

PERFORMANCE OF TURBO CODED OFDM MODULATION OVER AN AERONAUTICAL CHANNEL

Authors: Wannaw Assegu, Ibrahim Fofanah

Advisors: Dr.Arlene Cole-Rhodes, Dr.Richard Dean, Dr.Farzad Moazzami

Department of Electrical and Computer Engineering

Morgan State University

waass1@morgan.edu, ibfofl@morgan.edu

ABSTRACT

The main objectives of Integrated Network Enhanced Telemetry (iNET) are increased data rate and improved spectral efficiency. In this paper we propose the transmission scheme for the physical layer to be coded Quadrature Amplitude Modulation-Orthogonal Frequency Division Multiplexing (QAM OFDM) which enables high data rates and spectrum efficiency. However in high mobility scenarios, the channel is time-varying the receiver design is more challenging. In this paper pilot-assisted channel estimation is used at the receiver, with turbo coding to enhance the performance; while the effect of inter symbol interference (ISI) is mitigated by cyclic prefix. The focus of this paper is to evaluate the performance of OFDM with QAM over an aeronautical channel. The M-QAM with OFDM provides a higher data rate than QPSK hence it is chosen in this paper. The implementation is done using Inverse Fast Fourier Transform (IFFT) and the Fast Fourier Transform (FFT). This paper considers how the performance of Coded QAM OFDM can be enhanced using equalization to compensate for inter symbol interference, and using turbo coding for error correction.

KEY WORDS: OFDM, CP, Turbo Coding, Equalization, QAM.

1. INTRODUCTION

The Integrated Network Enhanced Telemetry (iNET), a study proposed by the Central Test and Evaluation Investment Program (CTEIP), seeks to enhance data rate between test articles and ground stations and test article-to-test article communication [1]. The need for increased data rate requires deploying spectrally efficient modulation techniques. Consequently OFDM, which is a special form of multicarrier modulation scheme with densely spaced sub carriers and overlapping spectra, is employed for the proposed iNET environment. In this paper we consider the performance of a higher modulation technique 64-QAM OFDM over an aeronautical channel and then propose the use of iterative coding and decoding algorithm.

The aeronautical channel is characterized by multipath, Doppler shift and noise and as a result spectrum efficient modulation is a challenge. However, multicarrier modulation schemes like OFDM are robust to multipath, and we shown how the use of cyclic prefix mitigates the effect of intersymbol interference (ISI) in [2]. Power efficiency of the proposed scheme is mitigated by the use of Turbo decoding. iNET proposes the use of OFDM in the physical layer of the Telemetry Network System because of its high spectral efficiency and its resilience to poor channel conditions. The paper is structured as follows. Section 2 provides a description of the different building blocks of the Turbo coded M-QAM. In section 3 we provide the system model comprising the different transmission and communication blocks. Map decoding and Trellis decoding are compared in section 4 and the simulated results are discussed. Finally, section 5 is reserved for conclusion and future work.

2. TURBO CODES

Traditionally, convolutional codes have been used extensively in many applications. However, when compared to turbo codes, turbo code is far more robust in performance. It has been shown in [3] that power efficiency of a turbo code outperforms 64-state trellis-coded modulation by 2.5dB at the bit error rate of 10^{-6} on an additive white gaussian noise (AWGN) channel. Because of the improved BER performance, turbo code is now employed in many applications but with a trade-off of added complexity in the decoding algorithm.

