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Interference Suppression for CDMA-UWB System using LBER Rake receiver

Nimmala Naresh
Assistant Professor,
Department of ECE
TKR College of Engineering and Technology.

Abstract:

UWB has increased over the past several years, developers of UWB systems began pressuring the FCC to approve UWB for commercial use. In Ultra Wideband (UWB) multi-user environments, the existence of severe multi-user access interference (MAI) can cause significant performance degradations. In this paper, we propose an adaptive least bit error rate (LBER)-Rake receiver for synchronous CDMA-UWB systems. The combining weights of the Rake fingers are adapted based on the LBER criterion for MAI mitigation. I study the receiver performance by varying the number of fingers under different number of users. Performance analysis has been done by generating the conditional probability density function of the receiver output. Results show that the proposed receiver can suppress MAI more effectively and leads to an increase in the number of supported users.

Keywords:

ultra wideband, rake, multi-user access interference, minimum mean square error, least bit error rate

1. INTRODUCTION:

Ultra-wide band (UWB) systems is an attractive technology offering improved ranging precision, high data rate, and enhanced multipath identification. In accordance with terms of FCC, UWB is not defined just to pulse transmission, but can be extended to a continuous transmission technology, as long as absolute signal bandwidth is greater than 500 MHz. In order to reduce interference with existing narrowband communication systems the maximum transmit power spectral density of UWB is restricted to -41.3dBm/MHz, which restricts the use of UWB to PAN.

Under a multiple access scenario, the presence of multiple signals transmitted at the same time is a typical source of interference for wireless signals, which affects considerably the bit error rate (BER) performance, the range and the capacity of UWB receivers. DS-CDMA is a well known multi access technique in the presence of narrowband interference and additive white Gaussian noise (AWGN). Multiuser detection techniques [6], which effectively cancel the MAI under AWGN, cannot be directly extended to multipath channels as these systems are very sensitive to signal mismatch and inter-chip interference.

Multiuser DS-CDMA detectors proposed in [7, 8, 9] for DS-CDMA can be extended to UWB communication, but the major drawback of these techniques is the very high computational complexity. Ideally, no MAI occurs if the codes assigned are orthogonal to each other, which is achievable only in downlink synchronous conditions. In the uplink, however, the sum of different multipath components among all users at the receiver end destroys the code orthogonality, which in turns gives rise to MAI and limits the total number of users sharing the channel. To eliminate MAI, different multiuser detection techniques have been proposed. One of the most frequently studied techniques is the adaptive multi-user detector (MUD), in which the minimum mean square error (MMSE) criterion is usually adopted to suppress ISI and MAI [8-9].

The adaptive MUD can be introduced after the Rake receiver [4], where the Rake receiver first attempts to resolve multipath components followed by interference mitigation via the MMSE adaptive MUD. Besides, the Rake finger coefficients can be directly designed to account for the interferences. In this regard, the MMSE criterion has been applied to find the combining weights of the Rake fingers to gather multipath signal energies and to suppress ISI [3]. However, the MMSE criterion does not lead to minimum BER (MBER) solution [10-12].

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In this paper, we apply the MBER criterion to obtain the Rake finger coefficients and extend it to suppress MAI in multi-user UWB channels. The proposed adaptive Rake receiver uses a least mean square (LMS) type of adaptive algorithm [10], and is referred to as the adaptive least BER (LBER)-Rake receiver. BER performance comparisons with the conventional maximum ratio combining (MRC)-Rake receiver and the adaptive MMSE-Rake receiver are made by varying the number of Rake fingers and the total number of users. The conditional probability density function (cpdf) for the output signal of the receivers is generated to analyze the effect of the MAI.

