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A Novel Interference Cancellation Scheme for NBI Reduction in MC-CDMA Systems

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Abstract

Narrowband Interference (NBI) affects the subcarriers of multi-carrier systems which in turn increases the bit error rate (BER) of the system In this Paper a novel Successive Interference Cancellation (SIC) multiuser detector has been implemented to suppress NBI. SIC detection is a simple and efficient method to suppress Multiple Access Interference (MAI) in imperfect power scenario. In the presence of NBI, subcarriers of MC-CDMA signals get affected and signal to noise ratio (SNR) of subcarrier varies, which in turn varies the power level of affected subcarriers. Numerical results show that SIC detector effectively mitigates NBI as well as MAI and this detector is Near-Far resistant also.

Keywords: Multicarrier Code Division Multiple Access (MC-CDMA), Narrowband Interference (NBI), Multiuser Detection (MUD), Multiple Access Interference (MAI), Successive Interference Cancellation (SIC).

INTRODUCTION

MC-CDMA is a new technology which is having characteristics of both OFDM and CDMA systems [1]. MC-CDMA systems are immune to multipath fading and can support high data rates and for this reason it is being considered as a potential candidate for 4G technology [2]. In MC-CDMA each data symbol is transmitted on a number of subcarriers and in case if one or two subcarriers go into deep fade, original signal can still be recovered using diversity combining techniques.Similar to conventional CDMA systems, Performance of MC-CDMA is interference-limited. It is affected by multiple access interference (MAI), which occurs because user's signals no longer remain orthogonal in an asynchronous channel. It also gets influenced by Additive white Gaussian noise (AWGN) on the way from transmitter to the receiver, which is inherent in a wireless communication system. Apart from MAI and AWGN, multicarrier CDMA systems sometimes get affected by another type of interference which is termed as narrowband interference (NBI) [3].NBI may arise in multicarrier systems because of following reasons.

1. Some unlicensed user operating in same band.
2. Intentional interferer may use high power narrowband signal to jam MC-CDMA system.
3. by unauthentic signals caused by non-linearity of power amplifiers.
4 by oscillations produced in electronic devices.
5. Adjacent cell interference in cellular mobile systems.

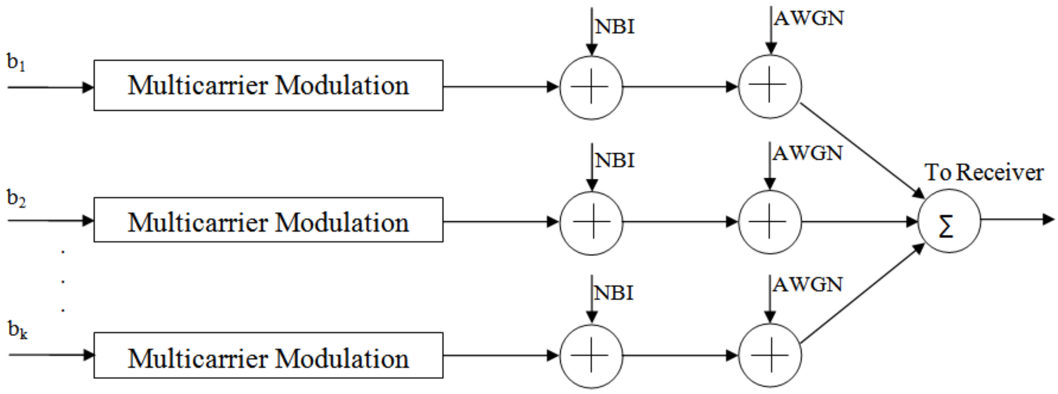

Figure 1: MC-CDMA signal with NBI and AWGN

Nowadays many systems such as UWB (ultra wide band), WLAN (wireless local area network), WIMAX (worldwide interoperability for microwave access), OFDM-LTE orthogonal frequency division multiplexing-long term evolution) etc. operate simultaneously to provide high data rate, so in such a scenario, it happens sometimes that one system may act narrowband interferer for the other system. NBI signals may also originate from remote controls of various household appliances or cordless phone systems. It has been observed that performance of MC-CDMA systems degrades substantially in the presence of NBI, as NBI may corrupt different subcarriers randomly and at the receiver end we will not be able to reproduce the transmitted signal properly. Till now all the available NBI elimination methods use additional circuitry, apart from detector (demodulator) to suppress NBI. Estimator/subtractor and frequency excision methods are employed to eliminate NBI. In estimator/subractor method predicted values of received signals are subtracted from actual received signal and interference is removed. In frequency excision method received signal is converted into frequency domain and exact location of NBI is determined [4-6].Both these methods need some filters and circuitry to remove NBI. In [7-8] notch filter is used prior to detector to eliminate NBI. In [9] Kalman-Bucy filter has been used to to filter out NBI from the received signal.

