Spectral Subtraction Approach for Interference Reduction of MIMO Channel Wireless Systems

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ABSTRACT

In this paper, a generalized spectral subtraction approach for reducing additive impulsive noise, narrowband signals, white Gaussian noise and direct sequence code division multiple access (DS-CDMA) interferences in multiple input multiple output (MIMO) channel DS-CDMA wireless communication systems is investigated. The interference noise reduction or suppression is essential problem in wireless mobile communication systems to improve the quality of communication. The spectrum subtraction scheme is applied to the interference noise reduction problems for noisy MIMO channel systems. The interferences in space and time domain signals can effectively be suppressed by selecting threshold values, and the computational load with the fast Fourier transform (FFT) is not large. Further, the fading effects of channel are compensated by spectral modification with the spectral subtraction process. In the simulations, the effectiveness of the proposed methods for the MIMO channel DS-CDMA is shown to compare with the conventional MIMO channel DS-CDMA.

Keywords: MIMO Channel, Spectral Subtraction, Interference Reduction, DS-CDMA.

1. INTRODUCTION

The code division multiple access (CDMA) is a desirable access scheme in wireless communication systems compared with the frequency division multiple access (FDMA) and the time division multiple access (TDMA) [1]-[13]. Several spread spectrum (SS) techniques using the CDMA have been developed and their performance is analyzed (see, e.g. [1], [2]).

In order to transmit large amount of data such as video, the SS becomes an indispensable technique. For example, the multi-carrier CDMA (MC-CDMA) is a combination of multi-carrier modulation and SS technique [3]. The MC-CDMA becomes an emerging technique in the field of next generation mobile radio communications. Due to the high performance multiple access schemes, it is suitable to support high speed data applications such as multimedia services.

Recently, the multiple input multiple output (MIMO) channel antenna system has much attention in wireless communication systems [4]-[6]. The MIMO channel system can promise improved efficiency of frequency utilization compared with the conventional systems. To achieve the advantages, several techniques such as minimum mean square error (MMSE) and maximum likelihood detection (MLD) are investigated [4].

On the other hand, various signal processing approaches for reduction of interference noise are proposed in noisy ill-condition channel environment for the SS-CDMA communication systems and so on [7]-[13]. For instance, a cancellation technique of interference is presented in [7], [10]. The interference is effectively removed in the simulations. In [11], an interference suppression method based on wavelet packet for DS-SS is proposed and obtained satisfactory simulation results. However, the interference is restricted to continuous sinusoidal wave and mixed interferences are not considered. The authors proposed a wavelet based method for reducing several types of interferences simultaneously for MC-DS-CDMA [13]. By using fuzzy rule based processing, interferences are flexibly and effectively removed. However, the system configuration using fuzzy rules is complicated.

In this paper, a noise reduction technique so-called spectral subtraction is introduced to the problem of noise reduction for MIMO channel wireless communication system. The spectral subtraction is a useful noise reduction technique in speech signal processing [14], [15]. To apply the MIMO channel wireless system, the spectral subtraction scheme is generalized. At the receiver, the generalized spectral subtraction with spectral modification for compensate the fading effect is used. The generalized spectral subtraction for space and time domain signals can effectively suppress the interferences and noise by selecting threshold values.

In section 2, the interference problems for MIMO channel wireless system is described. Section 3 shows a generalized spectral subtraction scheme. Simulation results are given in section 4. The approach is successful for reducing additive impulsive noise, narrowband signals, white Gaussian noise and DS-CDMA interferences in MIMO channel DS-CDMA wireless communication systems in the simulations. The effectiveness of the methods for noisy MIMO channel MC-DS-CDMA is shown to compare with the conventional MIMO channel DS-CDMA.

2. INTERFERENCE REDUCTION FOR MIMO CHANNEL WIRELESS SYSTEM

The features of our approach for noisy MIMO channel DS-CDMA wireless communication system are explained. The MIMO channel system with M transmit and N receive antennas is considered where the transmitted signals are assumed to be independent in time and space.

