

COMBINING MLSE AND MAP DETECTION: A NEW WAY TO DEVELOP HIGH-PERFORMANCE ADAPTIVE RECEIVERS

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Abstract – In this paper we propose a novel adaptive receiver for TDMA-based cellular land-mobile radio communications that merges the advantages of both SbS-MAP and MLSE receivers. The exploitation of the advantages of these two equalization techniques in a combined form yields to high performance adaptive receivers. In fact, extensive computer simulations show that the proposed receiver outperforms other adaptive receivers that rely either on SbS-MAP or MLSE detectors only.

I. AN OVERVIEW ON MLS AND SBS-MAP EQUALIZERS

Every equalization technique 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 [3].

The optimality criterion on which MLS receivers are based is the minimization of the error probability on a *per-sequence* basis [1]. The complexity of this algorithm grows linearly with the sequence length and is *optimal*, in an MLS sense, when the decision delay D is infinite. However, it has been shown that nearly optimum performance can be obtained with a finite decision delay D of the order of five-six times the memory introduced by the channel d [1,5]. When the channel is unknown and the hard-decisions delivered by the MLS equalizer are employed by the channel estimator to track the channel fluctuations, better performances are obtained for smaller values of D . In fact, a

value of $D=5d$, may be too large for channel tracking purposes [3,Chap.6] and, for this reason, improved versions of the adaptive MLS that employ "tentative" decisions with a limited decision delay d have been proposed (see Fig.1). 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 [3,Sect.6.3].

The optimality criterion exploited by SbS-MAP receivers is the minimization of the *symbol* error probability [4], [5,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 [2] and this has limited their application in practical environments [5,Sect.6.6]. However, these receivers have been recently "rediscovered" because they are able to generate *soft-information* in the form of APPs and this new interest has led to the derivation of new algorithms for the computation of the APPs that present a computational complexity of the same order of the VA for limited values of the decision delay [2]. 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 channel estimates* has been presented. The adaptive

receiver presented in [6] is based on this new *soft channel estimator* and on an SbS-MAP equalizer for data detection. However, as it will be shown in the following Sections, better performances can be obtained when an MLS receiver is used in place of the SbS-MAP one at the price of a slight increase in complexity.

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 reduced computational complexity and nearly optimum performance for large values of D . The proposed receiver, sketched in Fig.2, combines these features in order to enhance its performances. Roughly speaking, 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.

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:

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

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 $\{g(i;m), 0 \leq m \leq L-1, i \geq 1\}$ 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* [7], allows us to derive the following nonlinear Kalman-like channel estimator (for more details on the analytical derivation of eq.(2) see [6]):

$$\hat{G}(i/i) = \hat{G}(i/i-1) + C_G(i)[r(i) - \hat{r}(i/i-1)] \quad (2)$$

where $\hat{G}(i/i) = E\{G(i)|r_1^i\}$. 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 $\pi(i/i)$, 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. 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.

III. SIMULATION RESULTS

The performances of the proposed adaptive receiver of Fig.2 (as well as those described in Fig.1 and [6]) have been tested via computer simulations. The channel considered in all the simulations 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 with time correlation modeled by the usual zero-order Bessel function $J_0(\cdot)$ [8, Sect.2.4.2]. In all the carried out tests, the adopted modulation is BPSK, the preamble and slot lengths are L_p and L_s symbols, the throughput ρ is set to 0.8 (as in the GSM standard) and the values of the product Doppler bandwidth-signaling period $B_D T_S$ are 10^{-4} and $5 \cdot 10^{-4}$ (in the GSM environment, this corresponds to a mobile speed of 30 and 150 Km/h, respectively).

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 2 dBs at a measured BEP of 10^{-6} over the receiver proposed in [6]. In Fig.4, the gain of the proposed receiver over the one proposed in [6] is of 6 dBs at a measured BEP of 10^{-6} . These results tend to indicate that, when the channel variations are faster, the exploitation of higher decision delays is more effective.

We have also evaluated via computer simulation the performance of the proposed receiver in Fig.2 for different values of the preamble and slot length. The results are shown in Tab.I and support the conclusion that the proposed receiver is robust with respect to these two system-design parameters.

