A NOVEL MAP-MLSE ADAPTIVE RECEIVER WITH ENHANCED PERFORMANCE

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***Abstract* - Several contributions have recently shown that adaptive receivers based on Symbol-by-Symbol Maximum A Posteriori (SbS-MAP) equalizers are an attractive alternative to the more common ones based on Maximum Likelihood Sequence (MLS) detectors (see, e.g., [1,6]). However, these two equalizers present advantages that, if suitably exploited in a combined form, can be used to develop high performance adaptive receivers. In this paper, a novel adaptive receiver that merges the advantages of both SbS-MAP and MLS receivers is presented.**

I. AN OVERVIEW ON MLS AND SBS-MAP EQUALIZERS

Every equalization strategy is characterized by a decision delay and, in time-variant environments, the value of this delay greatly affects the performance of an adaptive receiver that exploits hard-decisions for channel estimation and tracking. In fact, D-delayed decisions imply the use of predicted channel estimates, the order of this prediction being D. As far as the order of the decision delay D is concerned, MLS and SbS-MAP equalizers present two opposite features: MLS equalizers deliver reliable data estimates when D is very large (at least five-six times the memory d introduced by the channel) [4], whereas SbS-MAP equalizers deliver reliable decisions for low values of D (of the order of the memory introduced by the channel) [1].

The optimality criterion on which MLS receivers are based is the minimization of the error probability on a *per-sequence* basis. The complexity of this algorithm grows linearly with the sequence length and is *optimum*, in an MLS sense, when the decision delay D is infinite. However, nearly optimum performance can be obtained with a finite decision delay of the order of five-six times the memory introduced by the channel [4]. When the channel is time variant and unknown, a value of D=5d, may be too large for channel tracking purposes and, for this reasons, improved versions of the adaptive MLS that employ "tentative" decisions (see Fig.1) with a limited decision delay d have been proposed [2]. However, due to the low value of the delay d, these tentative decisions generally exhibit a limited reliability that, in turns, degrades the receiver performance during deep faded periods.

The optimality criterion exploited by SbS-MAP receivers is the minimization of the *symbol* error probability [3], [4,Sect.6.6]. As it is well known, this algorithm is based on the computation of the probability of having received a symbol conditional on the past observations. Once these probabilities (*A Posteriori Probabilities*, APPs) are computed, the receiver selects as the decided symbol the one that has the highest a posteriori probability. The main drawback of an SbS-MAP receiver is due to its high computational complexity that is at least linear in the decision delay D [1] and this has limited their application in practical environments. However, these receivers have been recently "rediscovered" because they are able to generate *soft-information* in the form of APPs. For example, this soft-information is exploited in parallel concatenated coded systems during the process of iterative decoding; moreover, the APPs have been recently exploited in several other fields such as in blind equalization [5], channel estimation and tracking [6] and adaptive decoding [7]. In particular, in [6] a new channel estimator that is fed by the APPs of the states of the ISI channel (instead of the less informative hard-decisions) and that is able of generating reliable *zero-delayed filtered channel estimates* has been presented. This *soft channel estimator* represents the core of the proposed adaptive receiver.

II. THE PROPOSED ADAPTIVE RECEIVER

As mentioned in the previous Section, the most appealing feature of an SbS-MAP receiver is its ability of generating soft-information in the form of APPs, whereas the most appealing feature of an MLS receiver is reasonable computational complexity and nearly optimum performance for large values of D. The proposed receiver, sketched in Fig.2, combines these two features and it consists of an SbS-MAP detector that feeds a nonlinear, recursive and optimum (in an MMSE sense) Kalman-like channel estimator with the soft information given by the APPs of the state sequence of the ISI channel and of an MLS equalizer which outputs hard-detected data. Unlike the receiver in Fig.1, the one in Fig.2 *does not utilize* hard decided data for channel estimation and tracking so that unreliable "tentative" decision are not generated. This allows the receiver to build the VA trellis with more reliable zero-delayed channel estimates (in parallel with channel tracking) and to output the entire decided sequence with a decision delay equal to the length of the TDMA-slot. So doing, the proposed receiver yields to better performances than those obtained in [6] because the MLS equalizer operates at the largest decision delay (i.e., the TDMA-slot length), something an SbS-MAP receiver cannot do at a reasonable computational complexity.

