NOISE-PREDICTIVE TURBO EQUALIZATION FOR PARTIAL-RESPONSE CHANNELS

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System Overview

We consider an iterative decoding and detection system for magnetic recording channels. The system uses a zero-forcing equalizer to shape the channel response to a target polynomial, called a partial-response (PR) polynomial. We assume that the noise at the input to the equalizer is AWGN. Hence, noise enhancement and coloration occur at the output of the equalizer. The output of the equalizer, r_i, can be expressed as

$$r_i = a_i + \sum_{m=1}^{M} f_m a_{i-m} + n_i \ , \tag{1}$$

where $\{f_m\}$ are the target coefficients, $\{a_i\}$ is the input sequence and n_i is the colored noise.

The equalizer outputs are then decoded by an iterative decoding module, which includes a BCJR detector matched to the PR channel and a message-passing LDPC decoder. The two components operate independently while communicating soft information to each other. This scheme is often referred to as "turbo equalization". The turbo equalizer (TE) provides estimates of the a posteriori probability (APP) ratios of the coded bits. Both the BCJR and LDPC decoders are based on the assumption of AWGN. In this work, we aim to improve the system performance by incorporating noise prediction. This approach has previously been used to improve Viterbi detectors in PRML systems [1].

Turbo Equalization Using Noise Prediction

In noise prediction, one uses a set of known noise values, $\{n_k : k \in K\}$, to predict another unknown noise term, n_i. A linear predictor that minimizes the mean-squared prediction error,

$$E[e_i^2] = E[(n_i - \hat{n}_i)^2] = E[(n_i - \sum_{k \in K} c_k n_k)^2], \tag{2}$$

can be derived from the noise autocorrelation. For correlated noise, the error power is smaller than the noise power.

Fig. 1 depicts a noise-predictive turbo equalizer (NPTE). In each iteration, the APP ratios produced by the TE are used to obtain a subset of the colored noise terms that can be reliably estimated. If a bit's APP ratio falls inside one of two predefined intervals, [0, 1/R] or [R, ∞] (R>1), it is declared "reliable" and its value is set to 0 or 1, respectively. If M+1 consecutive bits, $\{a_i, a_{i-1}, \ldots, a_{i-M}\}$, are declared reliable, then the noiseless output of the PR channel can be reliably estimated. One can then calculate a colored noise estimate, $\tilde{n}_i$, by assigning the bit values, $\{\tilde{a}_{i-m}\}_{m=0}^{M}$, and the noisy channel output, r_i, in Eq. (1).

Next, a linear predictor of variable length is computed for each noise term. A search for neighboring noise estimates is performed on both past and future samples, up to a total of J adjacent neighbors. The search stops at the first "non estimated" noise term and results in a set of indices, $K^i=\{p,p+1,\ldots,-1,1,\ldots,f-1,f\}$, where $-J\leq p\leq 0$, $0\leq f\leq J$ and $f-p\leq J$. Note that K^i may be empty. In this case, no prediction will occur. The predicted noise can be written as

$$\hat{n}_i = \sum_{k=p}^{f} c_k^{K^i} \tilde{n}_{i+k} \ . \tag{3}$$

Thus, predictors of different noise terms use different sets of noise estimates combined with the appropriate coefficients. Moreover, the predictor of n_i may change between iterations.

Finally, new sample values together with associated variances are produced for each bit. The new samples are obtained by subtracting the predicted noise terms from the original channel outputs. Assuming feedback of correct noise estimates, we can rewrite the new values as

$$r_i' = r_i - \hat{n}_i = \sum_{m=0}^{M} f_m a_{i-m} + n_i - \hat{n}_i = \sum_{m=0}^{M} f_m a_{i-m} + e_i \ . \tag{4}$$

The new variances are the power of the prediction errors. These updated values and variances are fed back to the TE. In the next iteration, they replace the current noisy samples and variances that are to be used by the BCJR. This requires recalculation of the BCJR branch metrics but no modifications to the algorithm.

Simulation Results

Simulations were performed for a Lorentzian channel at recording densities of 2.60 and 2.85. The channel was equalized to PR4 and EPR4 targets using a 21 tap linear filter. The LDPC code has rate 8/9 and a codeword length of 4896 bits. The maximum number of decoding iterations was 24. Fig. 2 shows performance curves for a recording density of 2.60. It can be seen that NPTE with R=9 and J=2 on a PR4 channel (PR4-NPTE) outperforms a standard TE on an EPR4 channel (EPR4-TE). A similar effect was observed for a density of 2.85.

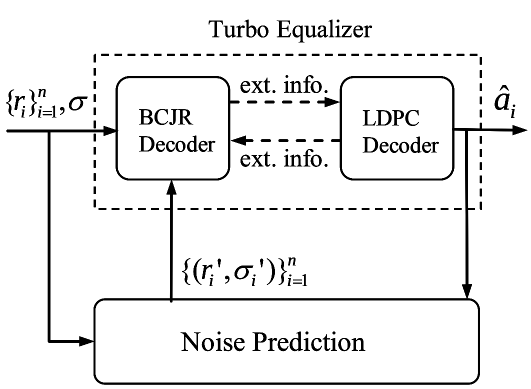

Fig. 1 NPTE system block diagram.

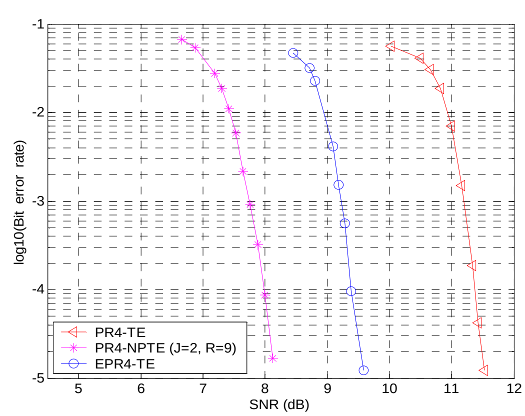

Fig. 2 Turbo equalizer performance (PW50/T=2.60).

References

[1] E. Eleftheriou and W. Hirt, IEEE Trans. on Magnetics, 32, 3968-3970 (Sept. 1996)