Figure 1 shows a model of MIMO channel wireless communication system. The individual signal is transmitted on each transmitter channel, and mixed signals are received at the receiver antennas. The received signals are independently distorted by signals such as other user’s and inter symbol interferences, additive noise and multi path fading on noisy transmission channels.

In our approach, to reduce the noise and interference effects, the generalized spectral subtraction scheme is used. Further, to estimate the exact bit information, maximum likelihood detector (MLD) [5] and independent component analysis (ICA) [16] are used prior to the generalized spectral subtraction.

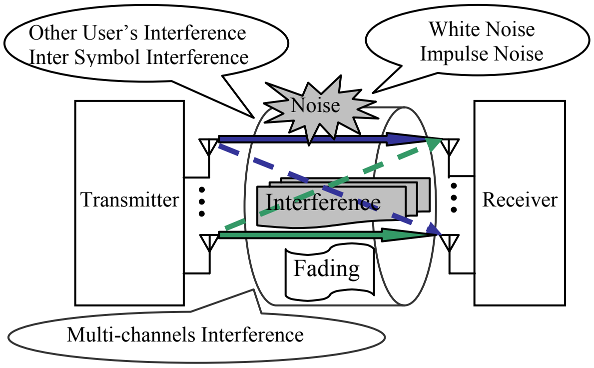


Figure 1: Interferences and Noise Problems in MIMO Channel Wireless Communication System.

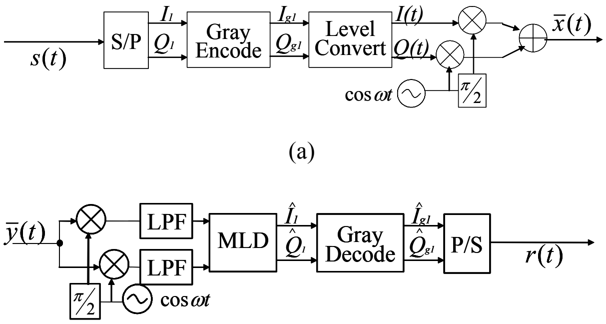
The MIMO channel DS-CDMA transmitter is composed of spread spectrum code multiplexer and the QPSK modulator shown in Fig. 2 (a). The transmitted signal $s(t)\in\{0,1\}$ is transformed to parallel data to obtain signal components $I(t), Q(t)\in\{+1,-1\}$ (Inphase component and Quadrature component). The QPSK signal is represented by

$$\bar{x}(t)=I(t)\cos\omega_c t-Q(t)\sin\omega_c t . \qquad (1)$$

where ω_c represents the center frequency of carrier signal.

The receiver is composed of spread spectrum code multiplexer, sequence estimator, QPSK de-modulator and the maximum likelihood detector (MLD) as shown in Fig. 2 (b). The sequence estimator has a role to separate the received signal statistically independent. The received signal is transformed to parallel components and de-modulated with LPFs. The transmitted signal is reconstructed as $r(t)$ by parallel to serial transform. The bit sequence is estimated by MLD. The estimation process is efficiently calculated by using Vitabi algorithm.

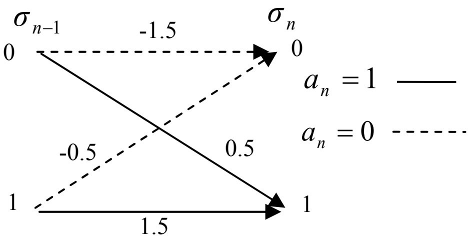
Figure 3 shows a trellis transition diagram for MLD. The state represented by σ_{n-1} varies to the next state σ_n in accordance with transmitted symbol a_n. The optimum path which corresponds to the optimum estimation of received sequence, is obtained by calculating minimum branch metric.



(a)

(b)

Figure 2: Structure of QPSK System. (a) QPSK Modulator, (b) QPSK De-Modulator.



σ_{n-1}	a_n	σ_n	output
0	0	0	-1.5
0	1	1	0.5
1	0	0	-0.5
1	1	1	1.5

Figure 3: Trellis Transition Diagram for MLD.

