BASEBAND TRELLIS CODED MODULATION WITH COMBINED EQUALIZATION / DECODING FOR HIGH BIT RATE DIGITAL SUBSCRIBER LOOPS

P. Mohanraj * , D.D. Falconer ** , T. A. Kwasniewski *

Carleton University , Ottawa , Canada

* Department of Electronics

** Department of Systems and Computer Engineering

Abstract

We present simulation based study evaluating the performance of trellis coded modulation with combined code/ISI sequence estimation, for high bit rate (800Kbits/sec) transmission on subscriber loops. The receiver contains the fractionally-spaced forward filter of a decision feedback equalizer (DFE) as a front end ; this is shown to suppress phase-synchronized crosstalk very effectively. The performance is further enhanced by the use of a trellis code with a large number of states, and a M-algorithm sequence-estimating receiver with a smaller number of states.

1. Introduction

Channel capacity results for the digital subscriber loop (DSL) systems presented in [Jos87] indicate that digital transmission at bit rates significantly higher than 160 Kbits/sec is possible on loops in the carrier serving area (CSA). Several transmission schemes such as multichannel transceiver [Tu89] and trellis precoding [Eyu90] are being studied to achieve high bit rate (800Kbits/sec and above) on local subscriber loops. In this work we present simulation studies for the performance evaluation of a trellis coded modulation system with combined code/ISI sequence estimator at the receiver.

The performance of a coded system depends on the minimum distance (d_{min}) between the received sequences. Minimum distances for codes of various complexity (i.e., number of states) were calculated using the method proposed in [Mes73]. It was found that the severe distortion of the subscriber loop channel necessitates the use of codes with large numbers of states to obtain reasonable coding gain.

An efficient VLSI realization of the transceiver is one of the major considerations in the design of the transceiver architecture. The architecture chosen for this study consists of a fractionally (T/2) spaced adaptive DFE(decision feedback equalizer) forward filter followed by a sequence estimator. The fractionally-spaced DFE forward filter acts as a pre-whitening filter for the sequence estimator [For72],[Cio89] and has been shown to suppress cyclostationary crosstalk [Abd89]. We evaluate the mean squared error performance of the fractionally spaced forward filter under stationary and cyclostationary crosstalk. The complexity of the sequence estimator depends on the number of states in the receiver. Reduced complexity sequence estimators such as M-algorithm [Moh86] and decision feedback sequence estimators [Hal89] offer significant performance improvement with reasonable complexity. The transmission system considered for this study is shown in Fig. 1. We determine the range (loop length) of the high bit rate digital subscriber loop system using an 8 state M-algorithm receiver by evaluating the probability of error for various loop lengths.

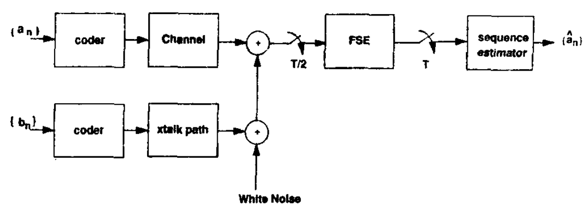

Fig 1. Trellis Coded Modulation System

2. Fractionally spaced receive filter

The impulse response of the subscriber loop extends over several hundred symbol periods in high bit rate DSL. To implement a receiver of reasonable complexity, it is necessary to shorten the length of the impulse response. A fractionally spaced receive filter can synthesize the best adaptive receive filter so as to minimize the the mean squared error due to precursor and postcursor ISI and noise [Git81]. Hence a fractionally spaced (T/2) forward filter is used as the receiver filter in this study.

It has been shown [Fun89] that the crosstalk interference exhibits cyclostationary behaviour when all of the interferers are phase synchronized to the same clock and it exhibits stationary behaviour when they have randomly distributed phase. The instantaneous power of the cyclostationary crosstalk varies periodically with the period equal to the symbol duration, while the power of the stationary crosstalk remains constant throughout the symbol period. The performance (mean squared error or SNR of DFE receiver) of the optimum fractionally spaced receive filter was calculated for an uncoded 2B1Q 800Kbits/s system on the worst case CSA loop (9kft,26Gauge) under cyclostationary and stationary interference assumptions. The results are shown in table 1. A receiver structure with 21 forward and 60 feedback taps has been considered. Further increase in the number of forward taps does not yield any significant improvement in the performance. The crosstalk path power transfer function was assumed to be $k * f^{3/2}$, where $k = 10^{-11.8}$ which includes the 12dB noise margin beyond the 99% worst case interference level from 49 crosstalkers. It can be observed that a significantly better performance can be obtained if the interferers are synchronized to the same clock.

