EQUALIZER FOR REAL TIME HIGH RATE TRANSMISSION IN UNDERWATER COMMUNICATIONS

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Abstract - **This paper concerns the equalization problem of an underwater high rate transmission system. As the channel delay spread is large compared with the data duration, we have developed an equalizer in order to minimize the calculus burden. Test on real data is also made.**

I - INTRODUCTION

This paper addresses the equalization problem of AIDA ('Acoustics for Image DAta') which is a european MAST ('MArine Science and Technology') program designed to transmit images thru the ocean channel for short distances (up to three kilometers). Due to the high data rate (up to 150 kb/s) and the predicted multipath underwater propagation, such a system has to cope with severe degradation caused by the intersymbol interference. Further more, the equalizer must be able to face slow variations as well as abrupt changes in the channel characteristics.

An additional problem is that classical transversal filters need too many coefficients to update for real time transmission: ordinarily, the number of taps required equals approximately four times the ratio of the channel delay spread divided by the data duration; the study of the channel impulse response then allows us to predict that one would need over than a hundred taps to update, each tap requiring at least two complex multiplications and additions for the easiest to implement adaptive algorithm : the stochastic gradient .We have developed an algorithm in order to reduce this number of coefficients.

II - TRANSVERSAL STRUCTURE

We have chosen a transversal structure in order to insure stability. The stochastic gradient algorithm is the smallest calculus burden algorithm as it requires 2N complex multiplications per cycle where N is the number of coefficients of the equalizer . Thus, the coefficients are updated with a classical gradient algorithm :

$$H_k=H_{k-1} + \mu\, Y_k^* e_k \qquad \text{(II.1)}$$

where $Y_k = [\, y_k, \ldots, y_{k-N+1}\,]^T$ is the observation vector (at time k), H_k is the equalizer coefficients vector , e_k is the error between the equalizer output and the decided signal.

Still, for AIDA transmission rate and for the simplest two paths channel characterized by

$$T(z) = 1 + Az^{-17} \qquad \text{(II.2)}$$

one would make $2 * 4 * 17 * 150\ 10^3 = 21\ 10^6$ complex multiplications and additions per second (a delay of 17 data duration is a typical channel reflected path delay, predicted with a ray tracing method [1]).

Further more, for the channel of equation (II.2), most of the equalizer coefficients are negligible (See Figure 1). In

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addition, the significative taps correspond decreasingly to the multiples of the channel delay i.e.:

$H(z) = \Sigma\, h_i\, z^{i}$

$\approx h_{17}\, z^{-17} + h_{34}\, z^{-34} + h_{51}\, z^{-51} + h_{68}\, z^{-68}$.

This is logical because the equalizer at high Signal to Noise ratio tries to insure :

$$T(z)H(z) \approx 1 \qquad \text{(II.3)}$$

where T(z) and H(z) are polynomials.

Also, if one doesn't take enough coefficients in his transversal filter, the error between the actual and the predicted output doesn't converge as shown by Figure 2 because the degree of H(z) is too small to obtain (II.3); but it doesn't diverge either, and still the coefficient corresponding to the channel delay is more important than the other ones (i.e. h_{17}, if one only takes 20 coefficients in the case described by the equation (II.2)).

We thus propose the following procedure to make a **sixteen coefficients transversal equalizer**. We periodically (for example every T_{work} equaling 500 data durations) sweep across the coefficient indexes corresponding to possible channel delays; (typically, for AIDA the ray tracing method allows us to predict some possible reflected path delays ranging till thirty data duration). At the end of a time period T_{work}, we select the - for instance two- largest transversal coefficients h_i and we decide that for the next T_{work} duration, we'll still udpate these largest weights but also coefficients whose indexes are multiples of the indexes of the largest coefficients indexes; (in the previous example, if h_{17} was the largest coefficient at time iT_{work} , we will update h_{17}, h_{34}, h_{51} and h_{68} between time (iT_{work} +1) and time $(i+1)T_{work}$). The remaining coefficients to be updated correspond to indexes within the possible channel delays, that were not updated during the last T_{work} duration. Consequently, if new propagation rays corresponding to those indexes appear at the receiver, the corresponding equalizer coefficients will rise and the equalizer is suited to non stationarities. The performance of this sixteen coefficients transversal equalizer is displayed in table 1 in the case of a two path simulated channel. It works as well as the classical transversal equalizer. This means that one should have a signal to noise ratio equal at least to 15dB.