When the condition of channel is satisfactorily noise free, the receiver works well. However, when the channel is noisy environment as shown in Fig. 1, the influence of noise causes bit errors. In such case, interference noise reduction process is necessary to improve the quality of communication.

3. SPECTRAL SUBTRACTION FOR MIMO CHANNEL SYSTEM

In this section, a generalized interference noise reduction and channel compensate scheme based on the spectral subtraction is introduced. It is implemented in the de-modulation algorithm at the receiver.

Space and Time Domain Spectral Subtraction

The principle of spectral subtraction is first transform signals to spectrum by FFT or short-time Fourier transform (STFT), and subtract the spectral amplitude, compensate phase characteristic and finally transform spectrum to signals by the inverse FFT (IFFT) or ISTFT [14], [15]. Figure 4 shows the principle of spectral subtraction.

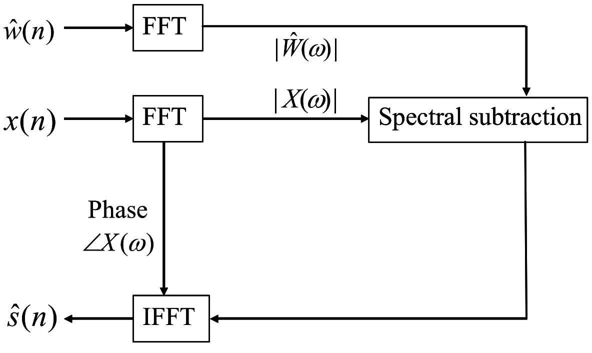


Figure 4: Principle of Spectral Subtraction.

Figure 5 shows a configuration of the proposed generalized spectral subtraction. The generalized spectral subtraction processes consist of mainly two steps.

The first step is to remove noise, in particular impulsive noise by spatial subtraction based on the FFT. The received multiple signals at time t represented by $x_i(t), i=1,2,\cdots,M$ are spatially transformed by using the FFT as

$$X_k(t) = FFT\{x_i(t)\}. \qquad (2)$$

When the *k*-th elements of $X_k(t)$ satisfy certain threshold conditions (overall or local average of spectrum criteria) as

$$|X_k(t)| \geq I_k, \qquad (3)$$

then all the elements are modified by

$$z_k(t) = \overline{X}_k(t) \qquad (4)$$

where I_k represents a positive threshold value and $\overline{X}_k(t)$ represents the local average of $|X_k(t)|$. When the element does not satisfy Eq.(3), the elements are not modified. Then the *k*-th signal of the antenna array is obtained by

$$\hat{z}_k(t) = IFFT\{z_k(t)\}. \qquad (5)$$

Further, in the following steps, the additive channel noise, in particular white Gaussian noise and interference of DS-CDMA is temporally subtracted. The *k*-th signal with the length *M* is transformed by using the STFT as

$$\hat{Z}_k(\omega,t) = STFT\{\hat{z}_k(t)\}. \qquad (6)$$

and the spectrum amplitude component is subtracted and modified when the certain threshold condition is satisfied as

$$\hat{X}_k(\omega,t) = \begin{cases} \left(|\hat{Z}_k(\omega,t)| - \beta|\overline{N}_k(\omega,t)|\right)e^{j\theta_k(\omega,t)}, \\ 0 \quad \text{if the sign is negative} \end{cases} \qquad (7)$$

where $|\overline{N}_k(\omega,t)|$ and $\theta_i(\omega,t)$ represent the average of absolute of noise with respect to frequency component and the phase characteristics of $\hat{Z}_k(\omega,t)$, respectively. Finally, the de-noised signals are obtained by

