A MODIFIED UWB PRAKERECEIVER USING MULTI-COMPARATORS+

مستقبلة (PRake) معدلة لأنظمة (UWB) باستخدام مقارنات متعددة

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Abstract:

Ultra-wideband (UWB) communication systems occupy huge bandwidths with very low power spectral densities. This feature makes the UWB channels highly rich in resolvable multipath. To exploit the temporal diversity, the receiver is commonly implemented through a Rake. The aim is to capture enough signal energy to maintain an acceptable output Signal-to-Noise Ratio (SNR) .In this paper, the performance of a modifiedPartial rake (PRake) receiver for an(UWB) communication systems is studied . The modification is based on adding a common single finger whose output is fed to multi-comparators distributed along the conventional PRakefingers. ABinary Phase Shift Keying – Time HoppingUltra-wideband (BPSK/TH/UWB) signal is used , in multi user environment ,this study is done on the Wireless Personal Area Network (WPAN) IEEE802.15.3a, CM3,(which is prepared in Matlab program using m-file code). The Simulationresults based on a Matlab code programs show the effect of modification in terms of Bit Error Rate (BER) enhancement. The results show improvements in the BER in both single user and multiuser situations.

Keywords: UWB, PRake, WPAN.

المستخلص:

تشغل أنظمة ذات الحزمة فوق العريضة (UWB) نطاق ترددي واسع مع كثافات طيفية منخفضة جدا وذلك ما يجعل هذه الأنظمة غنية بالانعكاسات المتعددة للإشارة . ولاستثمار الاختلاف الزمني للإشارة، عادة ما تصمم المستقبلة لهذه الأنظمة بطريقة (Rake) والهدف من ذلك لغرض إمساك قدرة كافية للإشارة المستلمة ولتحقيق مستوى مقبول لنسبةالإشارةإلى الضوضاء (SNR) .

في هذا البحث نناقش أداء تصميم معدل لنوع مستقبلة (PRake) وذلك بإضافة قناة مشتركة يتم مقارنة خرجها مع خرج كل إصبع من أصابع المستقبلة التقليدية عن طريق إضافة مقارنات تتوزع على أصابعالمستقبلة التقليدية . تم استخدام إشارة (BPSK-TH-UWB) في بيئة افتراضية لعدة مستخدمين وتم تنفيذ المحاكاة على (-WPAN IEEE 802.15.3a CM3) والتي استخدمت كبرنامج جاهز بلغة (Matlab) . أظهرت نتائج التحليل التي بنيت بمساعدة برنامج (Matlab)تحسنا ملحوظا في حسابات معدل الخطأ (BER) لكلا الموقفين في حالة المستخدم المنفرد أو عدة مستخدمين.

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Introduction:

In recent years, a significant research effort has been devoted to the study of ultra-wideband (UWB) communication systems. The basic principle behind ultra-wideband communications was first used in radar systems over thirty years ago. The Federal Communication Commission (FCC) regulation permits transmission of signals with -10 dB bandwidths that lie in the 3.1 to 10.6 GHz band, provided that the transmitted signals have an Effective Isotropic Radiated Power (EIRP) below -41.3 dBm in this band and a minimum bandwidth of 500 MHz [1]

UWB communication systems occupy huge bandwidths with very low power spectral densities. This feature makes the UWB channels highly rich in resolvable multipaths. To exploit the temporal diversity, the receiver is commonly implemented through a Rake. The aim to capture enough signal energy to maintain an acceptable output SNR dictates a very complicated Rake structure with a large number of fingers. Another aspect is to eliminate or combat the Inter-Symbol Interference (ISI) which distorts the transmitted signal and causes bit errors at the receiver, especially when the transmission data rate is very high as well as for which are not well synchronized[2].

A Rake receiver consists of a bank of correlators, where each correlator (or finger) is synchronized to a multipath component. Multipath energy may be coherently added at the receiver using different finger combining techniques. In Equal Gain Combining (EGC), for example, the signals from different fingers are equally weighted and added. Selection Combining (SC) consists of choosing the finger with maximum SNR. Maximum Ratio Combining (MRC) weights each finger corresponding to its SNR (or the strength of its corresponding multipath),[3].

