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Decoder Assisted Channel Estimation and Frame Synchronization

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UNIVERSITY HONORS PROGRAM

SENIOR PROJECT - APPROVAL

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College: Engineering Department: Electrical

Faculty Mentor: Dr. Mostafa Howlader

PROJECT TITLE: Decoder Assisted Channel Estimation
and Frame Synchronization

I have reviewed this completed senior honors thesis with this student and certify that it is a project commensurate with honors level undergraduate research in this field.

Signed: M. Mostafa H., Faculty Mentor

Date: 05.02.2001

Comments (Optional):

Extra ordinary performance. The quality of research is certainly better than an average MS Thesis work.

Decoder Assisted Channel Estimation and Frame Synchronization

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May 04, 2001
University of Tennessee

Abstract: In regards to turbo codes, to the author's knowledge, previous literature has treated decoder assisted frame synchronization and channel estimation as separate processes. Here a joint decoder assisted process of channel estimation and frame synchronization is proposed. In brief, the method entails using a sync word (SW) embedded mid-packet for both channel estimation and frame synchronization. The method will use a correlation-based frame synchronization that passes a list of possible delays to the turbo decoder. The turbo decoder will draw upon pilot symbol assisted modulation (PSAM) techniques for channel estimation using the coded SW.

I. Introduction

Turbo codes offer unprecedented and unparalleled error correction performance when used with perfect channel information, or side information (SI), that consists of channel noise variance, fading amplitude, and fading phase. In a AWGN channel, the turbo code is capable of coming within 0.7dB of Shannon's Limit [1]. For optimal results in a fading channel, turbo codes need to have perfect channel information. However, in real system perfect SI is not achievable and the performance suffers as a result. In lieu of unrealizable perfect SI, methods have been devised to estimate the channel information. One proven method employs *pilot symbol assisted modulation* (PSAM) [2,3] where the degradation depends on the fading channel parameters.

Because turbo codes operate at such low signal-to-noise ratio (SNR), conventional frame synchronization poses a problem. One proposed list-based method uses a conventional correlation method to generate a list of possible bit delays, which is passed to the turbo decoder. The turbo decoder then chooses the most likely delay within the list. Using decoder assisted frame synchronization, results have been achieved that surpass conventional methods of frame synchronization [4].

In this proposal, a joint method of frame synchronization and channel estimation is submitted. The method uses a mid-packet SW for both frame synchronization and channel estimation. Rather than adding the requisite pilot symbols for channel estimation, we propose that a properly distributed coded sync word can be used as effectively and without the increase in bandwidth.

The paper is organized with Section II consisting of the system model followed by the channel estimation methodology in Section III. The simulation results will be shown in Section IV followed by the conclusion in Section V.

II. System Model

(A) *Transmitter:* The system employs BPSK over a fading channel. The system model is shown in Figure 1. and is similar in nature to that shown in [5]. Information bits \mathbf{d} are grouped in packets of length N . A sync word $\mathbf{s} = (s_0, s_1, \dots, s_{L-1})$ of length L is placed mid-amble in the information packet. Then the data is encoded using a turbo encoder of 1/3 rate, constraint length $k_c = 3$, and code generator $(5,7)_8$. The encoded data is subsequently channel interleaved in such a way to evenly distribute the coded sync word across the entire packet for optimal channel estimation. This will be elaborated upon in a subsequent section.

(B) *Channel:* The channel consists of a complex multiplicative distortion with additive white Gaussian noise. The fading is modeled as a slow, flat fading channel with a Rayleigh distribution. The fading model has the autocorrelation according to Jake's isotropic scattering model [6]

$$R_c(\tau) = \sigma^2 J_0(2\pi f_d \tau), \quad (1)$$

where f_d is the relative Doppler between transmitter and receiver and J_0 is the zero order Bessel function. Note that the power of the fading is normalized to one. The complex AWGN has a two-sided noise spectral density $N_0/2$ for both real and imaginary components.

