Frequency Shift Based Multiple Access Interference Canceller for DS-CDMA Systems

Luis Gonçalves, Adão Silva, Atilio Gameiro
Instituto de Telecomunicações, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
email: *lgoncalves@av.it.pt*, *asilva@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 applies to UMTS-TDD. This frequency domain Canceller acts in the spreaded signal in such way that minimizes the interference and noise at its output (Minimum Mean Squared Error Criterium). The performance is evaluated in two detector configurations: one including the Frequency Shift Canceller (FSC) and the other plus a Parallel Interference Canceller (PIC). The results are benchmarked against the performance of the conventional RAKE detector and the conventional PIC detector.**

Keywords— **cyclostationary, redundant , frequency shift, PIC, DS-CDMA**

I. Introduction

Direct sequence spread-spectrum (DS-SS) code division multiple access (CDMA) has emerged as one of the most promising techniques to implement various radio communication systems. It presents significant advantages over Time Division Multiple Access (TDMA), namely frequency diversity, multipath diversity and more spectrum efficiency on multicell systems[1], which led to its choice as the technology for third generation cellular systems. The first generation of 3G systems will likely to be based on the conventional RAKE receiver, which is known to be limited by the multiple access interference (MAI) and require a very precise power control. To overcome these limitations and therefore enhance the capacity of CDMA systems, joint detection of the received DS-SS signals has been proposed to be used at the base station (BS) or at the user equipment. The optimum joint detector[2] although well known requires however a prohibitively high computational complexity, and consequently effort has been made to devise suboptimum algorithms with good compromise between performance and complexity that can be implemented without prohibitive costs in near future CDMA systems. This communication fits in this approach, and aims at presenting a moderate complexity MAI canceller operating on the broadband DS signal. The Frequency Shift Detector can be used either as standalone unit or it can be used prior to a PIC multiuser detector where it is intended to produce signals clean enough so that the first decisions of the PIC can be considered reliable enough to be used by the subsequent stages.

The DS-SS signal is a particular case of a stationary random modulation of amplitudes of pulses (symbols). This kind of signals are known to have cyclostationary properties [3], [4]. 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.

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 illustrate the performance provided by the new canceller. Finally in section five the main conclusions of this work are outlined.

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II. Theoretical Background

Let us consider a DS-SS signal:

$$s(t) = \sum_k a_k g(t - kT) \tag{1}$$

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

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

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 $\frac{i}{T}$.

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

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

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:

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

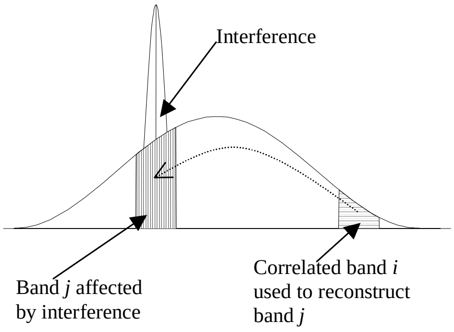

Fig. 1. Reconstruction of a band from another

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

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

where:

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

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 $\frac{i}{T}-\frac{1}{2T}, \frac{i}{T}+\frac{1}{2T}$ 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 1. 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. Principles of the Canceller

The architecture of the canceller is shown in figure 2, 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.

The input signal $r(t)$ in figure 2 is defined as $\sum_{u=1}^{U} s^{(u)}(t) + n(t)$ where U is the number of users and $n(t)$ is stationary noise with power spectral density $\eta_{in}(f)$. We consider without loss of generality that user one is the user of interest. The objective and design criteria for the canceller is to minimize the overall disturbance (MAI+noise) subject to the condition that $s^{(1)}(t)$ must not be distorted. This constraint implies that the filters in figure 2 which convert the band i to band m be of the form :

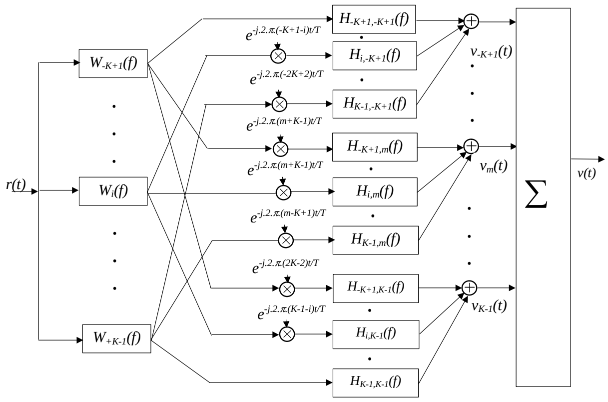

Fig. 2. Conceptual Schematic of the Canceller

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

where $G^{(1)}_{mB}(f)$ is defined as:

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

with $G^{(1)}(f)$ being the Fourier transform of $g^{(1)}(t)$.[1]

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

$$\begin{aligned} v_m(t) = & s^{(1)}_m(t)\left(\sum_i \alpha_{im}\right) \\ & + \sum_{u=2}^{U}\left[\sum_k a^{(u)}_k \beta^{(u)}_m(t-kT)\right] + n'_m(t) \end{aligned} \tag{10}$$

where:

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

The power spectral density of the noise term $n'_m(t)$ is:

$$\begin{aligned} \eta_{out_m}(f) &= \sum_i |\alpha_{im}|^2 \left|X_{i,m}(f)\right|^2 \eta_{in_{iB}}(f-\tfrac{m}{T}) \\ &= \sum_i |H_{i,m}(f)|^2 \eta_{in_{iB}}(f-\tfrac{m}{T}) \end{aligned} \tag{12}$$

where $\eta_{in_{iB}}(f)$ is defined as:

$$\eta_{in_{iB}}(f) = rect(fT)\eta_{in}(f+\tfrac{i}{T}) \tag{13}$$

The design criteria implies that the weights α_{im} are dimensioned so that:

$$\sum_{u=2}^{U}\left[\sum_k \left|a^{(u)}_k\right|^2 \int_f \left|\beta^{(u)}_m(f)\right|^2 df\right] + T_{Bt}\int_f \eta_{out_m}(f)df \tag{14}$$

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

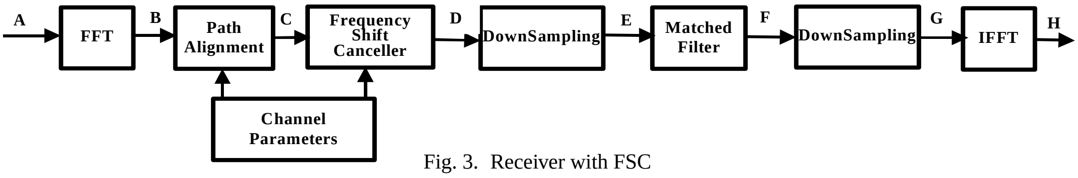

Fig. 3. Receiver with FSC

is minimized subject to the condition that $\sum_i \alpha_{im} = 1$. In (14) T_{Bt} is the burst duration time and the symbols a_k considered correspond to the ones existing in this burst.

Each band of the output signal $v(t)$ depends linearly of 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 the input and output bands in subbands of equal bandwidth. Then each output subband depends linearly of the input subbands with the same bandwidth and spaced by multiples of $\frac{1}{T}$ (symbol rate) of the output subband.

IV. Application of the Canceller to UMTS-TDD

In this section we present the numerical results illustrating the performance of the proposed detector configurations with UMTS-TDD signals. The proposed configurations are more suitable to be implemented in the uplink because the detectors require knowledge of the spreading codes of the active users. To evaluate the canceller performance a simulation chain was implemented. Basically this simulation chain is composed by a transmitter, a transmission channel and a receiver.

A. Transmitters

The transmitters are compliant with the 3GPP specifications for UMTS-TDD.

B. Channel Model

The channel model used in this work was the Geometrical Based Single Bounce Elliptical Model (GBSBEM) proposed by Liberti [5]. This model was developed for microcell and picocell environments. The propagation channel is characterized by L paths for each user, one in line of sight plus $L-1$ arriving from remote reflectors located randomly within an ellipsis where the base station and the mobile unit are at the foci. Each path is characterized by complex constant and a delay. The delay is uniformly distributed between zero and the maximum delay spread. The phase of the complex constant is uniformly distributed in $[0, 2\pi[$. The amplitude of the complex constant follows a Rayleigh distribution. The channel parameters are assumed to be constant within each burst.

