Narrow Band Interference Suppression In Multiuser CDMA System By Linear Prediction In Subband

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Abstract

Recently, much attention has been paid for interference mitigation technique for the CDMA system, since more capacity is available with same bandwidth. In this paper, we introduces a novel adaptive interference suppression techniques for the CDMA system with narrow band interference. The proposed interference rejection scheme employs the adaptive linear prediction techniques in the subband. In each subband, we can more easily find and cancel the narrow band signal as compared to the full band. Thus, the proposed interference rejection can be classified as another time-frequency techniques for the narrow band interference rejection(10). Computer simulation is conducted for the 3-G CDMA system with IF band sampling techniques, yielding better interference rejection and bit error rate performance as compared to conventional one. Also, optimum filter is analyzed and from the analysis, it can be shown the subband prediction techniques can suppress narrow band interference more efficiently.

1. Introduction

The code division multiple access (CDMA) is widely employed for the mobile communication system. Recently, the CDMA standard IS-95 is successfully employed for the cellular mobile communication system for many country. In IS-95 the up-link call capacity is limited by the multiple access interference (MAI), since the PN code is not exactly uncorrelated. Recently, the 3rd generation or 4th generation mobile communication system requires more bit rate for advanced wireless data service. Therefore, more sophisticated communication techniques is now being considered for next generation mobile communication. One of the promising technique is the interference mitigation technique[1,6]. The spreaded signal generated by another user is not exactly cancelled in the working IS-95. The only remedies for inter-ference is the matched filter used for PN sequence and strong convolutional code. Therefore some advanced interference cancelling techniques are considered, which yields more capacity for given channel.

In this paper, one of the promising adaptive interference cancelling technique is proposed and analysed. The considered interference is narrowband, so traditional linear prediction based interference cancelling technique can be used. However, the traditional transversal filter requires very long tap to excise narrowband interference, since it is well known that good frequency resolution requires long term time observations[7,8]. The long tap adaptive filter make it hardly implementable, since the complexity is proportional to adaptive filter taps. As the bit rate of the mobile communication increase, it is more important to reduce adaptive filter taps for given computing hardware environments[9,12]. Thus, in this paper, we introduce a new adaptive schemes that requires fewer adaptive filter taps with similar

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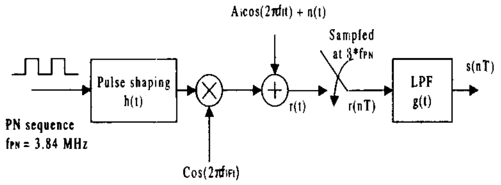
interference rejection performance. The proposed interference rejection employs the subband adaptive filter, where the narrowband interference is rejected in each subband. The computer simulation reveals that the proposed interference rejection scheme shows better rejection performance with fewer complexities. In this paper, also some analyses on the frequency response of the adaptive filter will be presented. Based on the analysis, we can find that the subband linear prediction technique is one of the promising schemes for the narrow band interference rejection.

This paper is organized as follows. In section 2, the 3rd generation CDMA system will be presented. In section 3, the proposed interference suppression technique will be introduced. In section 4, some analytical results for the proposed scheme will be presented. Computer simulation results will be presented in section 5. Finally, concluding remarks will be presented in section 6.

2. IF sampling for the 3-G CDMA system with interference

Let us consider the 3G-CDMA system, where the PN sequence has 3.84MHz rectangular pulse. The pulse shaping filter is the raised cosine filter with excessive bandwidth is 10%. The sequences are modulated and transmitted in RF frequency. At the receiver's end the received signal is the sum of the CDMA signal and narrow band interference and white Gaussian noise.