II. MULTI-USER UWB SYSTEM MODEL:

Consider a single-user that transmits a UWB BPSK modulated signal [1]:

$$b(t)=\sum_{i=-\infty}^{\infty} d[i]p(t\text{-}iTs) \quad (1)$$

Where {d[i]} ε {-1,1} represents the BPSK bit stream and p(t) is the UWB pulse with a symbol duration, Ts = J

$$p(t)=\sum_{j=0}^{J-1} c[j]\, g(t-jTc) \quad (2)$$

Where {c[j]}є{1,0} represents the jth chip of the UWB chip spreading of length J and Tc is the chip duration. g{t} can be either a 1st or 2nd derivative Gaussian pulse Thus, the composite multi-user CDMA-UWB signal in the uplink can be expressed as:

$$s(t)=\sum_{n=1}^{N} S\, n(t)bn(t) \quad (3)$$

Where N is the total number of users, and bn(t) is the nth UWB signal with information bit streams, dn[i] is modulated by respective spreading waveform, Sn(t). In this case, the Gold code sequences are used as the CDMA spreading code due to their high orthogonality values in synchronous conditions.

The multipath channel model considered in this paper is the standard model of the IEEE P802.15.3a Wireless Personal Area Networks [5]. This UWB channel model is derived from the Saleh-Valenzuela model with slight modifications which consists of L clusters and K rays [1]:

$$h_i\,(t)= X_i \sum_{l=0}^{L} \sum_{k=0}^{K} \alpha_{k,l}^{i}\, \delta(t-T_l^{i}-\tau_{k,l}^{i}) \quad (4)$$

Where X_(i) represents the log-normal shadowing,T_l^i is the delay of the lth cluster, α_(k,l)^i are the gain coefficients and τ_(k,l)^i is the delay of the kth multipath component relative to the lth cluster arrival time(T_l^i), and i refers to the ith realization.δ(.) is the Dirac delta function.

The receiver structure consists of a chip matched filter with an impulse response p(-t) followed by a Rake receiver. The received signal after passing through the multipath channel is given as [4]:

$$r(t)= \sum_{m=0}^{M} h_i\,(t)\, S'(t)+n'(t) \quad (5)$$

where s'(t) = s(t)p(-t) and n'(t) = n(t)p(-t) while n(t) is the additive white Gaussian noise (AWGN) with zero mean and variance No/2. M is the number of paths in the channel.

In order to recover the information bit stream transmitted by each user, the received signal is passed through a bank of correlators. Hence the output of the nth correlator is:

$$y_n(t) = r(t)S_n(t) \quad (6)$$

If we only consider the first user, the correlator output can be written as

$$y_1 = r(t)S_1\,(t) \quad (7)$$

$$=\sum_{m=0}^{M} h_i\,(t)\, S'(t)S_1\,(t)+n'(t)\, S_1\,(t) \quad (8)$$

$$=\sum_{m=0}^{M} h_i\,(t)d_1 + \sum_{m=0}^{M} \sum_{n=2}^{N} h_i(t)S_n(t)d_n + n'(t)S_1\,(t) \quad (9)$$

Where the first term in Equation (9) denotes the desired user Information with ISI, the second term denotes the MAI, and the last term is the noise component. In this paper, suppressing the MAI term is the main goal.

III. ADAPTIVE RAKE FOR CDMA-UWB:

The output of a conventional Rake receiver as shown in Figure 1 with L fingers is given by [3],

$$f(t)=\sum_{l=0}^{L-1} \beta_l\, y_1\,(t-\theta_l) \quad (10)$$

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Where βl=[β0,β1,β2… βL-1] are the Rake coefficients, and θl=[θ0,θ1,θ2… θL-1]are the finger delays. Assume that θl is fixed to a quarter of the symbol period as the optimal choice of delay [3], the over-sampled output signal can be written as,

$$f(k)=\sum_{l=0}^{L-1} \beta_l\, y_1{}'(k-l) \quad (11)$$

Where y1' (k) is the oversampled received signal. The final decision, x(k) of the detected symbols is simply obtained from the sign of f(k):

$$x(k)=sgn(f(k)) \quad (12)$$

A.Adaptive MMSE-Rake Receivers:

The MMSE criterion has been formulated to minimize the mean square error after equalization and the solution is

$$\beta_{MMSE}=argminMSE \quad (13)$$

Where the mean square error, MSE = E[(f(k)-x(k-D)2],and D is the delay parameter introduced to account for the delays in the channel and receiver.

