Frequency Shift based Multiuser Canceller for DS-CDMA Systems

Luis Gonçalves, Atilio Gameiro
Instituto de Telecomunicações, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
email: *lgoncalves@ av.it.pt*, *atilio@ av.it.pt*

Abstract — The cyclostationary properties of Direct Sequence Spread Spectrum signals are well known. These cyclostationary properties imply a redundancy between frequency components separated by multiples of the symbol rate. In this paper we present a Multiple Access Interference Canceller that explores this property and apply to UMTS-TDD. The results show total cancellation of the interference for any number of simultaneous users with the available redundant bands.[1]

I. Introduction

The Direct Sequence-Code Division Multiple Access (DS-CDMA) scheme was adopted for the next generation of mobile communications due to several advantages over the Time Division Multiple Access (TDMA) scheme. The most prominent advantages of CDMA over TDMA are frequency diversity, multipath diversity and more spectrum efficiency on multicell systems[1]. These systems due to the reception of signals which are not synchronous or/and affected by multipath are interference limited. This interference is worsened in the case of imperfect power control and is named Multiple Access Interference (MAI). To overcome the system capacity degradation due to MAI several Multiuser Detectors (MUD) were proposed in the literature to replace the conventional Matched Filter Detector[4, 5]. In the 80's the Maximum Likelihood Detector[2], called optimum detector was proposed, but it is too complex to be implemented despite its good performance. For that reason, suboptimum MUD's of lower complexity were proposed. These MUD could be classified into two classes: joint detectors and interference cancellation detectors. The idea of joint detection is to detect the data symbols of all users jointly in one step, using all the a priori knowledge about MAI. The idea of interference cancellation is to detect the transmitted data symbols, to reconstruct the contribution of these transmitted data symbols to the composite received signal and to cancel this contribution from the composite received signal[3].

The DS-SS signal is a particular case of a stationary random modulation of amplitudes of pulses(symbols). This kind of signals have cyclostationary properties[7], i.e., the statistical moments of second and greater order of the signal vary periodically with time. Those properties imply redundancy between frequency components separated by multiples of the symbol rate. It is this characteristic that we explore to propose a new MAI canceller.

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The paper is outlined as follows. In section two we show that in a DS signal non overlapping frequency bands separated by a multiple of the baud rate are linearly related. This result is used to present in section three the architecture of a MAI canceller that explores this redundancy. In section four we present simulation results that show the interference reduction provided by the new canceller. Finally in section five the main conclusions of this work are outlined.

II. Theoretical Background

Let us consider a DS-SS signal:

$$s(t) = \sum_k a_k g(t - kT) \qquad (1)$$

where $\{a_k\}$ is the sequence of information symbols, $\frac{1}{T}$ the symbol rate, $g(t)$ the Signature Waveform which is given by:

$$g(t) = \sum_{l=0}^{N-1} c_l q(t - lT_c) \qquad T_c = \frac{T}{N} \qquad (2)$$

where $\{c_l\}$ is the chip sequence, and N the spreading factor.

Let us consider that the signal is filtered by a bank of rectangular bandpass filters with bandwidth $\frac{1}{T}$ and centered at $\frac{i}{T}$, as shown in Figure 1.

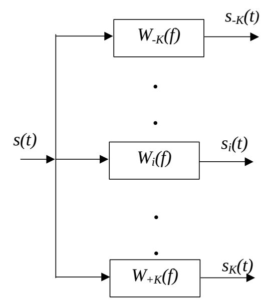

Figure 1: Bank of filters applied to the signal

If the elementary pulse $q(t)$ has bandwidth $\frac{1}{2T_c}(1+\alpha)$, where α depends of the pulse shaping filter, then the value of K needed to cover the whole bandwidth of the signal is:

$$K = \left\lceil \frac{N}{2}(1+\alpha) - \frac{1}{2} \right\rceil \qquad (3)$$

where $\lceil () \rceil$ denotes the integer immediately greater or equal than the input.

The output of the filter is given by:

$$s_i(t) = \sum_k a_k \; g_i(t - kT) \tag{4}$$

where:

$$\begin{aligned} g_i(t) \overset{\mathcal{F}}{\longleftrightarrow} G_i(f) &= G(f) \; W_i(f) \\ &= Q(f) \; W_i(f) \sum_{n=0}^{N-1} c_n \; e^{-j2\pi f n T_c} \end{aligned} \tag{5}$$

$s_i(t)$ is the bandpass signal whose baseband equivalent is:

$$\begin{aligned} s_{iB}(t) = s_i(t) \; e^{j2\pi i t/T} &= \sum_k a_k \; g_i(t - kT) \; e^{j2\pi i (t-kT)/T} \\ &= \sum_k a_k \; g_{iB}(t - kT) \end{aligned} \tag{6}$$

where:

$$g_{iB}(t) \overset{\mathcal{F}}{\longleftrightarrow} G_{iB}(f) = rect(fT) \; Q\left(f + \frac{i}{T}\right) \cdot \\ \cdot \sum_{n=0}^{N-1} c_n e^{-j2\pi\left(f + \frac{i}{T}\right) n T_c} \tag{7}$$

