However, she experienced spectacular growth since 2002. The Ultra Wideband allows high bandwidth and short range communication for very low power consumption. Thus, UWB technologies are being developed as an emerging wireless technology for high-speed wireless personal area networks and being considered for several technologies due to their attractive features [1].

Among the biggest problem faced by the UWB technology is the acquisition of signals and how these signals should be received in good conditions, where the multipath phenomenon has primordial effects on transmitted signals due to UWB channel characteristics. However, the multipath effects remain the significant challenge that should be confronted because the UWB signals use ultra-short impulses, where the more the impulses are very short the more the multipath will have harmful effects.

Primarily this issue is justified because the multipath phenomenon has a strong impact on the UWB communications and there is persistent need to consider their influences.

In 2002 the IEEE has proposed a first channel model dedicated to standard IEEE 802.15.3a (high data rate communication applications for WPAN), which is called " IEEE 802.15.3a Channel Model" or "Model 3a". Where the main objective is to allow a comparison of various UWB devices proposed for the physical layer [2], where four scenarios or Channel Models (CM1 to CM4) were taken into account.

The Rake receiver remains among the best receivers to counter the phenomenon of multipath fading. Theoretically, an ideal Rake receiver is a receiver that captures all the transmitted energy through a number of fingers equal to all the multipath components. This receiver type is defined by [3]. Really, it is impossible to have like that receiver with this approach in the reality; because it needs an infinite number of Rake fingers, so infinite number of correlators [38]. Thus, the A-Rake cannot be implemented. The maximum ratio combining (MRC) can be used while the performance close to the one met in the AWGN. Hence, the MRC implies coherently combining all the transmitted components to have optimal performance [4]. Due to the phenomenon of multipath and noise, the acquisition requires a prior channel estimation procedure, where the channel parameters (amplitudes and delays associated with each path) must be approximately known at the receiver [5-8].

In this work, our objective is to characterize the ultra-wideband communications using the Rake receiver through three types of receivers A-Rake, S-Rake, P-Rake [9]. The difference between these types resides on the number of paths taken into account at the receiver and in the manner of receiving the paths.

The reminder of this paper is structured as follows: In sections 2, we address the TH-UWB signal structure used during this work, followed by the Pulse Position Modulation (PPM) used and UWB signal format. In section 3 discusses the working principle of Rake receiver with descripting its different types. The section 4 gives simulations results. In section 5 some elements at the end to wrap up this work.

2 TH-UWB SIGNAL STRUCTURE

In multiple access transmission, different users sharing the same physical channel, therefore there's always a risk of interfering with each other. In order to avoid the negative effect of this harmful interference, different multiple access techniques were considered in IR-UWB. Among them, we have the Time Hopping (TH) technique.

The Fig. 1 shows the TH-UWB signal structure (train of symbols an(i)). As it is embedded, the state of a symbol among them is (0 or 1) for the PPM modulation according to the shifted delay δ.

Indeed the impulse is much shorter than the symbol duration Ts, for that reason the spectrum is spread, so it is possible during the time Ts seconds time interval to repeat several times that impulse. This matter creates a separation between users based on the technique of time hopping. The latter technique combines a specific code to each user to set up the impulses' locations within the symbol Ts. Therefore, the TH-UWB signal associated with the same information symbol is composed of Nf duration of Tf frames. Each frame comprises several impulses destined to different users, but only one impulse of them in the frame duration is taken into account for a specified user.