All the methods described above are applied before detection and require additional circuitry. Moreover these methods do not take care of either MAI or AWGN. In these methods NBI is modeled as either a sinusoidal signal or an autoregressive (random) process. It may happen sometimes that NBI, which affects a spread spectrum signal (MC-CDMA), is neither a sinusoidal signal nor it is an autoregressive process, but it may be a narrowband digital interferer signal which occurs randomly with variable intensity. So in such a case we will not get optimum results if NBI is modeled as either a sinusoidal signal or an autoregressive process. In this paper SIC multiuser detector is applied to mitigate digital NBI. Since MAI and AWGN degrade the performance of CDMA based systems. Multiuser detection has been proved to be an efficient technique to mitigate MAI and AWGN [10]. So SIC multiuser detector can be effectively employed to mitigate NBI also because NBI is modeled as digital interferer in this case.

PROPOSED METHOD (SIC Detector)

As shown in Fig. 2 below, some of the subcarriers has been corrupted by NBI signals randomly. In this process some subcarriers may be affected completely and some subcarriers may be affected partially by the NBI and if it is assumed that NBI signals affect different subcarriers with different amount of signal strength (because of their random occurrence), then SNR (signal to noise ratio) of subcarriers affected by NBI may vary.

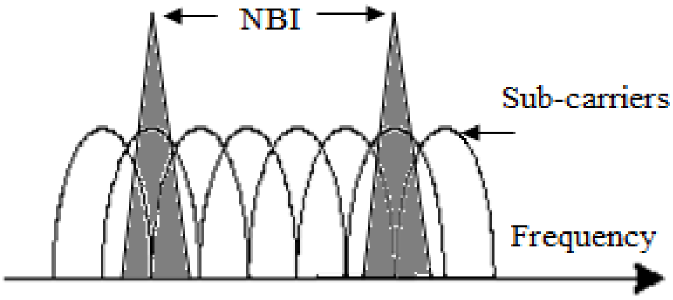

Figure 2: NBI affecting different subcarriers

We know that in SIC user's signals are subtracted serially in order of their received power i.e. from strongest to weakest [11-12]. In SIC strongest user's signal is subtracted from the composite received signal in first iteration and similarly in second iteration, 2^{nd} strongest user's signal is subtracted from the received composite signal and this process lasts till signals from all the users are subtracted from received signal. After each iteration a new strongest user is selected and subtracted. Suppose there are K numbers of user in ascending order. So according to equation below, data bit b_j is estimated by subtracting MAI of strongest user (K) from the composite received signal and this process is repeated till all data bits are estimated. So a SIC detector serially subtracts all the users from the outputs of correlators (matched filters) as shown in fig.3 below

$$\hat{b}_j = sign\left(y_j - \sum_{k=j+1}^{K} A_k \rho_{kj} \hat{b}_k \right) \quad (1)$$

A_k is amplitude of kth bit, ρ_{kj} is cross-correlation of kth and jth bit and $\hat{b}_k$ is estimated bit of kth user.

