Fast communication

Code shift for intercarrier interference cancellation in MC-DS-CDMA

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Abstract

A method for intercarrier interference (ICI) mitigation in MC-DS-CDMA systems based on the autocorrelation properties of the CDMA codes is presented. The proposed transmission scheme does not imply additional complexity to the system and the bit error rate at the receiver reaches the bound of performance of a MC-DS-CDMA system without ICI.

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1. Introduction

A multicarrier DS-CDMA (MC-DS-CDMA) system is an orthogonal frequency-division multiplexing (OFDM) system in which a direct sequence code-division multiple access (DS-CDMA) signal is transmitted on each OFDM subcarrier [4]. So, on each subcarrier, the signal of several users is multiplexed on the basis of the CDMA codes assigned to each user. In a conventional MC-DS-CDMA system, each user has a specific spreading code and the user employs this code to spread the data on each subcarrier. If the MC-DS-CDMA signal is transmitted in a mobile wireless channel, the intercarrier interference (ICI) caused by the Doppler spread degrades the performance of the system [2,5,7]. Taking into account the autocorrelation properties of CDMA codes [3], the effects of ICI can be mitigated by applying a cyclic shift to the spread codes in the different subcarriers, as it will be shown.

2. Code shift for ICI cancellation

Consider an MC-DS-CDMA system with $N_c$ subcarriers. A sequence of $N_c$ data symbols of user
where \( k \), \( A_k \), is serial-to-parallel converted onto \( N_c \) substreams. Within each substream, the data symbols are spread by means of the user-specific spreading code of length \( L \) chips. Let the code assigned to user \( k \) be expressed as follows:

\[
c_k = [c_k(0), \ldots, c_k(L - 1)]^T.
\]

Note that each data symbol \( A_k \) is spread over \( L \) OFDM symbols and, therefore, a block of \( N_c \) symbols is available at the receiver after \( L \) OFDM symbols are received.

In a conventional MC-DS-CDMA system, for a certain user \( k \), the spreading code is exactly the same in all subcarriers, so the \( q \)th OFDM symbol (\( 0 \leq q < L \)) of the \( p \)th block of \( N_c \) symbols parallel transmitted by user \( k \) can be written as follows:

\[
X_{k,OFDM}(p, q) = \sum_{m=0}^{N_c-1} A_k(N_c p + m)c_k(q)e^{j2\pi f_m t} \quad 0 \leq t < T_c.
\]

\( A_k(N_c p + m) \) represents the \( m \)th data symbol of the \( p \)th block of \( N_c \) data symbols, transmitted in subcarrier \( m \). \( c_k(q) \) is the \( q \)th chip of the spreading code \( c_k \) defined in (1). The data symbol rate is \( 1/T_{data} \), the chip duration is \( T_c = N_c T_{data} / L \) and the frequency of subcarrier \( m \) is \( f_m = m/T_c \). The duration of the OFDM symbol is \( T_{OFDM} = T_c + T_g \), where \( T_g \) is the guard interval for the transmission of the cyclic prefix.

In Fig. 1, the modified MC-DS-CDMA transmitter/receiver proposed to reduce ICI is shown. The OFDM symbols transmitted using the proposed system can be expressed as follows:

\[
X_{k,OFDM}(p, q) = \sum_{m=0}^{N_c-1} A_k(N_c p + m)c^m_k(q)e^{j2\pi f_m t} \quad 0 \leq t < T_c,
\]

where \( c^m_k(q) \) are the chips of the spreading code \( c^m_k \), employed on subcarrier \( m \) to generate the DS-CDMA signal. This code is obtained from the base code of user \( k \), \( c_k \), applying a cyclic shift of \( m \) chips, i.e., there exists a cyclic shift of one chip between the spreading codes used in adjacent subcarriers. The elements of the vector \( c^m_k \), are defined as

\[
c^m_k(q) = c_k((q + m)_L) \quad 0 \leq q < L,
\]

where \((x)_L \) represents the remainder of \( x \) divided by \( L \).