In acoustical underwater transmission, one often has to cope with several paths. In the case of AIDA, one expects a direct path, a path reflected at the sea surface and one at the sea bottom. Nevertheless, the number of significative transversal coefficients is still small; effectively, in order to insure (II.3), the polynomial H(z) needs significant coefficients at degrees multiples of the channel path delays (in data duration) and at degrees that are sums of the previous degrees (multiplication of two polynomials). Such a sixteen weights transversal filter has been tested in the case of a three paths channel and still it works as well as the classical transversal filter.

III- EQUALIZATION AND PHASE RECOVERY

An additional trouble is the phase recovery of the received signal, particularly in the case of a Doppler drift due for instance to the relative motion of the emitter and of the receiver. If no attempt to recover the phase is made, the previous equalizer cannot work properly. As a Costas loop does not work well in our multipath context [1], we have used an equalizer that jointly tries to cancel the intersymbol interference and provides a phase estimator [2]. This transversal filter builts the following output:

$$c_k = Y_k^T H_{k-1}\, e^{-i.\varphi_{k-1}}$$

where $Y_k = [\ y_k, \ldots, y_{k-N+1}\ ]^T$is the observation vector (at time k), H_k is the equalizer coefficients vector (only 16 selected weights among the N coordinates are non zero), φk is the receiver phase.

The filter coefficients are updated in order to minimize the Mean Square Error (MSE) :

$J(H, \varphi) = E[|ek|^2]$

where $ek=ak-c(H, \varphi)$,ck is the equalizer output, ak is the decided symbol at the output of the equalizer

Once more, the stochastic gradient enables to reach the minimum of J. This procedure leads to an algorithm that jointly estimates the 16 coefficients of the equalizer and the phase :

$$H_k = H_{k-1} + \mu Y_k^* \exp i \varphi_{k-1} \; e_k$$
$$\varphi_k = \varphi_{k-1} + \gamma Y_{k-1} \mathrm{Im}(a_k^* c_k)$$

This algorithm has been tested with multipath channels experiencing a global Doppler drift like the following one :

$T(z) = (1 + A.z^{-17} + B.z^{-28}) \exp(-i \Phi_k)$

where Φ_k represents a linear phase drift. For phase drifts up to 0.001 rad/symb, such a joint equalizer gives results with no significant difference with table 1.

Finally , in a non stationary context and when no a priori knowledge is available about the channel stationarities, the practical determination of the stepsize can be difficult and can be made self adaptive; this leads to the following equations[3] [4]:

$$c_k = Y_k^T H_{k-1} \exp -i \varphi_{k-1}$$
$$e_k = a_k - c_k$$
$$\varphi_k = \varphi_{k-1} + \gamma_{k-1} Y_{k-1} \mathrm{Im}(a_k^* c_k)$$
$$\gamma_k = \gamma_{k-1} + \alpha F_{k-1} \mathrm{Im}(c_k a_k)$$
$$F_k = F_{k-1}(1 - \gamma_k \mathrm{Re}(c_k a_k)) + \mathrm{Im}(c_k a_k)$$
$$H_k = H_{k-1} + \mu Y_k^* \exp i \varphi_{k-1} \; e_k$$

IV - TEST WITH REAL DATA

Some data were recorded on a short link (300 meters) through the Blyth river. The first and the second line of figure 3 show respectively the emitted and the received BPSK signal at baseband level. The previous algorithm with reduced number of taps to update was tested on the received signal. The output of the equalizer and the decided signal are respectively displayed on the third and the fourth line of figure 3. It shows that the algorithm works perfectly in this case.

V - CONCLUSION

This paper addresses the task of designing an equalizer to counter multipath propagation with large channel delay spread and phase loss. It works well on synthetic propagation channels as well as on real channels. It is especially well suited for realtime applications thanks to its small number of coefficients to update.

