EVOLUTIONARY WIENER-MASK RECEIVER FOR MULTIUSER DIRECT SEQUENCE SPREAD SPECTRUM

Abdullah A. ALSHEHRI [1], *Luis F. CHAPARRO* [2] *and Aydin AKAN* [3]

[1] Department of Electrical Engineering
Jeddah College of Technology, Jeddah, Saudi Arabia
[2] Department of Electrical and Computer Engineering
University of Pittsburgh, Pittsburgh, PA, 15261, USA, e-mail: chaparro@ee.pitt.edu
[3] Istanbul University, Avcilar, 34320, Istanbul, Turkey
phone: +(90) 212 473 7070/17914, fax: +(90) 212 473 7180, e-mail: akan@istanbul.edu.tr

ABSTRACT

In this paper, we propose a channel estimation procedure that together with a time-frequency Wiener mask permits the design of coherent receivers for direct sequence spread spectrum (DSSS) communication systems. Such a receiver excises intentional or non-intentional jamming signals while detecting the sent bit. Transmission channels spread the message signals in time and frequency and are typically modeled as random, time-varying systems. The estimation of the parameters of the channel model for one of the users, in uplink transmission, is possible by means of the spreading function obtained from the discrete time-frequency evolutionary (DET) kernel of the received signal and the pseudo-noise code corresponding to the user. Excision of arbitrary jamming signals, present in the received signal, is done by means of a Wiener mask implemented with the DET. The performance of the proposed receiver is illustrated by means of simulations, with different levels of channel noise, Doppler frequency shifts, jamming signals and different number of users.

Keywords*:* *Spread spectrum communications, Multipath channel modeling and estimation, Evolutionary time-frequency analysis.*

1. INTRODUCTION

Despite the advantages of Direct Sequence Spread Spectrum (DSSS) communications [1], the performance of DSSS systems degrades as the number of users increases and when broadband jamming signals appear in the received signal. In the uplink DSSS transmission, several active users are sending information to a base and each uses different channels. Multi-path, Doppler and jamming effects in each of the users' transmission channels need to be considered when attempting to equalize these effects in the receiver. The increase in mobility of users and in the number of wireless providers makes Doppler and jamming significant effects to consider in the design of coherent receivers.

Transmission channels are typically modeled as random, time-varying linear systems [2, 3]. In this paper we use such a model, and assume its parameters change at random from bit to bit (fastest fading) or over a number of bits (fast or slow fading). The system's impulse response is

$$g(n,m) = \sum_{\ell=0}^{L-1} \alpha_\ell e^{-j\psi_\ell n}\delta(m-N_\ell)$$

where $\{\alpha_\ell\}$ are attenuation factors, and $\{\psi_\ell\}$ are Doppler frequency shifts for each of the randomly varying paths L, and $\{\delta(m-N_\ell)\}$ are impulse responses of the all-pass system corresponding to the delays $\{N_\ell\}$ in each path. The channel is thus characterized by this set of parameters. The problem is to find from the received signal and the known pseudo-noise code, for any of the users, the parameters of this user's channel. The problem is complicated by the presence of information from other users.

For the estimation, we take advantage of the connection between linear time-varying models and related system functions [2, 4] with the time-frequency evolutionary spectral theory [5, 6]. In fact, if a linear time-varying system has $g(n,m)$ as its impulse response, then its corresponding time-varying frequency response, or Zadeh's function [7], is given by

$$G(n,\omega_k) = \sum_m g(n,m)e^{-j\omega_k m},$$

or the Fourier transform of $g(n,m)$ with respect to the delay variable m. The bi-frequency function is defined as the Fourier transform of $G(n,\omega_k)$ with respect to n, or

$$B(\Omega_s,\omega_k) = \sum_n G(n,\omega_k)e^{-j\Omega_s n}.$$

A clear connection exists between these two functions and the evolutionary time-frequency and frequency-frequency kernels [6, 8]. Finally, the spreading function, $S(\Omega_s,k)$, which will prove valuable in the estimation, is the inverse Fourier transform of $B(\Omega_s,\omega_k)$ with respect to ω_k, or equivalently, the Fourier transform of the impulse response function $g(n,m)$ with respect to the time variable n.