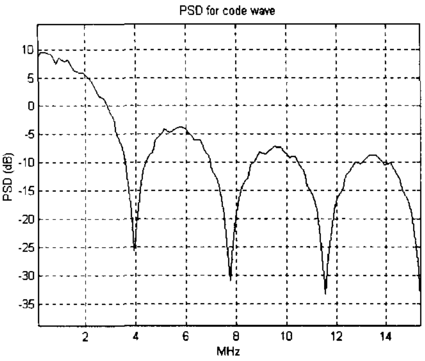


(Fig. 1) CDMA system with narrow band interference

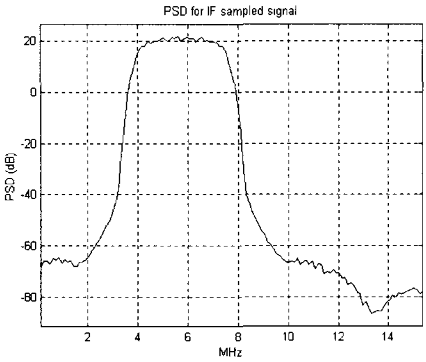
In Fig. 1, the schematics diagram for the simulated system is presented. In the receiver the RF(radio frequency) signal is demodulated into the IF frequency which is set to 190 MHz by analog local oscillator. The IF signal is sampled at the eight times of the baseband pulse frequency to avoid aliasing. Fig. 2 shows power spectral density(PSD) of long code PN sequence, whose amplitude is +1 and -1 and chip rate is 3.84MHz. It is shown that the main lobe lie exactly in 3.84 MHz and the 3 additional side-lobe exit, since 8 times over-sampling is done.

This shaped signal is now modulated by the carrier frequency. In the receiver(in Fig. 2), the received signal is demodulated by local oscillator which makes the RF signal lie into IF band whose center frequency is 190 MHz. Now consider the IF signal is sampled at 8*3.84 MHz. It is shown that the time domain signal has IF band components. Fig. 3 shows the PSD of the sampled IF signal. It is very important that the digital frequency is limited to 4*3.84 MHz by Nyquist theorem [1,2]. Therefore, the PSD depicted in Fig. 3 is limited to 4*3.84 MHz. And it is also important that the actual analog spectrum is the replicas of the harmonics of the Fig. 3. That is, the frequency components over 4*3.84 MHz is periodically replicas of the frequency components in [-4*3.84MHz,4*3.84MHz].

Now consider multiuser case. Fig. 4 shows the schematic diagram of the multiple user access system with interference exciser[14,15]. The modulated information symbols are spreaded by code pulse, and in the receiver the exciser is inserted in front of the despreading circuits. Each user's bit is detected by matched filter. The matched filter employs the long PN code assigned to each user. For improved detection performance, the advanced multiple user detection(MUD) schemes can also be employed after



(Fig. 2) Power spectral density of the long PN code



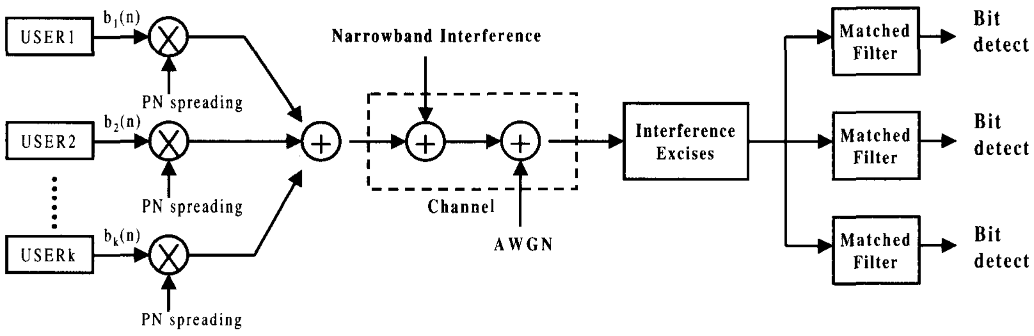
(Fig. 3) Power spectral density of the sampled IF signal

matched filter. But, in this paper, the research scope is limited to the narrow band interference cancellation in front of the matched filter.