2.1 Turbo Encoding

Turbo encoder is formed by the parallel concatenation of two recursive systematic codes (RSC). In Figure 1, we show the block diagram of a rate 1/3 turbo encoder. It uses two identical rate $\frac{1}{2}$ convolutional encoders. The binary data sequence x_0 is passed directly to the first encoder and an interleaved version is sent to the second encoder. Appropriate puncturing of parity bits from the two encoders can create a Turbo code of desired rate. The recursive systematic convolutional (RSC) encoder is obtained from the conventional convolutional encoder by feeding back one of its encoded outputs to its input. The conventional convolutional encoder is represented by a pair of generator sequences g_1 and g_2 and can be equivalently represented in a more compact form as $G = [g_1, g_2]$. The RSC encoder of this conventional convolutional encoder is then represented as $G = [1, g_2/g_1]$ where the first output (represented by g_1) is fed back to the input based on g_2 . The codeword is formed by the concatenation of the systematic binary data x_0 , with the parity bits from the first encoder and those from the second encoder.

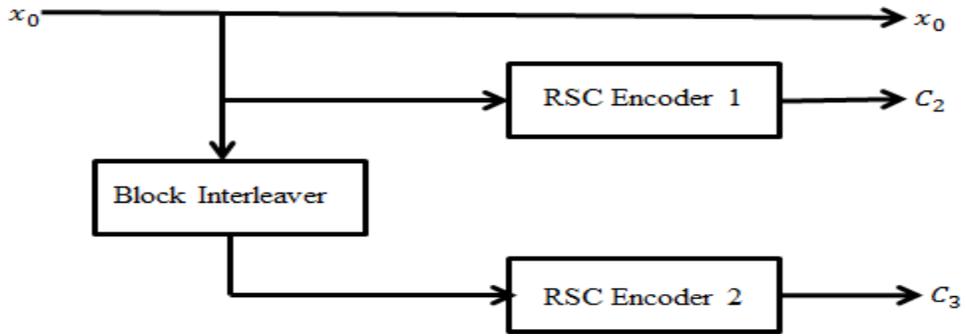


Figure 1: Turbo encoder

An example of an RSC Encoder is shown in figure 2, here the constraint length is three and the generator polynomials are binary 7 (for the feedback polynomial) and binary 5 (feed-forward). The RSC encoder is then represented as $G = (1, 5/7)$

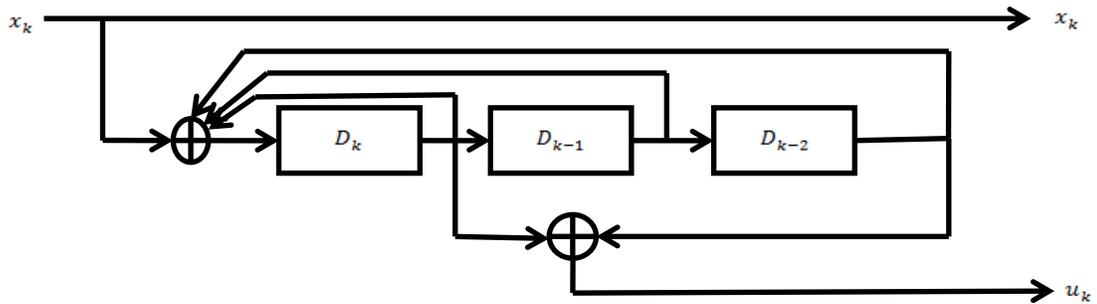


Figure 2: Recursive Systematic Convolutional (RSC) Encoder

2.2. Interleaver

An interleaver is used in the turbo code design shown in figure 2. The interleaver is deployed between the two encoders and it ensures that the two RSC encoders are working with different versions of the input data stream. In this design we used the most widely used interleaver; the block interleaver. As discussed in [4], it writes in column-wise from top to bottom and left to right and reads out-row wise from left to right and top to bottom. Figure 3 shows the block interleaver.