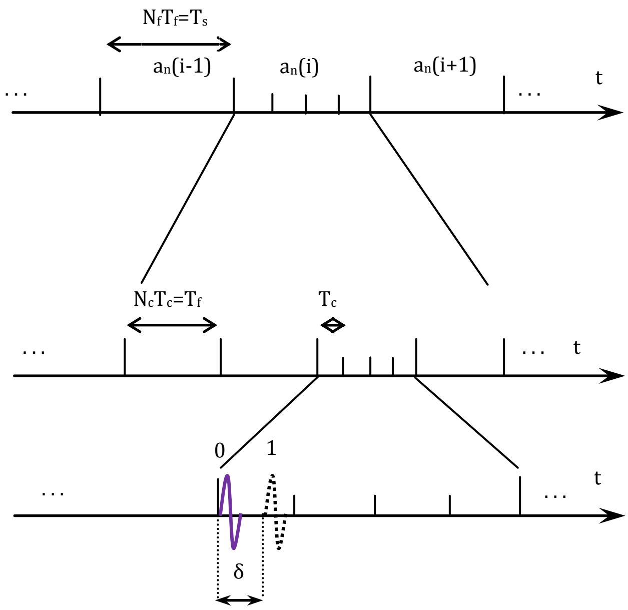


Figure 01: TH-UWB signal structure for PPM modulation

To determine the position of the impulse within the frame, this latter is divided into Nc chips of duration Tc to facilitate extracting codes of the impulse positions of each user. A specific code determines the position of the impulse within the frame (chip number) to each user. These codes are chosen to avoid interference between different users, and they are periodic codes over the number of frames in each symbol

2.1 PPM Modulation (Pulse Position Modulation)

Previously, the PPM has been used for optical communications as a classical modulation, whereas it remains untraditional for wireless communications. The interest in PPM increased with IR-UWB that has a very fine time resolution [32]. This modulation distinguishes between “0” and “1” through a small delay δ .

Basing on what it is mentioned before, the equation that represents the PPM modulation assigned to the signal transmitted for the desired user n is [13].

$$S^n(t) = \sqrt{E^n} \sum_{i=-\infty}^{+\infty} \sum_{j=-\infty}^{N_f-1} w(t - iN_fT_f - jT_f - c_n(j)T_c - \delta a^n(i)) \quad (1)$$

E^n	: Signal energy associated with the user n
T_f	: Frame duration
T_c	: Chip duration

N_f	: Number of frames
N_c	: Number of chips
$w(t)$	: Impulse shape, where $T_w < T_c$
a^n (i)	: Transmitted symbols a^n (i)∈{0, 1}
$c_n(j)$	: Time hopping code THC associated with the user n, with integer values in {0, N_c− 1} and periodic with period equals to N_f
δ	: Modulation factor

2.2 UWB Signal Format

Typically, the signal reconstitution is to find the information transmitted by exploiting the received signal accurately. Indeed, this is difficult especially in the UWB domain, because the transmitted signal undergoes many distortions related mainly to the propagation channel as well as antennas and electronic circuits. It is well known that the IR-UWB signals are composed of a suite of impulses whose short durations, which are confined within a specific time interval.

The received signal is a combination of different replicas of the transmitted signal that have undergone numerous deformations resulting mainly from the Inter-Symbol Interference (ISI), and from the Multi-User Interference (MUI) as well as the different noises due from coexisting systems signals (UWB and / or "narrowband").

The TH-PPM UWB signal for one user s(t) is defined by the following expression:

$$s(t) = \sqrt{E}\sum_{i=-\infty}^{+\infty}\sum_{j=-\infty}^{N_f-1} w(t - iN_fT_f - jT_f - c_n(j)T_c - \delta a(i)) \quad (2)$$

The impulse response of multipath model is then given by the following relation [10]

$$h(t) = X\sum_{l=0}^{L}\sum_{k=0}^{K}\alpha_{k,l}\delta(t - T_l - \tau_{k,l}) \quad (3)$$

L : number of packets

K : number of paths per packet

X : global "shadowing" effect

$\{\alpha_{k,l}\}$: attenuation coefficient of paths

$\{T_l\}$: arrival time of the 1st path of the lth packet

$\{\tau_{k,l}\}$: delay of the kth component of paths of the lth packet, according to the arrival time of the 1st path (τ1,l =0)

Then the expression of the received signal is given as follows :

$$r(t) = X\sqrt{E}\sum_{i=-\infty}^{+\infty}\sum_{j=-\infty}^{N_f-1}\sum_{l=0}^{Lc}\sum_{k=0}^{K}\alpha_{k,l}\tilde{w}(t - iN_fT_f - jT_f - c_n(j)T_c - \delta a(i) - T_l - \tau_{k,l}) + n(t) \quad (4)$$

Where $\tilde{w}(t)$ is the received impulse (distorted from that transmitted w (t)).