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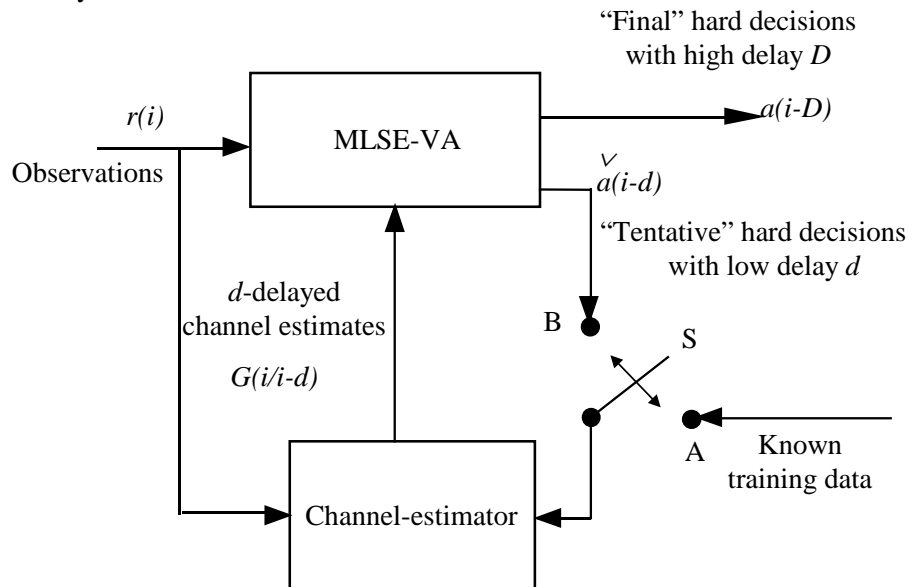


Fig. 1 - Conventional adaptive MLSE with "tentative" hard decisions that feed a RLS Kalman like channel estimator. The switch S is in position "A" during the training-intervals and in position "B" otherwise. The delays D and d for "final" and "tentative" decisions are typically set to five times and one time the delay-spread of the channel, respectively.

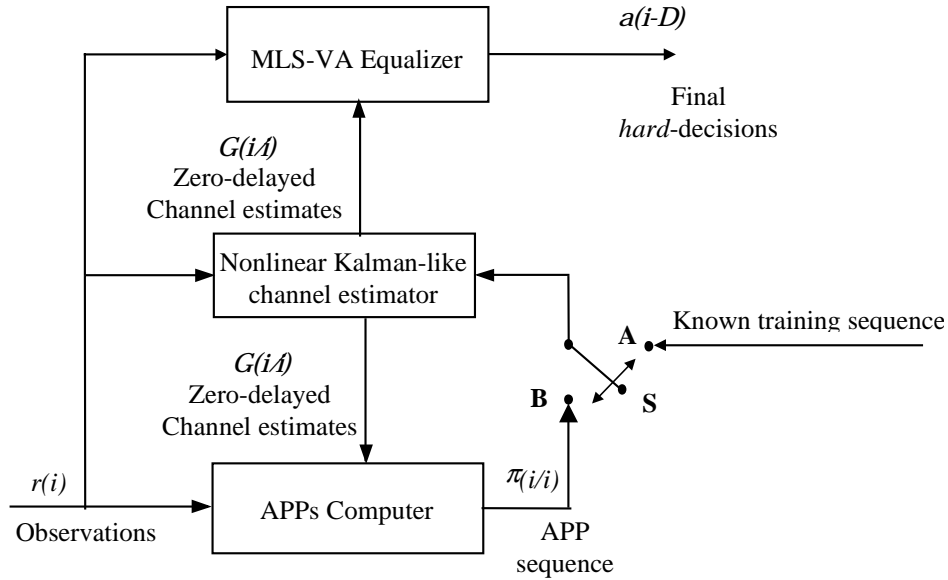


Fig. 2 - Block diagram of the proposed adaptive receiver. The switch S is in position “A” during the training-intervals and in position “B” otherwise. For each received sample $r(i)$ the APP computer (see Fig.2) computes $\pi(i/i)$ and feeds it to the channel estimator (2) for updating the channel estimate $\hat{G}(i/i)$. 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.