Several papers have focused on UWB Rake receivers in recent years. In [3] a literature review for different attempts in this field was presented. the performance of an MRC Rake receiver in an indoor multipath environment based on the $\Delta - K$ channel model is studied,[4] .

A semi-analytical study of three types of MRC Rake receivers is presented, based on indoor office channel measurements,[5]. Rake receivers based on Square Law Combining (SLC), where the signals from different Rake fingers are first squared then added, are compared to MRC Rake receivers in [6]. An analysis of the BER of MRC Rake receivers based on tap-delay channel models is presented in [7]

System architecture:

1-Transmitter

An Impulse Radio (IR) UWB system, using pulses p(t) of width $T_p$seconds is considered in this work. In a multiuser environment of Nu simultaneously active users, the unmodulated signaling waveform of the jth user is given by[8]:

$$s_j(t) = \sum_{i=0}^{Ns-1} p(t - iT_f - , C_j iT_c) \ldots\ldots\ldots\ldots\ldots(1)$$

where $N_s$is the number of pulse repetitions, $T_f$is the pulse repetition time, $T_c$is the chip duration such that there are $N_h$chips within T_f and $c_{j,i}$ □ $\{0, 1, \ldots, N_h - 1\}$ is the time hopping sequence for the j^{th} user.

Let *{dj}* be the data sequence available at the j^{th} user. *{dj}*is assumed to be a wide sense stationary random process with equiprobable symbols. Binary phase shift keying (BPSK) schemes is considered. Hence, the signal transmitted by the j^{th} user can be given as[8] :

$$s_j(t)=\sqrt{E_j}\sum_{i=0}^{Ns-1} d_{j,i}\,p(t-iT_f-C_{j,i}T_c) \ldots\ldots\ldots(2)$$

where $d_{j,i} \in \{-1, 1\}$ for BPSK, E_j is the available power for the j^{th} user , the result shapeof this transmitted frames as described below in Figure(1).

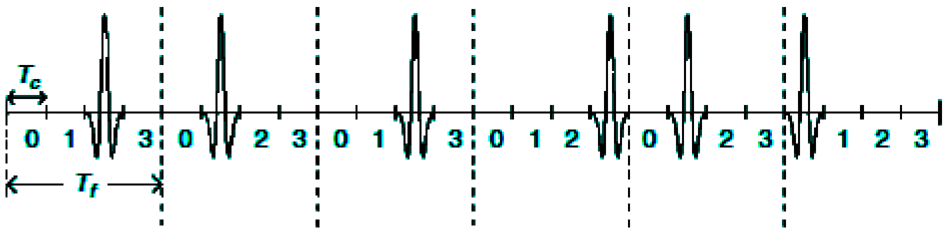

Figure (1) TH-UWB signal

2- The channel

The WPAN indoor multipath channel IEEE 802.15.3a is assumed. This channel is modeled as a linear, time-varying filter which is timeinvariant over a frame T_f duration with impulse response $h(t)$ and maximum excess delay spread T_{mds}. The IEEE 802.15.3a multipath model consists of the following discrete time impulse response [9]:

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

where $\alpha_{k,l}$ is the multipath gain coefficient, T_l is the delay of the l^{th} cluster, and $\tau_{k,l}$ is the delay of the k^{th} multipath component (ray) relative to the l^{th} cluster arrival time (T_l). In addition, we assume that the channel characteristics remain unchanged over the all transmitted bits.

h(t) can be written in the following form :

$$h(t) =\sum_{k=0}^{K} h_k\,\delta(t-\tau_k) \ \ldots\ldots\ldots\ldots\ldots(4)$$

Assuming that the minimum relative resolvable path is equal to T_C, then h(t) becomes: :

$$h(t) =\sum_{k=0}^{K} h_k\,\delta\,(t-(k-1)T_c) \ldots\ldots\ldots\ldots\ldots..(5)$$

3-The Receiver

The conventional PRake and the proposed PRake receivers will be discussed below:

3.1 The Conventional Rake Receiver

The Rake receiver consists of a bank of correlators or matched filters also called fingers. Each Rake finger is matched to a particular multipath component to combine the received multipath coherently. If the receiver uses all the L received paths, it is called All Rake (*ARake*) . However, the number of multipath components that can be utilized in a typical

