

# DSP-based ionospheric radio-link using DS-CDMA and on-line channel estimation

J.L.Pijoan, J.C. Socoro, J.A. Moran, F. Tarres

**Abstract**—In this paper, a new blind multiuser detection algorithm is presented. It can both cancel multiuser interference and estimate the multipath channel response in a blind way. The method has been specially conceived for low coherence bandwidth channels such as the ionospheric channel and exhibits very low computational requirements. Real-time measurements from a fully digital HF radio-link are presented that confirm the reliability of the method for the ionospheric channel.

**Index terms**—HF communications, blind channel estimation, multiuser detection, CDMA, ionospheric links.

## I. INTRODUCTION

Ionospheric communications are a good choice for low-rate, long-distance links, due to their low cost, independence of satellite in case of military conflict and low frequency carriers that allow direct analog-to-digital conversion. However, the transmission power required is high and narrow bandwidths are available. Moreover, the ionospheric channel presents slow varying multipath fading with very small coherence bandwidth ( $\approx 1$  KHz), narrowband interference with low signal-to-interference ratios (SIR) and poor signal-to-noise ratios (SNR) [1].

To overcome these limitations, a digital DSP-based Direct Sequence Spread Spectrum (DS-SS) ionospheric radio-link between Huelva and Barcelona has been developed using a new low complexity method (called *Dual Vector Minimum Output Energy - DVMOE*) to estimate the channel response in a blind way when a fading occurs [2]. DVMOE is a new MOE-based algorithm [3] with additional constraints that allows both multiuser interference cancellation (presenting *Near Far resistance*) and multipath channel estimation. DVMOE has been tested in a real-time HF radio-link and its feasibility and reliability in the ionospheric channel has been proved.

The rest of the paper is organized as follows. The radio-link is briefly described in section II. The system model is presented in section III and the formulation of DVMOE is introduced in section IV. Simulations and measurements from the real-time link are presented in section V. Finally, section VI contains the conclusions.

## II. DESCRIPTION OF THE LINK

A digital HF radio-link has been developed<sup>1</sup> with three main targets. First, to have a flexible digital platform able to implement any kind of communications scheme. Second, to evaluate the ionospheric channel by measuring those parameters of interest from the digital transceiver point of view, i.e., the time delay spread and the Doppler spread. The last goal is to implement a digital spread-spectrum ionospheric radio-link, taking advantage of SS capabilities, such as robustness against narrow-band interference, multipath fading and low SNR. Multiple signatures can be used for different users and to increase the bit rate of a single user as well. The main features of the system are listed below:

- Simplex communications. The transmitter is placed in Huelva and the receiver in Barcelona. The distance between both cities is 800 Km.
- Carrier frequency: 4-8 MHz. In this band, reflection is almost guaranteed during all the day. Higher frequencies are only available in daytime.
- Information rate:  $\approx 1$  Kbps per signature. Spreading factor is 31 and data modulation is DPSK. All these parameters are configurable.
- Full digital implementation. A direct analog-to-digital conversion (50 Msample/s) of the received signal and a digital down-conversion is performed. The baseband signal is then processed by 3 DSPs working in parallel. This structure allows the system to be extremely flexible and every modification is reduced to a software matter.

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A detailed description of the high speed acquisition and processing hardware can be found in [4]. The system can operate in two modes:

- Channel evaluation mode. A test signal is transmitted every minute 24 hours a day in order to measure the scattering function of the channel. This procedure does not require real-time operation and is described in detail in [1].
- Real-time operation. Information is transmitted and received in real-time. PN acquisition in low SNR environment with narrow-band interference and long fading has to be accurately designed [5]. Some multipath channel estimators have been developed to recover in a blind way when a fading occurs.

### III. SYSTEM MODEL

Let us consider a CDMA system with  $K$  synchronous users through a multipath channel. The received baseband signal can be modeled as:

$$r(t) = \sum_{k=1}^K \sum_{n=-\infty}^{\infty} A_k b_k(n) w_k(t - nT_b) + \sigma n(t) \quad (1)$$

where  $A_k$ ,  $b_k$  are the amplitude and bit of user  $k$ ,  $T_b$  is the bit duration and  $n(t)$  is a white gaussian noise with unit power spectral density.  $w_k(t)$  is the received waveform for user  $k$ :

$$w_k(t) = \sum_{i=1}^N s_k(i) h(t - iT_c) \quad (2)$$

where  $\{s_k(1), s_k(2), \dots, s_k(N); s_k(i) = \pm 1\}$  is the PN sequence for user  $k$ ,  $h(t)$  is the complex valued channel response (considered equal for all users),  $N$  is the processing gain and  $T_c$  is the chip interval. After chip-matched filtering, the waveform is sampled at chip-rate. The received discrete-time signal in one symbol interval is:

$$r(t) = \sum_{k=1}^K A_k b_k(n) S_{k1} \mathbf{h} + \sum_{k=1}^K A_k b_k(n-1) S_{k2} \mathbf{h} + \sigma \mathbf{n} \quad (3)$$

where  $S_{k1}$  and  $S_{k2}$  are the matrices of delayed replicas of the current and previous symbols and  $\mathbf{h}$  is the  $L$ -tap multipath channel response. For short distance ionospheric links,  $L$  is quite long compared to the symbol duration, so a not negligible part of the symbol is corrupted by the previous one. The observation interval is fixed to  $N$  in order to allow real-time implementation, and a *Near-Far* resistant blind channel estimator, able to deal with large values of  $L$ , is needed.

