New Controlled State-Expansion Sequence Estimation for TCM

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Abstract

We developed a new decoding strategy, namely, Controlled State-Expansion Sequence Estimation (CSESE) for Trellis Coded Modulation (TCM) schemes. TCM is a power efficient and bandwidth efficient coded modulation scheme [14,15], finds many advanced communication applications. Invention of TCM schemes initiated the era of development of bandwidth efficient coded modulation schemes. There is renewed interest for the invention of robust and efficient decoding strategies as well. The optimum decoding strategy for TCM schemes in the presence of Additive White Gaussian Noise (AWGN) is the Maximum Likelihood Sequence Estimation (MLSE)[12,14,15,18]. For the implementation of MLSE Soft output Viterbi algorithm is used. The complexity requirement of MLSE prohibits its use for bandlimited ISI channels practically. Later developments in the research arena emphasized on the development of sub-optimum decoding strategies for TCM schemes [1,17,21,22,25].

The new strategy we have developed, namely CSESE, is a controlled state-expansion sequence estimation approach emphasized on expansion of states of the trellis structure being processed, based on the decision parameters of the algorithm. Simulation results depicts that it is a faster approach. The number of states processed during each iteration varies with some of the coefficients which define the optimality of the algorithm.

1. Introduction

Over the decades, advancement in digital communication technology and ever increasing demand for faster and reliable data transmission stimulated the research for newer inventions. Trellis Coded Modulation (TCM) is an integrated coded modulation approach for high rate digital data transmission. Invention of TCM schemes motivated the researchers for the development of new bandwidth efficient coded modulation schemes and decoding strategies accordingly. Maximum Likelihood Sequence Estimation is the optimum decoding strategy for TCM schemes. But the higher computational complexity of MLSE prohibits its use in practice. Later developments in the research emphasize on the development of reduced complexity suboptimum decoding strategies. Reduced State Sequence Estimation (RSSE) is one of the sub-optimum approaches for TCM schemes, provides symmetric distribution of states for the reduced trellis structures [20,21]. It finds many wireless communication applications.

The new decoding strategy given in this paper, namely, Controlled-State Expansion Sequence Estimation (CSESE), is an integrated approach for TCM schemes transmission over bandlimited ISI channels. It comprises an algorithm for controlled-state expansion integrated with the MLSE implemented through soft output Viterbi algorithm. During each symbol interval, the CSESE determines the number of states to be processed in the next iteration, as a function of the expansion parameter defined in the algorithm. The algorithm provides faster decoding performance compared to RSSE[20,21] considered as conventional approach (c_RSSE).

This paper is organized as follows: In Section 2, general structure of TCM encoder/modulator has been explained and the optimum MLSE is explained. In the section 3, a brief description of finite state machine model of band-limited ISI channel and the conventional Reduced-State Sequence Estimation (RSSE) are given. The Section 4 explains CSESE. Computer simulation results and conclusions are given in section 5. Next Section contains the acknowledgment and, in the following section references are listed.

2. TCM Encoder

The general structure of TCM encoder/modulator employs redundant nonbinary modulation. It comprises a finite state convolutional encoder of rate $\tilde{m}/\tilde{m}+1$which governs the selection of modulation signals. When m-bits are to be transmitted per encoder/modulator operation, $\tilde{m} \le m$ bits are encoded by the convolutional encoder. The encoded $\tilde{m}+1$ bits select one of the subsets of M -ary signal set where $M = 2^{m+1}$. Remaining $m-\tilde{m}$ uncoded bits select one of $2^{m-\tilde{m}}$ signals of a subset for transmission. Trellis coded bits of size $m+1$ are mapped into one of the symbols of M-ary signal constellation by the mapping function $g_1(X_n,\sigma_n)$ where X_n is m-bits information transmitted and σ_n is encoder state.