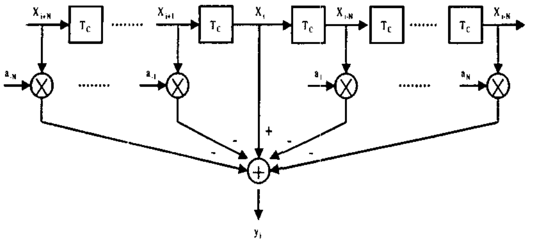
3. Narrow band interference cancellation with adaptive interference exciser

The narrow band interference can be estimated with conventional linear prediction techniques. In most cases, the narrow band signal can be estimated, since it has more correlation with samples as compared to the spreaded signal. However, the spreaded information signal can't be estimated, since it is assumed to be white sequence. Thus, the conventional adaptive transversal filter can be used for narrow band interference estimation. From the estimation, the interference is then subtracted from the received signal, yielding improved bit detection. This scheme is known as "interference exciser" which has been used for the military applications. Fig. 5 shows the interference exciser employing adaptive transversal filter[3]. Note that the received signal r(t) in Fig. 1, which is corrupted by strong narrowband interference, is inserted to the matched filter and sampled at the Chip rate Rc. The sampled signal xk, which is the input signals to the exciser is modeled as

$$x_k = d_k + V\cos(\Omega k T_c + \theta) + n_k \tag{1}$$



(Fig. 4) Multiple user access in narrowband interference environment



(Fig. 5) Transversal filter for narrowband interference rejection

where, d_k, n_k, V, Ω, θ, T_c are the spreaded information signal, white noise, amplitude, frequency and phase of interference signal and chip duration, respectively.

In Fig. 5, the adaptive filter predicts the current symbol xk using forward and backward input signals. More precisely, the predicted input $\widehat{x_k}$ is

$$\widehat{x_k}=\sum_{n=1}^{N}a_nx_{k-n}+\sum_{n=1}^{N}a_{-n}x_{k+n}, \tag{2}$$

where $\{a_n, a_{-n}\}$ is the two-sided adaptive filter coefficient and N is the number of adaptive filter taps. As in the adaptive line enhancer (ALE), the output of the predictor is the narrowband signals. In Fig. 2, the output of the exciser y_k is

$$\begin{aligned}y_k&=x_k-\widehat{x_k}\\&=x_k-(\sum_{n=1}^{N}a_nx_{k-n}+\sum_{n=1}^{N}a_{-n}x_{k+n}),\end{aligned} \tag{3}$$

where $\widehat{x_k}$ is the estimate of the interference signal. Thus, the output of the transversal exciser can suppress the narrowband signal[3]. The optimum coefficient a_{-N}^{opt}, a_{-N+1}^{opt}, $\cdots$, a_N^{opt} can be found by batch processing[4] or iterative scheme[3]. Although, the transversal filter can remove most of the interference, the transversal filter requires very long taps to excise the narrow band interference effectively, since it is hard to realize very narrow notch bandwidth with small taps FIR(finite impulse response) filter[1]. Moreover, the conventional transversal filter may excise the information signals as well as the interference signals, since most of the finite adaptive filter shows excessive notch bandwidth for the narrow band interference. Thus, in this paper, we propose a novel interference exciser, which requires less taps with improved interference rejection performance.

