Iterative DS-CDMA Anti-interference Technique Based on Interference Power Cognition

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Abstract. In the additive white Gaussian noise channel, an iterative anti-interference method based on interference power cognition is proposed, where the interference is broadband digital modulation signal and desired signal is direct sequence spread spectrum(SS) signal. The power ratio of SS signal and interference is detected by cognitive method, and threshold value is calculated meanwhile. After that, the order of iteration is chose based on power ratio and threshold, if the ratio is bigger than threshold, the SS signal is detected first, or vice versa. Result shows the BER performance is improved by using proposed method, the performance is improved from 4e-3 to 1e-4 by using the proposed method, when the spread gain is 63, the SNR is -5dB, and the SIR is -12dB.

Keywords: Spread spectrum signal, Iterative detection, Desired signal, interference cancellation.

1 Introduction

Spread-spectrum systems are naturally resistant to narrowband interference, existing active NBI suppression techniques can be grouped into three basic types: transform-domain techniques1, time-domain cancellation techniques2, and code-aided techniques3. As the name implies, transform-domain techniques operate by transforming the received signal into frequency domain, and masking frequency bands of interference. The basic idea of time-domain techniques is the difference of the time correlation between interference and spread spectrum signal. Reconstruct the interference and subtracted from the received signal to suppress the interference. If we know the spreading code of at least one user of interest, the code-aided techniques can take this advantage for interference cancellation(IC).

As the data rate growing, the bandwidth of the interference becomes wide. The performance of IC techniques mentioned above is deteriorated. The main reason of this phenomenon is these techniques treat the interference as random signal, without using priori information of interference. In this article, we consider the interference is digital modulated signal, which bandwidth is the same as the CDMA signal. An

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iterative detection based on power cognition4 is proposed: The power ratio of desired signal and interference is cognized for iteration order selection, if the ratio is bigger than the threshold, the CDMA is detected first, then reconstruct the CDMA signal and cancel it from the original signal, after that the interference is detected. On the other side, the ratio is smaller than the threshold, the iteration order is reverse. The threshold is calculated based on spreading code and SNR.

This paper is organized as follows. Section 2 presents system model, including the interference model and receiver model. Section 3 is devoted to the proposed detection method. The results are the subject of Section 4. Section 5 is the conclusion.

2 System Model

2.1 Interference Model

Fig.1. shows the block diagram of transmitter, the desired signal combines with the interference. The desired signal is spread spectrum signal, which is BPSK modulated after spectrum spread. The bandwidth of the interference is the same as the desired signal. BPSK modulation is chosen for interference. With different channel gains, the two signals combine together in receiver. The channel gains are assumed to be constant in detection interval.

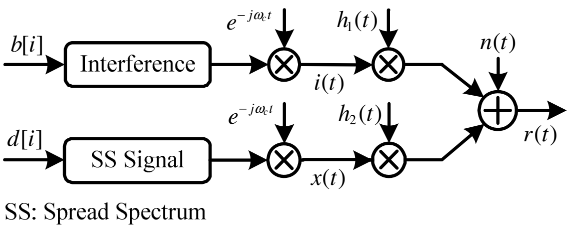

Fig. 1. Interference model

The baseband signal of interference is denoted as $I(t)=\sum_{i=-\infty}^{+\infty} b[i]S_b(t-iT_b)$, where $b[i]$ is the symbol transmitted by co-channel user at i th time slot, $i\in(-\infty,+\infty)$ .The transmitted interference is

$$i(t)=\mathrm{Re}[I(t)e^{-j\omega_c t}] \tag{1}$$

The baseband signal of desired signal is denoted as $X(t)=d(t)c(t)$, where $c(t)=\sum_{i=-\infty}^{+\infty} c(i)P_{T_c}(t-iT_c)$ is the spreading code, the function $P_{T_c}(t)$ is the shape pulse that length is T_c . $d(t)=\sum_{i=-\infty}^{+\infty} d(i)P_T(t-iT)$ is the data symbols, function $P_T(t)$ is the shape pulse that length is T .Data $d(i)$ is encoded and modulated by transmitter, the spread gain is $N=T/T_c$ .The carrier of desired signal is the same as the interference, the transmitted signal is

$$x(t)=\mathrm{Re}[X(t)e^{-j\omega_c t}] \tag{2}$$

Through the different channel, the received signal is

$$r(t) = h_1(t)x(t) + h_2(t)i(t) + n(t) \tag{3}$$

We have $T_c = T_b$ because the bandwidth of the interference and desired signal is the same.