We can then conclude that the output of the various bandpass filters are in fact frequency shifted versions of linearly related baseband pulse amplitude modulation (PAM) signals all modulated by the same information sequence $\{a_k\}$. This means that the information transmitted in the various bands $\left[\frac{i}{T} - \frac{1}{2T}, \frac{i}{T} + \frac{1}{2T}\right]$ is the same for $i = -K+1, ..., 0, ..., K-1$, and the DS-SS signal can be decomposed in $2K-1$ redundant signals. The last band is omitted because the frequency support of the signal at the output of $W_{\pm K}(f)$ does not fill a bandwidth equal $\frac{1}{T}$ (unless $\frac{N}{2}(1+\alpha) - \frac{1}{2}$ is an integer). This frequency of the DS-SS signal can be used to reconstruct highly disturbed or distorted bands as illustrated in Figure 2.

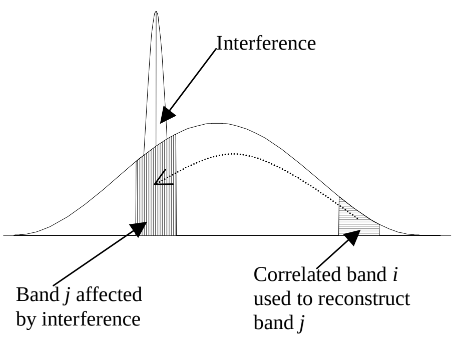

Figure 2: Reconstruction of a band from another

For example if band j is highly distorted while i is a clear one we can remove band j and then reconstruct it using the information in band i.

III. Theoretical Model of the Canceller

The architecture of the canceller is shown in Figure 3, for a given user. In a base station where all the signals have to be recovered the canceller consists of the replica of each basic receiver for each user.

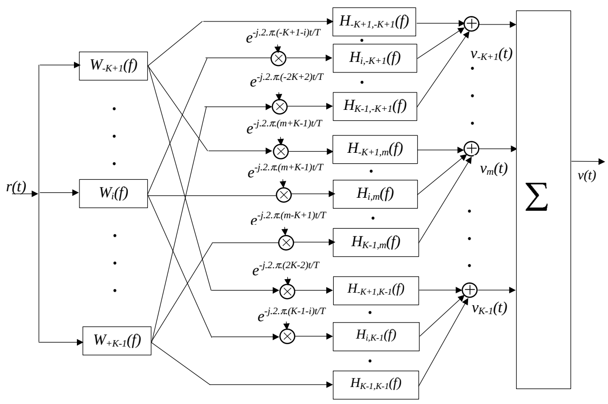

Figure 3: Conceptual Schematic of the Canceller

$r(t)$ in Figure 3 is defined as $\sum_{u=1}^{U} s^{(u)}(t)$ where U is the number of users and $s^{(1)}(t)$, without loss of generality, is the user of interest.

The objective of the proposed canceller is to minimize the interference and not distort $s^{(1)}(t)$. The constraint that $v(t)$ must contain a distortion free $s^{(1)}(t)$ implies that the filters in Figure 3 which convert the band i in band m be:

$$H_{i,m}(f) \propto X_{i,m}(f) = \frac{G_{mB}^{(1)}(f - \frac{m}{T})}{G_{iB}^{(1)}(f - \frac{m}{T})} \tag{8}$$

$G_{mB}^{(1)}(f)$ is defined as:

$$G_{mB}^{(1)}(f) = rect(fT) G^{(1)}(f + \tfrac{m}{T}) \tag{9}$$

where $G^{(1)}(f)$ is the Fourier transform of $g^{(1)}(t)$.[2]

In those conditions the band m of the signal at the output is:

$$v_m(t) = s_m^{(1)}(t) \left(\sum_i \alpha_{im} \right) + \sum_{u=2}^{U} \left[\sum_k a_k^{(u)} \beta_m^{(u)}(t - kT) \right] \tag{10}$$

where:

$$\begin{aligned} \beta_m^{(u)}(f) &= \sum_i \alpha_{im} X_{i,m}(f) G_{iB}^{(u)}(f - \tfrac{m}{T}) \\ &= \sum_i H_{i,m}(f) G_{iB}^{(u)}(f - \tfrac{m}{T}) \end{aligned} \tag{11}$$

The weights α_{im} are dimensioned so that

$$\sum_{u=2}^{U} \int_f \left| \beta_m^{(u)}(f) \right|^2 df \tag{12}$$

is minimized subject to the condition that $\sum_i \alpha_{im} = 1$.

[2] Signature waveform of $s^{(1)}(t)$

IV. Application of the Canceller to UMTS-TDD

In this section we present the numerical results illustrating the performance of the proposed canceller with UMTS-TDD signals.