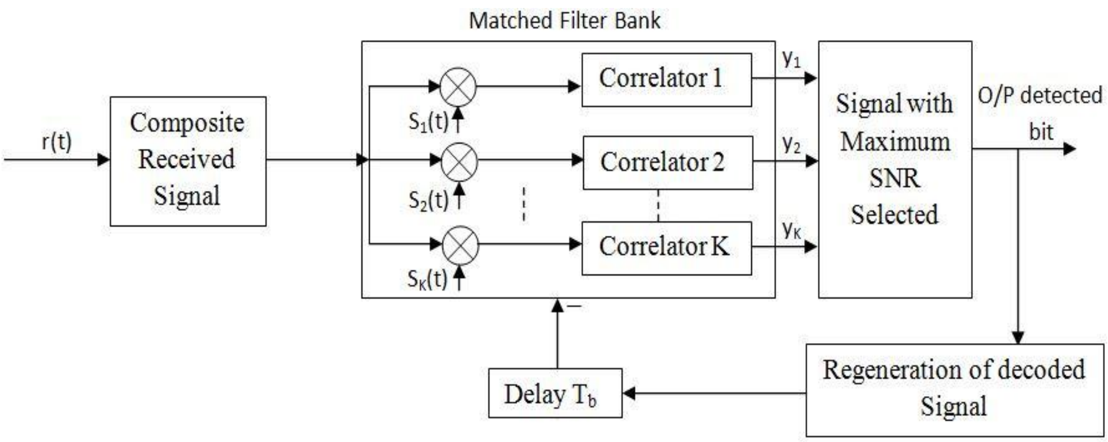

Figure 3: SIC multiuser detector

In this way all data bits of different users are estimated according to their descending signal strength (SNR).

In this paper, Problem of NBI has been presented in a different aspect. We know that in CDMA based system, users who are near to base station receive large amount of signal in comparison with the user who is far away from the base station which leads to Near-Far effect. So in near-far scenario a weak user is overwhelmed by the strong user and SNR of weak user gets decreased. As a result its detection becomes difficult. In a similar manner, addition of narrowband interference in MC-CDMA changes the SNR values of the contaminated subcarriers and the subcarrier which is completely overlapped by the NBI gets the minimum SNR value, whereas subcarrier corrupted partially by NBI will have somewhat higher SNR value but lower than the required threshold value. In near-far scenario, SNR of different users vary due to their location but in this problem changes in SNR of different users can occur due to NBI. NBI can be differentiated from AWGN and MAI in the sense that both these interferences are of wideband nature and they do not affect a particular subcarrier like NBI does. We know that SIC detector performs better in imperfect SNR (power) scenario. SIC detector arranges all these subcarriers in descending order of their SNR value. The biggest advantage of this method is that strongest subcarrier is subtracted first and remaining users are no longer affected by the high SNR of that user.

