Experimental performance of concatenated coding in shallow water channels.

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Abstract: In a series of phase coherent underwater acoustic communication experiments near the New England continental shelfbreak, the coding gain realized by a concatenated outer block code and trellis coded modulation (TCM) inner code was measured and compared to ideal asymptotic limits. Bit error rate as a function of output signal to noise ratio was computed to demonstrate practical, as opposed to asymptotic, coding gains.

INTRODUCTION

Adaptive decision feedback equalizer structures have been shown to be effective in combating the severe channel distortion and intersymbol interference found in many practical horizontal underwater acoustic communication channels specifically when phase-coherent modulation is used [1]. Given the time-variant nature of these channels, a degradation in tracking ability may occur when tap weight updates are delayed. A sub-optimal decoding method applicable to convolutionally encoded data streams in the presence of inter symbol interference (ISI) is obtained with a Viterbi decoder with a finite, truncated decision delay [2]. The inherent conflict between the delays required by the error coding algorithm and the intolerance to delays of a channel tracking algorithm is addressed in this work. Previous authors [3] have suggested a block interleaving structure that addresses opposing requirements at the expense of linear equalization for a portion of each data block. Consideration of the time constants of the adaptive receiver suggests a different approach. Over a large range of channel conditions, a recursive least-squares (RLS) tap update with a forgetting factor greater than 0.99 has proved adequate for tracking channel behavior. The time constant of this process is on the order of 100 symbols and delays on the order of tens of symbols may not be expected to compromise performance. An essential component of this receiver is the integrated phase-locked loop to account for doppler effects. Even without an evolution of the phase parameter, the phase correction required for each symbol may, in fact, change significantly on the scale of tens of symbols. With this motivation in mind, the receiver structure proposed here delays tap weight updates an amount adequate to realize coding gain in the Viterbi structure. The RLS parameter vector is simply applied discounting the delay while the phase correction is extrapolated.

RECEIVER STRUCTURE

The reader is referred to Stojanovic et. al. (1994) for a detailed discussion of the adaptive decision feedback equalizer. A coarse description of the signal processing steps is given here. The multi-channel input data stream forms the regressor for a set of feedforward taps. Decisions on previous symbols, either obtained in training mode or decision-directed mode, form the regressor for a set of feedback taps. The weights are then adapted based on a minimum mean square error criterion. A second-order phase locked loop provides carrier tracking. In this implementation, the combined output of the feedforward section is provided to the Viterbi decoder algorithm along with weights for the feedback taps. During each symbol interval, the Viterbi trellis is evolved in conventional fashion with an extrapolated carrier phase correction applied at each stage. The path metric is computed in two steps. First, a correction for ISI from previous symbols is computed for each state based on its unique symbol history. The output of the feedforward section is then corrected and compared to the symbol required for each allowed transition from the originating state. The squared magnitude of the difference is accumulated into total path metric. A preliminary decision is then released for addition to the feedback regressor and a final hard decision (with a larger yet delay) is also released. Schematically, the structure differs little from typical multi-channel DFE implementations with a Viterbi processing step replacing the slicer.

EXPERIMENTAL CONFIGURATION

An extensive data set was obtained during sea trials of the Acoustic Communications Advanced Technology Demonstration effort funded by the Office of Naval Research and conducted under the auspices of the Naval Undersea Warfare Center. Two surface vessels were deployed South of Cape Cod both over and off the continental
shelf. While receiving with a vertical line array on one drifting ship, transmissions were made from a second ship over a number of channels with differing range, bathymetry, and sound velocity profiles including both shallow (< 200 m) and deep (> 1000 m) depths. The three baseline waveforms were quadrature phase-shift keyed (QPSK), eight-level phase-shift keyed (8-PSK), and 16-level quadrature amplitude modulated (16-QAM) with TCM employed in the two higher level constellations. The 8-PSK modulation was based on Ungerboeck's proposed constraint length 3 code while the 16-QAM waveform utilized a constraint length 7 code. Source coding was employed through a cyclic, burst-error correcting code but outer code results will not be reported here. Both a medium frequency (3.5 kHz) and a high frequency (25 kHz) carrier was used with symbol rates of 1.25 kHz and 5 kHz, respectively. The performance summaries given below are based on approximately 2000 packets of each baseline waveform with 6300 symbols per packet. The data sets encompass the breadth of channels encountered and include both carriers.

EXPERIMENTAL RESULTS

Estimates of coding gain were obtained by generating histograms of symbol error rate versus output mean square error over all packets. Figure 1 presents such a summary for the 8-PSK TCM packets. For comparison purposes, the ideal error rate for QPSK transmissions over a dispersion-less channel with additive white gaussian noise is overlaid. Actual uncoded QPSK transmissions closely adhered to this ideal limit. An average coding gain of 2 – 3 dB was obtained. The asymptotic coding gain for the constraint length 3 code employed is 3.6 dB but coding gains at practical signal-to-noise ratios can be shown to fall short of this limit. If preliminary decisions are used for weight updates without any delay, the coding gain is reduced to less than 0.5 dB. Figure 2 is an equivalent summary for the 16-QAM TCM packets with the ideal error rate for 8-PSK transmission overlaid. The coding gain is more variable ranging from 2 dB to 5 dB. The asymptotic coding gain for the constraint length 7 code is 7.4 dB. A possible explanation for this may be the existence of non-Gaussian, impulsive biological noise sources.

FIGURE 1. The experimentally derived coding gain for trellis coded modulated signals over an aggregated range of underwater channels is seen by comparing the SNR for a given measured error rate (solid line) to the ideal performance of an uncoded signal over an AWGN channel (dashed line). The left panel gives results for a constraint length 3, rate 2/3 code while the right panel gives results for a constraint length 7, rate 3/4 code.

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REFERENCES