RAKE combiner is limited by power consumption issues, design complexity, and the channel estimation .Thus, in practice, only a subset of total resolved multipath components is used, e.g., Partial Rake (*PRake*) (which represent the type used in this paper) ,and Selective Rake (*SRake*) use a limited number of fingers. The PRake receiver uses the *M first arriving* paths out of *L* resolvable multipath components, while SRake searches for the *M best paths* out of *L* received MPCs to use them as RAKE fingersReferring to Figure (2), a reference or template signal matched to the incoming received signal is used by the Rake receiver. Each finger of the Rake uses a delayed version of the template signal to match the delay to a specific multipath component. In order to enable *symbol-rate* sampling, the received signal is correlated with a symbol-length template signal, and the correlator output is sampled once per symbol, The template signal matched to the whole pulse sequence of one information symbol $w_{temp}(t)$is given by [10]:

$$w_{temp}(t) = \sqrt{\frac{1}{N_f}\sum_{j=kN_f}^{(k+1)N_f-1}} d_j\, p_{rx}(t - jT_f - c_jT_c)\ldots\ldots(6)$$

The output of the lth finger of the Rake receiver for the k^{th} symbol is given by[10] :

$$z_{l,k} = \int_{-\infty}^{+\infty} r(t)\ w(t - \tau_l)dt\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Assuming a perfect match of the received signal with the reference signal, zero inter-frame and inter-symbol interference, and symbol rate sampling at the output of Rake fingers, then (7) can be rewritten in discrete time as[10] :

$$z_{l,k} = b_k\sqrt{E_b}\alpha_l + n_{l,k} \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

where $l = 0, 1, \cdots, L - 1$ and k represents the symbol index and $n_{l,k}$is given by[10]:

$$n_{l,k} = \sigma_n\int_{-\infty}^{+\infty} n(t)w_{temp}(t - \tau_l)\,dt \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

is the noise at the output of the correlators which is approximately distributed as $n \sim N(0, \sigma_{2n})$. The outputs of the correlators for the k^{th} symbol can be written in vector notation as[10] :

$$z_k = b_k\sqrt{E_b}\alpha + n_k \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

where $\mathbf{z_k} = [z_{0,k}, \cdots, z_{L-1,k}]^T$, $\boldsymbol{\alpha} = [\alpha_0, \cdots, \alpha_{L-1}]^T$, and $\mathbf{n_k} = [n_{0,k}, \cdots, n_{L-1,k}]^T$. Further, Rake receivers can use different combing schemes. Let
$\boldsymbol{\beta} = [\beta_0, \beta_1, \cdots, \beta_{L-1}]$ be the Rake combining weights. If maximal ratio combining (MRC) technique is used, the amplitudes of the received MPCs are estimated and are used as weighting vector $\boldsymbol{\beta}$ in each finger.
In case of ARake, the combining weights are chosen as $\boldsymbol{\beta} = \boldsymbol{\alpha}$, where
$\boldsymbol{\alpha} = [\alpha_0, \alpha_1, \cdots, \alpha_{L-1}]$ are the fading coefficients of the channel. If the set of indices of the M best fading coefficients with largest amplitude is denoted by S, then the combining weights $\boldsymbol{\beta}$ of an SRake are chosen as follows [10],

$$\beta = \begin{cases} \alpha_l & l \in S \\ 0 & \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Similarly, for PRake using the first *M* multipath components, the weights of MRC combining are given by [10],

$$\beta = \begin{cases} \alpha_l & l = 0, \ldots, M-1 \\ 0 & l = M, \ldots, L-1 \end{cases} \quad \ldots\ldots\ldots\ldots (12)$$

where $M \le L$. . The output after Rake combining is sent to the decision device and can be written as[10] :

$$y_k = b_k \sqrt{E_b} \sum_{l=0}^{L-1} \beta_l \, \alpha_l + n_k \ldots\ldots\ldots\ldots (13)$$

