A BLIND SPATIO TEMPORAL EQUALIZATION OPERATING ON A POLARIZATION SENSITIVE ARRAY

Y. Erhel [1], C. Perrine [2], D. Lemur [2] and A. Bourdillon [2]

[1] Centre de Recherches des Ecoles de Coetquidan, 2 Avenue Bournazel 56381 GUER France
phone: + (33) 2 97 70 76 22, fax: + (33) 2 97 70 76 15, email: yvon.erhel@st-cyr.terre.defense.gouv.fr

[2] Institut d'Electronique et de Télécommunications de Rennes, Campus de Beaulieu 35042 RENNES France
phone: + (33) 2 23 23 57 90, fax: + (33) 2 23 23 56 47, email: clency.perrine@univ-rennes1.fr

ABSTRACT

This paper presents an application of a blind spatio temporal equalization based on the Constant Modulus Algorithm (CMA). The context is the development of an operational system of transmission through the ionospheric channel for transhorizon radio links and the technical challenge is to increase significantly the data transfer rate of standard modems (typically 4.8 kbits/s in a 3 kHz bandwidth).

The multi channel receiving system is connected to an original array of collocated antennas which appears as polarization sensitive and, consequently, makes the separation of the incident multi paths efficient though there is no spatial diversity.

An experimental radio link has been tested with a range of 780 km. The corresponding results underline the improvement of the bit transfer rate which attains 30 kbits/s in a 9 kHz bandwidth resorting to a QAM 16 waveform.

1. INTRODUCTION

At the receiving point of a transhorizon radio link, each ionospheric path is characterized by the classical parameters direction of arrival (DOA), group delay, differential frequency Doppler shift and, in addition, by the structure of the incoming elliptical polarization that is DOA dependant [1]. In this particular context, it has been demonstrated that a set of collocated antennas can induce a significant decorrelation of the corresponding acquisitions under the evident condition that the sensors are different from each other [2].

This paper presents an operational system of long range transmission in the H.F. band (3-30 MHz) aiming at a data transfer rate which exceeds significantly the current standards (4.8 kbits/s in a 3 kHz bandwidth). A blind spatio temporal equalization, based on the constant modulus algorithm (CMA) is implemented on an array of 4 collocated active H.F. antennas in order to balance the distortions due to the propagation in an extended bandwidth.

Experimental results are presented to illustrate the capabilities of the system which has a range of 780 km and attains a transfer rate of 30 kbits/s in a 9 kHz bandwidth. Still compressed images are transmitted with a robust joint source and channel coding. Several received images are presented and appear quite consistent with the original.

2. ORIGINAL DEVICE OF COLLOCATED ANTENNAS

At the exit of the ionosphere, the elliptical polarization of an incident wave is described by the two parameters polarization ratio and inclination (of the major axis of the ellipse relative to the Earth's geomagnetic field) which are both DOA dependant [1]. The expression of the signal at the output of a given receiving antenna integrates a specific function of the DOA θ, named spatial response F(θ), which is complex valued due to the elliptical structure of the incoming polarization [3]. Consequently, a set of collocated sensors with different complex spatial responses has the capability to separate incident sources since they have different polarization parameters.

An original device of four H.F. active antennas with the same phase center has been developed. An optimization of the diversity of their complex spatial responses and a minimization of the mutual coupling are required for the final structure represented in Figure 1: it contains 2 orthogonal vertical loop antenna, 1 horizontal loop and 1 dipole with an original geometry.

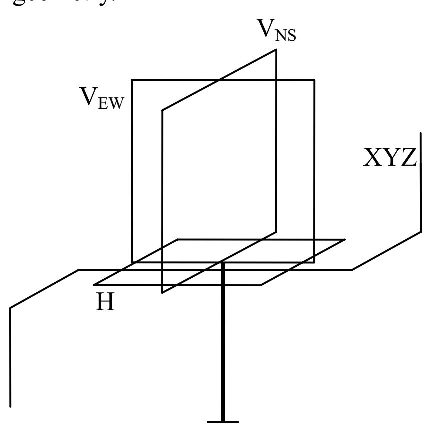

Figure 1 : array of 4 H.F. collocated antennas

The benefit of this device in the field of array processing is illustrated in Figure 2 where synchronous acquisitions on the four channels are plotted.