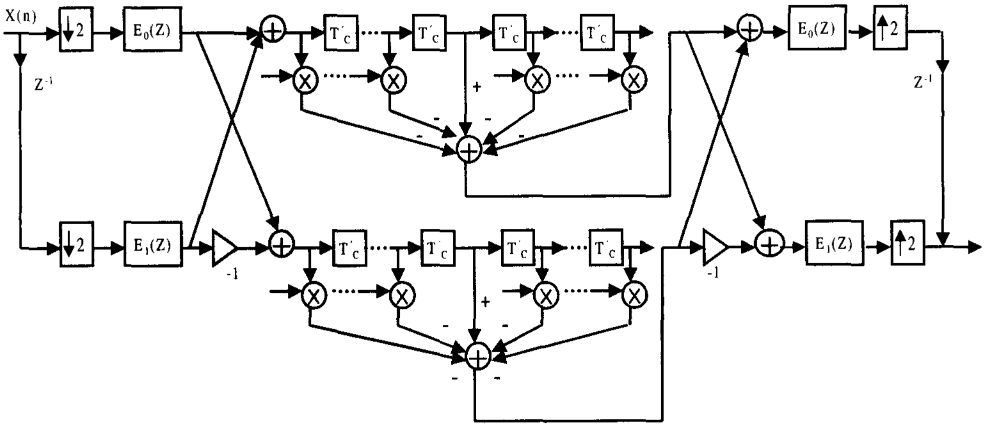
In this paper, we introduced a novel adaptive excision schemes, where the narrow band interference is rejected in each subband. Fig. 6 shows the schematic diagram of the proposed subband adaptive interference exciser. In Fig. 6, the 2-band polyphase subband decomposition scheme is employed[12]. The polyphase structure is known as an efficient implementation of the QMF(quadrature mirror filter) filterbank. Recently, it is reported that the subband adaptive filter shows improved performance for the adaptive line enhancer[1]. More precisely, it is shown in[1] that the subband digital filter can approximate an optimum filter with sharp frequency response, which is generally difficult for the conventional adaptive FIR filter with finite filter taps. Thus, it is expected that the SBADF(subband adaptive digital filter) shows improved performance for the narrow band signal extraction.

Now let us consider the computational complexities of the proposed adaptive exciser. The analysis filter $H_0(z)$ can be represented by

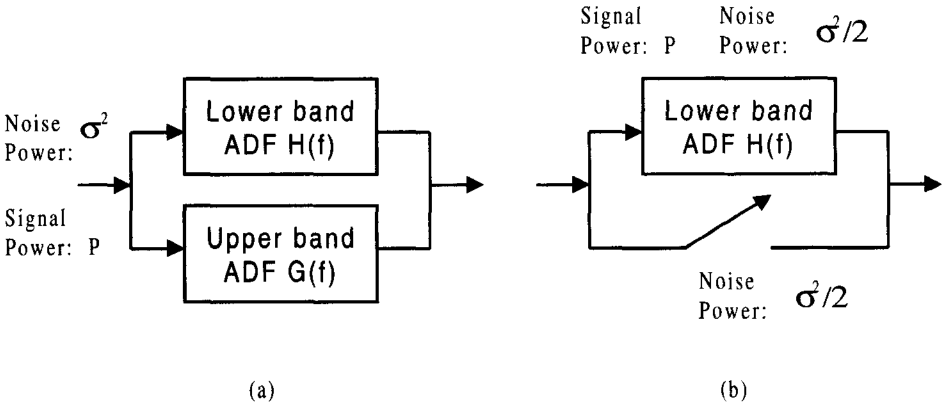
$$H_0(z)=E_0(z^2)+z^{-1}E_1(z^2), \tag{4}$$

which is known as type-I polyphase decomposition [12]. From (4),

$$H_1(z)=E_0(z^2)-z^{-1}E_1(z^2). \tag{5}$$



(Fig. 6) Interference exciser in the subband



(a) Before adaptation (b) After convergence

(Fig. 7) Linear prediction filter behavior in subband

We can find from (4) and (5) that there are some common factors between QMF filter banks. Thus, we can obtain efficient SBADF as depicted in Fig. 6, where the required total multiplication is N for N tap analysis filter bank[13]. In each subband, the two-sided prediction filters depicted in Fig. 2 predict and reject the interference signals. Comparing to the conventional transversal filter, the adaptive filters in each subband operates at a lower rate. Moreover, the prediction capability of the narrowband signal can be enhanced, since the SBADF has finer the spectral resolution for each subband[1]. It can be easily inferred as in subband ALE[1] that the subband which do not contain narrow band interference automatically transmits all of the information signal.