C. Receivers

Figure 3 depicts the basic configuration for the detector that includes the Frequency Shift Canceller. If we remove the Frequency Shift Canceller block the detector is a conventional RAKE. The Path Alignment and Downsampling are blocks whose operations are done in frequency domain despite the fact that the names reflect the correspondent time domain operations. The path alignment includes delay alignment and maximum ratio combining of the spreaded signal. The signal in A (figure 3) has a resolution of four samples per chip and the first downsampling has the same factor. The second downsampling takes a factor equal to the spreading factor. In H we have the signal before symbol decision. Notice that the Discrete Fourier Transform is made only once in each slot (and burst).

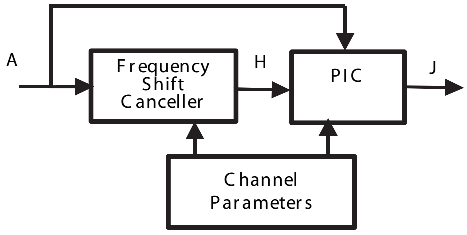

Fig. 4. Receiver including FSC plus PIC

The second detector configuration to be evaluated is the detector composed by FSC plus PIC (figure 4). The FSC in figure 4 corresponds to the whole receiver chain of figure 3. The FSC provides the signal for the symbol decision inside the PIC.

These two configurations are benchmarked with the conventional RAKE and conventional single stage PIC.

D. Results

The simulations were made with the parameters shown in Table I and the parameters estimates were assumed to be perfect.

TABLE I
SIMULATION PARAMETERS SETTINGS

Spreading Factor	16
Number of Taps	2
Channel	GBSBEM
Velocity	50 Km/h
Path Loss	3.7
BurstType	1
Maximum Delay Spread	2.0 μs
Degrees of Freedom of FSC	16
Number of samples per chip	4
Line of Sight Distance	300m
Number of bits simulated	1000000

The BER shown in all the following plots is the overall BER of the users considered. All multiuser detectors show better performance than the conventional RAKE being good alternatives to improve system capacity. The Frequency Shift Receiver shows better results, above E_b/N_0 of 12 dB, than the conventional PIC for eight and sixteen simultaneous users.

As can be seen in figure 5, 6 the FSC plus PIC is sufficient to remove practically all the interference for those scenarios. Further work is ongoing to determine if the number of freedom degrees (that directly translates in complexity) can be reduced