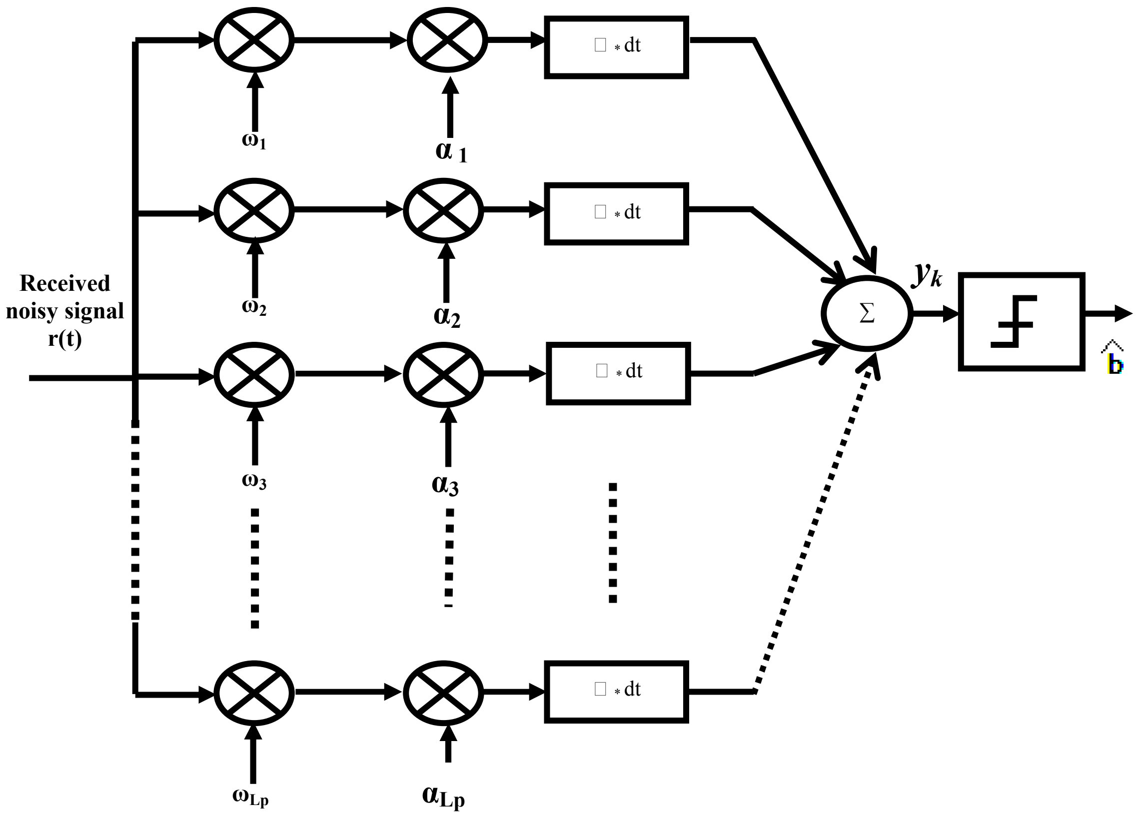

Figure (2)Conventional PRake receiver

3.2 The modified PRAKE receiver

In this modification a common new finger will be added and its output will be compared with the output of each finger of the conventional PRake using multi-comparators as shown below in Figure (3); the output of this added finger could has the form of :

$$A = \int K [\, \omega_o (\max(\alpha_1 \ldots\ldots \alpha_{Lp}) \, r(t) \,] \, dt \quad \ldots\ldots\ldots (14)$$