4. Filter tap convergence analysis for linear prediction in subband

Let us consider the filter behaviors in the subband. Without loss of generality, the input to the prediction filter has low frequency narrow band signal and the white signal. Fig. 7 shows the schematic diagram of filter tap convergence for the linear prediction in subband.

Let the input signal power is P and its spectrum lies in low frequency band. And the noise like broad band signal has has power σ^2. In the upper band only the noise is present. So the linear prediction filter converge to zero, since the optimum filter for upper band filter G(f) converges $G_{opt}(f)$ given by

$$\begin{aligned} &G_{opt}(f) = R_{nn}^{-1} P_{nn} \\ &\quad R_{nn} = E[N(k)N^t(k)] \\ &\quad P_{nn} = E[N(k)n(k+\varDelta)] \\ &\quad N(k) = (n(k), n(k-1), \cdots, n(n-N+1))^t \end{aligned} \tag{6}$$

where $n(k)$, $\varDelta$ are the noise presented in upper band and the prediction interval, respectively. Since the noise is uncorrelated P_{nn} is zero, $G_{opt}(f)$ is also uncorrelated. Thus, only lower band the linear prediction is done, but we can find that the noise power is now reduced from σ^2 to $\sigma^2/2$ which implies improved prediction performance as compared to conventional one.

More precisely, the optimum filter for the prediction filter satisfies the Wiener equation[7] given by,

$$\sum_{k=-N, k\neq 0}^{N} r(l-k)a_k^{opt} = r(l), \quad l=-N, \cdots, -1, 1, \cdots, N \tag{7}$$

where r(m) is the correlation function given by

$$r(m) = E\{x_i x_{i-m}\}. \tag{8}$$

In the subband, which do not has inter-ference, the input to the subband exciser is the spreaded modulated signal. Since the spreaded signal is assumed to be white, $r(m) = \delta(m)$. Thus, the optimum filter a_k^{opt} satisfy

$$\begin{pmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{pmatrix} \begin{pmatrix} a_{-N}^{opt} \\ a_{-N+1}^{opt} \\ \vdots \\ a_N^{opt} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{pmatrix} \tag{9}$$

Thus, the coefficients of the subband which does not contain the interference signal converge to zero. Thus, from (4), the output of the prediction filter y_k is the same as x_k. Then, the subband which has the interference signal predict and remove the interference signal. In this paper, the optimum filter for the subband exciser is derived based on the[5]. Let the input signal to the exciser depicted in Fig. 1 be

$$x_i = d_i + V\cos(\Omega iT + \theta) + n_i \tag{10}$$

where d_i, n_i, and T are the spreaded information signal with power S, noise, sampling interval, respectively, and V, Ω, θ are the amplitude, frequency, and phase of the jamming signal, respectively. The adaptive filter coefficients which minimize the output error y_i in the MMSE (minimum mean squares error) sense converge to the optimum filter a_k^{opt} satisfying the Wiener equation given by

$$H(\omega) = e^{j\omega NT}(1 - \sum_{k=-N, k\neq 0}^{N} a_k^{opt} e^{j\omega T}), \tag{11}$$

where r(m) is the correlation function given by

$$r(m)=E\{x_i x_{i-m}\}. \tag{12}$$

In (11), since the spreaded information signal d_i is white, the correlation function r(m) is

$$r(m)=(S+\sigma_n^2)\delta(m)+J\cos(m\Omega T) \tag{13}$$

where J is the jamming signal power[5]. As shown in[5], the optimum filter satisfying the Wiener equation is

$$a_k^{opt}=2A\cos(k\Omega T), \tag{14}$$

where A is

$$A=\frac{J}{2(S+\sigma_n^2)+J(2N-1+\frac{\sin(2N+1)\Omega T}{\sin\Omega T}} \tag{15}$$