SYSTEM MODEL

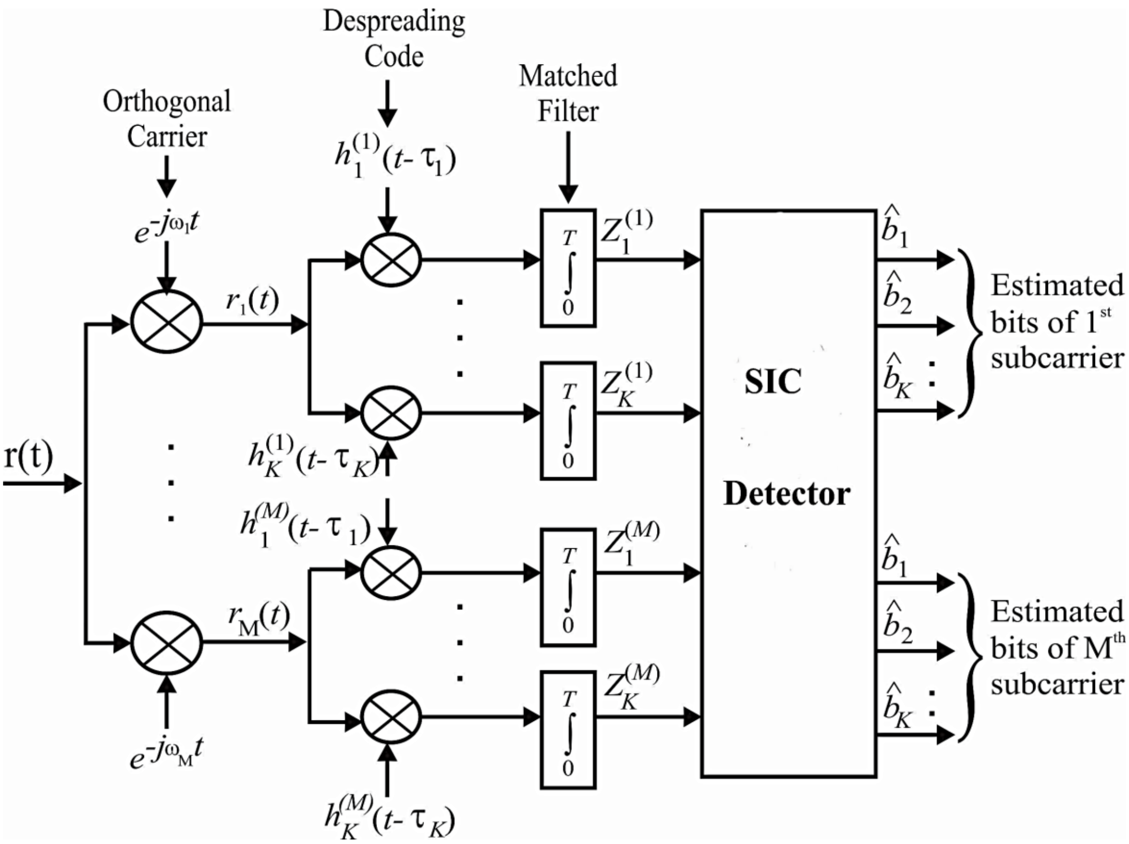

Figure 4: MC-CDMA SIC Detector

Fig. 5 shows an asynchronous MC-CDMA system with K users. Here τ_k is transmission delay associated with Kth user and it can be assumed that $0 \le \tau_1 \le \tau_2 \le ... \le \tau_k < T_b$.

Where T_b is bit duration

The received signal at the base station on the M^th^ subcarrier is given as:

$$r_m(t) = \sum_{k=1}^{K} A_k h_k^{(m)}(t-\tau_k) b_k + n(t) \tag{2}$$

Where,

A_k is the k^th^ user's amplitude.

h_k is the k^th^ user's spreading code.

b_k is the k^th^ user's transmitted bit.

$n(t)$ is additive white Gaussian noise (AWGN).

Here, outputs of matched filters on m^th^ sub-carrier are given as $Z_1^{(M)} \cdots\cdots\cdots Z_k^{(M)}$. Now SIC detector arranges all the outputs of M^th^ sub-carrier in ascending order of their signal strength. Now according to equation (3) , the estimate of bit of user j can be given as:

$$\hat{b}_j^{(M)} = sign\left(Z_j^M - \sum_{k=j+1}^{K} A_k^{(M)} \rho_{kj} \hat{b}_k^{(M)} \right) \tag{3}$$

Where

$A_k^{(M)}$ is the amplitude of k^th^ user bit on M^th^ subcarrier

ρ_{kj} is cross-correlation between k^th^ and j^th^ bit

$\hat{b}_k^{(M)}$ is the estimated bit of k^th^ user and

Z_j^M is matched filter output of the j^th^ user on M^th^ subcarrier

In a similar way SIC detector estimates all the users' bits of M^th^ sub-carrier in descending order of their signal strength. This process is simultaneously performed for all the sub-carriers. So in every iteration we get a bit vector of strongest users in descending order.

SIMULATION & RESULTS

In this paper an asynchronous (uplink) MC-CDMA system is considered. Gold code of length 31 is used as spreading sequence. Here it is assumed that narrowband interferer signals are of Gaussian in nature and it is assumed that these NBI signal affect different subcarriers randomly with variable intensity (Interference Power). Perfect subcarrier synchronization with no frequency offset is assumed. Each subcarrier will go for independent fading as channel is asynchronous (uplink). It is also assumed that there is no non-linear distortion of any kind. Channel is AWGN and modulation used is QPSK.

To observe the effect of NBI on different user signals, we take 4 users with each user transmitting 10,000 bits through the channel. Table.1 shows a matrix where diagonal elements [1 1 1 1] represent the amplitude (auto-correlation) of 4 users signals and non-diagonal elements represents the cross-correlation values. Now Table.2 shows the amplitude matrix of 4 users corrupted by NBI. It can be clearly observed that amplitudes of users are affected by NBI and also non-diagonal elements become non-zero which indicates that signals are affected by MAI as well. In Table.3, we can see that diagonal values are affected to a large extent and reason for this is the different power levels [1 10 5 4] of users. So near-far effect further increases the MAI which results in severe amplitude distortion.

