AN APTIVE TURBO DECODER FOR HIGH-DATA RATE APPLICATIONS

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ABSTRACT

This paper presents the application of a turbo coding technique combined with a bandwidth efficient method known as trellis coded modulation. A transformation applied to the incoming I-channel and Q-channel symbols allows the use of an off-the-shelf B/QPSK turbo decoder without any modifications. A conventional turbo decoder then operates on transformed symbols to estimate the coded bits. The uncoded bits are decoded based on the estimated coded bits and locations of the received symbols.

1. INTRODUCTION

Turbo codes, introduced in [1], have been shown to perform near the Shannon's channel capacity limit on Additive White Gaussian Noise (AWGN) channels. As a powerful coding technique, a turbo code offers a great promise for improving the reliability of communication systems such as those based on the DVB standard for Return Channel via Satellite(DVB-RCS)[2]. These systems adaptively control the modulation (BPSK, QPSK, 8PSK, 16QAM,etc.), the transmission rate, and the coding rate of an error-correcting code. However, the structure of a turbo decoder depends on the modulation scheme. Its decoding structure is different for a modulation scheme other than B/QPSK requiring larger decoder size or power consumption.

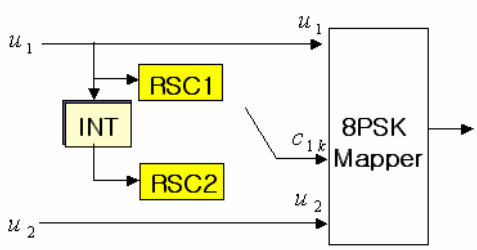
A single decoder need to decode all modulation schemes in order to need less hardware and less power consumption, and to reduce the receiver cost. In this paper, a novel decoding procedure allows the use of an off-the-shelf turbo decoder originally designed for a standard rate-1/2 turbo decoder over B/QPSK modulation, to decode some trellis coded modulation schemes over 2^m -PSK/QAM constellations, with $m \geq 3$.

In [3], the authors proposed to combine the turbo coding with the pragmatic trellis-coded modulation(TCM), where the received 8-PSK symbols are directly inputted in the turbo decoder, causing a reduction of the Euclidean distance, which is one of reasons for performance degradation. This paper proposes a new method for a pragmatic turbo decoding algorithm using the coset symbol transformation where received 8-PSK signals are transformed to QPSK signals after some manipulations. The novel turbo-coded TCM(TTCM) with two coded bits per symbol is based on a realization of rate $n/(n+1)$ trellis coded scheme using an off-the-self turbo decoder, originally design for a standard rate-1/2 turbo decoder for B/QPSK modulation.

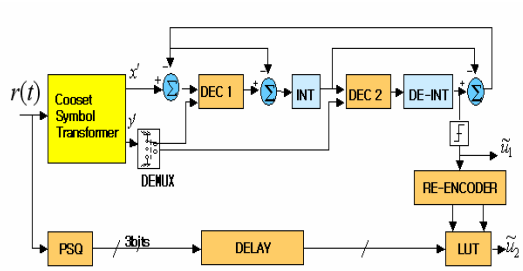
2.A NEW DECODING ALOGRITHM OF ADATPIVE TURBO DECODER

TCM is now a well-established method in a digital communication systems capable of achieving coding gain within 3 to 6 dB range of the Shannon channel capacity for a trellis coded 8-PSK system compared to an uncoded QPSK system. The application of turbo codes to TCM has received much attention in the literature. Hauro et al. have proposed a new turbo trellis coded modulation scheme[4]. As noted above,

unlike in [3], we have chosen to combine turbo codes with a pragmatic TCM, creating what we call the turbo-coded pragmatic TCM(TCPTCM). In this section, a turbo-coded pragmatic TCM with a rate-2/3 is presented. For the sake of clarity, only the case of 8-PSK modulation is considered, but it is easily generalized to M-PSK for M a power of 2. Figure 1 shows a rate-2/3 TCPTCM encoder/decoder structure. Encoder consists of two RSC (Recursive Systematic Convolution) codes, and interleaver (INT). Decoder consists of an off-the shelf turbo decoder (DEC1, DEC2) with rate 1/2, a phase sector quantizer(PSQ), coset symbol transformer(CST), and a re-encoder(RE). The decoding procedures require a standard turbo decoder without any modification in calculating the log-likelihood ratio, forward/backward state metric, and branch metric.