CH2827-4/90/0000-1669 $1.00 © 1990 IEEE

Table 1

Noise Characteristics	SNR in dB
Stationary	14.05
Cyclostationary	25.82

Another result that is of interest is the effect of the bandwidth of the lowpass filter, at the receiver front end, on the performance in the cyclostationary interference case. This is due to the fact that the degree of cyclostationarity depends on the bandwidth of the interfering process. It has been shown [Gar75] that when the bandwidth is strictly limited to 1/2T, then the process is stationary. The mean squared error performance of the optimum fractionally spaced forward filters for three different lowpass filter bandwidths (6th order butterworth filter with 3dB cutoff frequency at 150kHz, 200kHz, 250kHz) was calculated. The results shown in table 2 indicate that when the interference is band limited to 150kHz. which is less than 1/2T, the performance is approximately the same as the stationary case, but better performance is obtained when the degree of cyclostationarity is increased by increasing the lowpass filter bandwidth. The equalized crosstalk path spectra are shown in Fig. 2 (under the assumptions mentioned previously) for the three bandwidths considered along with the stationary crosstalk equalized spectrum. The similarity between the stationary case and the 150kHz bandwidth case is noticeable.

Table 2

Bandwidth	SNR in dB	
kHz	Cyclostationary	Stationary
150	14.05	13.88
200	25.82	14.05
250	40.45	13.96

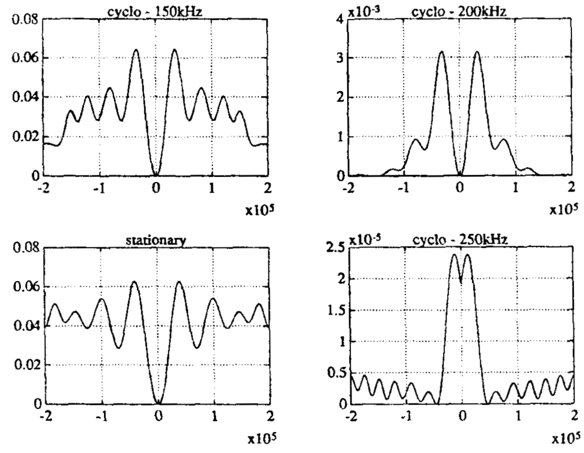

Fig 2. Equalized crosstalk path power spectra

3. Minimum distance of coded system on ISI channel

Trellis coded modulation was initially proposed by Ungerboeck [Ung82] to gain noise immunity for digital transmission on band limited channels. On an ideal AWGN channel, coding gains of the order of 3 to 6 dB were obtained using codes with 4 to 256 states. When these codes are used on dispersive channels, there is a considerable degradation in the coding gain. Ketchum [Ket87] has shown that on (1-D) channel these codes could incur upto 3 dB less coding gain as compared to that on the ideal channel. On subscriber loop channels with severe high frequency attenuation similar loss in the performance can be expected. Hence it may be necessary to use more complex codes with large numbers of states to obtain reasonable coding gains. The trellis codes considered here use an 8 level PAM signal set transmitting 2bits/symbol at a symbol rate of 400 Kbaud.

The performance of the coded system on a dispersive channel depends on the Euclidean distance between the received signal sequences [For72], and the distance spectrum of the trellis coded system depends on the transmitted sequence. It has been shown [Mes73] that for an uncoded system on dispersive channel, the minimum distance error sequences are given by relatively short error sequences. We have found this to be true for coded systems as well. The minimum distances for many random transmitted sequences were calculated. Exhaustive searching of all possible incorrect sequences is avoided by pruning parts of the error tree when the unmerged error sequence has a distance greater than that of a merged error sequence. This prevents the exponential increase in the computation time as the error sequence length is increased. Error sequences upto a length of 15 symbols were considered. The distance spectrum in Fig. 3 shows the frequency of occurence of error events with squared distance d^2 in a trial of 100 different (random) transmitted sequences for two different codes. Even though we did not consider all possible transmitted sequences we expect that the relative distances for the two codes would be the same. It can be observed that the more complex code (with 64 states) has a larger d_{min} compared to the simple 4 state code, and also that the 64 state code tends to have a higher proportion of sequences with larger than the minimum distance.