The frequency response of the exciser is

$$H(\omega)=e^{-j\omega NT}(1-\sum_{k=-N,k\neq 0}^{N} a_k^{opt} e j\omega T), \tag{16}$$

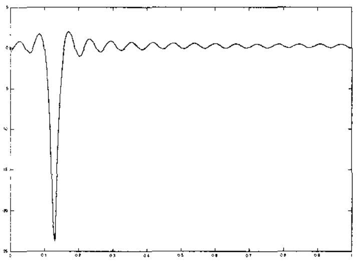
The optimum filter for the subband exciser can be derived with the subband correlation function. After some algebra

$$\begin{aligned}R_{p_0p_0}(m) &= \frac{1}{2}\{(S+\sigma_n^2)\delta(2m)+J\cos(2m\Omega T)\\ &+\sum_{k=-\infty}^{\infty}\{(S+\sigma_n^2)\delta(2k-1)\\ &+J\cos((2k-1)\Omega T)\}\psi(m-k)\}\\ R_{p_1p_1}(m) &= \frac{1}{2}\{(S+\sigma_n^2)\delta(2m)+J\cos(2m\Omega T)\\ &-\sum_{k=-\infty}^{\infty}\{(S+\sigma_n^2)\delta(2k-1)\\ &+J\cos((2k-1)\Omega T)\}\psi(m-k)\}\\ \psi(n) &= \frac{2}{\pi}\frac{(-1)^n}{1+2n}\end{aligned} \tag{17}$$

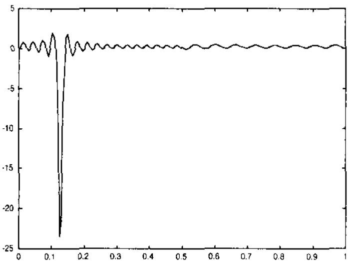
By solving the subband Wiener equation derived, we can get the optimum coefficients for the subband exciser given by

$$\begin{aligned}&\sum_{k=-N,k\neq 0}^{N} R_{p_0p_0}(l-k)a_k^{opt\,0}=R_{p_0p_0}(l),\\ &l=-N,\cdots,-1,1,\cdots,N\\ &\sum_{k=-N,k\neq 0}^{N} R_{p_1p_1}(l-k)a_k^{opt\,1}=R_{p_1p_1}(l),\\ &l=-N,\cdots,-1,1,\cdots,N\end{aligned} \tag{18}$$

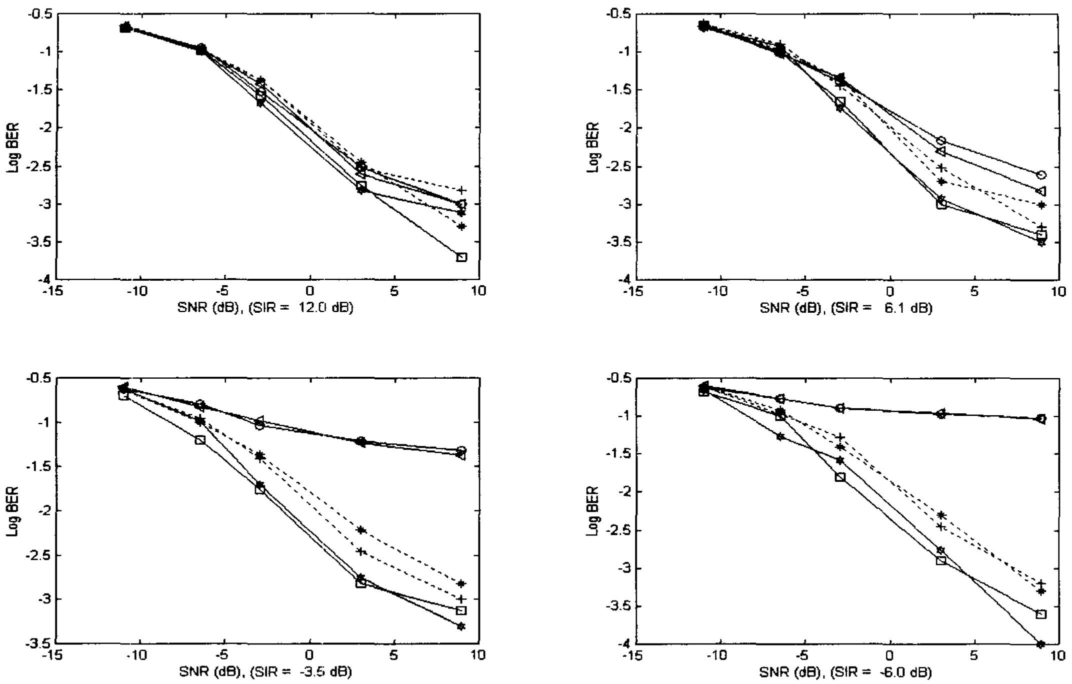
where $a_k^{opt\,0}$, $a_k^{opt\,1}$ are the optimum filter for the lower and upper band, respectively. The frequency response of the conventional and the subband exciser can be derived by (18). Fig. 8 shows the frequency response of the conventional and the subband exciser, where the filter length $N=32$, $S=1$, $\sigma=1$, $J=1$, $\Omega=0.1$, $T=1$. We can find that the subband exciser shows narrower notch band-