3 RESULTS WORKING PRINCIPLE OF THE RAKE RECEIVER

The Rake receiver belongs to the correlation receivers. Its general idea is to use the various components of the multipath to improve the final decision. This decision is practically limited because the receiver can analyze only a finite subset of Lc contributions which are called fingers (branches) of the Rake receiver.

The Rake receiver consists of several fingers of which the number corresponds to the number of multipath components taken into account. For each finger the phase correlation is performed as the following description. The received signal is multiplied by a signal "template" $m_l(t - iN_fT_f - \tilde{\tau}_l)$ which is adapted to the lth finger of the rake, then it is integrated over the information symbol's duration to give the decision signal. At this stage, a threshold detector based on the result of the correlator is sufficient to demodulate and determine the received symbol.

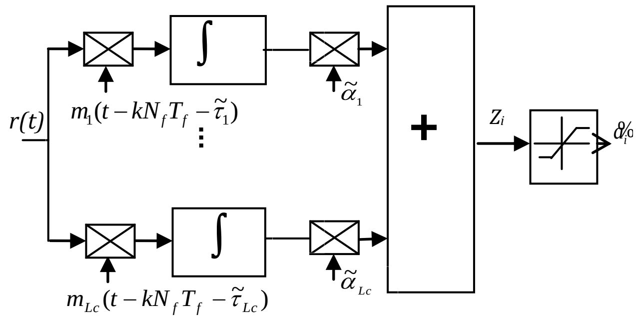


Figure 02: General structure of the Rake receiver

In the case of PPM modulation, a single template signal is used to give the decision signal, where the detector performs a comparison against the zero by seeing the sign of the result given by the correlator. The formula of the template signal for PPM modulation is given by :

$$m(t) = b(t) - b(t - \delta) \tag{5}$$

The resulting signal is integrated over a duration corresponding to the duration Ts of an information symbol. The weighted sum of the correlation results is then applied to a detector which determines the received symbol $\hat{a}_i$. The decision variable zi is given by the following expression :

$$z_i = \sum_{l=1}^{Lc} \alpha_l \int_{iN_f T_f}^{(i+1)N_f T_f} r(t) m(t - iNT_f - \tau_l) dt \tag{6}$$

In practice, the parameters $\{\alpha_l\}$ and $\{\tau_l\}$ are unknown a priori and should be estimated through à channel estimation process to have an idea on how the signals will be affected as done in [5-8].

Several options are also possible for the number of branches or fingers constituting the Rake receiver; i.e. the number of components included that define the type of Rake receiver. By this reason, there are three Rake receiver types that are described below.

3.1 A-Rake Receiver (All Rake)

It takes into account all the received paths, for that it may become very complex. In practice, it is so difficult to carry out this type of receivers [11].

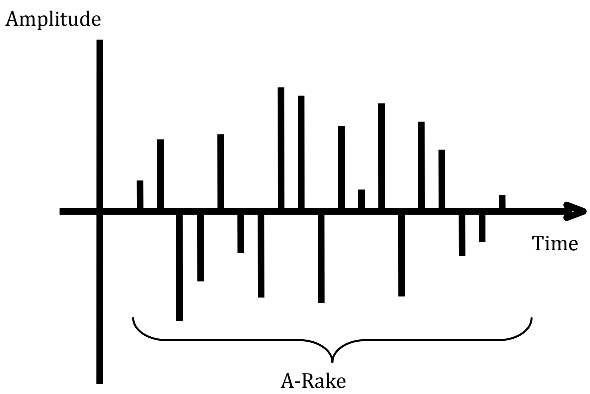


Figure 03: The paths that are taken into account by A-Rake

3.2 P-Rake receiver (Partial Rake)

In this type, only the first paths are considered at the receiver without any distinction between them [11].

