

Narrow-band Interference Suppression in Wavelet Packet Multirate Multicarrier Multicode CDMA System

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Abstract: Multicode (MCD) scheme can be used to transmit information with Multirates (MR) in Multicarrier Code-Division Multiple Access (MC-CDMA) system. Since wavelet packets (WPs) have lower sidelobes compared with sinusoidal carriers, then systems which use WPs as subcarriers are very effective in reducing the problem of intercarrier interference. The CDMA can suppress a given amount of interference. To mitigate the effect of narrow-band jammer interference, suppression filter (SF) can be used in the receiver. Also, to reduce multiple access interference diversity techniques can be used. In this paper, the bit error rate performance of a system denoted by WP-MR-CDMA is tested. The effects of SF type and number of taps were investigated. Also, the effect of service rates is presented.

Key-Words: Multirate, Suppression filter, Wavelet Packets

1 Introduction

The Wavelet Packets Multicarrier Multicode Code-Division Multiple Access (WP-MC/MCD-CDMA) system [1]-[6] uses WPs as subcarrier instead of sinusoidal one. This system outperforms the system which uses sinusoidal signals as subcarriers because:

(1) WPs have much lower sidelobes with negligible sidelobe energy leakage compared to sinusoid carriers that will reduce the problem of intercarrier interference (ICI) and multiple access interference (MAI).

(2) WPs are naturally orthogonal and well localize in both time and frequency domain, which relaxes the requirement of frequency or time guard between different user signals.

In [1]-[3], [5] and [6] three methods of space diversity namely, selection diversity (SD), equal gain combining (EGC) and maximum ratio combining (MRC) was used to combat the effect of multipath fading and thus enhance the system performance. In the above papers MRC shows better performance compared with EGC and SD, because of that MRC is used in this paper.

The narrow-band interference jamming signal can reduce the performance of the system [3]-[4] and [6]. To reject the narrow-band interference and thus im-

prove the system performance SF [8] can be employed [4] and [6].

Multirate services can be provided in CDMA system by two schemes. One is MCD scheme and another is multiprocessing gain (MPG) scheme [5]. In the MCD scheme, the number of multicode for each user varies according to the data rate while the processing gain of all users is fixed. In MPG scheme, the processing gain varies from user to user, but chip rate and number of multicode are fixed. In [5] the use of MCD scheme for multirate services to obtain a technique called WP-MR\MC\MCD-CDMA system has been proposed.

The aim of this paper is to explore the impact of MR and SF (type and number of taps) on the performance of the WP-MR\MC\MCD-CDMA system.

The paper is organized as follows. In the next section, we propose the model that we use in this paper. In Section 3, signal to interference plus jamming and noise ratio is presented. Section 4 presents the bit error rates (BER) based on MRC. In Section 5, to illustrate the efficiency of our system, the BER for the system is evaluated by means of MATLAB program. Finally, we conclude our paper in section 6.

2 System model

Transmitter and receiver of the WP-MR\MC\MCD-CDMA system are shown in Fig. 1. The transmitter consists of two parts which are MR\MCD part and spreading\WP modulation part while the receiver consists of three parts which are despreading\WP correlator, coding correlator part and the diversity combiner part. In this system there are $K = \sum_{\mathfrak{R}=1}^{\mathbb{N}} \sum_{k_{\mathfrak{R}}=1}^{K_{\mathfrak{R}}} k_{\mathfrak{R}}$ MR active users transmitting data simultaneously, where k indicates the user number, \mathfrak{R} indicates its service group and \mathbb{N} indicates the total number of service groups