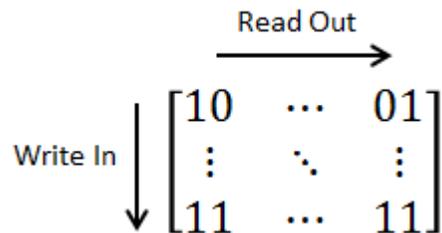


Figure 3: Block Interleaver

2.3. 64-Quadrature Amplitude Modulation (QAM) and OFDM

Orthogonal frequency-division multiplexing (OFDM) is a spectrally efficient multicarrier modulation scheme where a large number of closely spaced orthogonal subcarriers are used to carry data. The aeronautical channel is multipath channel which results in intersymbol interference (ISI) on each subcarrier channel due to pulse overlapping. It also causes Inter-carrier Interference (ICI) due to the non-orthogonality of the received signal [5]. The addition of cyclic prefix (CP) to each orthogonal OFDM symbol mitigates the problems of ISI and ICI. The cyclic prefix of length N_{cp} less than the FFT size N is formed by appending the last N_{cp} values from the OFDM transmitted symbol and adding those values to the front part of the same OFDM transmitted symbol. Where the number of samples allocated for cyclic prefix is calculated from the length N of the FFT, T the IFFT period and T_{cp} the duration of cyclic prefix as $N_{cp} = T_{cp} \times \frac{N}{T}$.

The need for an increased data rate by the iNET program has encouraged the need for higher modulation schemes. M-QAM is a higher order form of modulation and as a result it is able to carry more bits of information per symbol. In this structure, 4-, 16-, or 64-QAM which transmits 2, 4, or 6 bits per symbol is respectively proposed as the modulation scheme.

2.4. Turbo Decoding

The turbo decoding process is done iteratively using maximum a priori probability (MAP) decoding. Soft-input soft-output decoding of convolutional sub-codes is done with the use of a priori information of previous decoding steps. There are two stages involved in the decoding process; the initialization stage and the iteration stage. These stages are discussed below.

2.4.1. Initialization Stage

Figure 4 shows the block diagram of the initialization stage for a rate $\frac{1}{2}$ encoder. The multiplexer puts the two codewords C_2 and C_3 from figure 1 into data string. At the transmitter, there are two encoded sequences and we start by decoding one of them to get a first estimate of the information sequence. This estimate is then used as a priori information in the decoding of the second encoded sequence. This requires that the decoder is able to use a soft decision input and to produce a soft output [6]. At the receiver, let the received sequence corresponding to the information sequence x_0 and let r be the multiplexed sequence C_2 and C_3 . The MAP decoder calculates the a posteriori probabilities (APP) for each data symbol.

The soft input/output decision is determined by the log-likelihood ratio (LLR), $\lambda(k)$. Assuming an AWGN channel model with a received signal, $u(k)$ at time k , the LLR is given in terms of the probability ratio shown in (1) below:

$$\lambda(k) = \frac{\log P[u(k)=1|y]}{\log P[u(k)=0|y]} \quad (1)$$

Note that $\lambda(k)$ is a signed number for which a negative value indicates that zero is the most likely value of the bit, and a positive value indicates that the value of the bit is one.

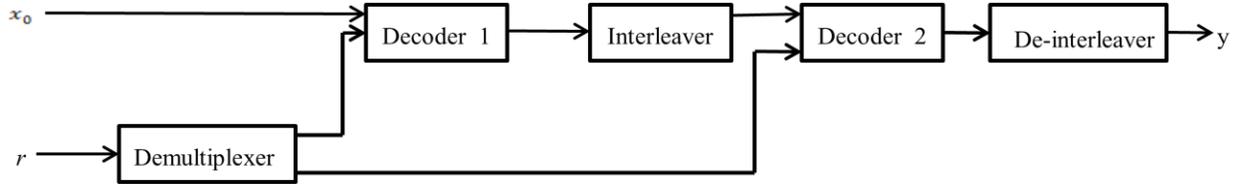


Figure 4: Turbo decoding-initialization stage

2.4.2. Iteration Stage

In the iteration stage, the soft outputs produced by the second decoder are de-interleaved and then fed into the first decoder. The first decoder works on this improved bit sequence and produces a soft output. This is, then interleaved, and passed onto the second decoder. As the number of iterations increases, the output of the second decoder approaches the MAP estimate [7]. This stage is demonstrated in Figure 5.