Table 1: Amplitude matrix of received composite signal without NBI (4 users)

1	0	0	0
0	1	0	0
0	0	1	0
0	0	0	1

Table 2: Amplitude matrix of received composite signal corrupted by NBI (4 users)

0.9551	0.0164	0.0071	0.0107
0.0263	0.9816	0.0073	0.0191
0.0278	0.0477	1.0058	0.0274
0.0107	0.0068	0.0136	0.9986

Table 3: Amplitude matrix of received composite signal corrupted by NBI with different power levels (Near-Far effect) (4 users)

0.9754	0.0736	0.0576	0.0147
0.0092	0.3141	0.0032	0.0101
0.0133	0.0152	0.4429	0.0056
0.0172	0.0583	0.0579	0.4999

Having observed the effect of NBI on MC-CDMA signals, now we will apply some remedial measures to detect the signals in the presence of NBI. For this 16 users are taken and each user transmits 10,000 bits. A total of 6 narrowband interferer are used which corrupts the users signal randomly with variable intensity.To get a fair analysis of NBI effect on the system we consider two different cases. In first case it is assumed that there is no near-far effect in the uplink and in second case it is assumed that Near-Far effect also exist along with NBI in the uplink.

Case:1(with equal power level) - In Fig. 6 we can clearly observe that in case of perfect power control in the presence of NBI, SIC detector gives excellent performance which is at par with the optimum detector, MMSE and decorrelator detector.

Table 4: Bits in error of each detector out of total 10000 bits under near-far condition

SNR	**1dB**	**2dB**	**3dB**	**4dB**	**5dB**	**6dB**	**7dB**
Optimum detector-NBI	.1999	.2017	.2030	.2043	.2051	.2059	.2071
Decorrelator detector-NBI	.0201	.0153	.0114	.0084	.0053	.0030	.0025
MMSE detector-NBI-	.0201	.0153	.0114	.0084	.0053	.0030	.0025
SIC detector-NBI	.0200	.0141	.0102	.0071	.0042	.0021	.0011
SNR	**8dB**	**9dB**	**10dB**	**11dB**	**12dB**	**13dB**	**14dB**
Optimum detector-NBI	.2115	.2163	.2191	.2227	.2248	.2288	.2340
Decorrelator detector-NBI	1.000e-03	3.750e-04	2.500e-04	0	0	0	0
MMSE detector-NBI-	1.000e-03	3.750e-04	2.500e-04	0	0	0	0
SIC detector-NBI	6.250e-04	2.834e-04	0	0	0	0	0