Now, the behavior of the proposed system against ICI is analyzed. When \( x_{k,OFDM}(p, q) \) is transmitted in a time-dispersive fading environment, the received signal on subcarrier \( m \) can be written as [5]

\[
Y^m_k(p, q) = A_k(N_c p + m)c^m_k(q)S(0) + \sum_{q=0}^{N_c-1} \sum_{v=m}^{N_c-1} A_k(N_c p + v)c_k^m(q) \\
\times S(v - m) + n_m,
\]

where \( n_m \) represents the amount of ICI between subcarriers \( v \) and \( m \). \( S(v - m) \) will be referred to as the ICI coefficient between \( v \)th and \( m \)th subcarriers.

In order to detect the data symbol \( A_k(N_c p + m) \), the \( L \) OFDM symbols that contain the whole spreading code must be received. Afterward, a correlation receiver can be employed [6]. Let \( Y^m_k(p) \) represent the vector that contains the \( L \) chips received during a whole spreading code period on subcarrier \( m \):

\[
Y^m_k(p) = [Y^m_k(p, 0), \ldots, Y^m_k(p, L - 1)]
\]

with \( Y^m_k(p, q) \) as defined in (5). Let us assume that the ICI coefficients \( S(v - m) \) remain constant during a whole spreading code period \( LT_c \). At the receiver, \( Y^m_k(p) \) is correlated with the spreading code \( c^m_k \) to obtain, after sampling with rate \( 1/(LT_c) \), the decision statistic for subcarrier \( m \), \( d^m_k(p) \):

\[
d^m_k(p) = A_k(N_c p + m)\rho(0)S(0) + \sum_{q=0}^{N_c-1} \sum_{v=m}^{N_c-1} A_k(N_c p + v) \\
\times \rho(v - m)S(v - m) + n'_m,
\]

where \( \rho(v - m) \) represents the correlation between \( c^m_k \) and \( c_k^m \) and \( n'_m \) represents the noise after the correlation.
Now, the ICI power in a whole spreading code period can be calculated:

\[ P_{ICI} = E \left[ \sum_{v=m}^{N_c-1} A_k(N_cP + v)\rho(v-m)S(v-m) \right]^2. \]  

(8)

If it is assumed that the transmitted data have zero mean and are statistically independent, and the average power of the symbols is the same on all the sub-carriers, then, the carrier-to-interference power ratio (CIR) [7] for subcarrier \( m \) \((m \in \{0,1,\ldots,N_c-1\})\) can be derived as

\[ CIR|_m = \frac{|\rho(0)S(0)|^2}{\sum_{v=m}^{N_c-1} |\rho(v-m)S(v-m)|^2}. \]  

(9)

Note that the CIR has been calculated considering a whole spreading code period. In the receiver, after the correlation operation, the amount of intercarrier interference is weighed not only by the ICI coefficients \( S(v-m) \), but also by the correlation values between the shifted CDMA codes of the interfering subcarriers, \( \rho(v-m) \), which fulfill the condition \(|\rho(v-m)| < |\rho(0)|\) if \( v \neq m \) [3]. Clearly, the CIR is larger in the proposed system than in a conventional MC-DS-CDMA system because the proposed system takes advantage of the autocorrelation properties of the CDMA codes.

Consider a system in which the ICI is due to a channel frequency offset and let \( \varepsilon \) denote the frequency offset normalized by the subcarrier separation [7]. The behavior of the CIR with and
without code shift is presented in Fig. 2. A system with 32 subcarriers that employs Gold codes of length 32 \[1,3\] has been considered. It can be observed that the CIR is increased more than 40 dB with the proposed technique.

3. Simulation results

In this section, the bit error rate (BER) obtained with the conventional MC-DS-CDMA system and the BER obtained with the MC-DS-CDMA system proposed in this communication are compared. The ICI is due to a constant frequency offset \( \varepsilon = 0.3 \). This value has been normalized by the subcarrier separation [7]. Also, additive white Gaussian noise corrupts the received signal. The simulated system has one active user with BPSK modulation on each subcarrier, \( N_c = 32 \) subcarriers. The CDMA codes are Gold codes of length 32. In Fig. 3, it can be observed that the results obtained with the proposed technique are the same as the results found when there is no ICI in the system.

4. Conclusions

In this paper, a MC-DS-CDMA transmitter/receiver system with very good resistance against

ICI has been presented. The proposed system takes advantage of the autocorrelation properties of the CDMA codes and it achieves the same bit error rate (BER) performance as a system without ICI. Additionally, the complexity of the proposed system is similar to the one of the conventional MC-DS-CDMA system and, also, the same technique used to assign the users’ spreading codes can be employed.

References