Reduced State Equalization of Multilevel Turbo Coded Signals

Oguz Bayat, Bahram Shafai, Osman N. Ucan

Northeastern University, Boston, MA, USA 02115

bayat.o@neu.edu, shafai@ece.neu.edu, uosman@istanbul.edu.tr

ABSTRACT

In this paper, a novel type of equalization technique, called "Double Decision Feedback Equalizer" (DDFE) is applied to multilevel turbo codes (MLTC) to improve bit error performance, and the entire system is called "Multilevel Turbo Equalization" (MLTEQ). In multilevel scheme, the parallel input data sequences are encoded at each level by turbo encoders, and then the coded data sequences are mapped to M-PSK signals, where M depends on the level quantity. After these modulated signals are passed through severe inter-symbol interference (ISI) and fading channels, the corrupted signals are equalized by an innovative iterative double decision feedback equalization technique, which uses adaptive LMS algorithm to estimate the channel taps with new equalization design. Then, the equalized signals are sent to the turbo decoders. The performance of new proposed MLTEQ system is investigated under non-frequency selective fading and frequency selective fading channels. As an application, two level turbo codes are simulated using 4-PSK modulation over AWGN, Rician, Rayleigh and Proakis B channels with 800 frame sizes. It is presented in the simulation results that satisfactory performance improvement is obtained with the proposed system over severe ISI and non-frequency selective fading channels.

I. INTRODUCTION

The challenge to find practical decoders for large codes had not been considered until turbo coding was introduced by Berrou et al in 1993 [1]. The performance of these new codes is close to the Shannon limit with relatively simple component codes and large interleavers. Turbo codes are a new class of error correction codes that enable reliable communications with high power efficiency. Turbo codes are the most efficient codes for low power applications such as deep space and satellite communications, as well as for interference limited applications such as third generation cellular and personal communication services.

Recently, there have been many attempts to improve the performance of turbo coded systems such as turbo trellis coded modulation (TTCM). For the same purpose, we construct a multilevel turbo codes with DDFE technique. Multilevel turbo coding maps the outputs of encoders to M-PSK signals, where each encoder is defined as a level. The number of encoders and decoders are equal for the multilevel scheme. For each level of multilevel encoder, there is a corresponding decoder, defined as a stage. Furthermore, except the first decoding stage, the information bits estimated from the previous decoding stages are used for the next stages.

In order to obtain a satisfactory bit error rate (BER) over severe channel at low signal to noise ratio (SNR), the improved equalization scheme has to be implemented into MLTC system. For this reason, we developed DDFE design to reduce the effects of the non-frequency, frequency selective fading and delay spread channels. The combined system is called multilevel turbo equalization. Although maximum a posteriori (MAP) equalizer is a well known optimum equalization by having satisfactory efficiency, it is bounded to low order modulation and short delay spread channels because of high complexity. The computational complexity of MAP equalizer is M^L for M-ary modulations, where L is the length of the ISI. Therefore, it is valuable to consider sub-optimum and reduced complexity equalization over frequency selective channels as in [6] and [7]. We propose a new turbo equalization technique that relies on double DFE. This technique is a reliable alternative to compensate the ISI effects at a relatively low computational cost. The receiver performance is improved by two consecutive DFE fed by the demodulator outputs and hard decisions of the turbo decoders.

This paper is organized as follows. Section II describes the design of multilevel turbo encoders. Section III describes the channel model, and the new DDFE based turbo equalization scheme. In section IV, multilevel turbo decoder is considered. Section V presents the performance of the proposed MLTEQ over AWGN, Rayleigh, Rician and Proakis B channels. As an application, two level turbo code constellation is investigated using 4PSK. Finally, conclusion is stated in section VI.

II. MULTILEVEL TURBO ENCODER

The main principle in the turbo coding scheme is to use two recursive systematic convolutional codes (RSC) with M memory in parallel. This means that the information sequence is encoded twice by using convolutional codes in the recursive systematic codes. In the first coding, information bits are coded directly, where the second coding is realized after scrambling the information bits. For scrambling the data, random interleaver is used. The output of the turbo codes consists of systematic data and parity data obtained by the RSC encoders.

