IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 3, May 2014.

www.ijiset.com

ISSN 2348 - 7968

Iterative Turbo Decoding With Weiner Filtered APP Channel Estimation over Impaired Channels

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Abstract: This paper considers iterative decoding of BPSK modulated symbols using turbo principles. A simple A Posteriori Probability (APP) channel estimator is integrated to the turbo decoder so that decoding without any prior phase information is possible. APP channel estimator can counteract phase noises and frequency shifts. By incorporating a sophisticated estimation filter such a Weiner filter into the APP channel estimator the channel estimation can be improved appreciably compared to a simple smoothing filter. BER results shows that the system achieves a near coherent performance in the absence of perfect carrier knowledge even with significant channel impairments and frequency shifts.

Keywords: *Turbo codes, A Posteriori Probability, channel estimation, coherent demodulation.*

1. Introduction

In the present scenario, communication systems use spectrally efficient coded modulations which are based on coherent demodulation of the received signal. Coherent demodulation requires a Phase Locked Loop (PLL) [8] circuitry to recover the phase of the transmitted signal from the received signal. But the received phase may get altered from the transmitted phase due to the reasons such as phase noise and Doppler shifts. Oscillators in a PLL circuitry will be seriously affected by the presence of even a small noise so that it can lead to drastic changes in frequency spectrum. This phenomenon that is peculiar to oscillators is referred to as phase noise [4]. The frequency shift caused due to the relative movement between satellite and ground station which is particular in satellite communication is referred to as Doppler shift; which can also account for a phase shift. Whenever the transmitted phase gets altered; the received signal can be decoded to correct code word only with the use of an expensive and very complex PLL. Thus it is necessary to consider some other alternatives for phase recovery.

By transmitting a known training sequence such as pilot symbols can be a method to estimate the channel. But it causes information rate loss. If the receiver does not use any channel information or phase synchronization, differential encoding with differential demodulation is the classical method for signaling. By combining the current MPSK symbol with the previously transmitted symbol, differential encoding generates the current transmitted DPSK symbols. So that information will be contained in the phase of the two symbols. Correspondingly by differential demodulation at the receiver side, a 3 dB loss in SNR versus BER occurs for M-PSK, M>2 [9]. Also differential PSK cannot guarantee an improved BER compared to coherent PSK technique. So differential encoding with differential demodulation is also not an optimal solution.

The capability of Turbo codes [1] to nearly achieve the Shannon capacity limit is utilized here. The error floor region is the major challenging peculiarity of turbo codes because of the presence of low weight code words. Turbo codes are actually not a single code rather it is a concatenation of two or more codes which can either be similar or dissimilar. This paper is based on the concept of turbo codes which outperforms all previously known coding schemes. This can be used whenever the operating saving is required as in satellite communication. Through iterative decoding along with APP channel estimation, decoding performance close to coherent decoding can be achieved [6]. A sophisticated estimation filter such as a Weiner filter integrated into APP channel estimator can appreciably improve the estimation compared to a Low Pass Filter. Since the APP channel estimation with Weiner filter is kept external to the turbo decoder, it won’t increase the decoding trellis complexity.

This paper is organized as follows. Section 2 describes the simple parallely concatenated turbo encoder system. Section 3 describes iterative turbo decoding with and without channel phase information. Section 4 provides the simulation results and finally Section 5 draws the conclusion.

ISSN 2348 - 7968

2. System Description

Figure 1 illustrates the proposed parallely concatenated turbo encoder which consists of two identical Recursive Systematic Convolution (RSC) encoders RSC-0 and RSC-1each with ½ rate and joined by means of an interleaver π. The total rate of the parallel concatenated turbo encoder is thus 1/3. Consider N bits of information sequence X_k which is fed to the turbo encoder to produce systematic and parity check bits. The information X_k is fed directly to RSC-0 to produce the parity bits P0. The same information X_k is interleaved by a random interleaver and fed to RSC-1 to produce the parity bits P1. The systematic and parity check bits are modulated using BPSK to produce the corresponding sequences A0, A1 and A2. Then these sequences are transmitted through an AWGN channel having noise variance N0.

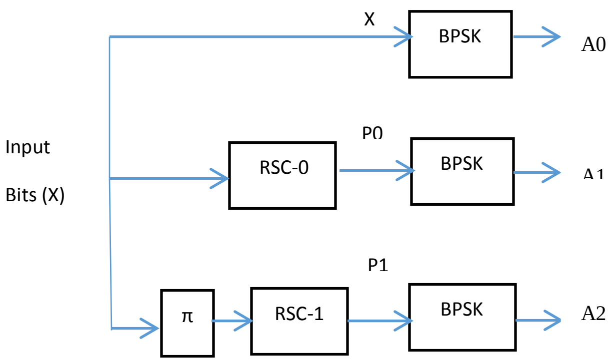


Fig.1 Turbo encoder

3. Iterative Turbo Decoding

Iterative decoding using turbo principle is used to decode the parallel concatenated system. Two cases are considered here; decoding with and without channel phase information [7].