Referring to a TDMA-based digital link impaired by time-variant multipath phenomena and AWGN, the baud-rate sampled complex sequence $\{r(i)\}$ received at the output of the equivalent low-pass randomly time-variant ISI channel can be modeled as

$$r(i)=\sum_{m=0}^{L-1} g(i;m)a(i-m)+w(i)\equiv G^{T}(i)\sigma(i)+w(i), \qquad (1)$$

where the transmitted sequence $\{a(i)\in B\}$ is constituted by M-ary complex independent identically distributed symbols taken from an assigned modulated constellation B and $\{g(i;m),$

$0 \le m \le L-1$, $i \ge 1\}$ in (1) is the T_S-sampled time-variant impulse-response of the overall link including the transmitting filter, the multipath-faded radio channel and the receiving filter.

An application of the so-called *Martingale Difference Representation Theorem*, allows us to derive the following channel nonlinear Kalman-like estimator (for more details on the analytical derivation of eq.(2) see [6]):

$$\hat{G}(i/i) = \hat{G}(i/i-1) + C_G(i)\left[r(i) - \hat{r}(i/i-1)\right]. \qquad (2)$$

The filtering gain $C_G(i)$ and the one-step MMSE prediction $\hat{r}(i/i-1)$ of the observation $r(i)$ in eq.(2) depend on $\pi(i/i) \equiv \left[P\left(\sigma(i) = \xi_1 / r_1^i\right)...P\left(\sigma(i) = \xi_N / r_1^i\right)\right]^T$, the vector of the APPs of the states of the ISI channel; this represents the *main novel feature* which distinguishes this channel estimator from the more conventional hard-decision based ones. For each received sample $r(i)$, the APP computer computes $\pi(i/i)$ and feeds it to the channel estimator (2) for updating the channel estimate $\hat{G}(i/i)$. In turns, this estimate is used step by step to build the branch metrics of the trellis of the Viterbi-detector. Finally, at the end of the TDMA-slot the VA outputs the entire estimated sequence on a per-slot basis.

III. SIMULATION RESULTS

The performances of the proposed adaptive receiver of Fig.1 (labeled RLS-MLS), of Fig.2 (labeled as Soft-VA) and of [6] (labeled as Soft-MAP) have been tested via computer simulations. The channel considered is the radio channel explicitly recommended by the GSM standard for test purposes [8,Fig.8.25.d]; this link is constituted by six equal-powered, T_S-spaced, Uncorrelated Scattering (US) taps affected by Rayleigh-distributed multipath phenomena. The adopted modulation is BPSK, the preamble and slot lengths are 8 and 40 symbols and the value of the product Doppler bandwidth-signaling period $B_D T_S$ is $5 \cdot 10^{-4}$.

In Fig.3 the superiority of the channel estimator fed by the APPs over the standard RLS one fed by the hard decisions is evident. Moreover, the proposed receiver allows us to obtain SNR gains of 6 dBs at a measured BEP of 10^{-6} over the receiver proposed in [6].

REFERENCES

[1] Y. Li, B. Vucetic, Y. Sato, “Optimum Soft-Output Detection for Channels with Intersymbol Interference”, *IEEE Trans. on Inform. Theory*, Vol.41, No.3, pp.704-713, May 1995.

[2] F.R. Magee, J. G. Proakis, “Adaptive Maximum Likelihood Sequence Estimation for Digital Signaling in the Presence of Intersymbol Interference”, *IEEE Trans. on Inform. Theory*, Vol.19, pp. 120-124, January 1973.

[3] K. Abend, B.D. Fritchman, “Statistical Detection for Communication Channels with Intersymbol Interference”, *IEEE Proc.*, Vol.58, No.5, pp.779-785, May 1970.