Multilevel turbo encoder and decoder consist of many parallel turbo encoder/decoder levels as in Figure 1. Firstly, information sequence is converted from serial to parallel in multilevel scheme. Each turbo encoder processes the information sequence simultaneously. The coded information sequence, known as parity data, can be punctured to obtain the desired encoder rate. In our application, encoder rate 1/3 is used with generator sequence g(7,5), so the parity data is not punctured. The parity and systematic data are converted from parallel to serial by a multiplexer, and then the encoder outputs are channel interleaved and mapped to the M-PSK modulation.

For 4-PSK mapping of two level turbo codes, the first bit is taken from the first level turbo encoder output and the second bit is taken from second level encoder output. For M-PSK, bits are obtained in similar way from M level turbo encoders.

III. DDFE BASED TURBO EQUALIZATION

After the information sequence is encoded and modulated using M-PSK, it passes through the equivalent discrete channel. The channel output can be shown as

$$m_k = a_k u_k + n_k \tag{1}$$

Where n_k is Gaussian Noise and $\sigma^2=N_0/2E_s$ is the variance of the noise, a_k is Rician fading amplitude, which varies by Rician probability distribution function (pdf).

Additionally, multilevel turbo equalization is applied to Proakis B channel. This channel is time invariant ISI channel having L_2 casual, L_1 anti-casual terms, and is known as severe ISI channel with 3 main taps and no pre-cursor and post-cursor taps. The output of the channel is equal to

$$m_k = \sum_{i=-L_1}^{L_2} \Gamma_i u_{k-i} + n_k \tag{2}$$

Where Γ_k are the coefficients of the equivalent discrete channel. After the M-PSK modulated information sequence is passed throughout the channel, it is demodulated to the BPSK information sequence. Then the BPSK modulated signals are sent to the joint equalization and decoding process at each level.

As shown in Figure 2, DDFE structure mainly consists of 3 linear transversal filters; the feed forward (FF) filter, and two feedback filters (FB), a channel interleaver (π), deinterleaver ($\pi°$) and two delay components. The decoder sturucture is made of two interleavers (π_1), two deinterleavers ($\pi_1°$), a demultiplexer and two soft input soft output (SISO) decoders, which exchange priori information.

In order to reduce the notation of the equations and figures, the notation is not changed when information passed throughout the interleavers. Only the channel output feeds the equalizer at the first iteration, therefore the equalizer uses training sequence to operate for the initial process. For the further iterations, the FF filter is fed by the channel output and the channel estimator output. The channel estimator uses both the hard decision of the first decoder and the channel output to estimate the channel information. The first feedback filter (FB_1) uses the hard decision of the first decoder whereas the second feedback filter (FB_2) uses the hard decision of the second decoder.

In order to perform DDFE equalization, the coefficient of the equalizer is computed as in [10] by using mean square error (MSE), which is based on minimization of the difference between the equalized data and the hard decision of the first decoder as follows

$$\mathrm{E}|e_k|^2 \quad \text{where} \quad e_k = \hat{d}_k^{(1)} - h_k \tag{3}$$

$$h_k = \sum_{j=-L_1}^{0} v_j r_{k-j} - \sum_{j=1}^{L_2} w_j \hat{d}_{k-j}^{(1)} \tag{4}$$

L_1 and L_2 are the numbers of feedforward and feedback coefficients, respectively. v is the coefficient of the FF filter, where w is the coefficient of the FB_1 filter. Since the equivalent discrete channel taps are not know in most of the cases in communication, the least mean square (LMS) algorithm is used to determine the filter coefficients because of its less complexity and high accuracy on time invariant channels at large frame sizes. By using the LMS algorithm, the coefficients of channel and feedback filters are estimated from the corrupted transmitted signal and the hard decisions of the decoders after the certain latency (τ) is introduced to the system..

After the first iteration, the coefficient vectors of the FF, FB_1 and FB_2 filters are respectively computed as

$$V_k = [v_{-L_1}(k), v_{-L_1+1}(k), \ldots\ldots., v_0(k)]^T \tag{5}$$

$$W_k = [w_1(k), w_2(k), \ldots\ldots., w_{L_2}(k)]^T \tag{6}$$

$$Q_k = [q_1(k), q_2(k), \ldots\ldots\ldots\ldots., q_{L_3}(k)]^T \tag{7}$$

In the LMS algorithm, the coefficients of the FF and FB filters are adapted as follows

$$V_{k+1} = V_k + \Delta_V R_k (\hat{d}_k^{(1)} - r_k) \tag{8}$$

$$W_{k+1} = W_k + \Delta_W \hat{D}_k^{(1)} (\hat{d}_k^{(1)} - h_k) \tag{9}$$

$$Q_{k+1} = Q_k + \Delta_Q \hat{D}_k^{(2)} (\hat{d}_k^{(2)} - \bar{d}_k) \tag{10}$$