$$\hat{s}_k(t) = ISTFT\{\hat{X}_k(\omega,t)\}. \qquad (8)$$

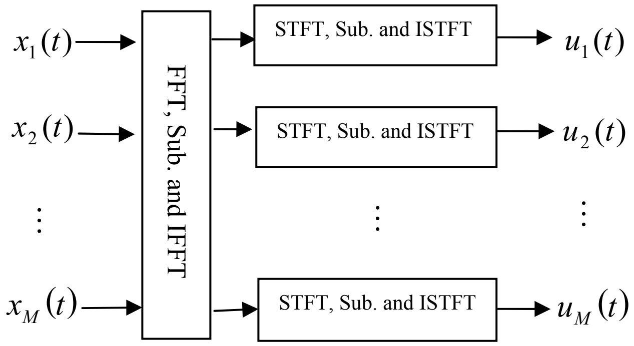


Figure 5: Spectral Subtraction for Space and Time Domain Signals at the MIMO Channel Receiver.

Spectral Modification

Next, a spectral modification method to compensate the flat fading effect in channel is shown. Figure 6 shows a generalized spectral subtraction and spectral modification scheme in time domain at the MIMO channel receiver. To estimate channel condition such as fading effect, a transmitted pilot signal $n_{pn}(t)$ is used in the generalized subtraction process. The test signal is selected as a random number sequence where the amplitude of spectrum is flat in the wide range of frequency.

The fading factor in frequency domain is defined as

$$\hat{R}(\omega) = \frac{|N_{pn}(\omega)|}{|N_{ts}(\omega)|}, \qquad (9)$$

where $N_{ts}(\omega)$ represents FFT of the received test signal. The characteristics show the fading effect of transmission channel. The spectral amplitude modification process is represented by

$$|\hat{S}(\omega)| = \begin{cases} |X(\omega)|, \ if \ \hat{R}_f(\omega) \approx 1 \\ |X(\omega)| \cdot \hat{R}_f(\omega), \quad \text{otherwise} \end{cases} \qquad (10)$$

Finally, the received signal is obtained by

$$\hat{s}(t) = IFFT\left\{|\hat{S}(\omega)|e^{j\theta(\omega,t)}\right\}. \qquad (11)$$

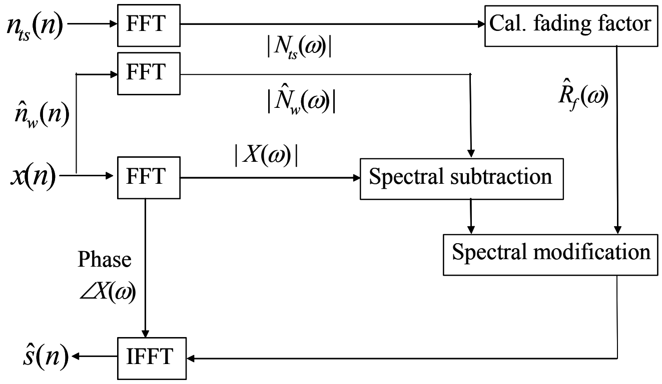


Figure 6: Generalized Spectral Subtraction and Spectral Modification Scheme at the MIMO Channel Receiver.

Bit Estimation Process at Receiver

The flow of the proposed receiver process for MIMO channel system is shown in Fig.7. First, the channel condition such as frequency flat fading effect is estimated using a pilot signal to determine the fading factor. Next, the generalized spectral subtraction in space and time domain is executed to reduce the noise and interference effects. Then, the ICA, inverse spread and de-modulation with MLD are used to estimate the received bit information.

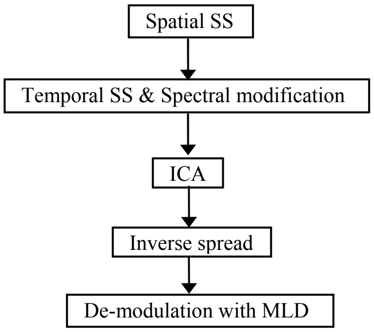


Figure 7: Structure of Receiver System using Spectral Subtraction and Spectral Modification with MLD and ICA.

4. SIMULATION RESULTS

In this section, simulation results are shown to demonstrate the effectiveness of our spectral subtraction approach.