4. Combined equalization and decoding

A sequence estimation receiver is implicitly assumed in any trellis coded modulation system. Two receiver architectures for trellis coded modulation system on ISI channels were considered. One is a DFE, to cancel the ISI, followed by a sequence estimator that uses the encoder trellis to decode the transmitted signal. The other is the combined equalization and decoding structure that uses the composite trellis of the encoder and the channel. It has been shown [Jos88] that the performance of the former is worse than an uncoded system with a DFE for DSL channel with severe ISI. Hence the combined equalization/decoding receiver was chosen for this study. The complexity of the Viterbi receiver for the latter is prohibitively high due to long channel response. Hence the reduced complexity M-algorithm is used in this study; note that this algorithm can allow fewer receiver states than the transmitter states. Preliminary estimates by us indicate that the current VLSI technology can support the implementation of an 8 state M-algorithm sequence estimator. A third alternative is the trellis coding combined with a modified version of Tomlinson precoding at the transmitter [Eyu90]. While this has been found to be effective, it requires additional coordination between the two ends, and may complicate the echo canceller.

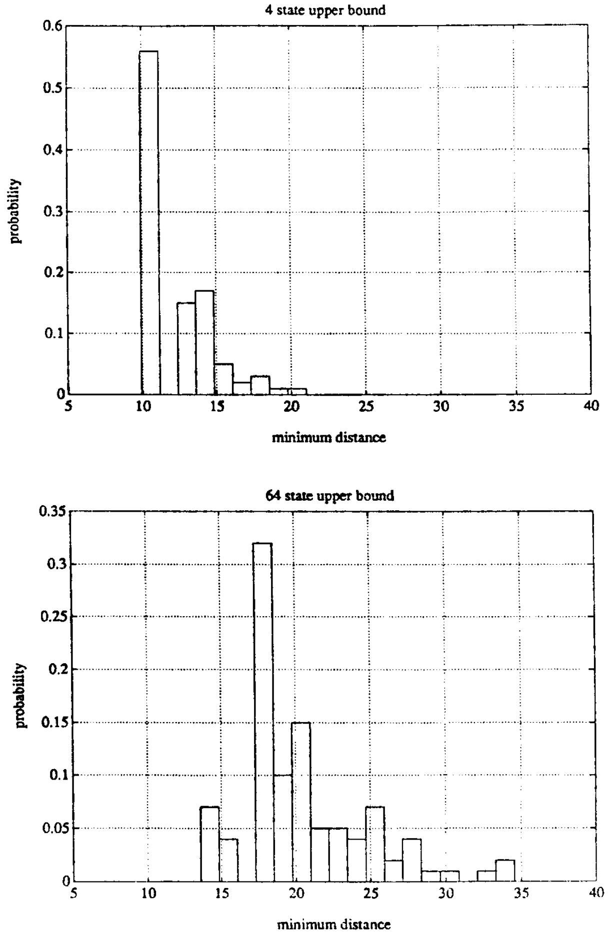

Fig 3. Distance Spectrum

Simulation results for the symbol error probability were obtained for 26 gauge loops of various lengths. Two codes with 4 and 64 states were considered in this study. While encoders of different complexity were considered, the receivers had a fixed number of states. An 8 state M-algorithm receiver with a decoding delay of 100 symbol intervals was used. A fractionally spaced (T/2) forward filter with 21 taps was used to suppress any precursor and to limit the postcursor length. The bandwidth of the lowpass filter at the receiver front end is 200kHz. The worst case interference from 49 crosstalkers was assumed [Tu89]. A 12 dB noise margin was provided by scaling the above level of crosstalk. The white noise power spectral density was assumed to be -110dBm/Hz.

Figure 4a shows the performance achievable using the trellis system with combined equalization and decoding under stationary interference for various loop lengths. Also shown in Fig. 4a is the performance of an uncoded system with a DFE receiver. Similar results for the cyclostationary interference condtions are shown in Fig. 4b. It can observed that the trellis coded system can provide longer loop coverage (of course with at least 8 times more complex receiver) compared to the DFE system. The transmission range under cyclostationary noise is significantly higher than that of the stationary noise.