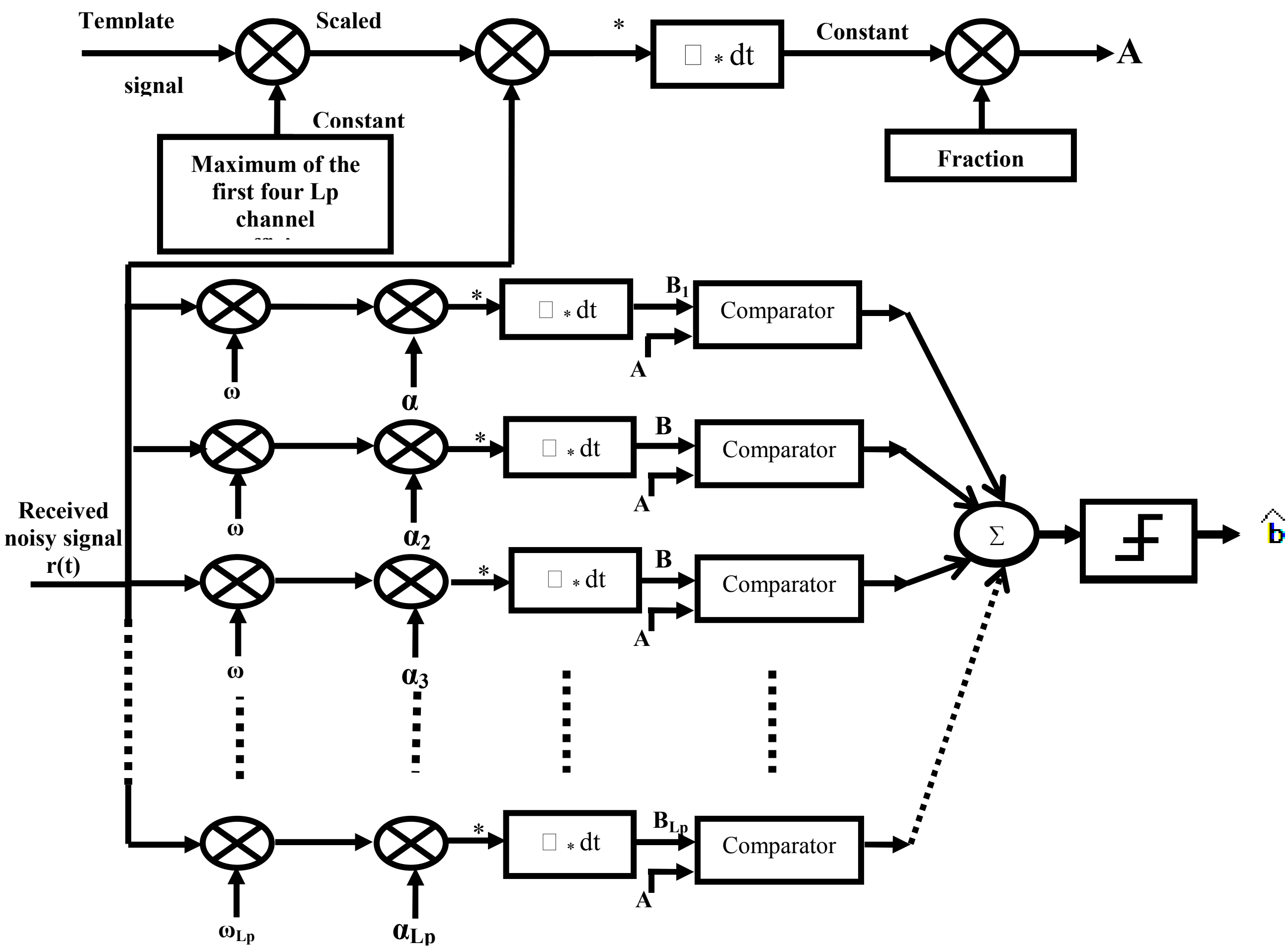

Figure (3)Modified Multi-Comparator PRake receiver

In other words , we use the template signal ω_o which would be scaled by multiply it with the maximum channel coefficients of the first five ones , this will give a scaled signal ,then we multiply it by the received noisy signal r(t) , and apply the resultant signal to the correlator which would give a certain constant value , this value would be scaled again by a fraction factor ranges from (0.3 to 0.7) , the output scaled value labeled as A in Figure (3) will be compared with the correlator output of each finger , labeled as B in Figure (3), the output of each comparator will be either (+1) or (-1) , these outputs will be summed and apply to decision device to give the estimated bit .