Performance Evaluation

In the simulations, two input two output channel DS-CDMA system with QPSK modulation is investigated. Table 1 summarizes the parameters used in the simulations.

Communication system	DS-CDMA
Modulation	QPSK
Spread code	*M* sequence (32)
Num. of Tx antenna	2
Num. of Rx antenna	2
Channel condition	AWGN, Interference, Fading

Table 1: Simulation Conditions.

It is noted that 32-th order *M* sequences are used. The noisy channels with AWGN, impulsive noise, narrowband interference and/or DS-CDMA interference are simulated.

The performance is evaluated by bit error rate (BER) varying the channel signal to noise ratio (SNR). The BER is represented by

$$\delta = \frac{\frac{1}{N}\sum_{t=1}^{N}\left|r(t)-s(t)\right|}{\frac{1}{N}\sum_{t=1}^{N}\left|s(t)\right|}\times 100 \, . \qquad (12)$$

And the SNR is represented by

$$SNR = 10\log\frac{E_b}{N_o}, \qquad (13)$$

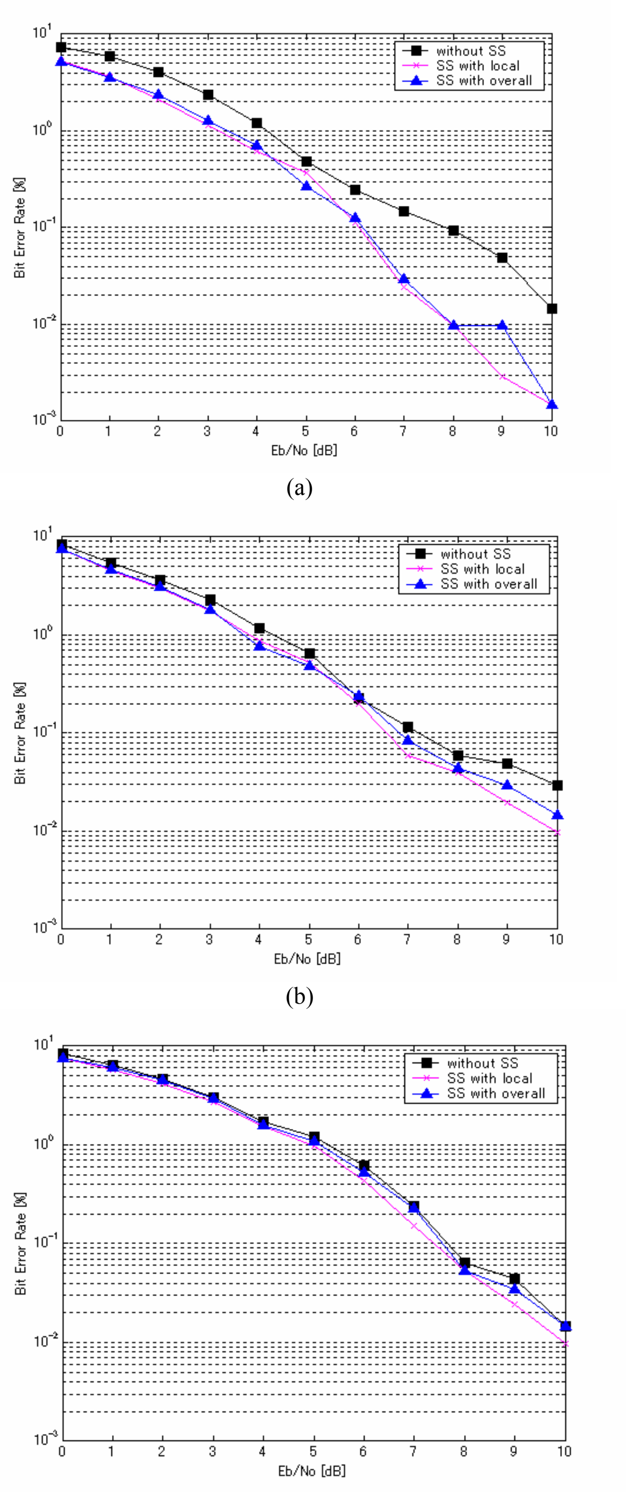
where E_b and N_o represent signal and noise powers, respectively.