In [5], we showed that for a single user DSSS a spreading function $S(\Omega,k)$ can be estimated using the discrete evolutionary transform (DET) of the received signal and the pseudo-noise code of the user, and that the estimated spreading function provides estimates of the model parameters. The case is complicated by the presence of the information from other users. We will show that it is still possible to estimate the parameters of the desired channel. Using these channel parameters, we then pose the excision of possible jammers as a non-stationary Wiener filtering problem and provide an efficient solution by means of a time-frequency mask [8, 9]. It should be mentioned that in this case, the jammer characterization is not required as in other methods [10, 11, 12].

We will show how the spreading function is used to estimate the channel parameters, and in particular how the evolutionary time-frequency kernel of the received signal can be used in estimating it and the channel parameters obtained. Moreover, as it will be shown, in the uplink transmission this function allows us to find the channel parameters corresponding to any of the active users.

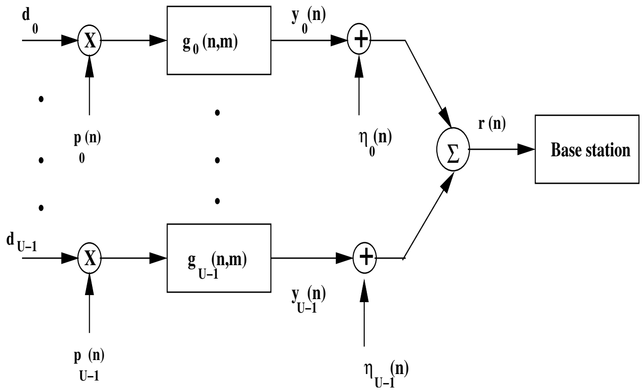

Figure 1: Multiuser communication channel (uplink).

2. CHANNEL MODELING AND ESTIMATION FOR UPLINK DSSS

In practical situations, several active users communicate through a base station in uplink and downlink modes. In the uplink transmission, the base station receives signals –each affected by a different channel– from different users and locations. Given the increasing number of wireless communication providers, it is possible to have unintentional jamming in this transmission. The main function of the base station receiver is to somehow separate these signals, and detect the transmitted bits corresponding to a particular user while getting rid of the jammers. The problem is then how to estimate the parameters of the channel corresponding to one of the users from the received signal and the knowledge of the user's unique pseudo-noise sequence, and then how the channel parameters can be used in the detection of the sent data.

2.1 Uplink Channel Modeling

Figure 1 illustrates the DSSS uplink transmission for U users, each having a different channel with impulse response $g_u(n,m)$, modeled as indicated before. If $p_u(n)$ is the unique pseudo-noise assigned to user u, the spread signals $\{s_u(n) = d_u p_u(n)\}$, $u = 0, \cdots, U-1$, are transmitted over the different channels and

$$r(n) = y(n) + \eta(n),$$

is the received signal, where $\eta(n)$ is the cumulative channel interference consisting of channel noise and possible jamming signals. For simplicity in the analysis, we assume each $p_u(n)$ to have the same length M_p.

When we replace $p_u(n)$ by its Fourier representation, the noiseless received signal becomes

$$\begin{aligned} y(n) &= \sum_{k=0}^{M_p-1} \left\{ \sum_{u=0}^{U-1} d_u \frac{P_u(k)}{M_p} \right. \\ &\quad \times \left. \left[\sum_{\ell=0}^{L_u-1} \alpha_{u,\ell} e^{-j\omega_k N_{u,\ell}} e^{j\psi_{u,\ell} n} \right] \right\} e^{j\omega_k n} \\ &= \sum_{k=0}^{M_p-1} Y(n,\omega_k) e^{j\omega_k n}, \end{aligned} \tag{1}$$

where $\{P_u(k)\}$ are the Fourier coefficients of $p_u(n)$, the term in square brackets is the time-varying frequency response function, $G_u(n,\omega_k)$, of the channel corresponding to the u^{th} user, and $Y(n,\omega_k)$ is the time-frequency evolutionary kernel corresponding to $y(n)$. For each user, the channel functions are related as indicated above and it is found that the spreading function $S_u(\Omega_s,k)$, as in the single user case [5], provides the parameters of the channel for user u and is connected with the kernel $Y_u(n,\omega_k)$. The problem with the uplink case is that the overall time-varying frequency response function is a matrix, given that the system is multiple input/single output, and cannot be used to obtain the corresponding spreading functions. Instead, we will show that the $S_u(\Omega_s,k)$ can be computed from $Y(n,\omega_k)$. In fact, from (1) we have for a user i