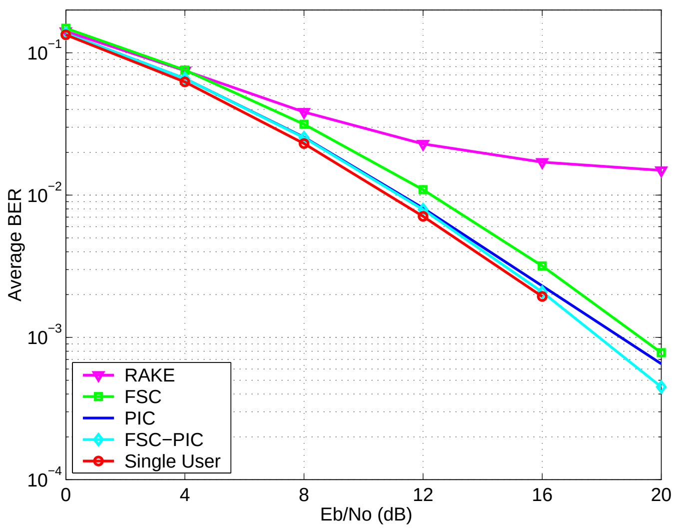

Fig. 5. Performance for 4 simultaneous users

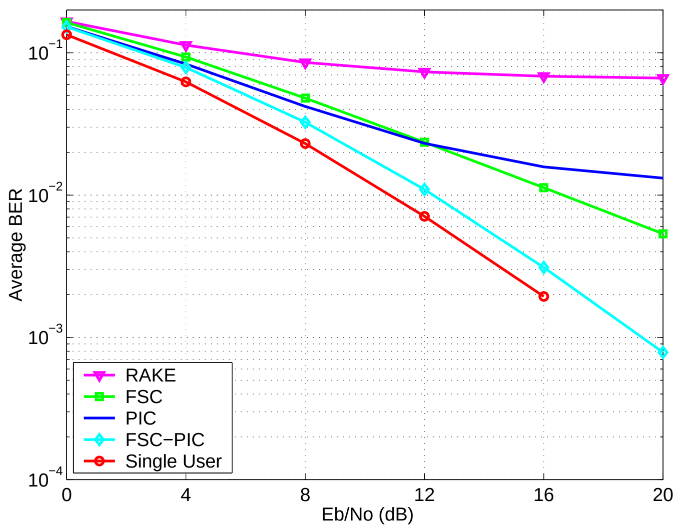

Fig. 7. Performance for 16 simultaneous users

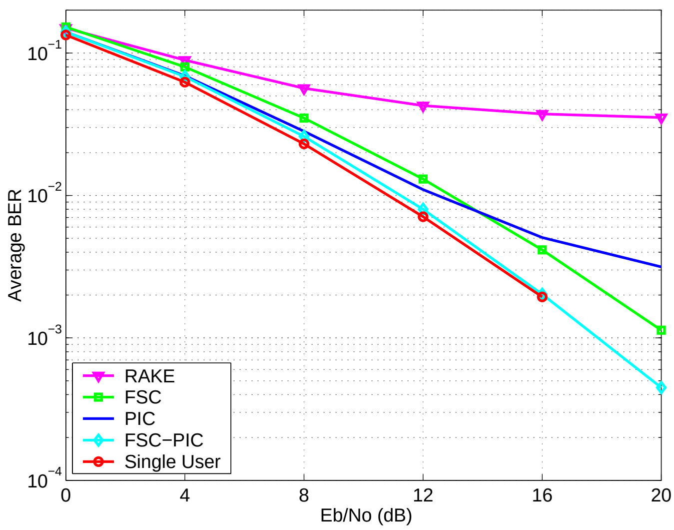

Fig. 6. Performance for 8 simultaneous users

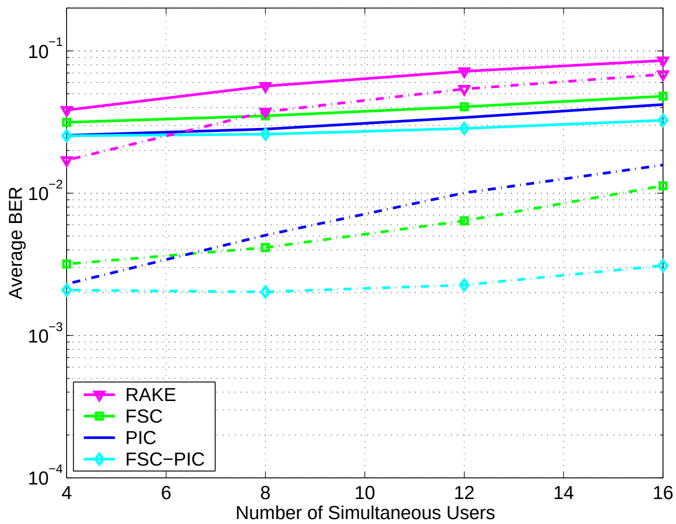

Fig. 8. Performance in function of the number of users for E_b/N_0=8dB (Solid Line) and E_b/N_0=16dB (Dash-Dot)

without significant performance penalty. For the case of sixteen simultaneous users in the same slot, there is still some gap relatively to the single user curve as shown in figure 7, but the cancellation gains are considerable.

V. Conclusions

In this work we presented a new MAI canceller, denoted Frequency Shift Canceller that explores the frequency redundancy of direct sequence signals. The proposed canceller was simulated in UMTS-TDD chain and the results compared against the PIC and RAKE receivers. The results show that considerable improvement is achieved against the RAKE and the FSC even outperforms the PIC for moderate to high values of E_b/N_0. The FSC was also tested as a precanceller to be used prior to a PIC and the results have shown that nearly complete interference cancellation in a UMTS-TDD scenario with up to eight simultaneous users in the same slot.

Future work involves implementation of the FSC for various spreading factors and to evaluate the performance degradation for imperfect channel parameters estimation.

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

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

[5] J. C. Liberti, T. S. Rappaport, *Smart Antennas for Wireless Communications: IS-95 and Third Generation CDMA Applications*, Prentice Hall, 1999.