[4] J.G. Proakis, *Digital Communication*, 2nd Edition, Mc Graw Hill, 1989.

[5] E. Baccarelli, R. Cusani, S. Galli, “A Novel Approach to Blind Deconvolution Based on Second Order Soft Statistics”, *IEEE International Conference on Communications*, ICC’98, Atlanta, USA, 7-12 June 1998.

[6] E. Baccarelli, R. Cusani, S. Galli, “A Novel Adaptive Equalizer with Enhanced Channel-Tracking Capability for TDMA-Based Mobile Radio Communications”, *IEEE JSAC - Special Issue on Wireless Communications*, vol.16, no.9, December 1998.

[7] E. Baccarelli, S. Galli, A. Fasano, “A Novel Receiver and a Related Performance Bound for Combined Equalization and Decoding of TCM-data in TDMA-Based Cellular Mobile-Radio Systems”, *IEEE International Conference on Telecommunications*, ICT’98, Porto Carras, Grecia, 22-25 June 1998.

[8] R. Steele, *Mobile Radio Communications*, Pentech Press, London 1992.

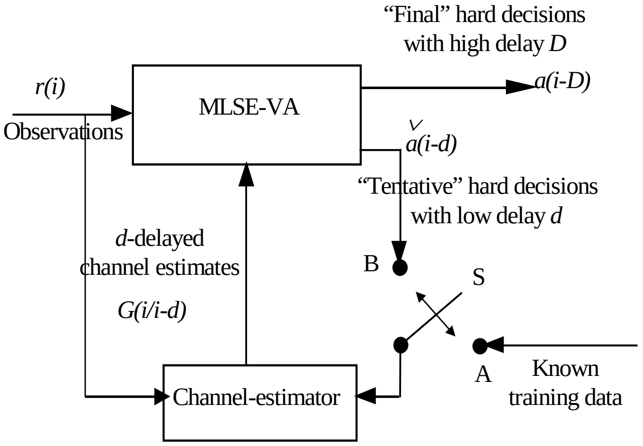

Fig. 1

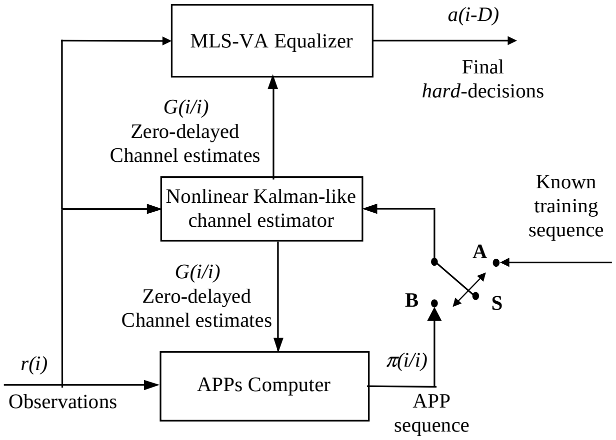

Fig. 2

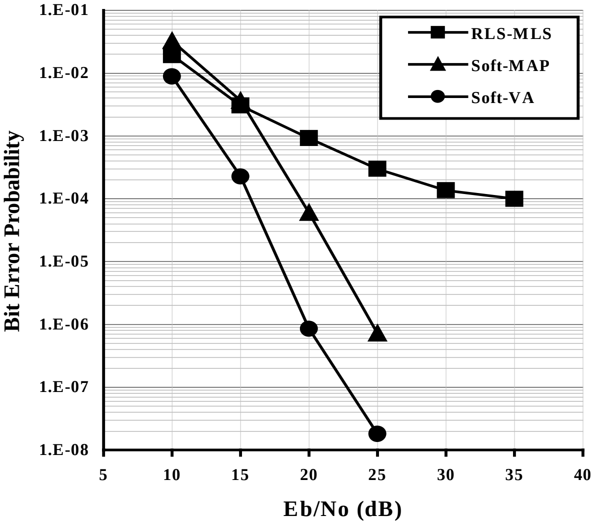

Fig.3