Where Δ is the step size of the LMS algorithm, and $R_k = [r_{k+L_1}(k), r_{k+L_1-1}(k), \ldots\ldots., r_k(k)]^T$ is the vector of the transmitted signal. The vectors below are the hard decision vectors of the decoders from the previous iteration.

$$\hat{D}_k^{(1)} = [\hat{d}_{k+L_2}^{(1)}(k), \hat{d}_{k+L_2-1}^{(1)}(k), ..., \hat{d}_{k+1}^{(1)}(k)]^T \quad (11)$$

$$\hat{D}_k^{(2)} = [\hat{d}_{k+L_3}^{(2)}(k), \hat{d}_{k+L_3-1}^{(2)}(k), ..., \hat{d}_{k+1}^{(2)}(k)]^T \quad (12)$$

After the corrupted transmitted signals are filtered by FF and FB_1 filters as shown in equation (4), it is deinterleaved (h_k) and subtracted from the output of the FB_2 filter. The DDFE output, which passes through the SISO decoders, is obtained as

$$\bar{d}_k = h_k - \sum_{j=1}^{L_3} q_k \hat{d}_k^{(2)} \quad (13)$$

During the initializing period, the coefficients of the FF filter at the first iteration are estimated from the training information sequence by the LMS criterion due to the fact that the hard decision of the decoder does not exist at the first iteration. Therefore, the DDFE structure behaves as linear equalizer fed by the training information sequence at the first iteration.

IV. MULTILEVEL TURBO DECODER

In turbo decoding, the maximum a posteriori algorithm is used to calculate the a posteriori probability of each bit with a perfect performance in each level of decoding process. The log likelihood ratio (LLR) is computed in [9] by using

$$\Lambda_k = \ln \frac{\sum_{S_1} \exp\left[\bar{\alpha}(s_k) + \bar{\gamma}(s_k \to s_{k+1}) + \bar{\beta}(s_{k+1})\right]}{\sum_{S_0} \exp\left[\bar{\alpha}(s_k) + \bar{\gamma}(s_k \to s_{k+1}) + \bar{\beta}(s_{k+1})\right]} \quad (14)$$

where $S_1 = \{s_k \to s_{k+1} : d_k = 1\}$ is the set of all state transitions associated with a message bit of 1, and $S_0 = \{s_k \to s_{k+1} : d_k = 0\}$ is the set of all state transitions associated with a message bit of 0. At the last iteration, we make the hard decision by using the second decoder output $\Lambda^{(2)}$ as follows

$$\hat{d}_k = \begin{cases} 1 & if \quad \Lambda^{(2)} \geq 0 \\ 0 & if \quad \Lambda^{(2)} < 0 \end{cases} \quad (15)$$

V. SIMULATION RESULTS

The BER performance of MLTEQ is evaluated over Rayleigh and Proakis B channels for frame size (N=800) in Figure 3 and 4, respectively. It is showed in Figure 3 that the performance of MLTC over AWGN channel is reached at the third iteration of MLTEQ system, when SNR is greater than 2.5 dB. MLTEQ system mitigates the effect of Rayleigh fading channel even at the second iteration when SNR is greater than 3.5 dB. Also if you compare MLTEQ system to MLTC system, MLTEQ has 2.2 dB gain for BER equal to 10^{-4}.

In Figure 4, the significant amount of gain is achieved at each iteration by reducing the frequency dispersive effects of Proakis B channel. When the SNR is 15 dB, the BER equal to 10^{-4} is obtained at the third iteration of proposed MLTEQ system.

VI. CONCLUSION

Multilevel turbo codes (MLTC) with double decision feedback equalizer (DDFE) called MLTEQ is presented in this paper. Simulation results are performed for two level turbo codes using 4-PSK over AWGN, Rician, Rayleigh and Proakis B channels, where frame size N=800 is selected. The DDFE overwhelms the effects of Rayleigh fading channel at the third iteration when SNR is greater than 2.5 dB, and DDFE also mitigates the ISI effects of Proakis B channel significantly at each iteration. Therefore, the desired bit error performance is achieved over severe ISI and non-frequency fading channels by proposed MLTEQ system at low number of iterations.