From [4], we can obtain the adaptive algorithm as follow

$$\beta_{l+1} = \beta_l - \mu[f(k) - x(k-D)]y_1'(k) \quad (14)$$

where μ is the step size

B.Adaptive LBER-Rake Receivers:

The MBER criterion is formulated to minimize the BER after equalization and the solution is defined as

$$\beta_{MBER}=argminP_E \quad (15)$$

Where the probability of error

$$P_E = \int_{-\infty}^{0} p(z;\beta)dz$$

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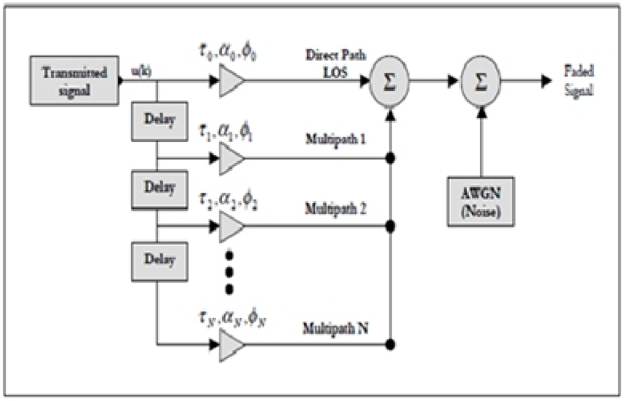

Fig 1. Adaptive Rake Receiver

We obtain the probability density function (pdf), p(z,β) as[10]

$$p(z;\beta)=\frac{1}{K\sqrt{2\pi\sigma}\sqrt{\beta_l^T\beta_l}}\sum_{k=1}^{K} \exp\left[\frac{-\left(z-z'(k)\right)^2}{2\sigma^2\,\beta_l^T\beta_l}\right] \quad (16)$$

where k are all the possible sequences of b(t),σ^2 is the additive Gaussian noise variance, z=f and z'(k)=x(k) f(k) is the decision signed variable.

Thus, the BER expression for the rake receiver is given by

$$P_E=\frac{1}{K\sqrt{2\pi\sigma}\sqrt{\beta_l^T\beta_l}} \times \sum_{k=1}^{K} \exp\left[\frac{-\left(z-z'(k)\right)^2}{2\sigma^2\,\beta_l^T\beta_l}\right] \quad (17)$$

$$P_E = \frac{1}{K}\sum_{k=1}^{K} Q(g(k))$$

Where $g(k)=\frac{\beta_l}{\sigma\sqrt{\beta_l^T\beta_l}}$ and Q is the Q-function. By normalizing β_l into $\frac{\beta_l}{\sqrt{\beta_l^T\beta_l}}$ to fix the solution to a vector of unit energy[4], and replacing the oversampled output, f(k) from the Rake fingers, the gradient of P_(E) with respect to β_lis defined as,

$$\nabla P_E=\frac{1}{K\sqrt{2\pi\sigma}}\sum_{k=1}^{K} \exp\left[\frac{-\left(f(k)\right)^2}{2\sigma^2}\right] \times x(k)y_1'(k) \quad (18)$$

Using a steepest-descent gradient algorithm, the Rake finger coefficients can be adapted as follows $\beta_{l+1} = \beta_l - \mu\nabla P_E$

We introduce an LMS-type adaptive algorithm by replacing k=1 and σ as radius parameter, ρ. Finally the proposed adaptive LBER-Rake receiver is

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$$\beta_{l+1} = \beta_l + \frac{\mu}{\sqrt{2\pi\sigma}} \exp\left[\frac{-f(k)^2}{2\sigma^2}\right] \times x(k) y_1^{'}(k) \qquad (19)$$

IV. RESULTS AND DISCUSSION:

In this section, we present performance analysis of three different Rake receivers, namely the conventional MRC-Rake receiver, adaptive MMSE-Rake receiver and the propose adaptive LBER-Rake receiver. The BER performances of these receivers using the UWB multipath single-user channel model are evaluated.