We reconstruct each band of the output signal $v(t)$ based in the input bands with bandwidth $\frac{1}{T}$ and spaced by multiples of $\frac{1}{T}$. The performance of the interference canceller could be enhanced if we divide each band in subbands. Then we reconstruct and minimize the interference for each subband (of each band) of the output signal $v(t)$ based in the input subbands with the same bandwidth and spaced by multiples of $\frac{1}{T}$. Also in some cases we could exchange complexity without compromising the performance not using all the input subbands separated by $\frac{1}{T}$ to reconstruct one output subband.

The power attenuation of the interference is defined as:

$$P_{at\_dB} = -10\log_{10}\left(\frac{\int_t \left|v(t)-s^{(1)}(t)\right|^2 dt}{\int_t \left|r(t)-s^{(1)}(t)\right|^2 dt}\right) \tag{13}$$

All the simulations were made with the discrete Fourier transform.

For the results shown in Figures 4 and 5 the following parameters were considered in the simulation:

1. U users with parameters defined by 3GPP for UMTS-TDD mode.
2. Spreading factor is 16 for all users.
3. The channels are defined $c^{(u)}(t) = \delta(t)+\delta(t-\tau_u)$
4. Number of redundant bands is 19.
5. Number of points of a band of bandwidth symbol rate ($\frac{1}{T}$) 128.

Figure 4 presents the power attenuation of the interference as a function of the number of users for a fixed number of points per subband.

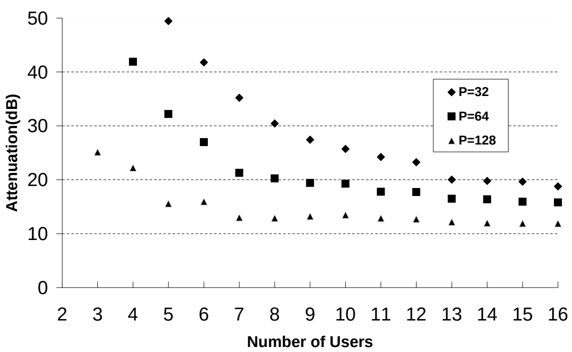

Figure 4: Performance of the canceller in function of the number of users for a fixed number of points (P) per each subband

As can be seen the performance decays exponentially with the number of users.

Figure 5 presents the power attenuation of the interference as a function of the number of points in each subband for a fixed number of users.

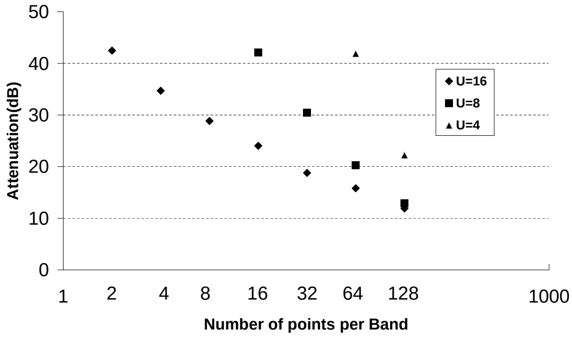

Figure 5: Performance of the canceller in function of the number points of each subband for fixed number of users(U)

The performance decays linearly with the number of points per subband.

In both Figure 4 and 5 several points that are outside the range of the attenuation scale are not displayed. Then the high attenuation values for those points are explained.

Analyzing (12) and translating to the discrete domain we have $(U-1)P+1$ constraints and $2K-1$ degrees of freedom. When the number of degree of freedom is superior or equal to the constraints we have total cancellation. For a small number of users with not enough degrees of freedom nearly total cancellation is achieved because the functions $X_{i,m}(f)G_{iB}^{(u)}(f-\frac{m}{T})$ (see (11)) take similar values between adjacent frequency points.

V. Conclusions

In this paper a new MAI canceller based in the cyclostationary properties of the DS signal was proposed. The performance results, without loss of generality, for UMTS-TDD signals show that with the proper degrees of freedom total cancellation is achieved. The total cancellation is achieved for any number of simultaneous users if we cancel narrow (sub)bands (one point each) at a time because we have superior number of redundant bands. In the case of wider (sub)bands and few users despite the fact that there are not enough degrees of freedom similar results are achieved.

References

[1] Ryuji Kohno, Reuven Meidan and Laurence B. Milstein, *Spread Spectrum Access Methods for Wireless Communications*, IEEE Communications Magazine, January 1995

[2] Sergio Verdu, *Minimum Probability of Error for Asynchronous Gaussian Multiple-Access Channels*, IEEE Transactions of Information Theory, January 1986

[3] Anja Klein, *Multi-user detection of CDMA signals - algorithms and their application to cellular mobile radio*, PhD Thesis, Kaiserslautern, 1996

[4] Alexandra Duel-Hallen, Jack Holtzman and Zoran Zvorar, *Multiuser Detection for CDMA Systems*, IEEE Personal Communications, April 1995

[5] Shimon Moshavi, *Multi-User Detection for DS-CDMA Communications*, IEEE Communications Magazine, October 1996

[6] Gardner, William A., *Cyclostationarity in Communications and Signal Processing*, IEEE PRESS, 1994

[7] Gardner, William A., *Exploitation of Spectral Redundancy in Cyclostationary Signals*, IEEE Signal Processing Magazine, April 1991