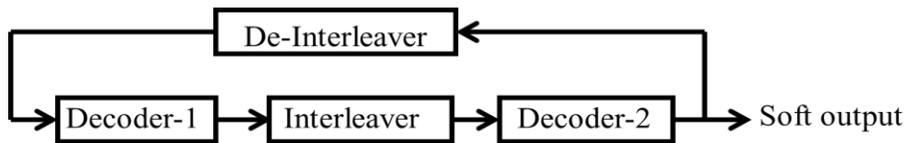


Figure 5: Turbo decoding-iteration stage

3. SYSTEM MODEL

Figure 6 shows the block diagram of the system. At the transmitter, a sequence of binary data consisting of zeros and ones is turbo encoded at a rate of $\frac{1}{2}$. The encoded data is mapped into 64-QAM and the symbols are transmitted in parallel by assigning each symbol to one transmission carrier. An inverse fast Fourier transform (IFFT) is used to convert this signal to the time domain, and to maintain the orthogonality between subcarriers. The guard band is inserted into the OFDM symbol by copying the end of the symbol and appending this to the start. The received signal has been corrupted by AWGN and multipath on the channel.

The receiver performs the reverse operations of the transmitter by removing the guard band, and then performing the IFFT to bring the signal to the frequency domain. The subcarriers are then removed and the data is converted back to baseband signal, and decoded by using MAP decoder which produces the binary message signal.

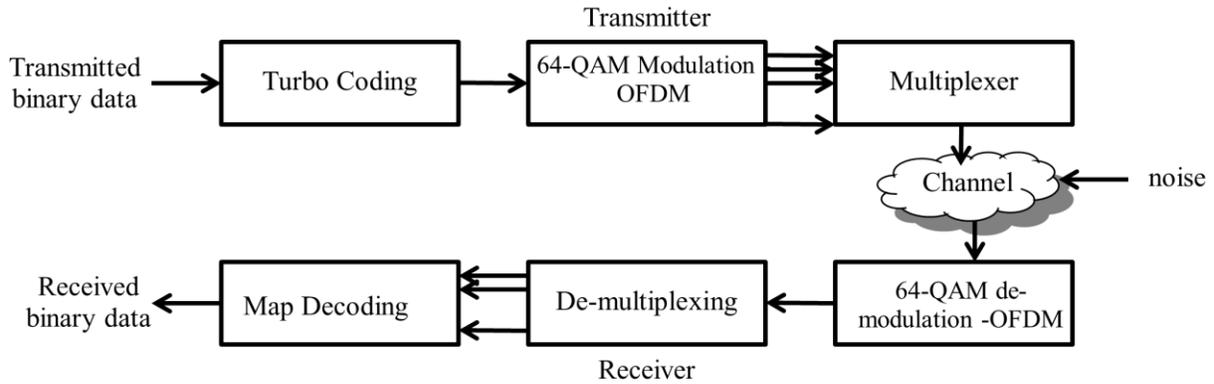


Figure 6: Turbo coded 64-QAM system model

4. RESULTS

In figure 7, the performance of map decoding and Viterbi hard decision decoding are compared. The comparison is based on rate $\frac{1}{2}$ convolutional coding with Viterbi hard decision decoding versus map decoding over AWGN.

The general polynomial for the rate $\frac{1}{2}$ convolutional encoder are with generator polynomials $g_1=101(5 \text{ in octal})$ and $g_2=111(7 \text{ in octal})$ and constraint length of 3.

As shown on figure 7, maximum a posteriori decoding outperforms Viterbi decoding through out the whole range of E_b/N_0 . We note from figure 6, that MAP decoding achieves 10^{-4} symbol error rate at about 4.7 dB and Viterbi decoding achieves at about 7.6 dB, which is about 3dB gain for using MAP decoding.