VII. REFERENCES

[1] C. Berrou, A Glavieux, and P. Thitimasjshima, "Near Shannon-limit error correcting coding and decoding: Turbo codes (1)", in Proc., IEEE Int. Conf. on Commun., (Geneva, Switzerland), pp. 1064-1070, May 1993.

[2] H.Imai and S.Hirakawa, "A new multilevel coding method using error-correcting codes", IEEE Trans. On Inform. Theory, Vol.IT-23, pp.371-377, May 1977.

[3] G.J. Pottie and D.P.Taylor, "Multilevel codes based on partitioning", IEEE Trans. Inform. Theory, vol.35, pp.87-98, Jan. 1989.

[4] J. G. Proakis, Digital Communications, McGraw-Hill, Fourth edition, 2000.

[5] B. L Yeap, T.H. Liew, L. Hanzo, "Comparative Study of Turbo Equalization Schemes Using Convolutional Turbo and Block Turbo Coders", IEEE Trans. Wireless Comm., vol.1, April 2002

[6] C. Loat, A. Glavieux, J. Labat, "Turbo Equalization: Adaptive Equalization and channel decoding Jointly Optimized", in IEEE journal on Selected Areas In Comm., vol. 19, pp. 1744-1752, September 2001.

[7] M. V. Eyupoglu, U. H. Qureshi, "Reduced State Sequence Estimation With Set Partitioning and Decision Feedback", IEEE Trans. Comm. Vol. 36, pp. 13-20, January 1988.

[8] O. Bayat, B. Shafai, O.N. Ucan "Improvement in equalization over fading channels" CDSP workshop, Northeastern University, Boston, MA, 2004.

[9] O. Bayat, A. Hisham, O. N. Ucan, O. Osman, "Performance of Turbo Coded Signals over fading channels", Journal of Electrical & Electronics Engineering, vol.2, pp.417-422, 2002.

[10] O. Bayat, B. Shafai, O.N. Ucan "An efficient channel equalization on the transmission of Turbo Coded Signals" in 2004 Proc. CIC conf., pp.58-64, Las Vegas, Nevada.