Performance Analysis for Generalized Spectral Subtraction

First, two criteria for selecting threshold values are investigated. The values are determined based on the overall average and the local average of spectrum.

Figure 8 shows a comparison of BER using time domain spectral subtraction (conventional spectral subtraction). Figure 8 (a), (b) and (c) represent the BER in AWGN, impulsive noise plus AWGN, narrowband interference plus AWGN environments, respectively. Here three plots in the figures represent the spectral subtraction using the overall average, local average thresholds and without using noise measures. When the noise is stationary such as AWGN, the performance of local and overall averaging show the lower BER compared with the without noise measure threshold. Both of the averaging do not show the distinct difference. While, when the noise is non-stationary such as impulsive and narrowband interference, the threshold value based on local average shows slightly lower BER.

Next, the proposed generalized spectral subtraction in space and time domains is evaluated in without fading channel environment. Figure 9 shows a comparison of BER for the generalized spectral subtraction, the conventional spectral subtraction (time domain) and without spectral subtraction. Figure 9 (a), (b) and (c) represent the BER in AWGN, impulsive noise plus AWGN, narrowband interference plus AWGN environments, respectively. When the noise is stationary such as AWGN, the improvement of the proposed spectral subtraction is small in Fig. 9 (a) as in the case of Fig. 8. However, when the noise is impulsive or narrowband interference in Fig. 9 (b) and (c), the improvement of BER is large compared with the conventional spectral subtraction. It is shown that the BER of the proposed approach is improved in various interference noise conditions. It is noted that when the number of channel is large, the computational load for our spectral subtraction becomes extremely large.