A.Simulation Parameters:

For simplicity, the UWB chip spreading[j] is set to [1 0 0 0]. The step size μ used by both the adaptive MMSE-Rake receiver and the proposed adaptive LBER-Rake receivers is 0.002, respectively. The radius parameter of the proposed receiver is chosen as ρ^2=0.79σ. The receiver's performances are studied by varying the number of Rake fingers, l and the number of total users, N.

Simulations are performed over N_c=100 channel realizations of channel model CM1.The generated impulse responses are averaged over 100 channel realizations. Gold code sequences of length 31 are used for all simulations. We assume that the receiver has perfect synchronization and the finger delay is chosen to give optimal performance gain.

B. BER Performance Comparisons:

Figure 2 shows the BER performance of different UWB receivers under consideration at a data rate of 333 Mbps in channel CM1. A total of ten simultaneous users are simulated. It is observed that the proposed LBER-Rake receivers significantly outperform the MRC-Rake and MMSE-Rake receivers. It is noticed that the MRC-Rake receiver cannot attain good BER performances with the number of fingers, l = 5 and l = 10. At a BER of 10-5, the 5-finger and 10-finger LBER-Rake receivers achieve a gain of about 4.5 dB, respectively, compared with the MMSE-Rake receiver having the same finger number. Furthermore, the 20-finger LBER-Rake receiver achieves a gain of about 5 dB compared with the 20-finger MMSE-Rake receiver. This indicates that using fewer fingers, the LBER-Rake receivers can reduce the MAI more effectively than the MMSE-Rake receivers.

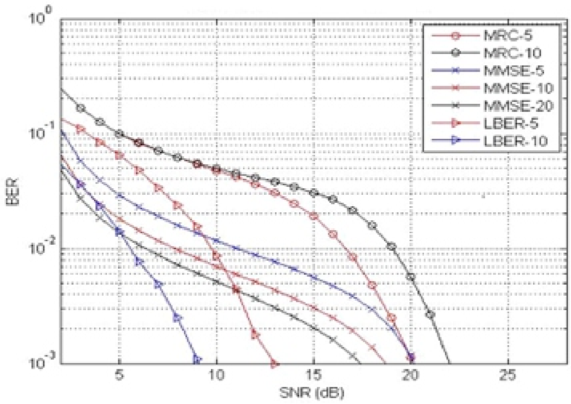

Fig 2.BER Comparisions of MRC,MMSE and LBER Rake receivers with different number of users

Figure 3 illustrates the BER performance versus the total number of shared users using the proposed adaptive LBER-Rake receivers and the adaptive MMSE-Rake receivers. The number of Rake fingers is set to l = 5. When the total number of users increases, the LBER-Rake receiver can achieve better performance over the MMSE-Rake receiver. At a BER of 10-5, the 2-user LBER-Rake receiver only achieves a gain of about 1 dB compared to the 2-user MMSE-Rake receiver. This performance gain is increased to around 2 dB and 4 dB when the total number of users is 5 and 10, respectively. Hence, the LBER-rake receiver is more effective in minimizing the effect of MAI.

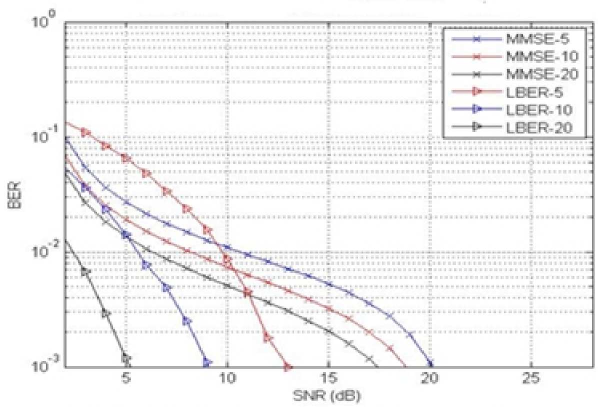

Fig 3. BER comparisions of MMSE and LBER Rake receivers with different number of users

Figure 4 shows the maximum number of simultaneous users that can be supported by different UWB receivers at a BER of 10-4. The number of Rake fingers is fixed to l = 10. It is observed that the proposed adaptive LBER-Rake receiver can support more active users than both the MRC-Rake and adaptive MMSE-Rake receivers at different Eb/No values.