2.2 Receiver Model

Fig.2. shows the block diagram of receiver, the time and frequency synchronization is assumed here. After A/D transform, the received signal $r(t)$ is changed into

$$r(n) = h_1(n)x(n) + h_2(n)i(n) + n(n) \tag{4}$$

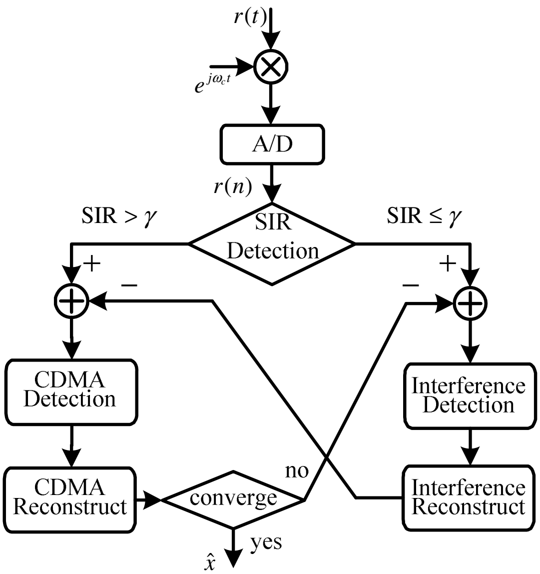

Fig. 2. Receiver model

$h_1(n)$ and $h_2(n)$ are channel gains, which are assumed to be constant in detection interval. The channel gain can be attained by cognitive techniques.

After we get $r(n)$, the SIR is detected by energy detection technique, which is widely used in cognitive radio. The iterative anti-interference process is shown in Fig.2., when the SIR is bigger than threshold γ, we detect the CDMA signal at first, then reconstruct and cancel it from the original received signal $r(n)$, after that, the interference is detected from the cancelled signal. While, when the SIR is smaller than threshold, vice versa. The iteration is combined by detection, reconstruction and cancellation.

3 Cognitive Detection Method

3.1 SIR Detection

We detect the SNR and INR separately, which is the power ratio of desired signal and Gaussian noise, the power ratio of interference and Gaussian noise respectively4. When we detect the INR, the desired signal is not transmitted, as equation (3) shown, the received signal is

$$r(t) = h_2(t)i(t) + n(t) \tag{5}$$

From the continual K samples5, we get

$$\varepsilon = \sum_{n=1}^{K} \left(\frac{h_2(n) \cdot i(n) + n(n)}{\sqrt{N_0 W}} \right)^2 \tag{6}$$

The W is the signal bandwidth, N_0 is the power spectrum density. We assume the channel gain $h_2(n)$ is constant in K samples, the ε in equation (6) is a non-central chi-square distributed random variable with K degrees of freedom. The non-centrality parameter is

$$\lambda = \sum_{n=1}^{K} \left(\frac{h_2(n) \cdot i(n)}{\sqrt{N_0 W}} \right)^2 = \frac{K \cdot |h_2(n)|^2}{\sigma^2} \tag{7}$$

From equation (7), we get $\text{INR} = \lambda / K$.

As the same method, we can get the SNR. Combing the channel gain of the desired signal and interference, we get the $\text{SIR}=|h_1(n)|^2 / |h_2(n)|^2$.

3.2 Iterative Detection

The decision variable of CDMA signal is

$$U(g) = \sum_{l=(g-1)N}^{gN-1} c(l) r(l) \tag{8}$$

From equation (8), we get the decision value of desired signal $\hat{x}(n) = U(g) / |U(g)|$. Then, reconstruct and cancel the desired signal from original signal $\tilde{r}(n) = r(n) - h_1(n)\hat{x}(n)$. As the bandwidth of interference is same as the CDMA signal, we get interference decision value from the cancelled signal $\hat{i}(n) = \tilde{r}(n) / |\tilde{r}(n)|$.