$$Y(n,\omega_k) = \frac{d_i P_i(k)}{M_p} G_i(n,\omega_k) + \frac{\sum_{u\neq i} d_u P_u(k) G_u(n,\omega_k)}{M_p},$$

from which we solve for $G_i(n,\omega_k)$ and find the corresponding spreading function as

$$\begin{aligned} S_i(\Omega_s,k) &= \mathscr{F}^{-1}_{\omega_k} \left[\frac{M_p Y(\Omega_s,\omega_k)}{d_i P_i(k)} \right. \\ &\quad \left. - \frac{\sum_{u\neq i} d_u P_u(k) B_u(\Omega_s,\omega_k)}{d_i P_i(k)} \right]. \end{aligned} \tag{2}$$

The last term in the above equation displays the influence of the other users in the determination of the channel parameters for a specific user, and the connection with the evolutionary discrete kernel. We will see that when estimating the parameters of the channel for some user, the effect of the other users is not very significant.

2.2 Uplink Channel Parameter Estimation

The DET [6] of $y(n)$, letting the window $V_q(n,m) = e^{j\omega_q(n-m)}$, for $\omega_q = \psi_{i,\ell}$ is giving by

$$\begin{aligned} Y_{\psi_{i,\ell}}(n,\omega_k) &= d_i \sum_{s=0}^{M_p-1} \frac{P_i(s)}{M_p} \left[\sum_{\ell=0}^{L_i-1} \alpha_{i,\ell} e^{-j\omega_s N_{i,\ell}} e^{j\psi_{i,\ell} n} \right] \\ &\quad \times \sum_{m=0}^{M_p-1} e^{j(\omega_s-\omega_k)m} + \Gamma(n,\omega_k) \\ &= d_i P_i(k) G_i(n,\omega_k) + \Gamma(n,\omega_k), \end{aligned} \tag{3}$$

where the last equation is due to the summation with respect to m being $M_p\delta(s-k)$, and that the effect of the other users is given by

$$\Gamma(n,\omega_k) = \sum_{u\neq i} d_u \sum_{s=0}^{M_p-1} \frac{P_u(s)}{M_p} \left[\sum_{\ell=0}^{L_u-1} \alpha_{u,\ell} e^{-j\omega_s N_{u,\ell}}\right] \times \sum_{m=0}^{M_p-1} e^{j\psi_{u,\ell}m} e^{j\psi_{i,\ell}(n-m)} e^{j(\omega_s-\omega_k)m}.$$

From equation (3), we then have that

$$G_i(n,\omega_k) = \frac{Y_{\psi_{i,\ell}}(n,\omega_k) - \Gamma(n,\omega_k)}{d_i P_i(k)}, \qquad (4)$$

from which the spreading function $S_i(\Omega_s,k)$ is found to be

$$\begin{aligned} S_i(\Omega_s,k) &= \sum_{i,\ell} \alpha_{i,\ell}\delta(\Omega_s - \psi_{i,\ell})\delta(k - N_{i,\ell}) \\ &= \mathscr{F}_{\omega_k}^{-1}\left[\frac{Y_{\psi_{i,\ell}}(\Omega_s,\omega_k)}{d_i P_i(k)}\right] - \frac{\Gamma(\Omega_s,k)}{d_i P_i(k)}, \end{aligned} \qquad (5)$$

where

$$\Gamma(\Omega_s,k) = \frac{1}{M_p}\sum_{u\neq i}\sum_{s=0}^{M_p-1}\sum_{\ell=0}^{L_u-1} d_u P_u(s)\alpha_{u,\ell} \times e^{-j\omega_s(N_{u,\ell}-k)} e^{j(\psi_{u,\ell}-\psi_{i,\ell})k}\delta(\Omega_s - \psi_{i,\ell}),$$

is a noise-like component.

Thus, the spreading function $S_i(\Omega_s,k)$ found this way provides the corresponding channel parameters for user i, with a certain amount of noise from the other users, as large peaks located at delays and Doppler shift frequencies and with magnitude equal to the attenuation factors. This is when considering frequencies that coincide with the Doppler shift frequencies for the i^{th} user. For any other frequency, the spreading function appears noise-like. It is possible to obtain a fast computation by expressing (6) in a matrix form and adapting the matrices to the i-user. Figure 2 illustrates the spreading function in the multi-user uplink transmission.