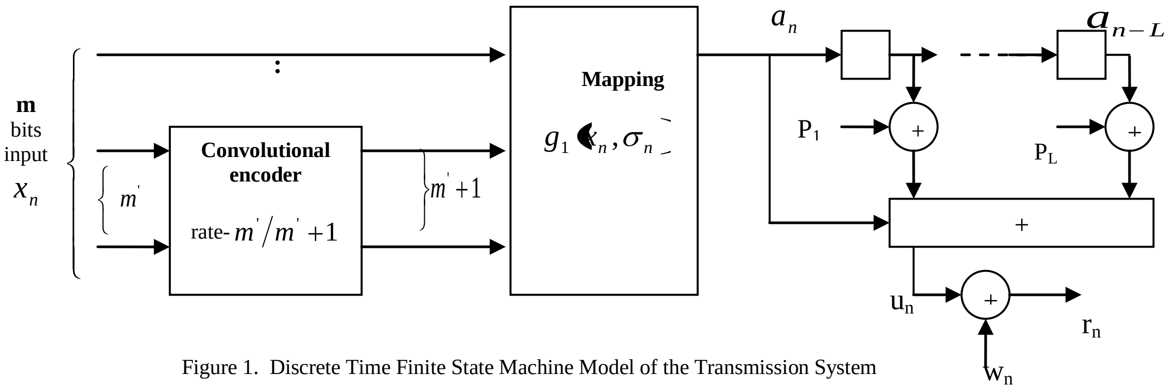

Figure 1. Discrete Time Finite State Machine Model of the Transmission System

If the transmitted symbols are corrupted by AWGN samples, MLSE becomes the optimum solution. MLSE processes the noisy symbol sequence received iteratively. The MLSE traces the encoder trellis to find the minimum metric path for Likelihood symbol sequence estimation. The path metric $M_n(..a_n)$ computation at each node of the trellis during the discrete time interval n is given by

$$M_n(..a_n)=M_{n-1}(..a_{n-1})+|r_n-a_n|^2 \qquad (1)$$

where $\{r_n\}$ is the noisy received symbol given by

$$\{r_n\}=\{a_n\}+\{w_n\} \qquad (2)$$

where $\{w_n\}$ is AWGN samples, and $M_{n-1}(..a_{n-1})$ is the metric computed during the interval n-1.

3. Bandlimited ISI Channel and FSM

In a band-limited digital communication system, intersymbol interference (ISI) is the primary obstacle to high speed data transmission. For practical implementations the ISI intervals are limited. Accordingly, the TCM encoder and the ISI channel can be viewed as a combined finite-state machine (FSM), and, hence can be represented by the combined ISI-Code trellis called super-trellis whose states are given by the product of encoder states and the ISI states[13,18,20]. The receiver performs Maximum-Likelihood Sequence Estimation of the noisy symbol sequence received by processing the super-trellis. The SOVA searches for a minimum cost path in the super- trellis. The path metric computation is given by

$$M_n(..a_n)=\min_{\{\mu_{n-1}\}\to\mu_n}\left\{M_{n-1}(..a_{n-1})+\left|r_n-\sum_{i=1}^{L}p_i a_{n-i}-p_0 a_n\right|^2\right\} \qquad (3)$$

where μ_n is the state of super trellis and L is the finite ISI channel memory length assumed. The term $u_n=\sum_{i=1}^{L}p_i a_{n-i}$ represents ISI cancellation by linear equalization and $\{p_i\}$ are the tap gains of the Linear Time Invariant filter [18].

In RSSE, for the assumed channel memory length L, ISI-code trellis complexity is reduced by truncating the channel memory length L to J. Likelihood sequence estimation performs the metric computation as given by

$$M_n(..a_n)=\min_{\{\mu_{n-1}\}\to\mu_n}\left\{M_{n-1}(..a_{n-1})+\left|z_n-\sum_{i=J+1}^{L}p_{n-i}\hat{a}_{n-i}-\sum_{i=1}^{J}p_i a_{n-i}-a_n\right|^2\right\} \qquad (4)$$

where the second term in the metric computation provides ISI cancellation due to previous symbols transmission not represented by the truncated combined states of reduced state trellis structure.