Simulation scenario :

1- Simulation parameters

In order to compare the performance of PRake receivers on the multipath channel described in section 2.2 , the UWB system is simulated for an indoor environment using Matlab code programs . The simulation parameters are listed in Table(1) , below :

Table (1) Some of system simulation Parameters

System section	*Parameter*	*Symbol*	*value*
Transmitter 2nd derivative gaussian pulse to represent TH_UWB	Sampling frequency	f_C	100 GHz
	Chip time	T_C	0.5 nsec
	Pulse duration	T_P	0.5 nsec
	Frame Time	T_f	2 nsec
	Number of bits generated by the source	-	10000
Channel The model IEEE 802.15.3a to represent indoor multipath channel	Channel bin duration has the same value of T_P	t_S	0.5 nsec
Receiver PRake	Number of PRAKE fingers	L_P	5
	Total Multipath Gain	TMG	1
	Bit energy-to-Noise ratio	E_b / N_o	variable

2- Simulation results

In this section acomparison performance based on the BERcalculations for the conventional PRake and the Modified PRake will be presented, the scenario consists of a transmitter which transmit a TH-BPSK-UWB signal through a multipath indoor channel ,(Assuming perfect synchronization and no Inter Symbol Interference (ISI) present) ,to an intended receiver with the presence of interferers simulated as another user by the system , the number of users could be (2 , 3, 5) this interference is simulated as an added power (-70 dBm) , to be closer to reality we generate different stream bits (random generated bits , time delay , time hoping frame) for each user , the distance (3.16 m) used equally between the transmitter and the intended receiver as well as the interferers.The results clearly show that ,as in Figure (4) , for single user , , the BER for the modified PRAKE record (1.1×10^{-3}) for SNR (29 dB) with a fraction factor (0.3) ,while the conventional PRAKE gives (1.05×10^{-2}) for the same SNR . For 2 users ,as shown in figure 5 , the performance of the modified PRake still give better results than that of the conventional PRAKE ,it gives (6.6×10^{-3}) for SNR(29 dB)and fraction factor (0.3), while the conventional PRAKE gives (2.08×10^{-2}) at this level .But when use it with 4 users it gives (1.7×10^{-2}) at SNR 0f (29 dB) and the conventional PRake gives (3.6×10^{-2}), as shown in Figure (6) .

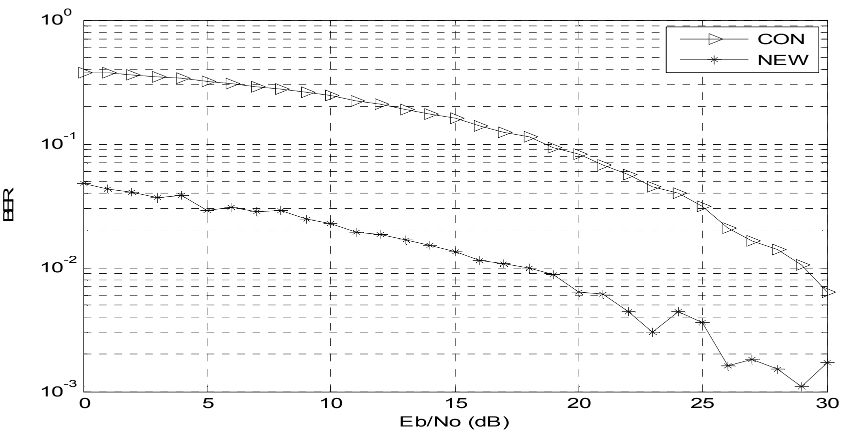

Figure (4) BER vs S/N for single user , with fraction factor (0.3)