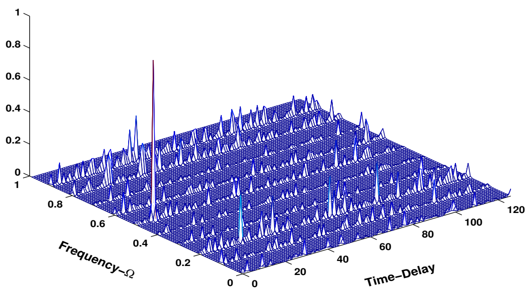

Figure 2: Spreading function of user 2 in multiuser communication channel (uplink) of 6 users.

3. WIENER MASKING RECEIVER

The presence of a jammer, besides the channel noise, in the received signal complicates the detection of the sent data. In great part this is due to the fact that typically there is no *a priori* information about the type of jammer and therefore most of the existent jammer excision approaches would not be very useful. Typically, they are adapted to a type of jammer [10, 11, 12]. A different approach, is to consider the jammer excision as a non-stationary mean-square estimation problem, and in particular to consider the generation of a time-frequency Wiener mask [9, 8].

To pose the problem in the Wiener form, we first use the Doppler shift and the attenuation estimates. Consider the data for the Wiener problem as $\rho_u(n) = r(n)e^{-j\hat{\psi}_{u,0}n}/\hat{\alpha}_{u,o}$ or

$$\rho_u(n) = d_u p_u(n - \hat{N}_{u,0}) + \left[\sum_{\ell,i\neq u} d_u \alpha_{i,\ell} e^{j\psi_{i,\ell}n} p_i(n - N_{u,\ell}) + i(n)\right] \frac{e^{-j\hat{\psi}_{u,0}n}}{\hat{\alpha}_{u,o}},$$

where $i(n) = \eta(n) + j(n)$ is the interference ($\eta(n)$ channel noise and $j(n)$ a jammer), and we assume that $\hat{N}_{u,0}$, $\hat{\psi}_{u,0}$ and $\hat{\alpha}_{u,0}$ correspond to the path closest to the line of sight for a u^{th} user. Clearly the second term in the above equation is a non-stationary interference and the desired signal is $d_u p_u(n - \hat{N}_{u,0})$. The evolutionary spectrum of the data $\rho_u(n)$ can be implemented with its DET as $|R_u(n,\omega)|^2$. Likewise, the evolutionary spectrum of $d_u p_u(n - \hat{N}_{u,0})$, independent of d_u and $\hat{N}_0$, is $|P_u(n,\omega_k)|^2$ where $P(n,\omega_k)$ is the DET of $p_u(n)$.

The Wiener mask is then implemented by

$$M(n,\omega_k) = \frac{|P_u(n,\omega_k)|^2}{|R_u(n,\omega_k)|^2}, \qquad (6)$$

and the estimate of $d_u p_u(n - N_{u,0})$ is found as the inverse DET of the masked $R_u(n,\omega_k)M(n,\omega_k)$. After obtaining the estimate of the desired signal, we just multiply it by $p_u(n - \hat{N}_{u,0})$ and find its average to obtain decision variable capable of determining whether 1 or -1 corresponds to d_u.

4. SIMULATIONS

To illustrate the performance of the proposed procedures we simulate a multiple–user uplink base-band system to transmit binary phase-shift keying (BPSK) coded data. The aim of is to show the robustness of the proposed procedures under very restrictive conditions. Thus, the channel models are allowed to vary at random from bit to bit within certain restrictions: the number of paths is allowed to vary from 1 to 4, the delays can vary from 0 to $0.5M_p$, and the Doppler shifts to vary from the 0 to $\pm 0.001\pi$. The attenuation factors are set to vary linearly with the delays. The simulations are thus related to a very bad situation, and despite this we will show that the results are encouraging. Moreover, using the fast computation of the spreading function, indicated before, makes the simulations not very expensive computationally.