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The MRC-Rake receiver requires an Eb/No of at least 12dB in order to support effective signal transmission and the limit of the maximum number of supported users is 8. Although the maximum supported users at Eb/No = 20 dB is identical for both the LBER-Rake and MMSE-Rake receivers, the proposed LBER-Rake receiver is able to support more users when Eb/No < 20 dB.

These results indicate that the LBER-Rake receiver is more robust to noise estimation errors, in which the estimation accuracy of the channel equalization coefficients is less affected by the noise introduced to the multipath channel. Hence, the proposed receiver is more preferable in multi-user UWB environments.

C. Results Analysis:

In this section, we analyze the performance of different receivers by studying the conditional pdf of the output signal, P(f(k)|d[i] = ±1) with a 5-finger Rake at an Eb/No = 25 dB in channel CM1. The number of simultaneous users is set to N = 10. All parameters are chosen so that ISI suppression is sufficient and MAI becomes the major interference to the received UWB signals. Fig. 5 shows the

Histograms for the conditional pdf P(f(k)|d[i] = ±1) of the output signal from the three receivers. It is observed that the two conditional pdfs of the conventional MRC-Rake receiver are inseparable, which implies that it fails to eliminate interference effectively.

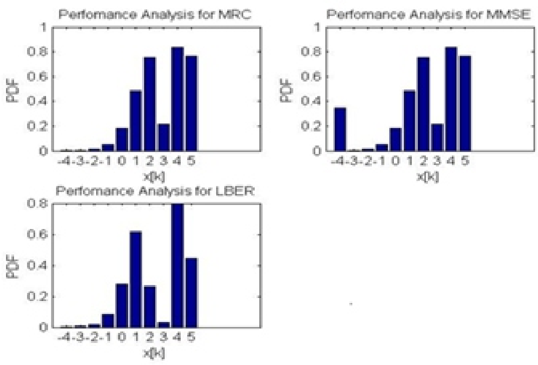

Fig 4.Conditional pdf of the output signal for MRC, MMSE and LBER-Rake receivers

On the other hand, the two conditional pdfs of the output signals from the proposed adaptive LBER-Rake receiver are well separated with a mean value closer to the transmitted signal levels than that of the MMSE-Rake receiver.

Notice that the LBER-Rake receiver attempts to estimate the best fit conditional pdf which has a wider curve width, whereas the MMSE-Rake only attempts to reduce the noise variance of the conditional pdf by minimizing the MSE of the output signal which has a narrower curve width. Moreover, the MSE minimization is limited by the amount of AWGN noise present in the channel as discussed in the previous section. This is the reason why the proposed LBER-Rake receiver can suppress the MAI introduced by the UWB multipath fading channel more effectively and thus obtains a better BER performance.

V. CONCLUSION:

An adaptive multi-user Rake receiver using the LBER criterion in the design of the finger coefficients has been proposed to resolve the multipath components as well as to mitigate ISI and MAI in realistic UWB multipath fading channels. It has been demonstrated using the standard channel models that the LBER-Rake receiver using fewer fingers is capable of achieving better BER performances over the traditional MRC-Rake and MMSE-Rake receivers. From the result analysis, the LBER-Rake receiver is found to have better ability in suppressing MAI compared with the MMSE-Rake receiver. Hence, it can be concluded that the proposed adaptive LBER-Rake receiver is more favorable in CDMA-UWB channels characterized by severe MAI effects. Future work can be achieved by extending the proposed Rake receiver to non-linear receiver.

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