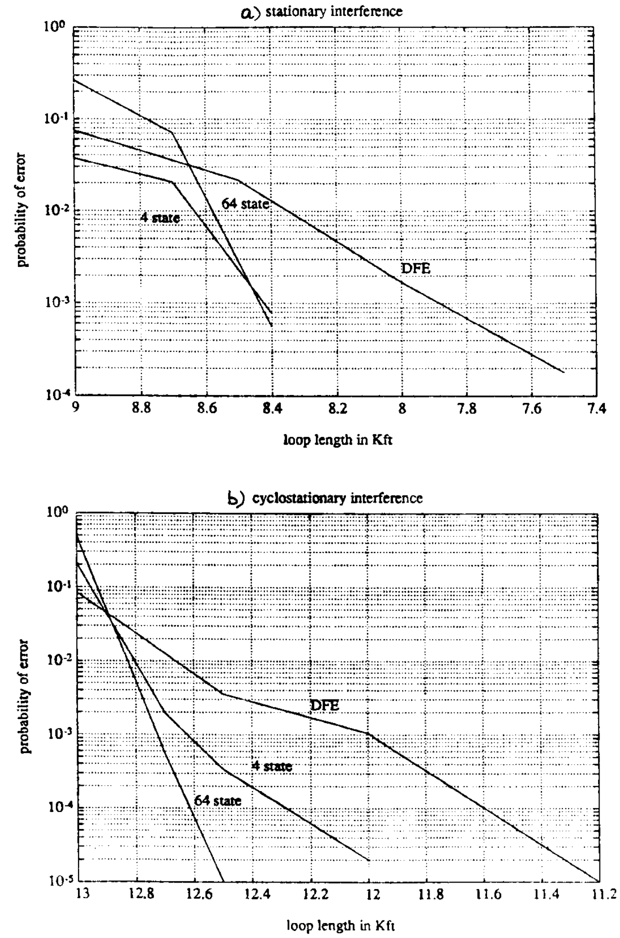

Fig 4. Performance of the coded system

Conclusion

In this paper we have reported a simulation study to determine the performance of a trellis coded modulation system for high bit rate digital subscriber loop. We consider the transmission scheme with all the equalization performed at the receiver as an alternative to the transmitter equalization. We observe that trellis codes with large numbers of states are needed to obtain reasonable coding gain on a channel with severe ISI, such as DSL. Coded modulation along with a reduced complexity sequence estimator (combined equalization and decoding with fewer states) can improve the the transmission range of the high bit rate DSL system. The results indicate that achieving high bit rate transmission on the worst case CSA loops with 12 dB noise margin under stationary interference conditions is not possible, while loops longer than the CSA limit can be covered under cyclostationary interference. The bandwidth of the receiver lowpass filter is observed to have a significant effect on the performance of the receiver under cyclostationary interference.

Acknowledgements

This work was partly supported by Telecommunications Research Institute of Ontario (TRIO) and by the Canadian Commonwealth Scholarship Scheme.

References

[Abd89] M. Abdulrahman , ' Decision Feedback equalization with cyclostationary interference for DSL ', M.Eng. Thesis, June 1989 , Department of Systems and Computer Engineering, Carleton University.

[Cio89] J. Cioffi, et al, ' Data transmission with mean-square partial response ', Conf. Record, Globecom '89.

[Eyu90] M.V. Eyuboglu, et al, ' Trellis precoding for high-rate transmission on subscriber loops ', IEEE HDSL Workshop '90.

[For72] G.D. Forney, ' Maximum likelihood sequence estimation of digital sequences in the presence of intersymbol interference ', IEEE Trans. on Comm. , May '72.

[Fun89] A. Fung, et al, ' A facility for near end crosstalk measurements on ISDN subscriber loops ', Conf. Record, Globecom '89.

[Gar75] W.A. Gardner, ' Characterization of cyclostationary random signal processes ', IEEE Trans. on Inform. Theory, Jan '75.

[Git81] R.D. Gitlin , et al, ' Fractionally-spaced equalization: An improved digital transversal equalizer ', B.S.T.J, Feb '81.

[Hal89] A. Duel-Hallen, et al, ' Delayed decision feedback sequence estimation ', IEEE Trans. on Comm. , May '89.

[Jos87] V. Joshi, et al, ' Channel capacity bounds for the subscriber loops ', Pacific Rim Conference on Communication, Computer and Signal Processing, '87.

[Jos88] V. Joshi, ' Sequence estimation techniques for enhanced digital subscriber loop transmission capability ', Ph.D. Thesis, June '88, Department of Systems and Computer Engineering, Carleton University.

[Ket87] J. W. Ketchum, ' Performance of trellis codes for M-ary partial response ', Conf. Record, Globecom '87.

[Mes73] D.G. Messerschmitt , ' Geometric theory of Intersymbol interference' B.S.T.J, Nov '73.

[Moh86] S. Mohan, et al, ' A multiprocessor architecture for (M,L) algorithm suitable for VLSI implementation ', IEEE Trans. on Comm., Dec '86.

[Tu89] J.C. Tu, et al, ' Crosstalk limited performance of a computationally efficient mutichannel transceiver for High rate DSL ', Conf. Record, Globecom '89.

[Ung82] G. Ungerboeck, ' Channel coding with multilevel/phase signals ', IEEE Trans. on Inform. Theory, Jan '82.