The presence of multi paths (generated by the ionospheric channel) induces fading. The minimums of power do not appear at the same time on the four channels. The reason is that the incident sources are combined with varying phases on each antenna: these are the arguments of the antenna responses to the incoming polarizations. The diversity of the spatial responses results in a partial decorrelation of the four received signals.

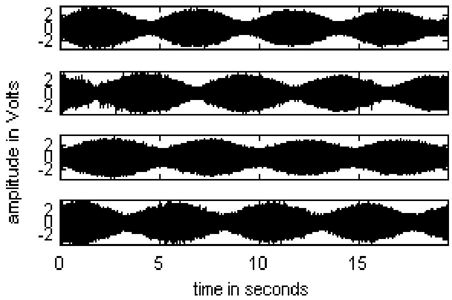

Figure 2 : 4 channel acquisitions

3. BLIND SPATIO TEMPORAL EQUALIZATION

The complete receiving system which has been developed integrates the operations which are synthesized on Figure 3.
The spatio temporal equalization is implemented, for each one of the NC=4 receiving channels, as a F.I.R. filter involving NR delayed samples.
The different samples of the acquisitions are picked up in the extended observation vector

$$\mathbf{X}_{ext}(k) = [\mathbf{X}(k)^T \, \mathbf{X}(k-1)^T \ldots \; \mathbf{X}(k-NR+1)^T]^T$$

where $\mathbf{X}(k)$ denotes the vector of the NC acquisitions at instant k.
In a previous stage of this project, the least mean squares (L.M.S.) algorithm was derived and required the transmission of training sequences. It has been investigated to remove this constraint with a blind algorithm in order to increase (slightly) the actual data transfer rate and to authorize the connection of asynchronous subscribers.
A global estimation of the vector $\hat{\mathbf{W}}$ containing the NC*NR tap coefficients is performed resorting to the constant modulus algorithm (CMA) [4]. In this application, the blind criterion to be minimized is the dispersion of second order:

$$D^{(2)} = E(|z_k|^2 - R_2)^2$$

where $R_2 = E[|c_n|^4]/E[|c_n|^2]$
is a statistics of the complex transmitted symbols $\{c_n\}$ and

$$z_k = \hat{\mathbf{W}}^T \mathbf{X}_{ext}(k)$$

is the sample at the output of the equalizer.

The CMA, optimum for a PSK modulation, is still efficient for QAM constellations with a limited number of states as used in the project: the variations of amplitude are moderate and the algorithm converges. The real time computation of the tap vector results from a descent along the gradient of the above mentioned criterion according to the relation:

$$\hat{\mathbf{W}}(k+1) = \hat{\mathbf{W}}(k) - \lambda \mathbf{X}_{\mathbf{ext}}^{*}(k) z(k)(|z(k)|^2 - R_2) \qquad (1)$$

The constant step-size parameter λ has been adjusted as a result of preliminary simulations in order to optimize the speed of convergence and the mean square error of the algorithm.
The synchronization techniques are classically based on an approached maximum of likelihood running on the equalized samples [5]. The carrier recovery resorts to the following phase detector:

$$e_k = \Im\left\{ \mathrm{csgn}(z_k^*)(z_k - \hat{c}_k) \right\} \qquad (2)$$

where $\mathrm{csgn}(x) = \mathrm{sgn}(\Re\{x\}) + j\,\mathrm{sgn}(\Im\{x\})$ and $\hat{c}_k$ is the estimated symbol.
The timing recovery is based on the Zero Crossing Detector with an error signal e_k expressed as:

$$e_k = \Re\left\{ (\hat{c}_{k-1}^* - \hat{c}_k^*)\, z(kT - T/2 + \hat{\tau}_{k-1}) \right\} \qquad (3)$$

where $\hat{\tau}_{k-1}$ is the estimated time delay at the stage k-1. That method implies that the sampling frequency is twice more than the symbol rate.
The interpolation calculates a weighted sum of four temporal samples of the filtered observations, the corresponding coefficients being parabolic functions of the fractional interval as described in [5].