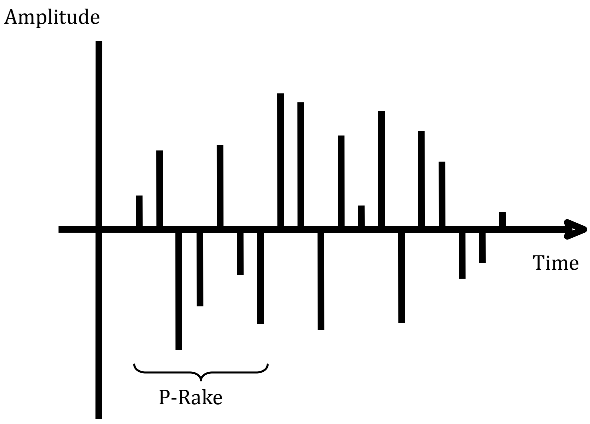


Figure 04: The paths that are taken into account by P-Rake

3.3 S-Rake receiver (Selection Rake)

This type of receivers picks up only the most important paths are taken into consideration. According to the IEEE channel, the concerned paths are those having undergone an attenuation of more than 10 dB compared to the strongest path, not necessarily the first arrived path, (the remains α_l will be null, except one that corresponds the best path which is equal to the fading coefficient of the corresponding path).

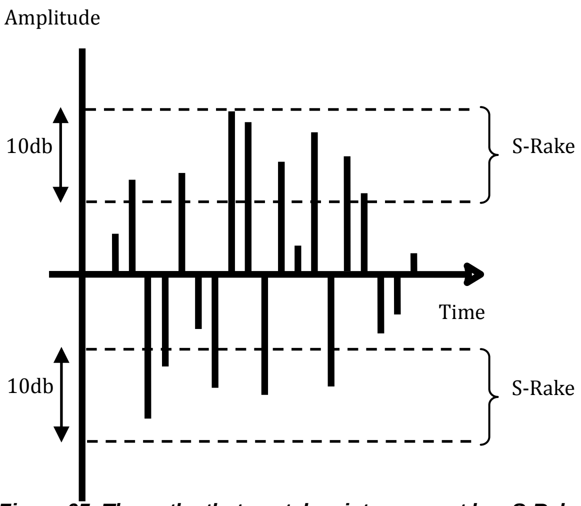


Figure 05: The paths that are taken into account by S-Rake

4 SIMULATION RESULTS

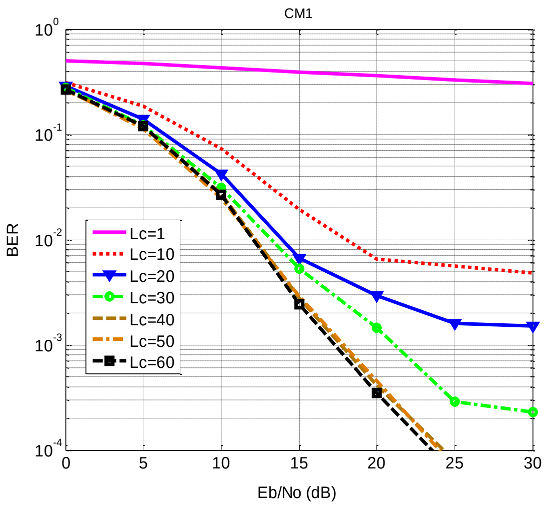
The TH-UWB signal is modulated with PPM modulation and built according to the following parameters:

- ✓ Data rate: Rd=50Mbps
- ✓ Number of frames in a symbol Nf=2
- ✓ Number of chips in a frame Nc=10,

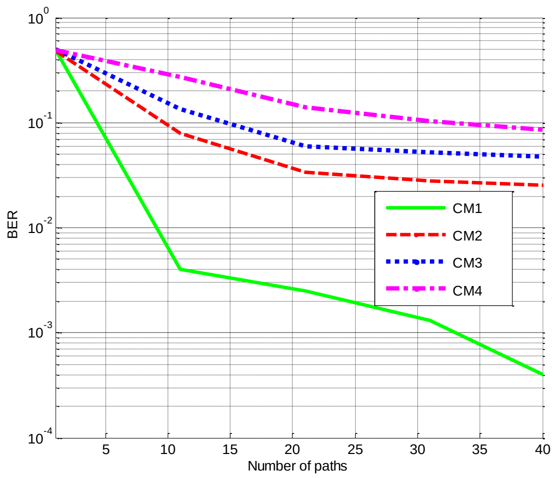
where $c_n(j)$ is the Time Hopping Code (THC) associated with the desired user in jth frame and it is between {0, Nc− 1}