(a) Encoder/modulation



(b) decoder structure

Figure 1. Rate-2/3 turbo-coded pragmatic TCM encoder/decoder

2.1 Mapping of bits to signal

Two information bits (u_1, u_2) are encoded to produce three coded bits (u_2, u_1, c_{1k}), which are mapped onto 8-PSK signal points, where c_{1k} is the output of the standard turbo encoder and is punctured. The signal points are labeled by a triplet (u_2, u_1, c_{1k}), as shown in Figure 2.

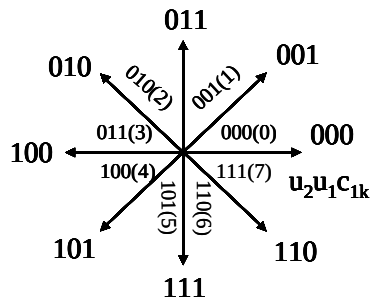


Figure 2. Labels and phase information of 8-PSK constellation

2.2 Coset Symbol Transformer (CST)

Let (x, y) denote the I- and Q- channel values of the received 8-PSK symbols $r(t)$. Let φ denote the phase of the received signal.

$$r(t) = x + jy \tag{1}$$

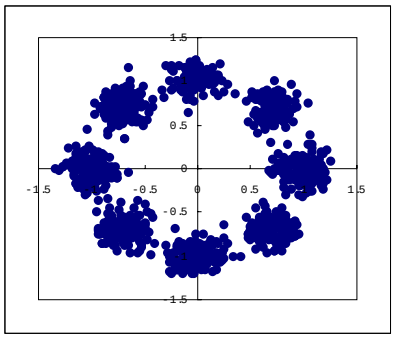
$$\varphi = \tan^{-1}(y / x) \tag{2}$$

In order to use the turbo decoder with rate-1/2, a transformation is applied such that the 8-PSK points are mapped into QPSK points labeled by (u_1, c_{1k}), as shown in Figure 2. The x' and y' projections in the transformed QPSK constellation are obtained from the received 8-PSK symbols by Equation (3).

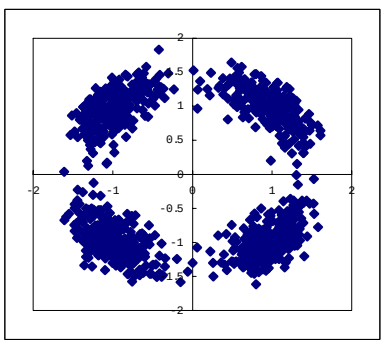
$$\begin{aligned} x' &= \sqrt{2}\cos(2(\varphi + 5\pi/8)) \\ y' &= \sqrt{2}\sin(2(\varphi + 5\pi/8)) \end{aligned} \tag{3}$$

$\sqrt{2}$ is the scaling factor to project onto QPSK points with $(\pm 1, \pm 1)$, $5\pi/8$ is the

phase rotation constant to map into the QPSK point with (u_1, c_{1k}) : $(11) \rightarrow \pi/4, (01) \rightarrow 3\pi/4, \quad (00) \rightarrow 5\pi/4$, and $(10) \rightarrow 7\pi/4$. Figure 3 shows the received 8-PSK symbols transformed into QPSK symbols at E_b/N_0 of 12dB.



(a) Received 8-PSK symbols



(b) Transformed into QPSK symbols

Figure 3. Transformed QPSK symbols (E_b/N_0 of 12dB)

2.3 Phase Sector Quantizer(PSQ)

The signal vector space is quantized to determine the locations of received symbols, and PSQ in Figure 1 is used for decoding the uncoded bits, u_2. The PSQ is designed with the assumption that the in-phase(I) and quadrature (Q)components of the received signals $r(t)$, will be converted to q quantization bits. The circuit is shown in Figure 4. Three comparators and two absolute generations produce the three bits of phase information indicating one of the sectors. Each of the three phase information bits gives information about the location of the received vector: ϕ_2 and ϕ_3 indicate the quadrant and the remaining one bit indicates the location within the quadrant. When |I| < |Q|, ϕ_1 is 1. In Figure 2, the numbers in 8-PSK constellation are denoted, ϕ_1, ϕ_2, ϕ_3.

