Performance of a Flexible Form of MC-CDMA in a Cellular System

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Abstract: In this contribution, we investigate a variant of the traditional MC-CDMA system in the case of downlink communication. In the proposed MC-CDMA system, we can independently select the number of chips per symbol (N_{chip}), the number of carriers (N_{carr}) and the FFT length (N_{FFT}), so the available resources can be used more effectively. The bandwidth of this flexible MC-CDMA system is proportional to N_{chip}, while the spectral density of the power spectrum is inversely proportional to N_{chip}: the transmitted power is independent of N_{chip}. Furthermore, the flexible MC-CDMA system spreads the power of a smallband interferer over a large bandwidth, so the immunity of the system to smallband interferers increases for increasing N_{chip}. In the presence of a dispersive channel and for the number of users equal to N_{chip}, the powers of the useful component, the interference and noise are independent of the number of chips per symbol, while an optimal guard interval can be found that maximises the performance.

1. INTRODUCTION

As orthogonal multicarrier (MC) techniques have good bandwidth efficiency and can offer an immunity to channel dispersion, these techniques are excellent candidates for high data rate transmission over dispersive channels. To cope with the high bit error rates caused by the strong attenuation of some carriers, orthogonal MC systems have been investigated in combination with code-division multiple-access (CDMA) [1-10]. By combining CDMA with the orthogonal MC technique, coding is provided by spreading the data on the different carriers using the CDMA codes, so frequency diversity is obtained. One of the combinations of CDMA and orthogonal multicarrier is the MC-CDMA system, where the data symbols are first spread using the CDMA codes and then modulated on the orthogonal carriers. The MC-CDMA system has been proposed for downlink communication in mobile radio [3-10].

In this contribution, we consider the downlink transmission of a cellular MC-CDMA system. We investigate a variant of the traditional MC-CDMA system. In the proposed, flexible MC-CDMA system, the number of chips per symbol N_{chip} can be chosen independently of the number of carriers N_{carr}, which offers us a higher flexibility as compared to the traditional MC-CDMA system, where the number of carriers was fixed to the number of chips per symbol. Furthermore, as the carriers inside the rolloff area give rise to severe performance degradation [11], we only use the carriers outside the rolloff area, which means that the FFT length N_{FFT} exceeds the number of carriers ($N_{FFT}>N_{carr}$). In the proposed variant of the MC-CDMA system, we can independently choose N_{chip}, N_{carr} and N_{FFT}, so the available resources can be used more effectively.

2. SYSTEM DESCRIPTION

The conceptual block diagram of the considered system is shown in figure 1 for one user. The data symbols $\{a_{i,m}\}$ transmitted at a rate R_s, where $a_{i,m}$ denotes the i-th symbol transmitted to the user m, are multiplied by a higher rate chip sequence $\{c_{n+iN_{chip},m}|n=0,...,N_{chip}-1\}$, $c_{n+iN_{chip},m}$ denoting the n-th chip of the sequence belonging to user m during the i-th symbol interval. The complex chip sequence corresponding to user m consists of the product of a real-valued orthogonal chip sequence of length N_{chip} (e.g. Walsh-Hadamard), corresponding to the considered user, and a complex-valued random chip sequence (e.g. a complex-valued pseudo-noise sequence of length $L>>N_{chip}$), equal for all users of the same cell and having the same rate as the orthogonal sequences. In other cells, the orthogonal sequences are reused by multiplying them with another random sequence. These hybrid sequences have better correlation properties than the pure Walsh-Hadamard sequences.