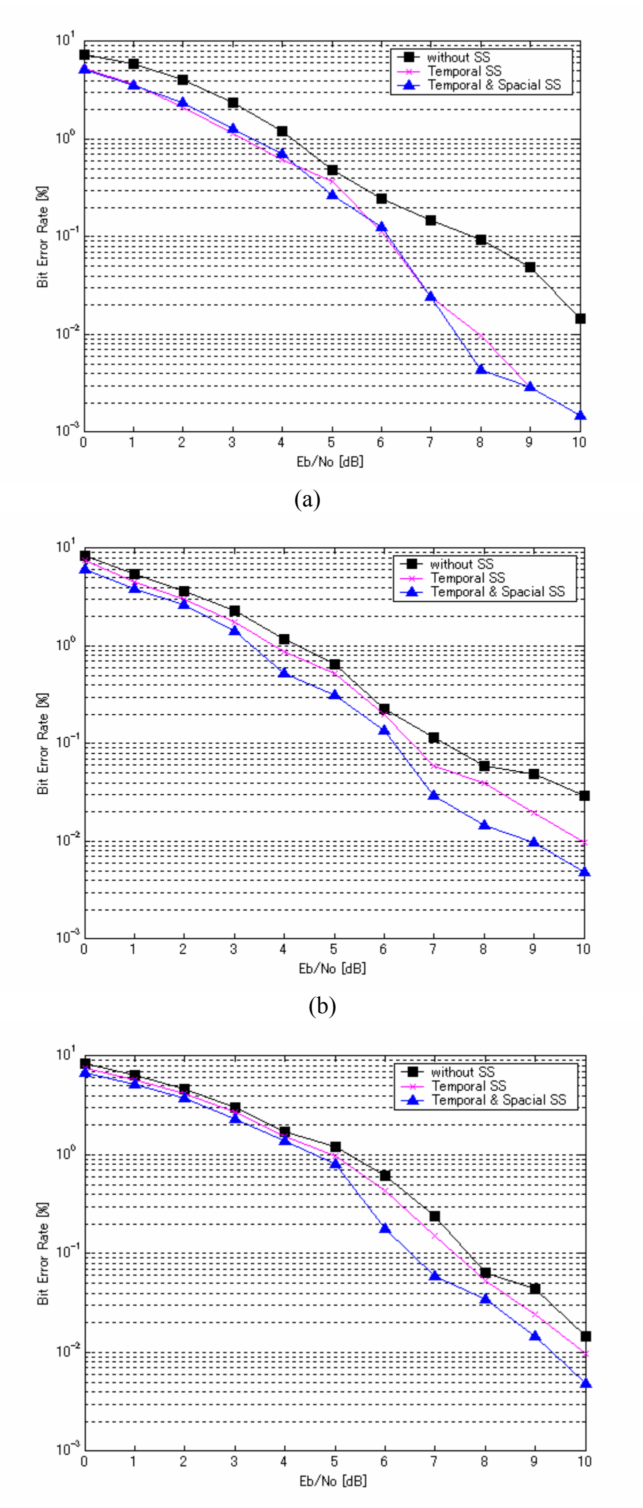


(a)

(b)

(c)

Figure 8: Comparisons of Bit Error Rate Using Different Threshold Values in Spectral Subtractions. (a) BER in AWGN environment, (b) BER in impulsive noise and AWGN environment, (c) BER in narrowband interference and AWGN environment.



(a)

(b)

(c)

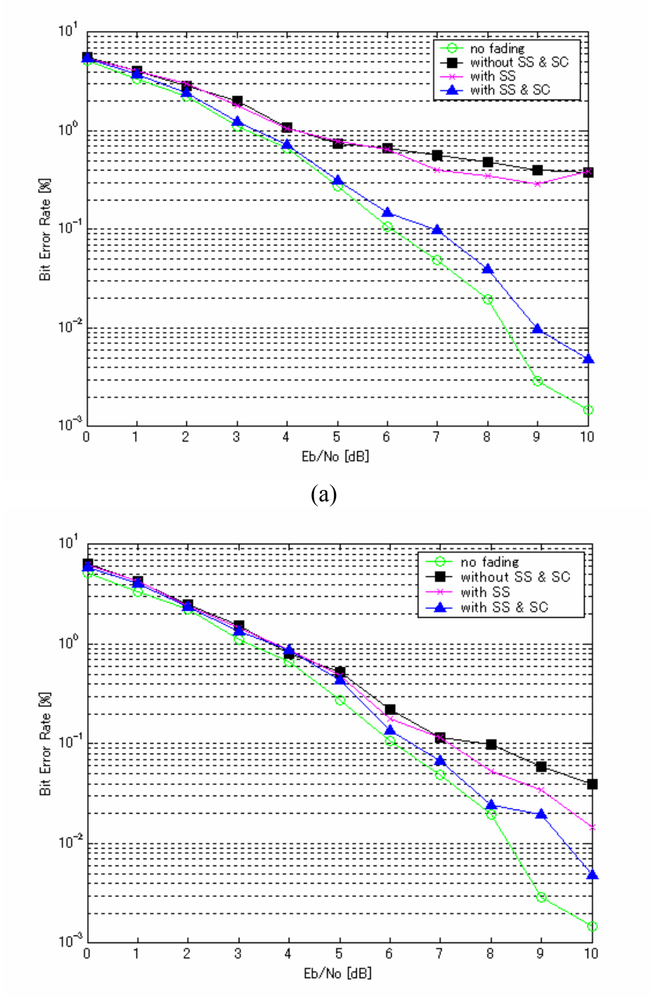
Figure 9: Comparisons of Bit Error Rate Using Generalized Spectral Subtractions. (a) BER in AWGN environment, (b) BER in impulsive noise and AWGN environment, (c) BER in narrowband interference and AWGN environment.

Further, the effectiveness of the generalized spectral subtraction and spectral modification for channel compensation scheme is examined in the simulations. The BER characteristic is evaluated in AWGN and fading condition. Figure 10 shows a comparison of BER in higher frequency and high frequency band fading channel conditions. It is shown that the BER is extremely improved by the spectral modification (spectral compensation: SC) in Fig. 10. The BER performance is close to that of without fading.