### IV. FORMULATION OF DVMOE

Let us consider user 1 as the user of interest. The proposed receiver is:

$$b_1(n) = \text{sgn}\{\mathbf{r}^H (S_{11} \hat{\mathbf{h}} + \mathbf{x})\} \quad (4)$$

where  $\hat{\mathbf{h}}$  and  $\mathbf{x}$  are calculated following the minimum output energy criterion:

$$\min_{\hat{\mathbf{h}}, \mathbf{x}} \{J\} = \min_{\hat{\mathbf{h}}, \mathbf{x}} \left\{ E \left[ \left| \mathbf{r}^H (S_{11} \hat{\mathbf{h}} + \mathbf{x}) \right|^2 \right] \right\} \quad (5)$$

subject to the constraints:  $|\mathbf{S}_{11} \hat{\mathbf{h}}|^2 = 1$  and  $\mathbf{S}_{11} \hat{\mathbf{h}} \perp \mathbf{x}$ .

When the output energy is minimized,  $\hat{\mathbf{h}}$  is an estimation of the channel response and  $\mathbf{S}_{11} \hat{\mathbf{h}} + \mathbf{x}$  is orthogonal to the multiple access interference. This method can be seen as an extension of [3], considering the received waveform as a linear combination of delayed replicas of the PN sequence. It has been called *Dual Vector MOE* (DVMOE) because the minimization of two vectors has to be performed. A steepest descent approximation can be calculated by:

$$\begin{aligned} \hat{\mathbf{h}}(n+1) &= \hat{\mathbf{h}}(n) - \mu_h \nabla_{\hat{\mathbf{h}}} J \\ \mathbf{x}(n+1) &= \mathbf{x}(n) - \mu_x \nabla_{\mathbf{x}} J \end{aligned} \quad (6)$$

Three important characteristics should be emphasized. First, as the nominal signature is not fixed but depends on vector  $\hat{\mathbf{h}}$ , the stationary solution does not suffer from the *mismatch* problem. Second, DVMOE behaves not only as a multiuser detector, but also as a blind *Near Far* resistant channel estimator able to deal with a higher number of users than other methods ([6],[7]) for a given channel length. The basis of the method is the linear independence among received vector  $\mathbf{S}_{11} \mathbf{h}$  and the rest of  $2K-1$  vectors from (3). For  $L < N/3$ , a correct estimation can be achieved for a number of users  $K < N - L + 1$ . For  $N/3 < L < N$ , the contribution of previous bits becomes more significant and  $2K < N - L + 1$ . Finally, DVMOE is a low complexity method. It can work with an observation interval of length  $N$  and only adds  $4NL + L$  operations per symbol more than the blind detector from [3]. A real-time implementation has been successfully tested and results are presented in next section.

It is easy to show that  $\nabla_{\hat{\mathbf{h}}} J = \mathbf{S}_{11}^H \nabla_{\mathbf{x}} J$ , so  $|\nabla_{\hat{\mathbf{h}}} J| \ll |\nabla_{\mathbf{x}} J|$ . Hence,  $\mu_x \ll \mu_h$  to ensure small excess errors. Increasing the number of active users or the *Near Far* ratio will make both gradients higher, so lower convergence speed will be achieved since smaller steps  $\mu_x$

and  $\mu_h$  will have to be used. This fact will lead to slightly lower convergence speed than other subspace methods ([6],[7]).

## V. SIMULATIONS AND REAL TESTS

A number of simulations have been performed in order to prove the robustness of DVMOE in front of the number of users, *Near Far* and channel length. Gold sequences of length 31 and a 15-tap complex valued multipath channel response have been used, so one half of the observation interval is corrupted by previous symbols. All the interfering users are 5 dB stronger than the user of interest. Figure 1 shows the evolution of the channel estimation error for different number of users. An estimation error lower than 0.1 is achieved in 1000 iterations without increasing the filter size if the number of users is lower than 5.

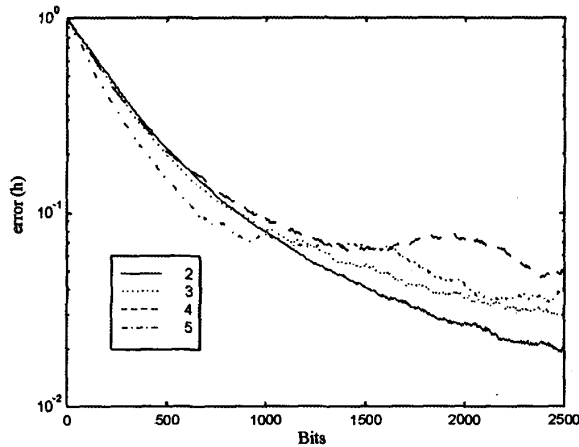


Figure 1. Convergence speed of DVMOE.  $L=15$ ,  $NF=5$  dB

In figure 2, the stationary solution is obtained and BER versus  $E_b/N_0$  is evaluated with a 12-tap multipath channel. For a number of users lower than 5, the MMSE solution is achieved in a blind way.