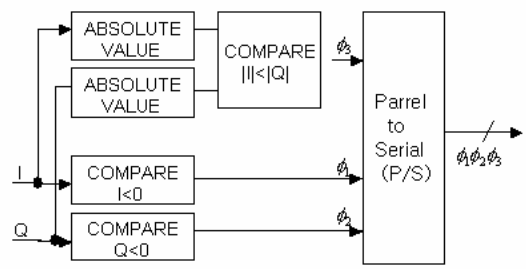


Figure 4. Phase sector quantizer and Soft decision mapping block

CST outputs, (x', y'), are used by an iterative MAP turbo decoder to produce estimates, $\tilde{u}_1$, of u_1. The value $\tilde{u}_1$ is then encoded by the rate 1/2 turbo code encoder providing estimates, $\tilde{u}_1$ and $\tilde{c}_{1k}$ of u_1 and c_{1k} . After the turbo decoder estimates the coded bits, it remains to determine the uncoded bit. This is accomplished by making a threshold decision. Using the estimated code bits, $\left(\tilde{u}_1, \tilde{c}_{1k}\right)$, and phase information, (ϕ_1, ϕ_2, ϕ_3) , we have to determine the uncoded bit, $\tilde{u}_2$ of u_2. Due to the structure of the turbo decoding algorithm, every decoder delays the data by a fixed number of symbol periods. The phase information bits ϕ_1, ϕ_2, ϕ_3 must be delayed by the amount of turbo decoding delay to match with the reconstructed code sequence.

A simple look-up table(LUT) as shown in Table 1 can be used to estimate $\tilde{u}_2$. As an example, if re-encoded bits $\left(\tilde{u}_1, \tilde{c}_{1k}\right)$ are (00) and the phase information $\left(\phi_1, \phi_2, \phi_3\right)$ is (111), then $\tilde{u}_2$ =0.

Table 1 Look-up table for estimating $\tilde{u}_2$

estimated coded bits $\left(\tilde{u}_1, \tilde{c}_{1k}\right)$	ϕ_1, ϕ_2, ϕ_3	$\tilde{u}_2$
00	(000),(001),(110),(111)	0
	(010),(011),(100),(101)	1
01	(000),(001),(010),(111)	0
	(011),(100),(101),(110)	1
10	(000),(101),(110),(111)	0
	(001),(010),(011),(100)	1
11	(000).(001),(010),(011)	0
	(100),(101),(110),(111)	1

3. SIMULATION RESULTS

The performance computer simulations to compare the performance of a turbo-coded pragmatic TCM(TCPTCM) is compared to pragmatic TCM(PTCM) and published simulation results of the turbo-coded TCM method in [4]. TCM method of Hauro *et al.* in [4]. The simulation results are plotted (Figure 5) for comparable 2-bps/Hz systems: 1) uncoded QPSK; 2) rate-2/3 pragmatic TCM(PTCM) with a single 64-state convolutional encoder; 3) rate 2/3 turbo-coded pragmatic TCM(TCPTCM, in Figure 1 with two 16-state RSC encoders, a 500-bit random interleaver, and five decoding iterations; and 4) rate-2/3 turbo TCM with two 16-state RSC encoders, 500-bit random interleaver, and five decoding iterations[4]. At a BER of 10^{-5}, TCPTCM achieves a 2 dB gain relative to PTCM. Compared to [4], the proposed decoder exhibits a small loss of less than 0.2 dB.

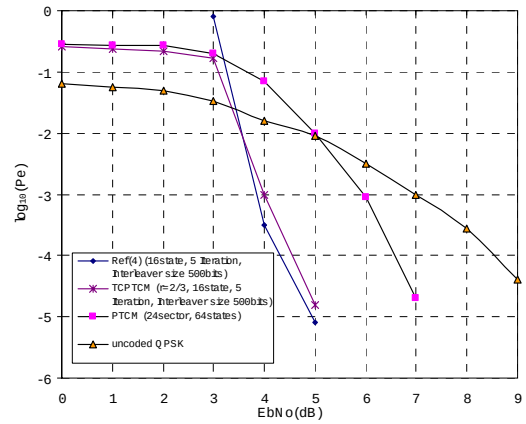


Figure 5. Bit error rate performance comparison between pragmatic TCM (PTCM), turbo-coded pragmatic(TCPTCM), and turbo TCM(TTCM)

4. CONCLUSION

In this paper, we presented the turbo-coded pragmatic TCM with two coded bits per symbol, based on a realization of rate n/(n+1) trellis coded scheme using an *off-the-shelf* turbo decoder originally designed for a standard rate-1/2 turbo decoder for the B/QPSK modulation. Compared to conventional turbo TCM, though the proposed decoder exhibits a small loss of less than 0.2 dB, but it needs less hardware, consumes less power, and reduces the receiver cost. The proposed approach may be extended to a variable coding rate(rate-5/6 and rate-8/9) , which depends on how many uncoded bits are assigned. Also, it can be used for 2^m - QAM constellations with $m \geq 4$.

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