Reduced State Trellis Structure is also obtained by grouping the states of super-trellis by implementing set-partitioning concept [20,21]. Resulting structure has the metric computation of the form

$$M_n(..a_n)=\min_{\{\mu_{n-1}\}\}\to\mu_n}\left\{M_{n-1}(..a_{n-1})+\left|z_n-\sum_{i=J+1}^{L}p_{n-i}\hat{a}_{n-i}-p_0 a_n\right|^2\right\}$$

(5)

where second term in the ISI cancellation eliminates the ISI due to symbols not represented by the RSSE trellis.

4. Controlled State-Expansion Sequence Estimation

The new CSESE is a fast suboptimum decoding strategy for TCM schemes in the ISI environment. The CSESE is an integrated approach for Likelihood sequence estimation of TCM signals corrupted by the channel ISI and AWGN. It provides variable computational complexity for the algorithm. The metric computation is given by

$$M_n(..a_n)=\min_{\{\mu_{n-1}\}\to\mu_n}\{M_{n-1}(..a_{n-1})+\left|z_n-\sum_{i=J+1}^{L'}p_{n-i}\hat{a}_{n-i}-\sum_{i=1}^{J^1}p_i a_{n-i}-a_n\right|^2 \qquad (6)$$

where L' and J' are varied index parameters of CSESE. During each symbol interval, CSESE performs Likelihood Sequence Estimation and find the best-survivor node. Accordingly, the number of states-expansion for the next interval is determined. The decision parameter of the algorithm determines the nodes of combined ISI-code trellis to be expanded in the succeeding interval. The CSESE strategy reduces the computational complexity of the decoder by reducing the number of nodes expanded. The technique does not require additional storage and, the only overhead introduced is the decision parameter estimation. The error performance of CSESE has been evaluated for 4-state 16-QAM TCM scheme for a specific ISI channel simulated. The simplest case of c_RSSE that is Parallel Decision Feedback Decoding as the conventional approach (c_PDFD) has been simulated for comparison.

5. Results and Discussions

The CSESE performance is evaluated for 4-state 16-QAM TCM scheme in the ISI environment, in the presence of AWGN. The results are compared with the error performance obtained for c_PDFD. Error performance of uncoded 8-QAM is evaluated and considered for comparison, and, ISI free performance for 4-state 16-QAM TCM scheme evaluated through MLSE has also been considered.

The Figure 2 depicts the error performance for transmission over bandlimited ISI channel characterized by the impulse response coefficients p0=0.707 and p1=0.707. The decision parameter x2 is assumed as AWGN variance V. The curve No.2 from right represents the error event probability Vs SNR for CSESE. The curve No.3 represents the error event probability Vs SNR for the c-PDFD approach and the curve No.4 shows the error performance for ISI free condition. It is observed that CSESE performance is close to that of c-PDFD performance with a small amount of performance degradation. The degradation of about 0.5db at an error rate of 10^{-4} is observed. The curve 1, from right to left shows the error performance of 8-QAM uncoded scheme.

The reduced execution time of CSESE is shown in the Figure 3. It is noted from the Figure 3 that for the decision parameter x1, CSESE execution is about 20% faster than c_PDFD execution. The Table 1 shows the total number of states expansions reduced. The number of states biased from expansion increases at high SNR, and, varies as a function of the decision parameter.

The Figure 4 shows the error performance of CSESE for the decision parameters x1,x2 and x3. It is noted that better performance is obtained for x3, with a degradation of 0.2 dB over c_PDFD.

The simulation results depict that the error performance characteristics obtained with the CSESE strategy is close to the performance obtained by c-PDFD, with 15 to 20 percent of reduced in execution time. The performance is a function of optimality of controlled state-expansion. The technique can be extended to complex trellis structures.