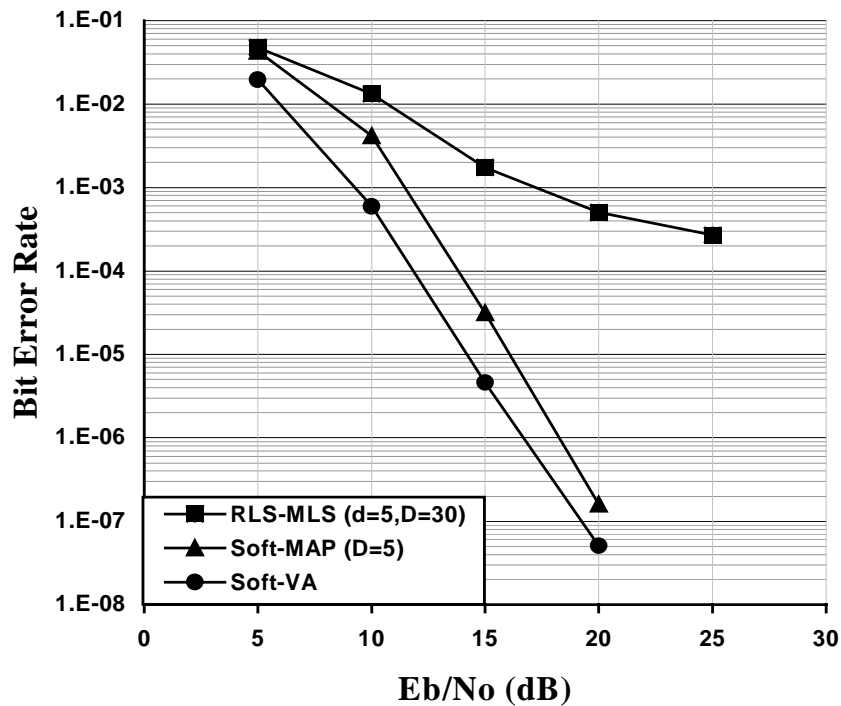


Fig. 3 - Performance comparison on the six-tap test channel described at the beginning of Sect.III. The receivers considered are the RLS-MLS of Fig.1, the receiver in [6] that employs the *soft channel estimator* followed by an SbS-MAP equalizer (curve labeled “Soft-MAP”) operating at a delay D and the proposed receiver of Fig.2 (curve labeled “Soft-VA”). Parameters: $L_p=12$, $L_f=60$, $B_D T_S = 10^{-4}$.

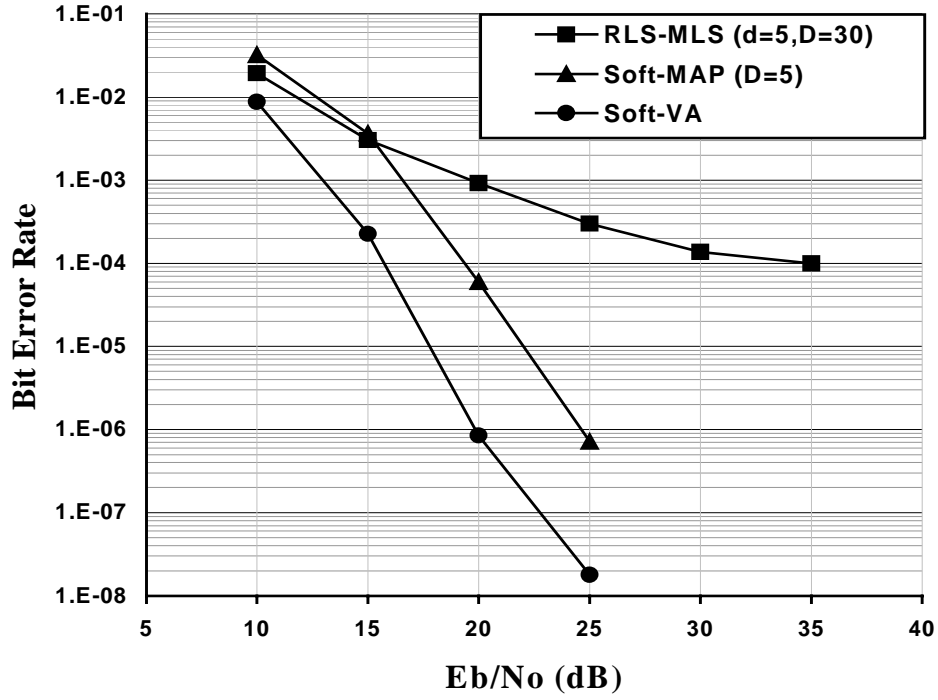


Fig. 4 - The same as in Fig.3 but with $L_p=8$, $L_f=40$, $B_D T_S = 5 \cdot 10^{-4}$.

(L_p, L_s)	(8,40)	(12,60)	(16,80)	(20,100)
$E_b/N_o=10$ dB - $B_D T_S=10^{-4}$	$1.42 \cdot 10^{-3}$	$5.72 \cdot 10^{-4}$	$7.34 \cdot 10^{-4}$	$8.45 \cdot 10^{-4}$
$E_b/N_o=15$ dB - $B_D T_S=10^{-4}$	$1.61 \cdot 10^{-5}$	$5.25 \cdot 10^{-6}$	$8.72 \cdot 10^{-6}$	$1.17 \cdot 10^{-5}$
$E_b/N_o=15$ dB - $B_D T_S=5 \cdot 10^{-4}$	$2.26 \cdot 10^{-4}$	$6.03 \cdot 10^{-4}$	$8.02 \cdot 10^{-4}$	$1.01 \cdot 10^{-3}$
$E_b/N_o=20$ dB - $B_D T_S=5 \cdot 10^{-4}$	$8.56 \cdot 10^{-7}$	$3.87 \cdot 10^{-6}$	$8.54 \cdot 10^{-6}$	$1.26 \cdot 10^{-5}$

Tab. I - Performance of the proposed receiver of Fig.2 versus the parameters L_p and L_s for the six tap channel described in Sect.III.