After that, reconstruct and cancel the interference from original signal $\tilde{r}(n) = r(n) - h_2(n)\hat{i}(n)$. We get the decision variable of desired signal again. This is the process of iteration when the SIR is bigger than threshold. On the other side, the interference is detected at first. When the CDMA signal is convergence, iteration is stopped.

3.3 Threshold

As we show before, the key problem of iteration is the iteration order decision, which is based on the SIR threshold γ. We give a numerical analysis result here.

The SNR is defined as $\mathrm{SNR} = |h_1|^2/\sigma^2$, where the σ^2 is the power of Gaussian noise. The INR is $\mathrm{INR} = |h_2|^2/\sigma^2$. To the interference, there are CDMA signal and Gaussian noise interfere its decision. The joint PDF of CDMA signal and Gaussian noise is[7]

$$f(x) = \frac{1}{2}\left(\frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x-h_1)^2}{2\sigma^2} \right) + \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x+h_1)^2}{2\sigma^2} \right) \right) \tag{9}$$

The bit error rate of interference decision is

$$P_e^B = P\left(X < -h_2\right) = \int_{-\infty}^{-h_2} f(x)dx \tag{10}$$

Rewrite equation (10) as

$$P_e^B\left(\mathrm{SNR},\mathrm{INR}\right) = P\left(X < -\sqrt{\mathrm{INR}}\right) = \int_{-\infty}^{-\sqrt{\mathrm{INR}}} f(t)dt \tag{11}$$

Where the $f(t)$ is

$$f(t) = \frac{1}{2\cdot\sqrt{2\pi}} \left\{ \exp\left[-\frac{\left(t-\sqrt{\mathrm{SNR}}\right)^2}{2} \right] + \exp\left[-\frac{\left(t+\sqrt{\mathrm{SNR}}\right)^2}{2} \right] \right\} \tag{12}$$

After the interference is detected, we reconstruct and cancel it from the original signal, the desired signal decision variable is

$$\tilde{r}(n) = h_1(n)x(n) + h_2(n)\left(i(n) - \hat{i}(n)\right) + n(n) \tag{13}$$

As the error rate of interference is $P_e^B\left(\mathrm{SNR},\mathrm{INR}\right)$, the CDF of resident interference $i(n) - \hat{i}(n)$ is based on it.

$$\xi\left(n\right) = i(n) - \hat{i}(n) = \begin{cases} 0 & 1 - P_e^B \\ +2 & P_e^B/2 \\ -2 & P_e^B/2 \end{cases} \tag{14}$$

From equation (14), we know the mean of resident interference is 0, and variance is $4P_e^B\left(\mathrm{SNR},\mathrm{INR}\right)|h_2|^2$ [6]. As the dispreading process, the resident interference $\xi(n)$ is transformed into different form, and the new form is also a Gaussian random variable.

The power of dispread CDMA signal is $N|h_1|^2$, then the SIR is

$$\eta = \frac{N\left|h_1\right|^2}{4P_e^B\left(\mathrm{SNR},\mathrm{INR}\right)\left|h_2\right|^2 + \sigma^2} \tag{15}$$

We can get the bit error rate of desired signal based on SIR η and error function $Q(x)=\int_x^{\infty}\exp(-t^2/2)dt\Big/\sqrt{2\pi}$ [6]

$$\begin{aligned}P_e^C(\text{SNR},\text{INR}) &= Q(\text{SNR},\text{INR}) \\ &= Q\left(\sqrt{\frac{N\cdot\text{SNR}}{4P_e^B(\text{SNR},\text{INR})\cdot\text{INR}+1}}\right) \\ &= \frac{1}{\sqrt{2\pi}}\int_{\sqrt{\frac{N\cdot\text{SNR}}{4P_e^B(\text{SNR},\text{INR})\cdot\text{INR}+1}}}^{\infty}\exp\left(-\frac{x^2}{2}\right)dx\end{aligned} \tag{16}$$

Derivation calculus for INR, we get the BER peak of desired signal

$$\frac{\partial Q(\text{SNR},\text{INR})}{\partial\text{INR}}=0 \tag{17}$$

The simplification of equation (17) is

$$f\left(-\sqrt{\text{INR}}\right)\sqrt{\text{INR}}-2\int_{-\infty}^{-\sqrt{\text{INR}}}f(t)\,dt=0 \tag{18}$$

When the SNR is determined, we can get the threshold γ form equation (18).