4. EXPERIMENTAL RESULTS

An operational radio link has been set up between Valensole (South Alps) and Rennes (range of 780 km) using carrier frequencies in the 8-10 MHz band. The transmitter contains a fully flexible modulator generating a waveform with adjustable parameters: symbol duration, roll-off factor and number of constellation states.
The transmitted files contain still compressed images with a size of 256x256 pixels. The compression resorts to a multi stage wavelet decomposition associated with a vectorial quantization (Self Organizing Feature Map) of the components [6]. The resulting compression rate is equal to 16. A joint source-channel coding is mapped with an error protection based on Reed Solomon codes.
In the presented experiment, the transmitted waveform is a QAM 16 modulation; its Nyquist envelope had a roll-off factor equal to 0.2. The symbol duration is equal to 0.13 ms (9 kHz bandwidth) and the bit transfer rate is equal to 30 kbits/s. The average signal to noise ratio SNR for each channel equals 16 dB. The efficiency of the array processing is demonstrated by comparing the spectrum of the transmitted signal (Figure 4.a), the spectrum of the received signal on one channel with the best SNR (Figure 4.b) and the spectrum at the output of the equalizer (Figure 4.c). In presence of multipaths, the dispersion of the time delays is responsible for the distortion of the received spectrum which contains several “holes” (Figure 4.b). These defaults are corrected by the spatio temporal equalization (Figure 4.c).