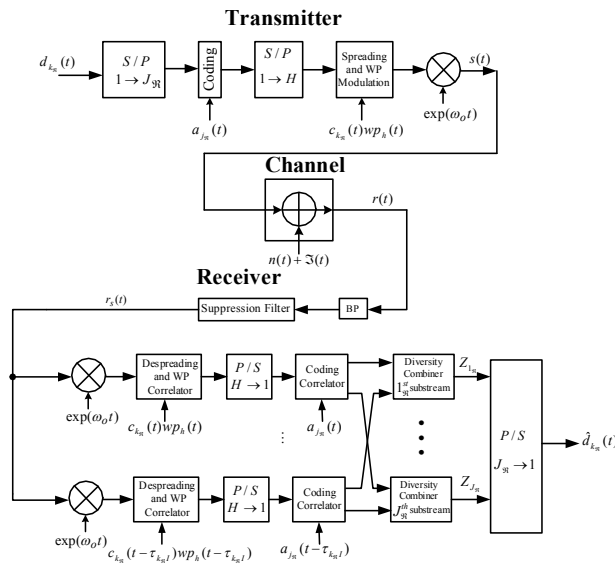


Fig.1: Transceiver of WP-MR\MC\MCD-CDMA system.

Each user can provide at any time only one kind of rate service from the \mathbb{N} code sets he has. At the transmitting side, the data stream of k^{th} , $d_k(t)$, is serial-to-parallel (S/P) converted into $J_{\mathfrak{R}}$ substreams, $d_{k_{\mathfrak{R}}j_{\mathfrak{R}}}(t)$, coded by the orthogonal signal $a_{j_{\mathfrak{R}}}(t)$ and then added. The resulting signal is again S/P converted into H superstreams, $d_{k_{\mathfrak{R}}j_{\mathfrak{R}}h}(t)$, spreaded by the pseudo-random noise (PN) sequence $c_{k_{\mathfrak{R}}}(t)$ and then used to modulate a wave packets $wp_h(t)$. The resultant superstreams are summed up and modulated by a sinusoidal carrier $\exp(j\omega_o t)$ before being transmitted. Assuming perfect power control such that the power of all users is the same and equal to P , then the transmitted signal of k^{th} user from the \mathfrak{R}^{th} service group is given by [5]

$$s_{k_{\mathfrak{R}}}(t) = \sqrt{2P} \sum_{h=1}^H \sum_{j_{\mathfrak{R}}=1}^{J_{\mathfrak{R}}} \text{Re} [d_{k_{\mathfrak{R}}j_{\mathfrak{R}}h}(t) a_{j_{\mathfrak{R}}}(t) c_{k_{\mathfrak{R}}}(t) \times wp_h(t) \exp(j\omega_o t)] \quad (1)$$

Note that the $d_{k_{\mathfrak{R}}}(t)$ has $T_{\mathfrak{R}} = T/(J_{\mathfrak{R}}H)$ duration and the PN code sequence has N_n length and $T_n = T/N_n$ duration, where T is the symbol duration. The signal $s_{k_{\mathfrak{R}}}$ passes through a Nakagami distributed channel [7] before being detected by the receiver. The impulse response of the channel is given by

$$h_c(t) = \sum_{l=1}^L \beta_{k_{\mathfrak{R}}l} e^{j\phi_{k_{\mathfrak{R}}l}} \delta(t - \tau_{k_{\mathfrak{R}}l}) \quad (2)$$

where L is the number of propagation paths and $\beta_{k_{\mathfrak{R}}l}$, $\phi_{k_{\mathfrak{R}}l}$, and $\tau_{k_{\mathfrak{R}}l}$ are gain, phase and time delay of the l^{th} path, respectively. The output of the channel for the $k_{\mathfrak{R}}$ user is given by

$$y_{k_{\mathfrak{R}}}(t) = h_c(t) * s_{k_{\mathfrak{R}}}(t) = \sum_{l=1}^L \beta_{k_{\mathfrak{R}}l} e^{j\phi_{k_{\mathfrak{R}}l}} s_{k_{\mathfrak{R}}}(t - \tau_{k_{\mathfrak{R}}l}) \quad (3)$$