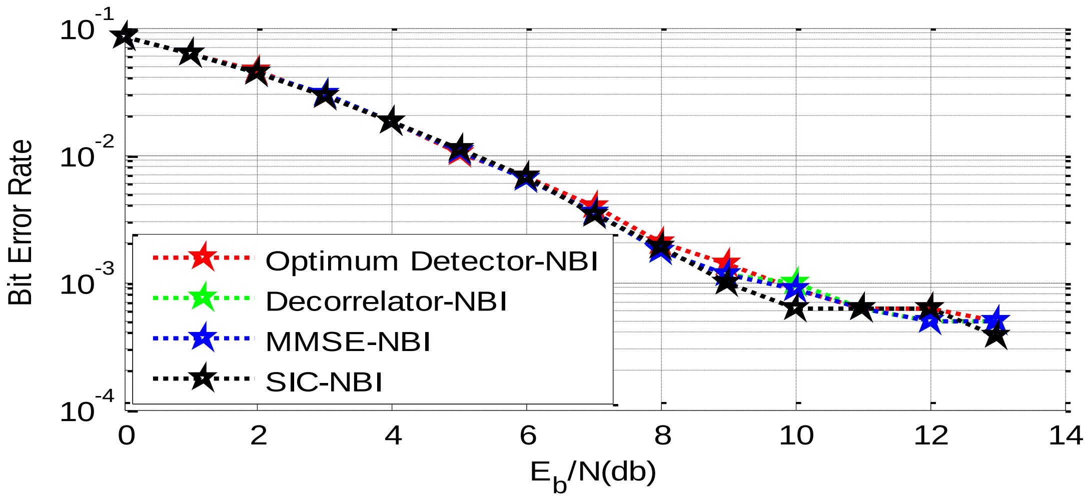

Figure 5: BER performance with NBI

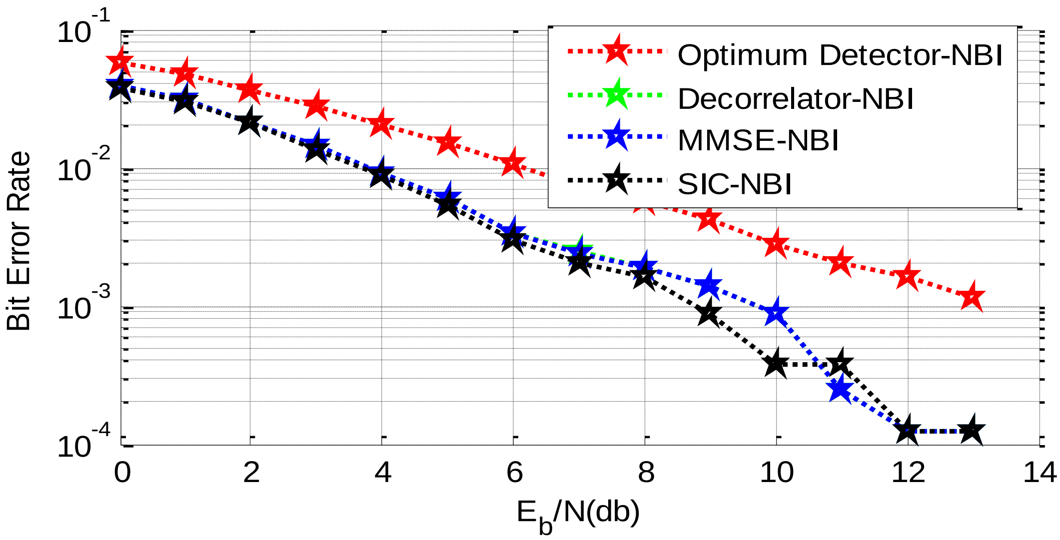

Figure 6: BER performance with NBI under near-far effect

We know that in equal power level scenario and without any NBI, performance of SIC slightly degrades in comparison with optimum, MMSE and decorrelator detector. So it is obvious that SIC gives good performance because NBI signals varies the power level (SNR) of affected signals. Moreover SIC gives the lowest computational complexity (K iterations) in comparison with optimum (2^K iterations), MMSE (K^2 iterations) and decorrelator (K^2 iterations).

Case: 2 (With Near-Far effect) - In this case different power level are provided to all 16 users randomly. It is observed from the Fig. 7 that BER performances of optimum detector degrades in the presence of near-far effect and NBI, but SIC, MMSE and decorrelator detectors gives excellent performance. The Performance of MMSE and decorrelator is at par with each other. So it can be analyzed that these suboptimal detectors are near-far resistant and performance of SIC is the best among all these detectors. We can also analyze the performance of all the detectors from Table 4, where bit error rate of all the detectors are shown. It can be observed that SIC detector has lesser number of error bits under all the SNR values. SIC detector gives zero error bits for 10dB to 14dB SNR values. Reason for such an excellent BER performance of SIC is the disparity among power levels of different users. Error bits for MMSE and Decorrelator are equal in number under every SNR values, so they give exactly same performance. Error bits for optimum detector goes on increasing with every SNR values, it means this detector is not robust to NBI and near-far effect.

CONCLUSION

In this paper we exploited the feature of SIC detector which detects the users in descending order of their signal strength and simulation results show that SIC detector performs well in the presence of both NBI and Near-Far effect. So a SIC detector is both NBI and Near-Far resistant and at the same time it effectively mitigates MAI. Hence SIC detector is an efficient technique to be employed in a real scenario as near-far effect is inherent because of geographical location offset of users. Moreover there is no need to add extra circuitry either at transmitter end or at receiver end to mitigate NBI. The biggest drawback associated with SIC detector is one additional bit delay(latency) after each iteration, which increases with the number of users.

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