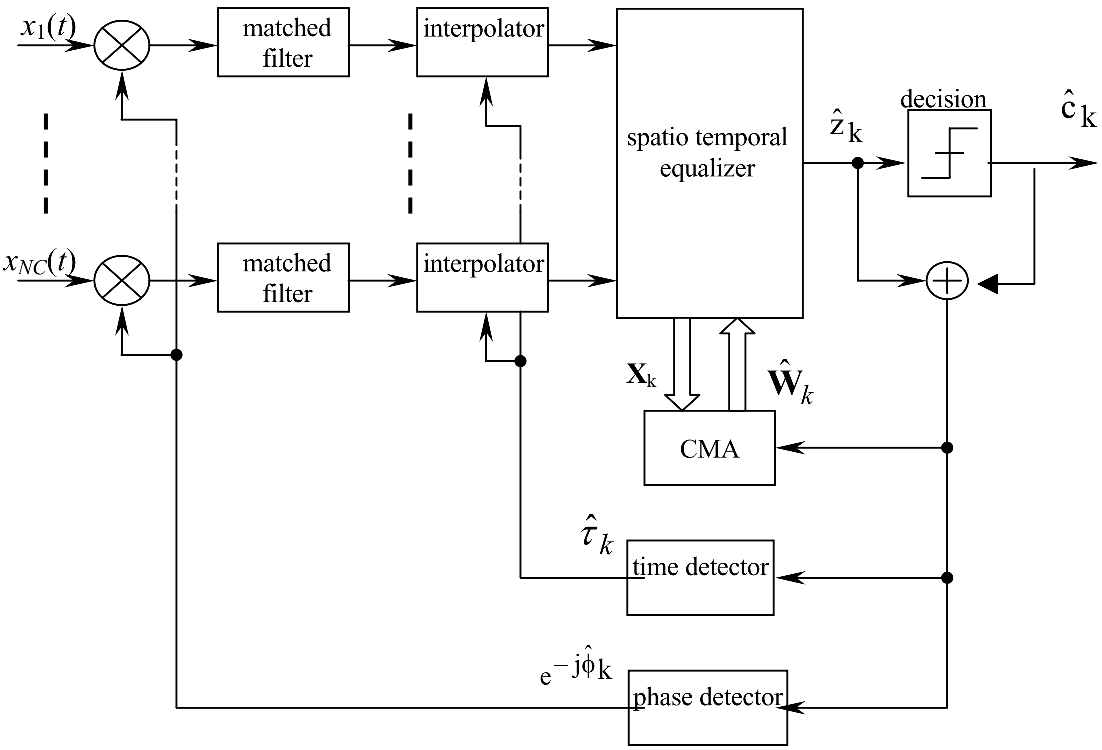

Figure 3 : synopsis of the signal processing

This remark justifies the improvement of the quality of service which is noticed on Figures 5 (a) to (c) when the decoded images after a single channel (b) or a four channel (c) processing are compared with the original image (a).

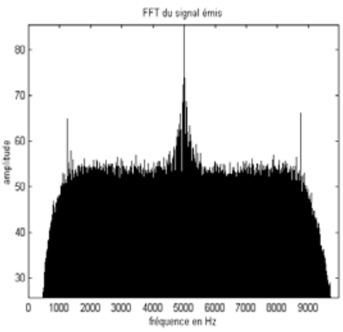

Figure 4.a : transmitted spectrum

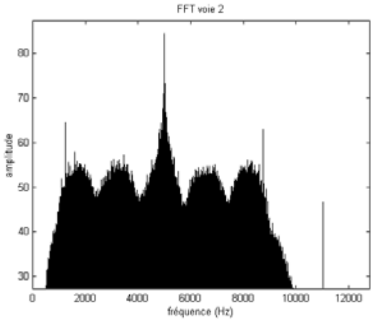

Figure 4.b : received spectrum (single channel)

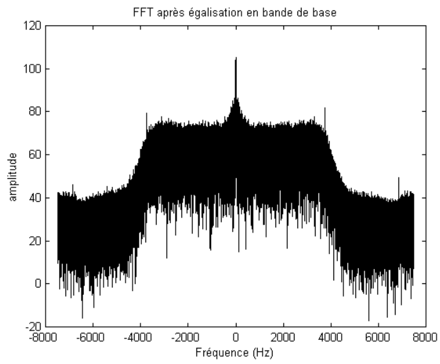

Figure 4.c : spectrum of the output of the equalizer

The visual perception is confirmed by the measurement of the number of errors and the peak signal to noise ratio of the restored images. The transmitted compressed file contains 32768 bits and the numbers of errors are 88 (corresponding to a BER equal to 2.7 10^{-3}) for the single receiving channel case and 31 (BER =9.5 10^{-4}) for the 4 receiving channels case. The respective PSNR are equal to 18.5 dB and 32.5 dB.

Figure 5.a : original LENA image

Figure 5.b : restored image after a single channel processing

Figure 5.c : restored image after a 4 channel processing

The equalization is adjusted with NR=6. This choice is coherent with the estimation of the delay spread $\Delta\tau g$ that can experimentally be done from Figure 4.b. Actually, the gaps in the received spectrum appear with a period of approximately $\Delta f=1200$ Hz in the frequency domain: this fact can be interpreted as the reception of two incident signals separated by a differential group delay of $\Delta\tau_g = \frac{1}{\Delta f} = 0.833$ ms. This value is close to 6 symbol durations and justifies the choice of the number of taps in the temporal equalization. Besides, the speed of convergence has been measured considering that the mean square error in the steady-state should be less than a threshold equal to 10% of the mean energy of the transmitted symbols. It appears that this learning sequence has a duration of approximately 2000 symbols.

5. CONCLUSION

An operational system of transmission has been presented, the receiving part of which resorts to an array processing with two main originalities. The first one is the polarization sensitivity of the collocated sensors that realizes an efficient decorrelation of the acquisitions. The second one is the practical implementation of a blind spatio temporal equalization based on the constant modulus algorithm.

This technical solution significantly improves the performances of the H.F. modems "on the shelf" (data transfer rate of 4.8 kbits/s in a 3 kHz bandwidth). Actually, the equalization balances the distortion induced by the propagation in an extended bandwidth up to 9 kHz so that the transfer rate attains 30 kbits/s.

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