The received signal is given by [3]-[6]

$$r(t) = \sum_{\mathfrak{R}=1}^{\mathbb{N}} \sum_{k_{\mathfrak{R}}=1}^{K_{\mathfrak{R}}} y_{k_{\mathfrak{R}}}(t) + n(t) + \mathfrak{I}(t) \quad (4)$$

Where $n(t)$ is the Additive White Gaussian Noise (AWGN) and $\mathfrak{I}(t)$ is the Binary Phase Shift Keying (BPSK) narrow-band interference jammer (NBIJ) given by [3], [4] and [6]

$$\mathfrak{I}(t) = \sqrt{2\mathfrak{I}} \zeta(t) \cos [2\pi(f_o + \Delta)t + \psi] \quad (5)$$

The NBIJ has \mathfrak{I} power, Δ offset interference carrier with respect to signal carrier, ψ phase and $\zeta(t)$ information sequences. The receiver is assumed to be synchronous designed to detect the first substream, of the first user's, of the first WP which propagate via first path. To remove the out-of-band noise, the $r(t)$ passed through a Band Pass Filter (BPF). The filtered signal is then passed through a tapped SF which has an impulse response given by [8]

$$h_s(t) = \sum_{m=-M_1}^{M_2} \alpha_m \delta(t - mT_n) \quad (6)$$

Where M_1 and M_2 represent the number of filter taps on the left and right of the center tap, respectively. The value of α_m is given in [4, section 3]. For each tap, the output of the SF is given by.

$$r_s(t) = \left(\sum_{\mathfrak{R}=1}^{\mathbb{N}} \sum_{k_{\mathfrak{R}}=1}^{K_{\mathfrak{R}}} y_{k_{\mathfrak{R}}}(t) + \hat{n}(t) + \mathfrak{I}(t) \right) * h_s(t) \quad (7)$$

Where $\hat{n}(t)$ is the filtered AWGN. The output of the filter is demodulated by a locally generated carrier, depressed by user PN sequence, $c_{k_{\mathbb{R}}}(t)$, demodulated by $w_{p_h}(t)$ and correlated over a period T to recover superstream which is then parallel-to-serial (P/S) converted. Each output of the P/S is multiplied by the code $a_{j_{\mathbb{R}}}(t)$, correlated over a period T and then combined by diversity combiner to recover the substream $Z_{j_{\mathbb{R}}}$. Finally, each combiner output of the $J_{\mathbb{R}}$ substream is P/S converted to recover $\hat{d}_{k_{\mathbb{R}}}(t)$.

3 Signal-to-interference plus jamming and noise ratio

To find the output signal to interference plus jamming and noise ratio (SIJNR), we need to find the power for the desired signal, the variances for the interferences, jamming and noise. The desired signal, the interferences, the jamming and the noise terms consists of two parts, the Inphase (I) and Quadrature (Q) parts [1]. Without loss of generality, the inphase part is considered in this paper.

The desired inphase signal power (S), is the power of the signal for the first user of the first rate, of the first wavelet packet which propagate via first path given by [1]

$$S = \frac{P(N_n T)^2}{2} \beta_{11}^2$$

The interference variance consists of six variances [4]-[6] which are, the self-interference variance (σ_{DSI}^2), the multipath interference variance (σ_{MPI}^2), the multi-carrier interference variance (σ_{MCI}^2), the wavelet packets interference variance (σ_{WPI}^2), the multiuser interference variance (σ_{MUI}^2) and the multiservice interference variance (σ_{MSI}^2). Thus and assuming the BPSK modulation is used, the total interference variance, σ_{TI}^2 , is given by:

$$\begin{aligned} \sigma_{TI}^2 &= \sigma_{DSI}^2 + \sigma_{MPI}^2 + \sigma_{MCI}^2 \\ &\quad + \sigma_{WPI}^2 + \sigma_{MUI}^2 + \sigma_{MSI}^2 \\ &= \frac{P(N_n T)^2}{2} MI \end{aligned} \quad (9)$$