3.1 Decoding with known channel phase

The received signal is represented as,

$$R0=A0+n$$

$$R1=A1+n$$

$$R2=A2+n$$

where R0, R1, R2 are the received signals corresponding to systematic bits, parity bits P0 and parity bits P1 respectively and n represents complex noise. Receiver decodes the received code words using BCJR algorithm. The receiver consists of two decision decoders and an interleaver (π)-deinterleaver (π^{-1}) device. The inputs to the first decoder BCJR-0 are R0 and R1 where R0 is the received signal that corresponds to the systematic bits and R1 is the received signal that corresponds to parity bits from RSC-0. For the very first iteration BCJR-0 assumes uniform a priori probabilities 1/M, where M is the modulation order. It computes the Log A Posteriori Probability Ratio (LAPPR) which is defined as LAPPR=log $\{(\frac{P(X^k=1|\bar{R})}{P(X^k=0|\bar{R})}\}$, where $\bar{R}$=R0R1 and k=0,1,…..N-1.

The intrinsic information $\log\{(\frac{P(X^k=1)}{P(X^k=0|}\}-2\frac{R0^k}{\sigma^2}$ is subtracted from the LAPPR and the resultant extrinsic information is sent to BCJR-1 after interleaving along with R2 which is the received signal that corresponds to the parity bits from RSC-1. For all stages LAPPR is calculated and the received code words are decoded according to LAPPR. If LAPPR is greater than unity, it is decoded to one else zero. This LAPPR values are used to calculate the a priori probability. The second decoder BCJR-1 works in the same manner by exchanging the extrinsic information between the decoders. The iteration stops when convergence is reached.

3.2 Decoding with unknown channel phase

Now consider that the receiver is completely unaware of the channel phase information. Here iterative decoding is aided with an APP channel estimator. Then the channel model is,

$$R0_k = h_k\, A0_k+n_k \qquad (2)$$

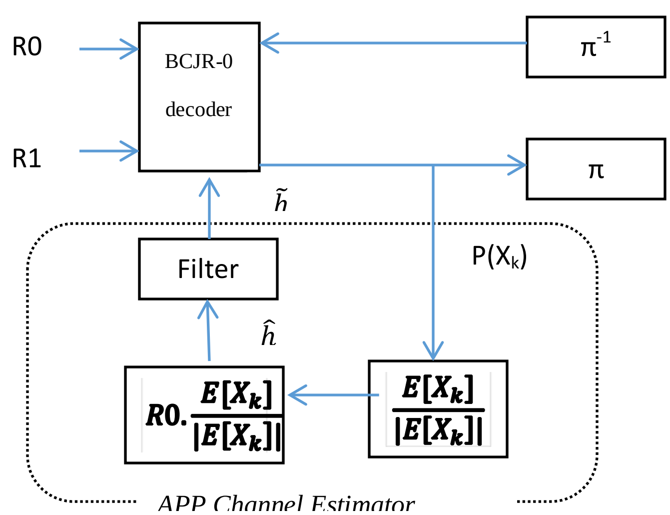


Fig.2 Turbo decoder with APP channel estimator

ISSN 2348 - 7968

where h_k is the time varying rotation and is given by $h_k = e^{\varphi_k}$ with φ_k is the unknown channel phase. The unknown channel phase can be modeled in two ways;(i) constant unknown phase offset (ii) constant frequency offset which models Doppler scenario.

BCJR-0 can also estimate $P(X_k)$ along with LAPPR. Using this $\frac{E[X_k]}{|E[X_k]|}$ can be computed. Let the instantaneous channel estimates can be computed using the relation,

$$\widehat{h_k} = R0.\frac{E[Xk]}{|E[Xk]|} \qquad (3)$$

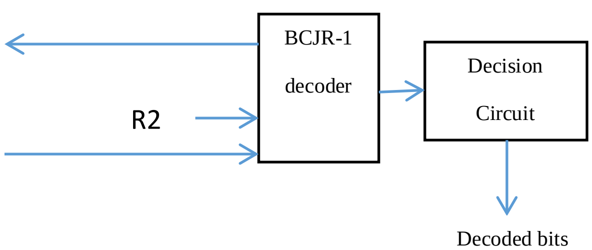
At each iteration instantaneous channel estimates are calculated and then filtered through the sophisticated estimation filter such as a weiner filter f_k which generates the filtered channel estimates,

$$\tilde{h}_k = \hat{h}_k * f_k \qquad (4)$$

At each iteration, the filtered channel estimates get improved thereby $R0_k$ gets updated and in this fashion the process goes on until convergence is reached.

4. Simulation Results

MATLAB is used as the platform for simulation. A block of 10000 message bits were used and SNR has been varied between 0 to 9 dB. Iterative turbo decoding performance under coherent condition and channel impairments such as a constant phase offset and Doppler shift has been plotted both considering the cases of using a low pass filter and a wiener filter in APP channel estimator. From the graph itself it is evident that almost at fourth iteration the BCJR algorithm converges. Also near coherent performance has been achieved by iterative turbo decoding even under unknown channel phase information. Results show better performance for a wiener filter which is included in the APP channel estimator rather than a low pass filter.