4 Simulation Results

The parameter of simulation is given in Table 1.

Table 1. Simulation parameter

SF: Spread Factor	63
Spread code	m sequence
CDMA data rate(bps)	19.2Kbps
Interference data rate (Kbps)	SF$\times$19.2
SNR	$-8,-5$ dB
SIR	$-21\sim 9$ dB

With different iteration order, the BER performance is given in Fig.3., when the $\text{SNR}=-8,-5\text{dB}$. As the figure show, when the SIR is low, the BER performance is better if we detect the interference first. On the other side, when the SIR is high, BER performance is better when we choose to detect the CDMA signal first.

There is a intersection of two different iteration order that is the SIR threshold, which is used for iteration order selection. Fig.4. shows the numerical results of threshold when he $\text{SNR}=-8,-5\text{dB}$. The SIR threshold are $\gamma=-10.1\text{dB}$ and -7.7dB respectively, which is the same as the intersections in Fig.3.

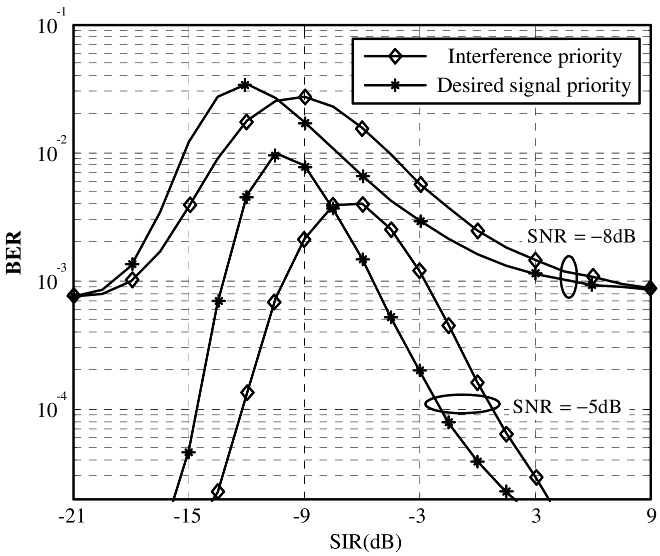

Fig. 3. BER performance of different iterative order when the SNR are −8 and −5 dB

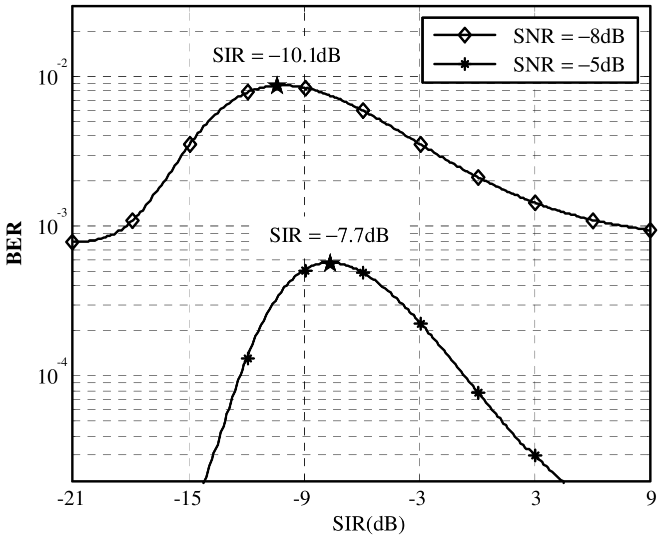

Fig. 4. Numerical results of threshold as the SNR are . −8 . and −5 dB

As we stated before, when the SIR is detected by cognitive technique, and threshold is calculated, the iteration order can be select for better BER performance. When the SNR is −5dB , and SIR is −12dB , the BER is improved from 4e-3 to 1e-4 as we detect the interference at first. On the other side, when the SIR is −3dB , the BER is improved from 1e-3 to 1e-4 as we detect the desired signal at first.

5 Conclusion

Consider the interference is linear modulation signal, a iterative anti-interference method based on power cognition technique is proposed in spread spectrum communication. The iteration order is determined by SIR threshold which is calculated by numerical method. The simulation result shows the validity of the proposed method.

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