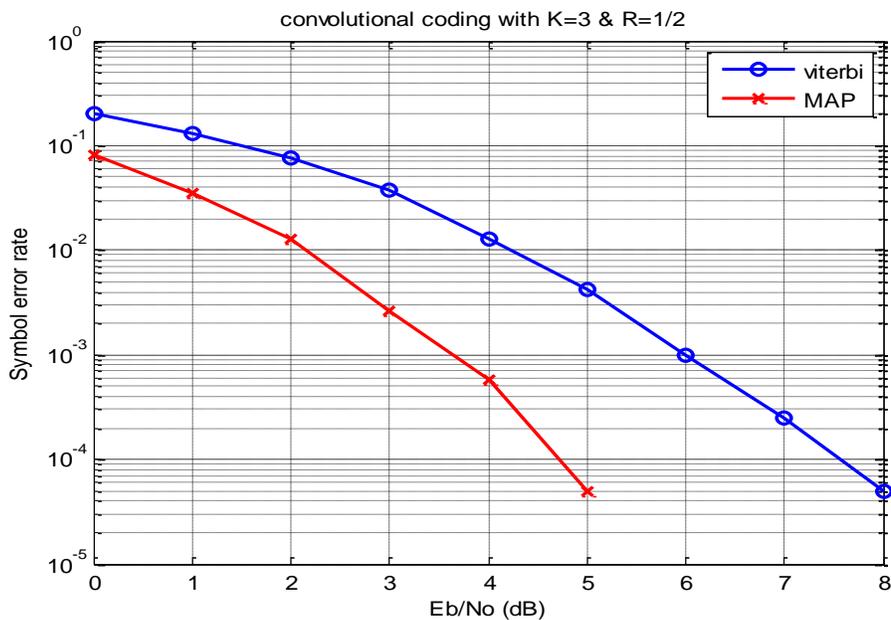


Figure 7: comparison of Viterbi decoding with Maximum a posteriori decoding

5. CONCLUSION AND FUTUREWORK

In this paper we have demonstrated that iterative decoding (MAP) outperforms Viterbi decoding in an additive white gaussian noise (AWGN) channel. The simulated result shows, at 10^{-4} symbol error rate MAP decoding achieved about 4.7 dB and Viterbi decoding about 7.6 dB which is about 3dB gain for using MAP decoding. Based on figure of [2], we showed that coding and equalization outperforms equalization without. Having shown that map decoding has a gain of about 3dB over Viterbi decoding, we are expecting an improved performance by using turbo coding. This improved performance is a motivation for future research where turbo coded OFDM will be studied extensively for improved error correction and implemented with equalization and with puncturing.

ACKNOWLEDGMENT

The authors would like to express their sincere appreciation to TRMC, SRC and CSC for their continued support and Dr.Arlene Cole-Rhodes, Dr.Richard Dean and Dr.FarzadMoazzami for their valuable contributions.

REFERENCES

- [1] "iNET Network Telemetry System Architecture," May 2004.
- [2] I. Wannaw Assegu, "Performance of coded 16-QAM OFDM modulation with equalization over an aeronautical channel," in *International Telemetering Conference (ITC)*, Las Vegas, 2011.
- [3] A. G. C. B. Stephane Le Goff, "Turbo-Codes and High Spectral Efficiency Modulation," in *Communications, 1994. ICC '94, SUPERCOMM/ICC '94, Conference Record, 'Serving Humanity Through Communications.'* IEEE International Conference on, New Orleans, LA, 1994.
- [4] R. H. Morelos-Zaragoza, *The art of error correcting coding*, 2nd edition John Wiley & Sons, Ltd..
- [5] Mathuranathan, 1 June 2011. [Online]. Available: <http://gaussianwaves.blogspot.com>. [Accessed 3 July 2012].
- [6] J. D. Andersen, "A Turbo Tutorial," Department of Telecommunication Technical University of Denmark.
- [7] Valenti, "An Introduction to Turbo Codes," Unpublished, 1996.