(Fig. 8) (a) Frequency response of the conventional linear prediction



(Fig. 8) (b) Frequency response of the linear prediction in subband



(Fig. 9) BER performance for various SIR(signal to interference ratio)
line circle : user 1 with no rejection,
line triangle : user 2 with no rejection,
dotted + : user 1 with conventional rejection,
dotted* : user 2 with conventional rejection,
line rectangle : user 1 with subband rejection,
line hexagon : user 2 with subband rejection,

dth. Thus, it is expected that the subband exciser can reject less useful information signals.

5. Computer simulation

The computer simulation is done base on the block diagram depicted in Fig. 2. The PN code is generated by the LFSR (linear feedback shift register) defined in IS-95 specification, where the characteristic polynomial is given by $p(x) = x^{42} + x^{35} + x^{33} + x^{31} + x^{27} + x^{26} + x^{25} + x^{22} + x^{21} + x^{19} + x^{18} + x^{17} + x^{16} + x^{10} + x^{7} + x^{6} + x^{5} + x^{3} + x^{2} + x^{1} + 1$. The processing gain for spread spectrum is 16 and the adaptive filter tap is 32. The convergence constant is optimized with simulations.

Fig. 9 shows the BER(bit error rate) performance for multiuser bit detection with narrow band interference. The computer simulation has been conducted for various SIR(signal to interference ratio) and SNR(signal to noise ratio). Be sure that the direct spread spectrum has no gain under Gaussian noise. In Fig. 9, we can find that the as the SIR increase the interference rejection is useful for improved BER performance. Also the proposed subband rejection shows some improved BER performance, especially low SIR condition. The improved performance can be inferred from the analysis presented in the previos section. Since the subband prediction has sharper frequency response for narrow band signal extraction, it reject less information bearing signal as compared to conventional rejection scheme.

6. Conclusion and further works

Recently, many works has been done for interference rejection for next generation wireless communications. More sophisticated communication signal processing techniques should be employed for improved bandwidth efficient modulation such as QAM and OFDM. One of the promising techniques is the adaptive equalization and interference rejection. For various mobile communication environment, such as cellular, wireless LAN, the inter- ference pattern is different for the velocity of the mobile station (stationay, pedestrian, vehicular etc). The bandwidth efficient modulation such as 32-QAM exploit amplitude information. Thus, the amplitude distortion should be corrected. The subband adaptation technique presented in this paper can be employed some interference environment where the narrow band interference is a major degradation source of communications.

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