2.1 Single User Transmission

Let us first consider the transmission to one user. The spread data symbols are mapped on the carriers as shown in figure 2 and then modulated using the inverse FFT of length N_{FFT}, resulting in the time-domain samples

$s_{j,k}$, the k-th sample of the j-th FFT block, at a rate 1/T. The transmitted time-domain samples are cyclically extended with a guard interval ν to cope with the channel dispersion and applied to a unit-energy square-root Nyquist filter. The power spectrum of the complex envelope of the resulting transmitted signal is shown in figure 3. The flexible MC-CDMA system uses a bandwidth $B = (N_{carr}/N_{FFT})/T = N_{chip}R_s\ (N_{FFT}+\nu)/N_{FFT}$. The occupied bandwidth B is proportional to N_{chip} and, as the transmitted power P_s is independent of the number of chips, the spectral density of the power spectrum is inversely proportional to N_{chip} (figure 3a). A guard interval ν introduces a ripple in the power spectrum proportional to ν and at the same time it gives rise to an increase of the used bandwidth B (figure 3b). To normalise the transmitted power ($P_s=R_sE_s$, where E_s is the energy per symbol) the transmitted samples are multiplied by a factor $\mathrm{sqrt}(N_{FFT}/(N_{FFT}+\nu))$.

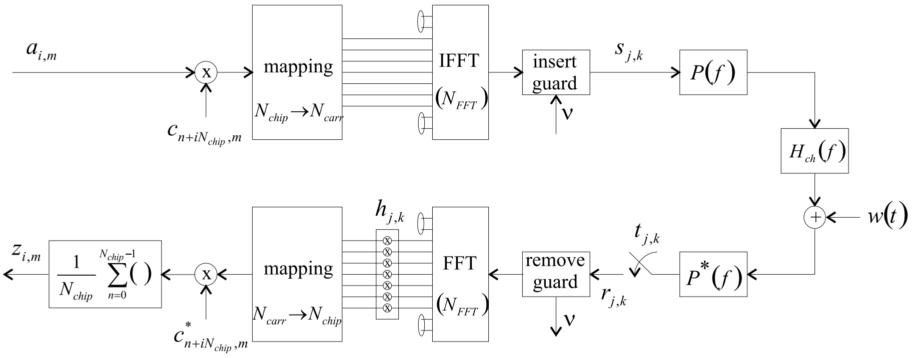

Figure 1. Conceptual block diagram of the flexible MC-CDMA system for one user

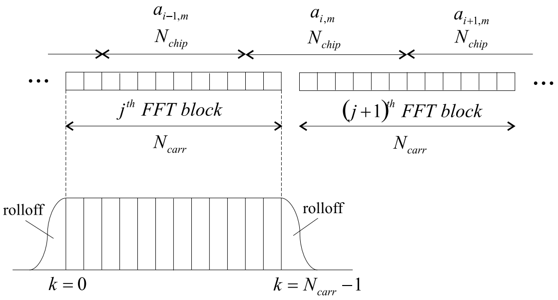

Figure 2. Mapping of the chips on the carriers

In the case of an ideal channel and when the transmitted signal is only disturbed by additive white Gaussian noise (AWGN) with a spectral density

N_0, the guard interval can be omitted. The resulting signal-to-noise ratio at the input of the decision device equals E_s/N_0.