and MI is given by

$$\begin{aligned} MI &= \frac{\Omega}{2} \sum_{\substack{m=-M_1 \\ m \neq 0}}^{M_2} \alpha_m^2 \\ &\quad + \left[2 \sum_{m=-M_1}^{M_2} \alpha_m^2 + \sum_{m=-M_1}^{M_2} \alpha_m \alpha_{m+1} \right] \\ &\quad \times \frac{\Omega}{12T_n(N_n H)^2} \left[\frac{Q_x K_1}{J_1} \sum_{h=1}^H \sum_{h'=1}^H \xi_{hh'} \right. \\ &\quad \left. - \sum_{h'=1}^H \xi_{h'1} + Q_x \left(\sum_{h=1}^H \sum_{h'=1}^H \xi_{hh'} \right) \sum_{\mathbb{R}=2}^{\mathbb{N}} \frac{K_{\mathbb{R}}}{J_{\mathbb{R}}} \right] \end{aligned}$$

where $\Omega = var[\beta_{k_1 1}]$, Q_x represents the sum of all amplitude levels of multipath components and $\xi_{hh'}$ is the partial cross-correlation functions between wavelet packets [1]. in this paper exponential.

The noise variance, σ_n^2 , and the jamming variance, $\sigma_{\mathfrak{S}}^2$, are given by [3]-[6].

$$\begin{aligned} \sigma_n^2 &= \frac{P(N_n T)^2}{2} \left[\frac{H\Omega}{N_n(E_s/N_o)} \sum_{m=-M_1}^{M_2} \alpha_m^2 \right] \\ &= \frac{P(N_n T)^2}{2} NI \end{aligned} \quad (10)$$

$$\begin{aligned} \sigma_{\mathfrak{S}}^2 &= \frac{P(N_n T)^2}{2} \frac{\mathfrak{S}HT^2}{4} \\ &\quad \times \left[\sum_{m_1=-M_1}^{M_2} \sum_{m_2=-M_1}^{M_2} \alpha_{m_1} \alpha_{m_2} \sigma_{\mathfrak{S}}^2(m_1, m_2) \right] \\ &= \frac{P(N_n T)^2}{2} \mathfrak{S}I \end{aligned} \quad (11)$$

where $N_o/2$ is the double sided power spectral density, E_s is the mean received symbol energy and $\sigma_{\mathfrak{S}}^2(m_1, m_2)$ is as given by [6, eq. 22] and [8, eq. 19]. Using, (8), (9), (10) and (11), the SIJNR, γ_o , can be written as

$$\gamma_o = \frac{S}{\sigma_{TI}^2 + \sigma_n^2 + \sigma_{\mathfrak{S}}^2} = \frac{\beta_{11}^2}{MI + NI + \mathfrak{S}I} \quad (12)$$

4 Bit error rate

A common method used to measures the performance for communication systems is, the average bit error rate (BER), \bar{P}_e , which is given by

$$\bar{P}_e = \int_0^\infty f(\gamma) P_e(\gamma) d\gamma \quad (13)$$

where $P_e(\gamma)$ is the instantaneous bit error rate of γ_o and $f(\gamma)$ is the probability density function of γ_o . The $f(\gamma)$ depends in the input signal to interference plus jamming and noise ratio (γ_i) and the type of diversity used. Because MRC technique shows better performance than SD and EGC in [1]-[3], [5] and [6], it will be used in this paper to calculate the BER for the system. The \bar{P}_e for MRC is given in [3, eq. 40].

5 Results and discussions

In this section, using the above analytical results, the BER performance of the system in the presence of narrow-band interference is presented. The effect of changing the numbers of SF taps is investigated. Also, the BER performances of the system for three types of service groups, namely low rate (LR), medium rate (MR) and high rate (HR) is presented. The following parameters are used to evaluate the BER for the system by mean of MATLAB program.

Wavelet packets, Daubechies 3, $H = 4$, $N_n = 512$, $L = 3$, $\mathfrak{S}/S = 40dB$, $T_n = 3 \times 10^{-8} \text{ sec}$, $J_{LR} = 2$, $J_{MR} = 4$, $J_{HR} = 8$, $K_{LR} = 20$, $K_{MR} = 10$ and $K_{HR} = 50$.