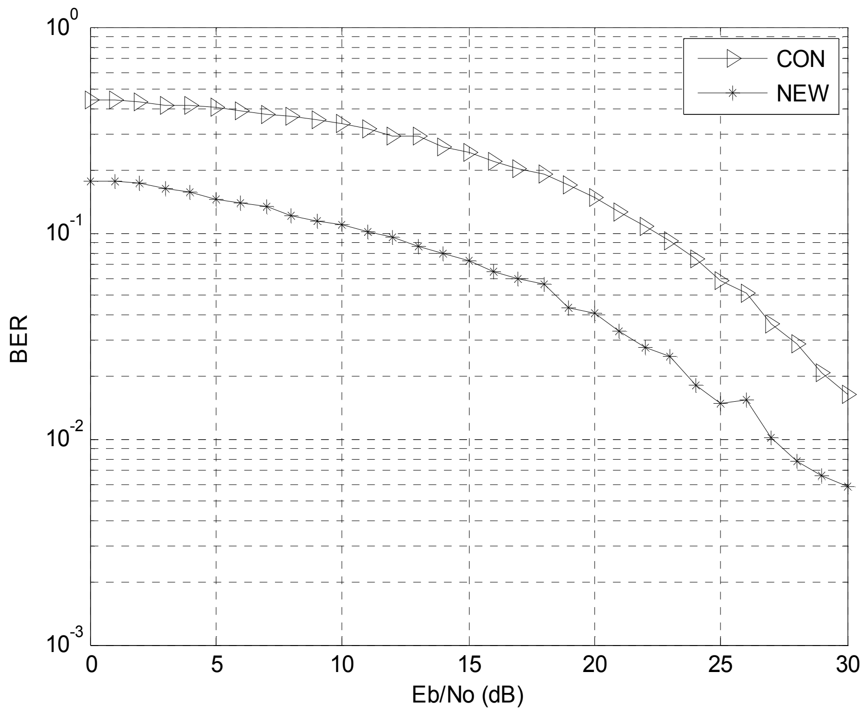

Figure (5) BER vs S/N for two users , with fraction factor (0.3)

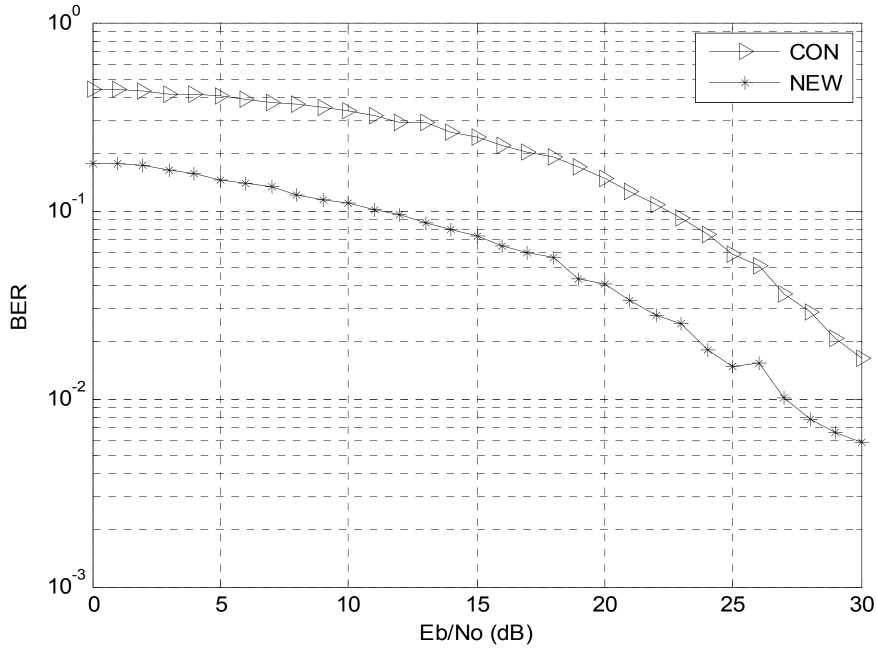

Figure (6) BER vs S/N for three users, with fraction factor (0.3)

It should be noted that this modification faced this multiuser scenario without any assistance like channel equalizer or receiver diversity techniques or even channel coding , indeed this support will add an enhancement for the modified PRAKE BER achievement.

Conclusion:

In this paper, we have presented the performance comparison of a modified and the conventional PRakereceivers over a standard IEEE 802.15.3a UWB channel. The simulation results show that for the modified receiver in a single user environment with Tx-Rx separation of 3.16 m, a BER of 10^{-3} can be achieved using 5 fingers (correlators) with E_b/No = 18dB, while the conventional PRAKE record this level at (28 dB) . In the case of multiuser (2 users) situation having with the same distance from the transmitter (3.16m) ,modified PRAKE still give better records in BER than that of the conventional PRAKE ,but with lower performance , especially when increase the interferers to 4.It is clear that the added branch to th PRake fingers influenced by the value of the fraction factor and an adaptation for this factor will give better results , especially without an assistance of channel coding or equalizer this modification will record better performance and this will be our future work .

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