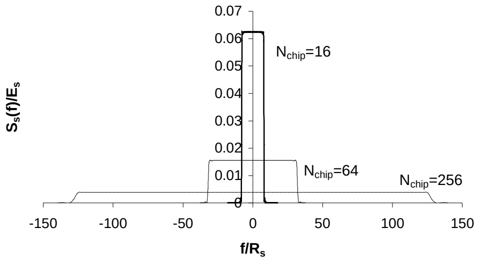

Figure 3a. Power spectrum for different N_{chip}

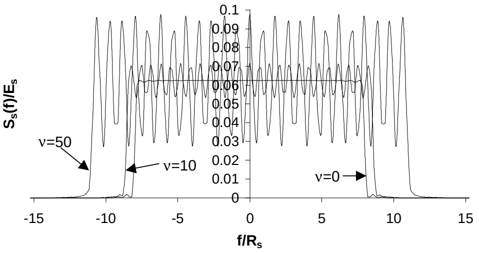

Figure 3b. Power spectrum for different guard intervals

2.2 Influence of a Narrowband Interferer

Let us consider the case of the transmitted signal disturbed by a narrowband interferer with power P_J, frequency f_J and phase θ_J. Due to the random character of the chip sequence, the interference components after multiplying with the chip sequences are uncorrelated and behave as AWGN. The interference power is equally spread over a bandwidth $N_{chip}R_s$ and has a power spectral density of $1/N_{chip}\,P_JX(f_J)$, where $X(f_J)\leq 1$ is shown in figure 4 as function of the interferer frequency. The quantity $X(f_J)$ equals 1 for interferer frequencies f_J outside the rolloff area that coincide with a carrier frequency. The signal-to-interference ratio at the input of the decision device is given by

$$SIR = N_{chip}\frac{P_s}{P_J X(f_J)} \geq N_{chip}\frac{P_s}{P_J} \qquad (1)$$

The SIR is independent of N_{carr} and N_{FFT} and as the SIR increases for an increasing N_{chip}, the immunity of the flexible MC-CDMA system to narrowband interferers increases.

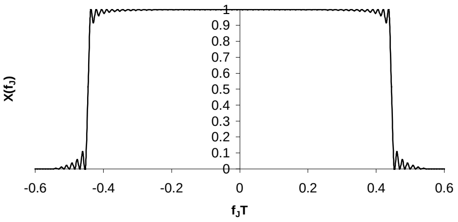

Figure 4. Transfer function smallband interferer power, $N_{FFT}=64$

3. MULTIUSER INTERFERENCE

When different users are present, multiuser interference (MUI) can occur. We can distinguish two types of MUI: intracell and intercell MUI. In the case of an ideal channel, no intracell interference is introduced, as the signals of the different users of the same cell are orthogonal. Signals of users belonging to adjacent cells are uncorrelated with the signal of the considered user, as the hybrid sequences are constructed with different random sequences, so the users of the adjacent cells will introduce MUI. The intercell MUI caused by the users of cell β is given by

$$MUI_{\beta} = \frac{N_{FFT}}{N_{FFT}+\nu}\frac{1}{N_{chip}}\sum_{\ell} E^{\beta}_{s,\ell} \approx \frac{1}{N_{chip}}\sum_{\ell} E^{\beta}_{s,\ell} \qquad (2)$$

where $E^{\beta}_{s\ell}$ is the energy per symbol of user ℓ of cell β. When the guard length is small as compared to the FFT length, the intercell MUI is essentially independent of the guard length and the FFT length.

3.1 Dispersive Channel

In the case of a dispersive channel, intracell interference will be introduced as the orthogonality between the different users is lost. Assuming g(t) is the impulse response of the cascade of the transmit filter, the channel and the receiver filter, which is matched to the transmit filter, the samples at the input of the receiver yield

$$r_{j,k} = \sum_{j'} \sum_{k'} g\left(\left(k - k' + (j - j')(N_{FFT} + \nu)\right)T\right) s_{j',k'} + w_{j,k} \qquad (3)$$

$$k = -\nu, \ldots, N_{FFT} - 1 \quad ; \quad j = -\infty, \ldots, +\infty$$

where $w_{j,k}$ is white Gaussian noise with power spectral density N_0. The channel is normalised such that the power of the signal of user m equals $P_{s,m}=E_{s,m}R_s, \forall m$. The receiver selects the N_{FFT} samples outside the guard interval for further processing. The selected samples are demodulated using the FFT. The FFT outputs outside the rolloff area are applied to a one-tap MMSE equaliser with equaliser coefficients $h_{j,k}$, to scale and rotate the FFT outputs. The resulting samples are mapped into blocks of N_{chip} samples and correlated with the chip sequence of the considered user to obtain the samples at the input of the decision device

$$z_{i,m} = \sum_{i'} \sum_{m'} \sqrt{E_{s,m'}} a_{i',m'} I_{i,i',m,m'} + W_{i,m} \qquad (4)$$

