NOVEL MULTI-LEVEL MAGNETIC RECORDING USING MODERN ERROR CORRECTION

P. Shah[1], M.Z. Ahmed[1], M. Ambroze[2], C. Tjhai[2], P.J. Davey[1]
[1] Centre for Research in Information Storage Technology, University of Plymouth, Plymouth PL4 8AA, UK.
[2] Fixed and Mobile Comms. Research, University of Plymouth, Plymouth PL4 8AA, UK.
Email:{purav.shah,m.ahmed,m.ambroze,ctjhai,p.davey}@plymouth.ac.uk

Introduction

It has been shown that multilevel techniques operate closer to the channel capacity than binary for a bandwidth limited channel experiencing Additive White Gaussian Noise (AWGN) at increased Signal to Noise Ratio (SNR) [1]. Previous work[2] suggested that multi-level techniques, offered little, if any improvement of the magnetic recording capacity compared to the binary(two-level) system, and is eventually limited by amplitude irregularities in the magnetic channel. This paper looks at a new approach of applying powerful Error Correction Codes (ECC) on the multi-level magnetic recording channel and investigating the improvement in the performance.

The main idea behind multilevel recording is to enable storing of more information bits per transition on the magnetic medium. Several magnetisation levels could be used with the multi-level channel. It is known that at higher code rates for AWGN channels, binary codes tend to deviate very quickly from their theoretical performance[1]. In order to achieve very low error-rates at a particular SNR, it is necessary to use state of the art ECC like Turbo Codes. This paper examines the use of multilevel data in conjunction with Turbo codes, for a high density magnetic recording channel, to achieve increased channel capacity for a particular SNR in the operating region of the magnetic recording devices.

Simulation Model

Figure(1) shows a multi-level approach of a basic Partial Response - Maximum-A-Posteriori(PR-MAP) system with ECC. A complete software simulation of the PR channel with AWGN noise is performed using turbo codes as the ECC. The recording channel being assumed to be longitudinal, where the readback voltage from an isolated transition is approximated by a Lorentzian function with PW_{50}/T as the normalised recording density. The readback pusles obtained after adding the AWGN are equalised using the best Generalised Partial Response (GPR) target. This controls the Inter Symbol Interference(ISI) introduced by the Lorentzian function. Finally the PR equalised data is decoded using a trellis based MAP(BCJR) decoder [3].

Turbo Code Specifications: The outer ECC codes used for the simulation is 1/3 rate turbo code. The design of turbo codes is achieved using tail-biting recursive systematic convolutional codes with feed-forward polynomial $F_f = [37]_8$ and feed-back polynomial $F_b = [23]_8$ for an overall rate 1/3 turbo code. The turbo decoder is iterative parallel concatenated MAP decoder with extrinsic information exchange. The interleaver used is a S-random interleaver[4]. The block length is set to 500 information bits and the maximum number of iterations is set to 50. At least 100 error blocks were collected for each BER point.

Denoting the code rate of the ECC as R_1 and the code-rate for the 4-level system as $R_2 = 2$, the overall code rate of the 4-level system is

$$R = R_1 \times R_2 = 2R_1 \tag{1}$$

The channel SNR definition used for the system in the simulations is

$$SNR_{channel} = 10\log_{10}\left(\frac{1}{2\sigma^2}\right) \tag{2}$$

where σ is the standard deviation of the Gaussian Noise distribution.