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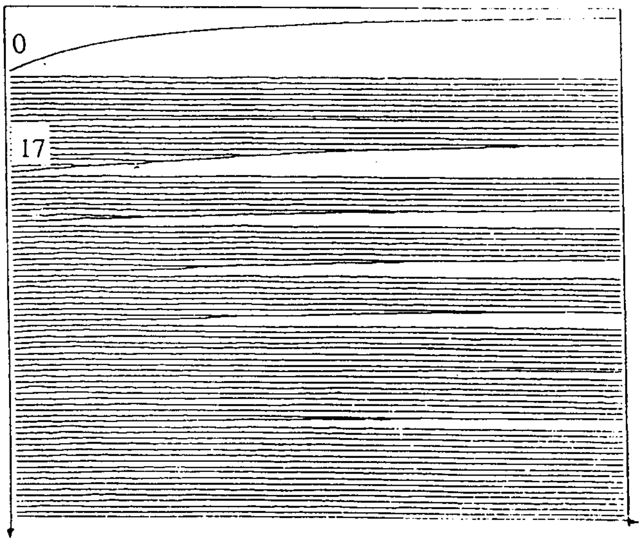

Figure 1 Coefficients when N is large enough

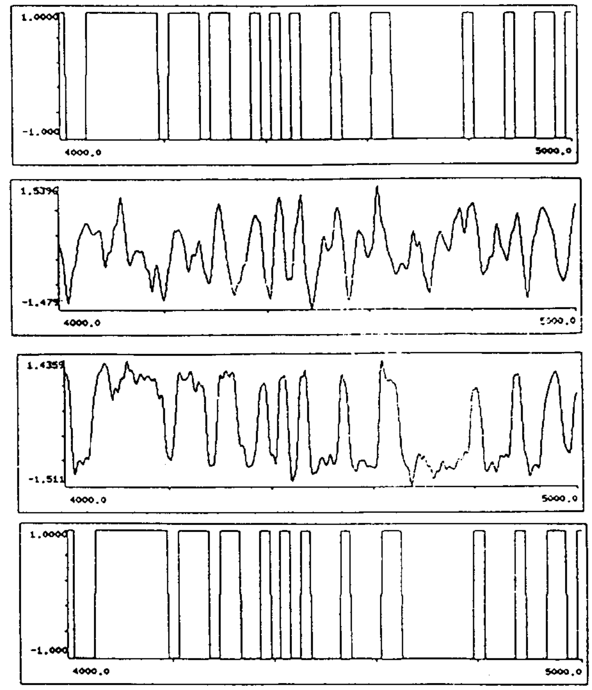

Figure3 Real data

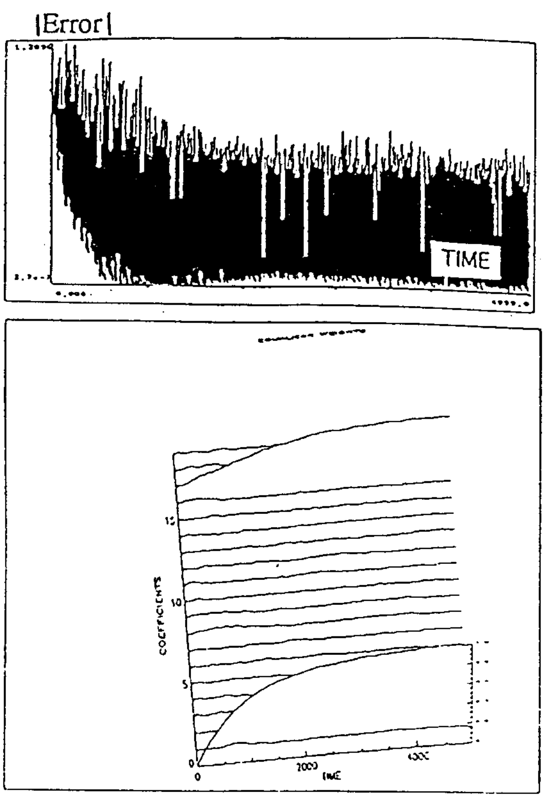

Figure2 Error and coefficients when N is too small

channel: 1direct path (amplitude 1) +one reflected path (delay 17) whose amplitude equals :	S/N (dB)	MSE TRANSV. (N=70)	MSE TRANSV. (N=16)
0,4	30	5,0E-3	9,1E-3
0,4	20	3,7E-2	8,3E-2
0,4	10	0,24	9,5E-2
0,4	3	0,57	0,21
0,8	30	3,5E-2	5,2E-2
0,8	20	0,10	0,10
0,8	10	0,35	0,15
0,8	3	0,76	0,23
0,99	30	8E-2	0,11
0,99	20	0,25	0,13
0,99	10	0,48	0,16
0,99	3	0,80	0,27

Table 1