- ✓ Signal energy E^n is normalized to "1"
- ✓ Impulse duration is Tw =0.2ns
- ✓ Modulation factor $\delta = 0.2ns$
- ✓ Sampling rate 25 GHzs.

The number of paths taken into account plays an important role in the signal reception. The Fig. 6.a represents the BER versus SNR for different numbers of paths, using the model CM1. The Fig. 6.b represents the BER versus the number of paths for all channel models. It is noted that from 50 paths, there is no significant improvement in the BER. This result is also confirmed by [12-13, 14], where they proved that about 50 fingers are required in the UWB channels between 3 and 10 GHz to have a negligible loss of performance. These 50 fingers correspond to the paths containing 85% of the energy of the impulse response of the channel. The spreading of the multipath channel and the number of significant paths impact the number of fingers needed for a Rake. The author in [15] also shows that the more the number of fingers increases, the less performance difference between P-Rake and S-Rake.



(a)



(b)

Figure 06: Influence of the paths number on BER Evaluations: (a) BER versus SNR for different numbers of paths; (b) BER versus number of paths, SNR = 20dB

The Fig. 07 shows the BER evaluation using CM1 for all the rake receiver types: A-Rake, S-Rake and P-Rake. Knowing that the first type is used to pick up all paths arriving at the receiver; the S-Rake type picks up all paths having undergone an attenuation of 10 dB relative to the strongest path, the P-Rake type takes into account only the first paths, the number of paths considered in this case is Lc=5. It is shown that the BER performance assessed by the receiver A-Rake is better than the other types, yet this receiver type does not exist practically.

The S-Rake is a Rake whose implementation is feasible. It works on the L highest channel paths.The more efficient the channel estimation, the stronger is the signal-to-noise ratio (Eb/No). The S-Rake has a reduced complexity compared to the A-Rake receiver. The P-Rake is an approximation of the S-Rake where it works only on the L first paths which are most often the strongest.

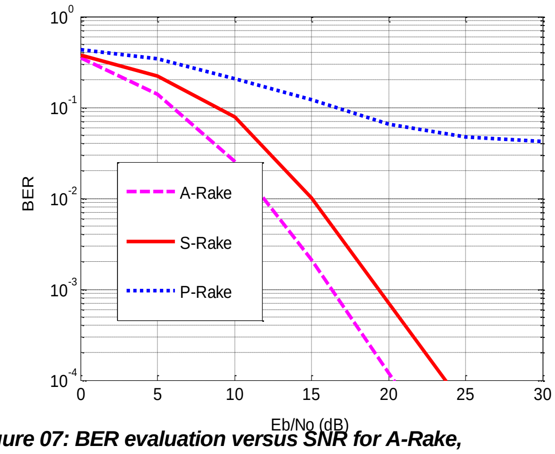


Figure 07: BER evaluation versus SNR for A-Rake, S-Rake, and P-Rake

5 CONCLUSION

In this work, we have studied various features related to Ultra-broadband communications. When the signals are received, the number of fingers of the RAKE receiver has a great importance during the reception. Nevertheless, the number of paths required to have better performances is from 20 paths and more, where it was what found by [9] from 10 paths. It is also clear to show that the more the order of the model increases, the more the communication is bad, as it is also observed according to [5, 9-10]. The A-Rake receiver is a preferable type but practically this type of receivers is not realistic due to the number of fingers required which is very high. The S-Rake receiver remains accessible when receiving UWB signals compared to other types due to its construction which is more practical and more realistic. The P-Rake receiver is considered as an approximation to the S-Rake receiver.

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