Results and Discussions

The initial exhaustive search for the best GPR target gave the polynomial of the type $(1 - 0.8D - 0.2D^2)$ for 4-level recording for a PW_{50}=1.2 and $(1 - 0.5D - 0.5D^2)$ for 2-level(binary) recording for a PW_{50}=2.4. Results

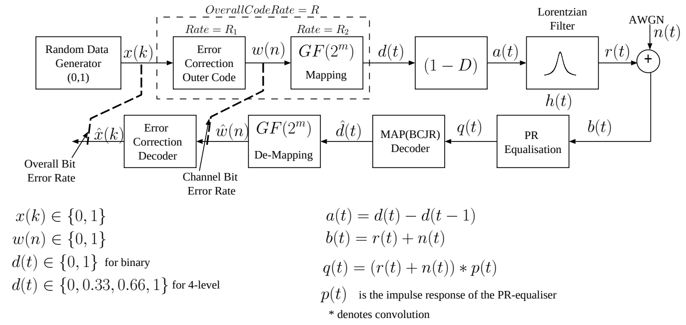

Figure 1: Simulated Multilevel Magnetic Recording System

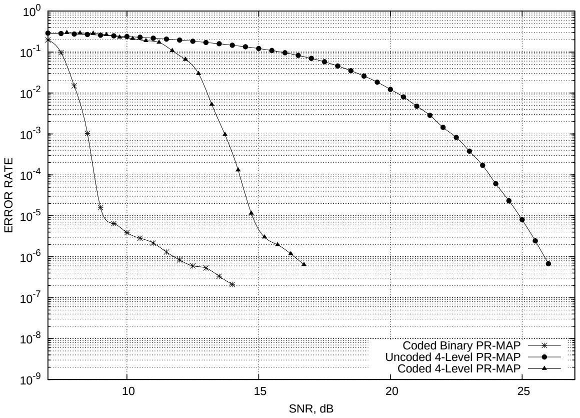

Figure 2: Error Rate vs SNR Performance Comparison of Multilevel Magnetic Recording Systems

shown in figure(2) show the variation of error rate on SNR for different configurations of the multi-level recording system. For an uncoded 4-level system, the desired base error rate of 10^{-5} is achieved at 25 dB SNR. To achieve the BER, the 4-level system with ECC requires almost 10 dB less channel SNR compared to the uncoded 4-level system. Also, it is seen that the coded binary system needs 6 dB less SNR than the coded 4-level system. The error floor of binary coded and 4-level coded systems is similar. At lower density, the colouration of the AWGN introduced by the PR equaliser would be less. Also, the use of multi-level signalling enables the use of lower rate ECC with larger minimum distances. In the normal operating region (19-22dB channel SNR) of the magnetic recording systems , it is seen from figure(2) that if both the binary and 4-level system performance curves are extended for a higher SNR, the error flow rate merges. This error floor merge is caused by the ECC properties and not by the modulation technique used. Hence, since both binary and multi-level coded systems have similar performance, at higher SNR, multi-level system works much closer to the capacity than the binary system.

Conclusions and Future Work

Simulation results were presented for the binary and multilevel, coded and uncoded PRML systems. Application of multilevel signalling has been shown to be beneficial, when the operating region of magnetic devices and low error rates were discussed. The error floor region which is the operating region of magnetic recording devices was shown and it was presented that the binary coded system had similar error floor to that of 4-level coded system. Lower rate codes with better ECC properties used with multilevel signalling and lower recording densities could have better performance compared to higher rate binary coded systems with high recording densities. Also the use of $GF(4)$ codes could give better performance than the $GF(2)$ codes used in the simulations. This could be a possible enhancement of the system described in this paper, resulting in improvement for multi-level magnetic recording systems incorporated with ECC.

References

[1] J. G.D. Forney and G.Ungerboeck, “Modulation and coding for linear gaussian channels,” *IEEE Transactions in Information Theory*, vol. 44, pp. 2384–2415, October 1998.

[2] N. D. Mackintosh and F. Jorgensen, “An analysis of multi-level encoding,” *IEEE Transactions on Magnetics*, vol. 17, pp. 3329–3331, nov 1981.

[3] L. Bahl, J. Cocke, F. Jelenik, and J. Raviv, “Optimal decoding of linear codes for minimising sybmol error rate,” *IEEE Transactions in Information Theory*, vol. 20, pp. 284–287, mar 1974.

[4] D. Divalsar and F. Pollara, “Turbo codes for pcs applications,” *Proceedings of IEEE*, vol. 1, pp. 54–59, June 1995.