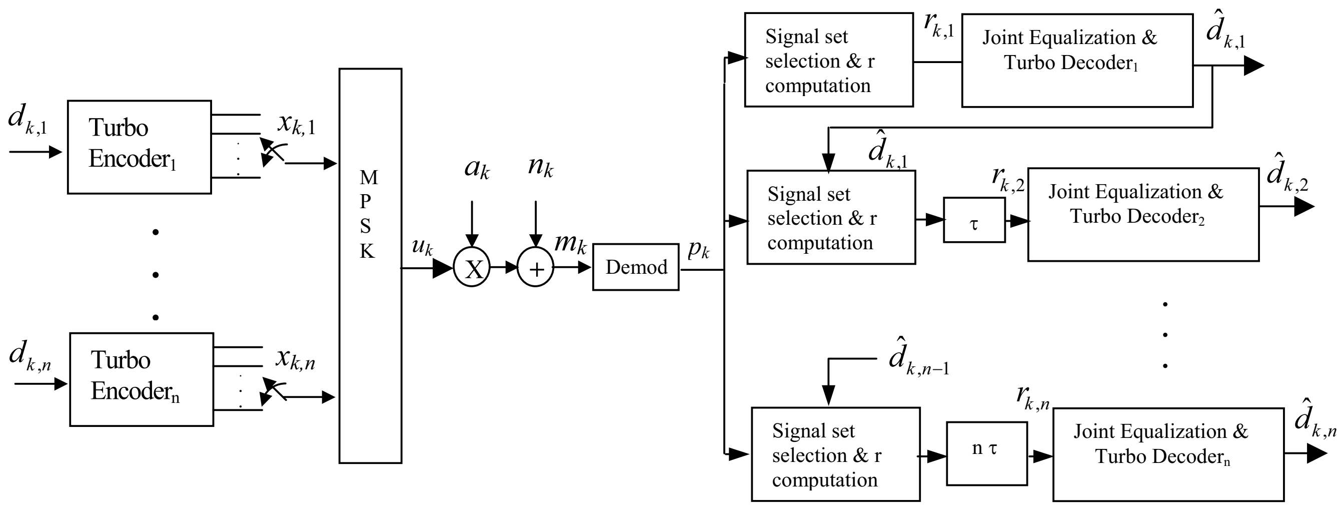

Figure 1. MLTEQ structure block diagram

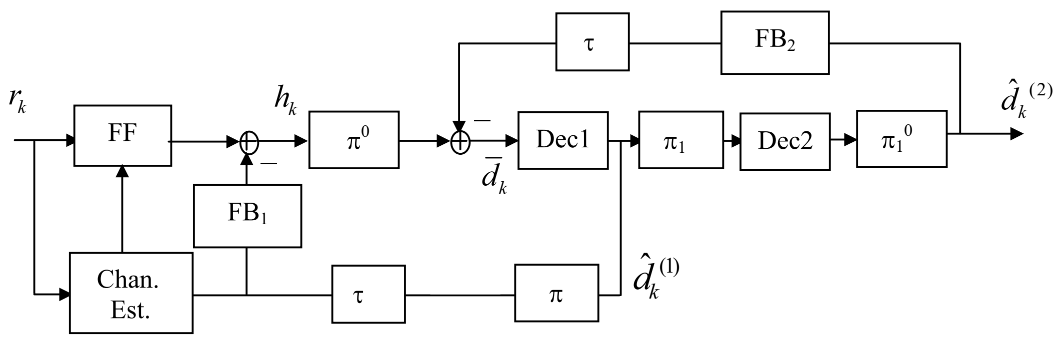

Figure 2. Joint DDFE and turbo decoder structure

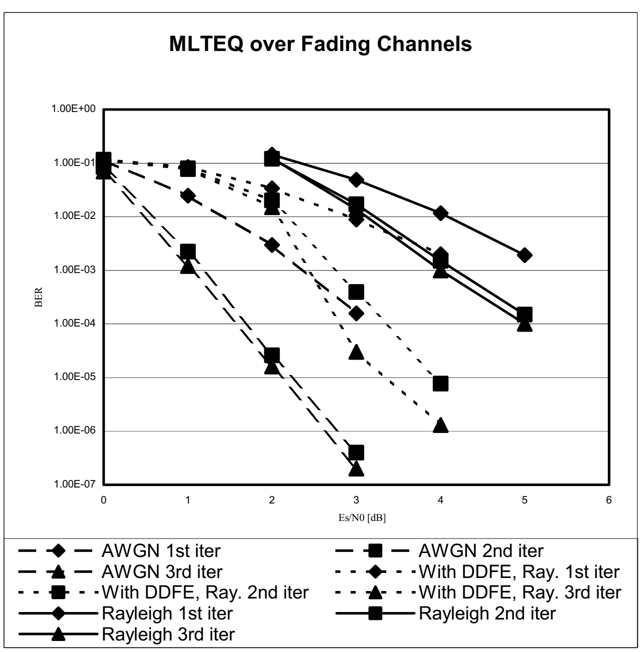

Figure 3. Performance of MLTEQ over Rayleigh Channel

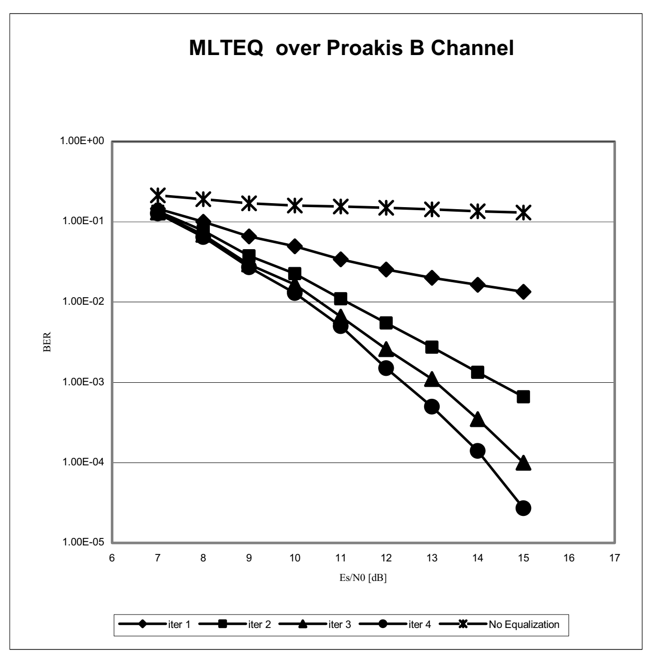

Figure 4. Performance of MLTEQ over Proakis B Channel