Apart from simulations, the method has been tested in the real-time digital ionospheric radio-link described in section II. In order to evaluate DVMOE as a channel estimator, a reference of the instantaneous channel response is needed. One of the interfering users (i.e. user 2) is sent with a power 20 dB higher than the rest of users and the bits and signature are known at the receiver. Hence, the reference can be calculated by:

$$\mathbf{h}_{ref} = (\mathbf{S}_{21}b_2(n) + \mathbf{S}_{22}b_2(n-1))^{-1} \mathbf{r}(n) \quad (7)$$

where  $()^{-1}$  stands for pseudoinverse.

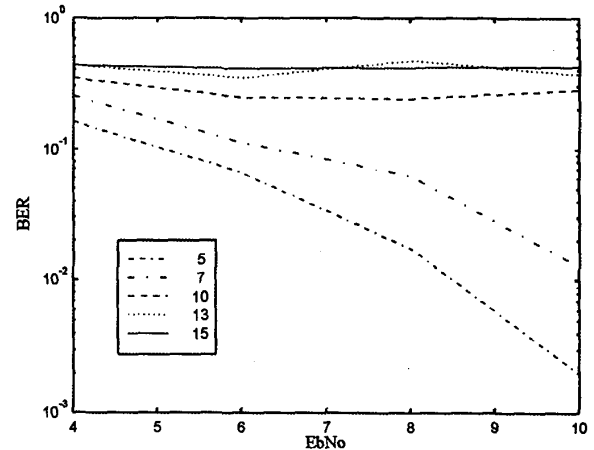


Figure 2. Influence of the number of users.  $L=12$ ,  $NF=5$  dB

The estimation error can now be defined as:

$$e = \|\hat{\mathbf{h}} - \mathbf{h}_{ref}\|^2 \quad (8)$$

Figure 3b shows the evolution of the estimation error versus time in a real transmission with two users. Bit rate is 600 bps with DPSK modulation, processing gain is 31 and sampling rate is 4 samples/chip. Noise power is measured before transmission and SNR at the filter input is shown in figure 3a. In seconds 2,4 and 7, the channel estimation error grows due to an input signal fading. Once the SNR of the user of interest reaches a certain level ( $>0$  dB), DVMOE is able to self-recover in a blind way in a few iterations. Averaged BER values between  $10^{-2}$  and  $10^{-3}$  (without coding) have been measured from a great number of transmissions in different situations.

## VI. CONCLUSIONS

A new blind MOE algorithm (DVMOE) for DS-CDMA systems has been presented. It is able to cancel multiuser interference and to estimate the multipath channel response at the same time, showing a good tradeoff between channel length and maximum number of users without increasing the observation interval. DVMOE exhibits very low computational cost and it has been successfully tested in a real-time HF radio-link.

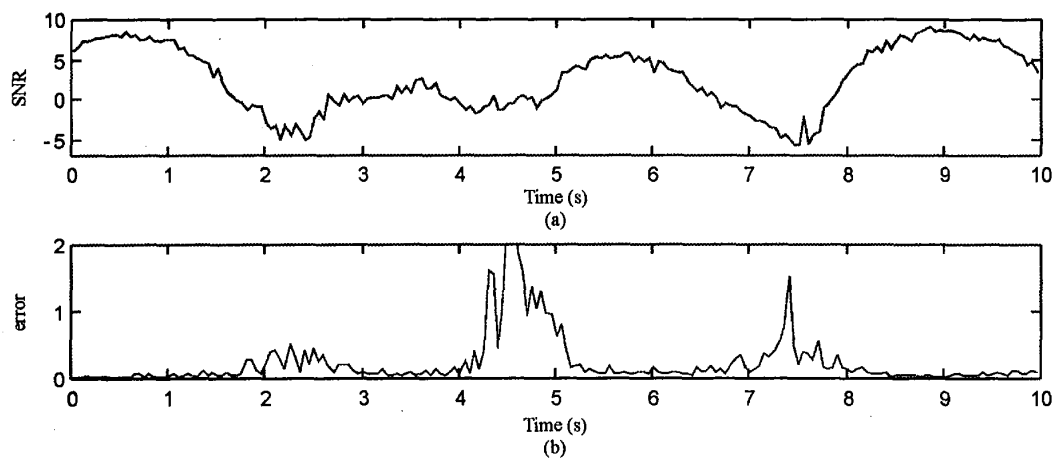


Figure 3. Evolution of signal to noise ratio (a) and estimation error (b) in a real transmission. Day: 99/11/18 Time: 11:04 UT

## VII. REFERENCES

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