where $W_{i,m}$ is a zero-mean complex-valued Gaussian noise term and $I_{i,i',m,m'}$ is the interference caused by the i'-th symbol of user m' on the i-th symbol of the considered user m. In order to eliminate the dependency of the symbol interval i, we consider the time-average of the power of the samples at the input of the decision device, given by

$$E\left[\left|z_{i,m}\right|^2\right] = \frac{N_{FFT}}{N_{FFT} + \nu}\left(P_U + P_I\right) + P_N \qquad (5)$$

where P_U is the time-average of the power of the average useful component, P_I consists of the time-average of the sum of the powers of the fluctuation of the useful component, caused by the random character of the chip sequences, the intracell multiuser interference and intersymbol interference. The last contribution in (5) P_N is the time-average of the power of the additive Gaussian noise component.

In figure 5, the powers $(1-P_U)$, P_I and P_N are shown as function of the number of chips per symbol for the maximum load, i.e. the number of users equals N_{chip}. For large N_{chip}, the powers are essentially independent of N_{chip}: as for large N_{chip} the interference power is proportional to the number of users and inversely proportional to the number of chips per symbol, the total interference power is essentially independent of N_{chip} for the maximum load.

In figure 6, the powers $(1-P_U)$, P_I and P_N are shown as function of the guard interval for the maximum load. The interference power decreases for an increasing guard length, as the signals at the borders of the FFT blocks are less affected by the dispersive channel when the guard length increases, i.e. the intersymbol interference decreases. For large guard lengths, the interference power reaches a lower limit: the interference is mainly determined by the multiuser interference. The useful power and noise power only slightly vary with the guard length. However, due to the factor $N_{FFT}/(N_{FFT}+\nu)$, the performance will decrease for an increasing guard length. An optimal guard length can therefore be found at intermediate guard lengths.

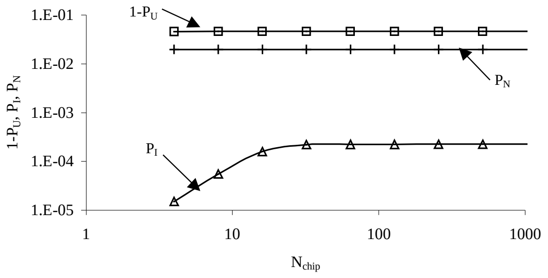

Figure 5. 1-P_U, P_I and *P_N* as function of the number of chips per symbol

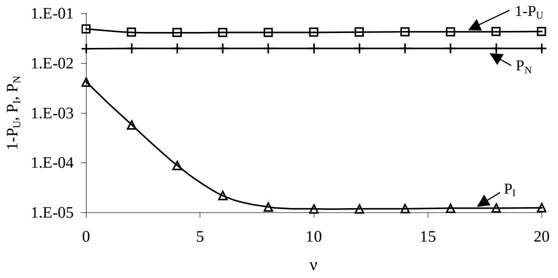

Figure 6. 1-P_U, P_I and *P_N* as function of the guard interval

4. CONCLUSIONS

We have investigated a flexible form of MC-CDMA in a cellular system. The power spectrum of the transmitted signal has a bandwidth that increases with the number of chips per symbol, while the power spectral density is inversely proportional to N_{chip}. Furthermore, the immunity of the flexible MC-CDMA system to narrowband interferers increases for increasing N_{chip}, as the interferer power is spread over a large bandwidth. The presence of different users gives rise to multiuser interference. However, in an ideal channel, no intracell MUI is introduced as all users in the same cell are orthogonal. Users of other cells will introduce intercell MUI, as they are uncorrelated with the users of the considered cell. The flexible MC-CDMA system is also investigated in the presence of a dispersive channel. For the maximum load, the flexible MC-CDMA system is essentially independent of the number of chips per symbol. Furthermore, an optimal guard interval can be found that maximises the performance.

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