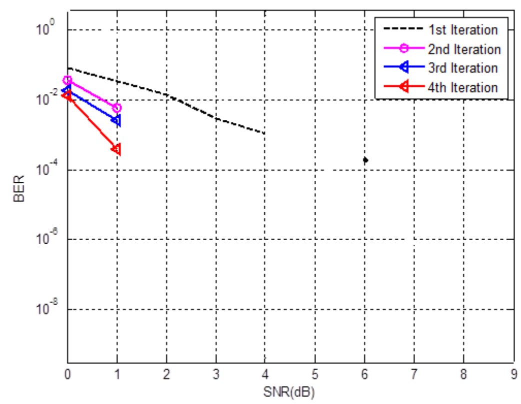


Fig.3. Iterative turbo decoder performance under coherent decoding

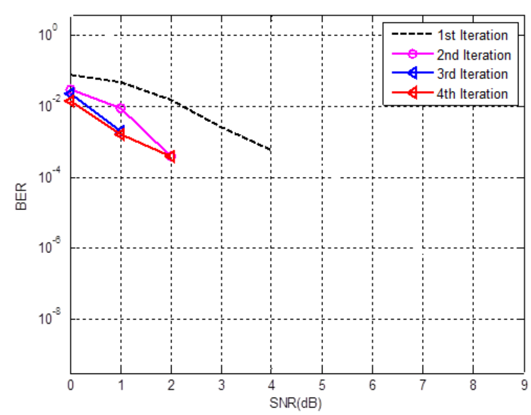


Fig.4. Iterative turbo decoder performance with low pass filtered APP channel estimator under a constant phase offset of $\pi/16$ rads

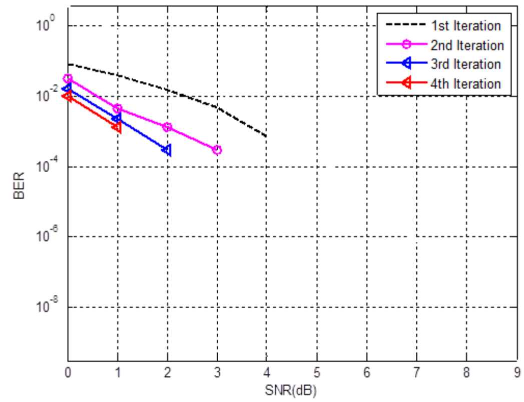


Fig.5. Iterative turbo decoder performance with low pass filtered APP channel estimator under frequency offset

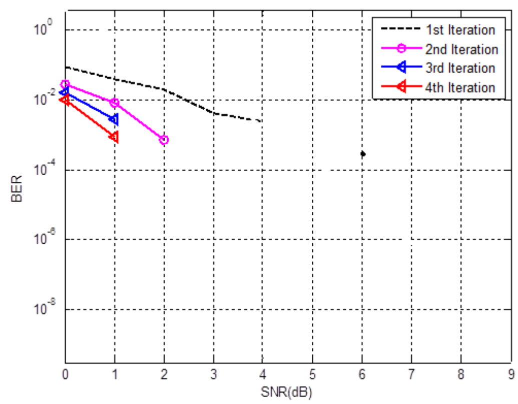


Fig.6. Iterative turbo decoder performance with wiener filtered APP channel estimator under a constant phase offset of $\pi/16$ rads

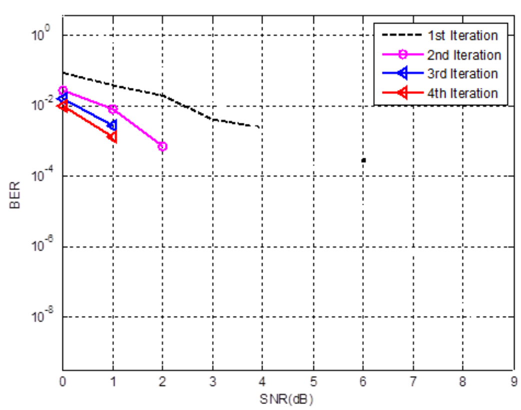


Fig.7. Iterative turbo decoder performance with wiener filtered APP channel estimator under frequency offset

5. Conclusion

Iterative turbo decoding has been used to decode the parallely concatenated system without using differential demodulation, pilot symbols or any training sequences as in traditional receivers. A simple APP channel estimator can be used to estimate the channel. Its performance can be improved by incorporating a wiener filter instead of a low pass filter. It achieves a near coherent performance decoding without any channel phase information even in presence of significant channel impairments. By analyzing coherent demodulation with our approach, it is evident that this system which can be easily encoded and decoded is highly applicable for deep space communication which demands limited power consumption and high coding gains. The BER results shows the performance improvement by using wiener filter even under severe channel impairments.

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