5.1 Effect of service rates and number of filter taps

Fig. 2 shows the BER performance of the system as function of E_s/N_o for the three service group using double-sided (DS) three taps SF ($M_1 = 1$, $M_2 = 1$) and five taps SF ($M_1 = 2$, $M_2 = 2$). As it can be seen from the figure, increasing the service rate improve the BER and as the number of taps increases the BER performance is improved. Also, it can be noted that the worst case for the HR outperform the best case of MR and the worst case for the MR outperform the best case of LR.

5.2 Effect of Number of filter taps

Figure 3 shows the BER performance as a function of E_s/N_o without SF and with five taps DS SF, three taps DS SF, three singles-sided (SS) SF ($M_1 = 0$, $M_2 = 3$), and five taps SS SF ($M_1 = 0$, $M_2 = 5$). As expected, the BER performance is improved by using SF. It can be noted that as the number of taps increases for SS or DS filter, the BER performance is improved. Also, an improvement can be achieved by using DS filter for the same number of the total taps as SS filter.

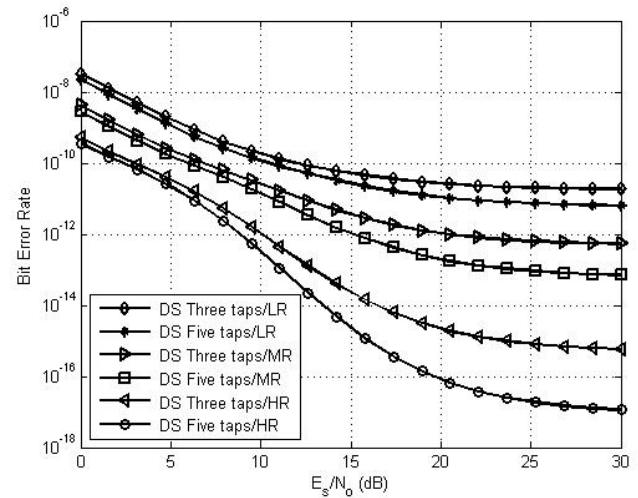


Fig. 2 Effect of service rates and number of filter taps.

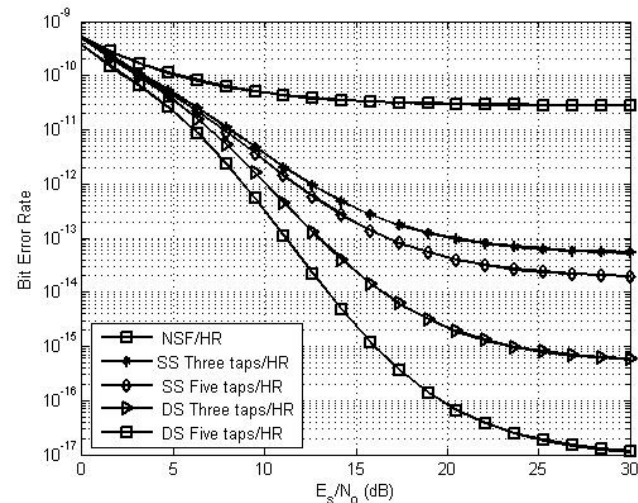


Fig. 3 Effect of number of filter taps on BER performance.

6 Conclusion

The BER of WP-MR\MC\MCD-CDMA system overlaying a narrow-band BPSK waveform and employing SF in the receiver has been evaluated. The results presented in this paper are consistent with other published results. It is found that the performance is improved by using SF and the double-sided SF is superior to single-sided SF for the same number of total taps. Also, it has

been shown that high rate service outperforms the other service rates.

Acknowledgements: The authors are grateful to Applied Science Private University, Amman, Jordan for financial support granted to cover publication fee of this research article.

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