Furthermore, the BER performance under varying the following factor is evaluated.

$$SFR = 10\log\frac{N_{pn}}{N_{ts}} \tag{14}$$

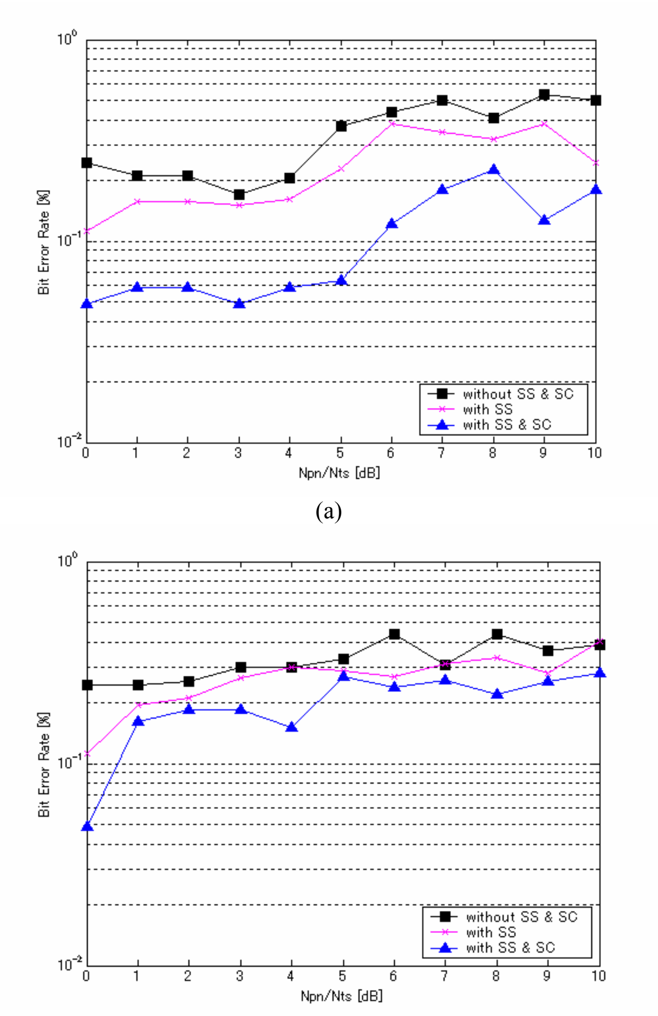
Figure 11 (a) and (b) show comparisons of BER in AWGN and higher frequency fading environment and in AWGN and high frequency band fading environment, respectively. When the value of factor becomes large, the amount of fading becomes large. Then, when the value of factor is large, the BER performance is low. However, the BER performance is particularly improved when the proposed generalized spectral subtraction and spectral modification is used compared with the conventional spectral subtraction in the figures.



(a)

(b)

Figure 10: Comparisons of Bit Error Rate in Fading Conditions. (a) BER in AWGN and higher frequency fading environment, (b) BER in AWGN and high frequency band fading environment.



(a)

(b)

Figure 11: Comparisons of Bit Error Rate with Varying The Factor in Eq. (14). (a) BER in AWGN and higher frequency fading environment, (b) BER in AWGN and high frequency band fading environment.

5. CONCLUSIONS

In this paper, a generalized spectral subtraction approach for reducing additive impulsive noise, narrowband signals, white Gaussian noise, DS-CDMA interferences and fading effect in MIMO channel DS-CDMA wireless communication systems was proposed. The interference noise reduction or suppression was essential problem in wireless mobile communication systems to improve the quality of communication. The spectrum subtraction scheme was applied to the interference noise reduction problems for noisy MIMO channel systems. The interferences in space and time domain signals could effectively be suppressed by selecting threshold values, and the computational load with the FFT was not large. Further, spectral modification for compensating fading effect in channel is shown. In the simulations, the effectiveness of the proposed methods for the MIMO channel DS-CDMA was shown to compare with the conventional MIMO channel DS-CDMA.

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