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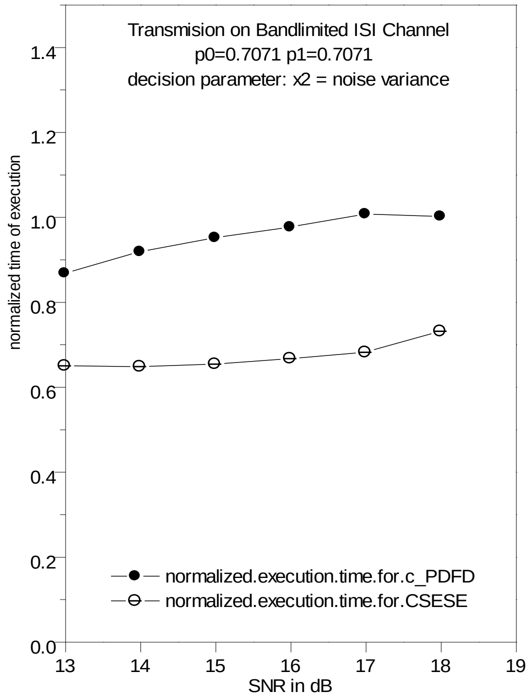

Figure 2. Error Event Probability Vs SNR
for channel: p0=0.707,p1=0.707,
for decision parameter x2=0.5*noise variance

SNR in dB	No. of State Discarded from expansion		
	for Decision Parameters x1,x2,x3 in terms of Noise variance V		
	x2=V	x1 =0.5V	x3=0.1V
17	13	3	1
16	34	8	1
15	100	25	1
14	229	45	1
13	434	112	4

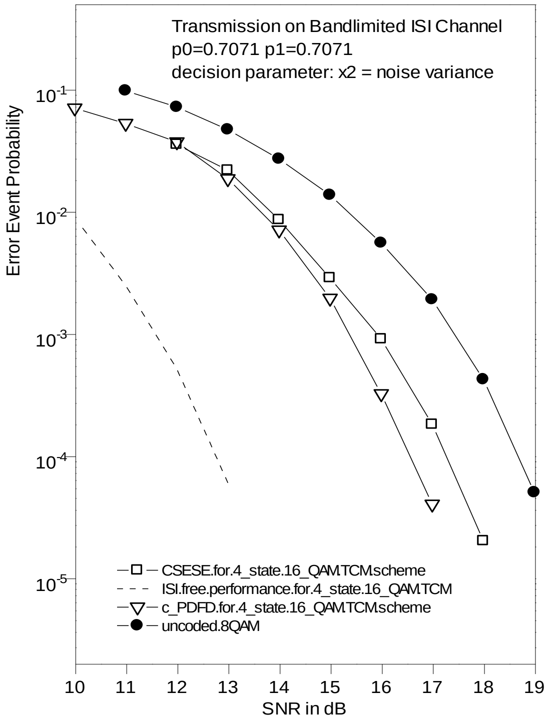

Figure 3. Normalized Time Vs SNR

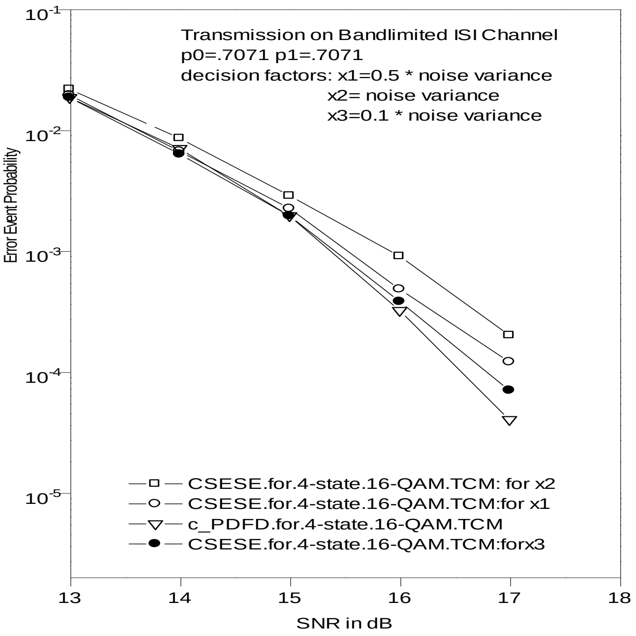

Figure 4. Error Event Vs SNR for different decision parameters

TABLE 1
NUMBER OF STATES NOT EXPANDED

ACKNOWLEDGMENT

The authors would like to thank the reviewers of this paper. Also the authors would like to thank Mrs. Shivakumarappa Bandakkala for the extended help

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