To determine the goodness of the proposed detecting procedures we consider first simulations when the received signal is affected by Gaussian channel noise only. We thus perform 10,000 Monte-Carlo trials for each signal to noise ratio (SNR) value of the channel noise (ranging from -2 dB to 16 dB). The bit error rate (BER) is computed for the range of SNRs for one of 4 users in an uplink transmission. An upper bound in the BER plots is obtained for the situation when like in a RAKE receiver we use a shifted version of the pseudo-noise corresponding to the desired user (we use the estimated $N_{u,0}$ parameter corresponding to the closest to the LOS received signal). A lower bound is obtained for the ideal situation when the parameters of the corresponding channel are known (see Fig. 3 for results). The second simulation consists of including a broad jammer and channel noise in the received signal. The simulations results in Fig. 4 correspond to the case of uplink transmission with 4 users, and we consider the cases when the channel white noise has SNRs of 5 and 15 dB, and the jammer is a linear chirp with a jammer to signal ratio varying from -2 to 8 dBs.

As expected, the estimation of the parameters and correspondingly the BER improves as the noise SNR increases, and gets worse as the JSR increases (for a fixed SNR). Considering the stringent conditions imposed on the simulations, these results indicate that the performance of our procedures will improve considerably when these conditions are relaxed. The Wiener mask rids the received signal of the channel noise as well as jammer signals present in it.

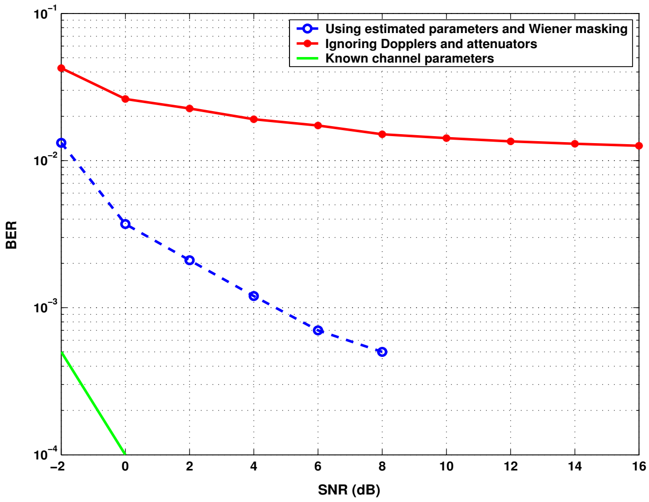

Figure 3: BER vs SNR for uplink transmission.

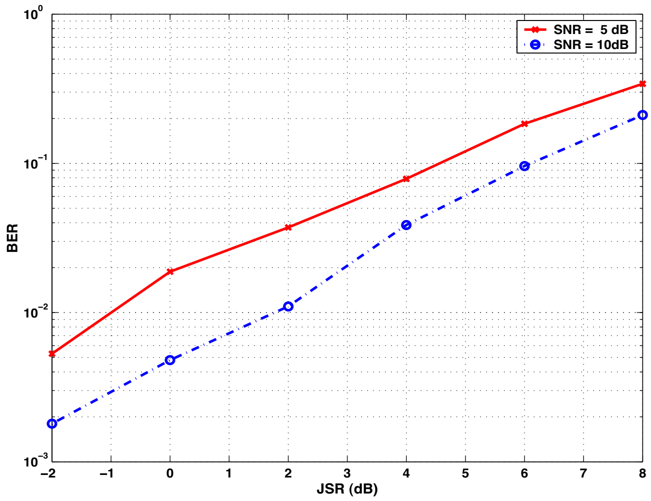

Figure 4: BER vs JSR for uplink transmission.

5. CONCLUSIONS

In this paper we have proposed a new coherent receiver for a multi-user direct sequence communication uplink transmission. It is based on parameters of the transmission channel for a certain user, and on a Wiener mask to excise interference signals. Assuming a linear time varying model for the channel, that changes randomly for the duration of one or a set of transmitted bits, we have shown that the channel parameters associated with one of the users in the uplink can be estimated from the discrete evolutionary transform of the received signal and the pseudo-noise code for the user. Using the connection between the DET and the spreading function, a blind estimation procedure have been proposed. Since detection of the transmitted bit is complicated by the presence of jamming signals, the proposed receiver includes a non-stationary Wiener mask that attempts to get rid of a general type of jammer and channel noise. Simulations of an uplink DSSS system with the proposed receiver several users indicate the goodness of the proposed methods.

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