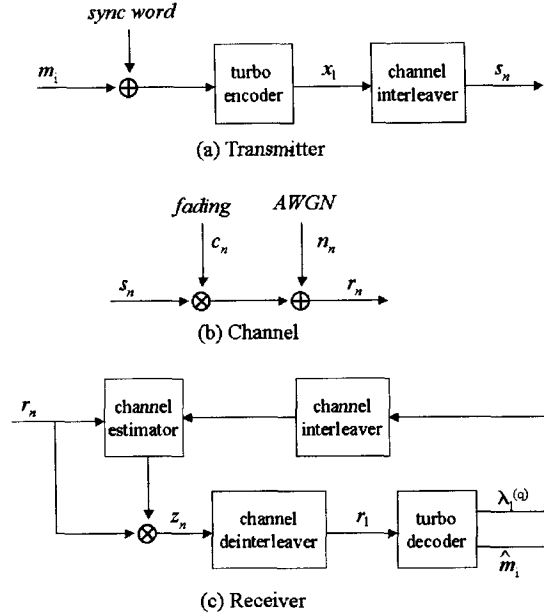


Figure 1. System Model

(C) *Receiver*: The receiver is shown in Figure 1. As indicated in the channel section, the fading is slow with respect to the symbol period and flat with no intersymbol interference. Also, perfect carrier and symbol timing is assumed. The received sequence is

$$r_n = c_n(s_n) + n_n, \quad (2)$$

where c_n is the fading described above and n_n is a complex Gaussian random variable with variance $\sigma^2 = N_0/(2E_s)$ for both real and imaginary components. The sequence r_n is initially used to estimate the channel information (fading amplitude and phase and variance of the noise), then sent through a channel deinterleaver before being passed to a turbo decoder implemented using a log-MAP decoder. The channel estimation is further refined upon further iterations [3]. Where [3] implements the refined channel estimation using inserted pilot symbols, we estimate the channel using the available coded SW.

III. Channel Estimation using Sync Word

The channel estimation technique in conjunction with turbo PSAM has been shown to achieve favorable results depending on the channel parameters [3]. The tradeoff associated with conventional PSAM is there is an increase in bandwidth of the transmitted signal through the addition of pilot symbols. In our proposed method, the *existing coded sync word will be used as the pilot symbols* to estimate the channel. Our method will require no increase in transmitted bandwidth and achieve identical results, if designed correctly, as conventional PSAM.

The channel estimation algorithm for PSAM can be directly applied to the coded sync word in what we will refer to as sync word assisted modulation (SWAM). The turbo channel estimation algorithm for SWAM is described in the following, notice that it is a variant of the turbo PSAM proposed in [3].

For the first iteration, the decoder assisted channel estimation does not have *a priori* symbol estimates and estimation is accomplished using only the coded sync word. An approximation of the best minimum mean square estimate for the first pass is described by

$$\hat{c}_n = \sum_{i=-N_c}^{N_c} w_i v_p y_{n-i}^{(p)}, \quad (3)$$

where w_i is the set of filter coefficients according to Wiener-Hopf equations, v_p is a transmitted coded sync word symbol and $y_{n-i}^{(p)}$ is the received value of closest sync word symbol to y_{n-i} . After the initial estimation, the channel estimation uses *a priori* symbol estimates generated from the turbo decoder and is described by

$$\hat{c}_n = \sum_{i=-N_c}^{N_c} w_i v_{n-i} y_{n-i}, \quad (4)$$

where v_{n-i} is the turbo symbol estimates and y_{n-i} is the received symbols. Here, the channel gain is found using all of the received symbols in conjunction with the symbol estimates of the turbo decoder after the first iteration.

Note that for sufficiently small filter lengths relative to the fade rate, ($N_c \ll 1/f_d T_s$), the filter coefficients are approximately equal. The filter is then a moving average that is simpler than the Wiener filter and achieves the same results. Our simulations use the moving average approximations.

The most accurate estimation is achieved if the sync codeword is completely and evenly distributed across the transmitted packet. If the sync word is clustered in the middle of packet, then the channel estimates at the edges of the packet will not be as optimal leading to degradation of performance and likewise if the sync word is clustered at any other location. To distribute the sync word across the channel, a balance has to be achieved between the packet size, block channel interleaver structure, the exact placement of the sync word, and the channel demands. Figure 2 illustrates the encoding process and the resulting distribution. Note that for turbo encoding which employs recursive systematic convolutional encoding, a portion of the parity symbols is unknown due to the intrinsic pseudo-random interleaver. One option is to ignore the unknowns which will drop the number of coded SW symbols by a 1/3. Another option is to puncture and replace with a known symbol. The tradeoff can be seen in the simulation section.

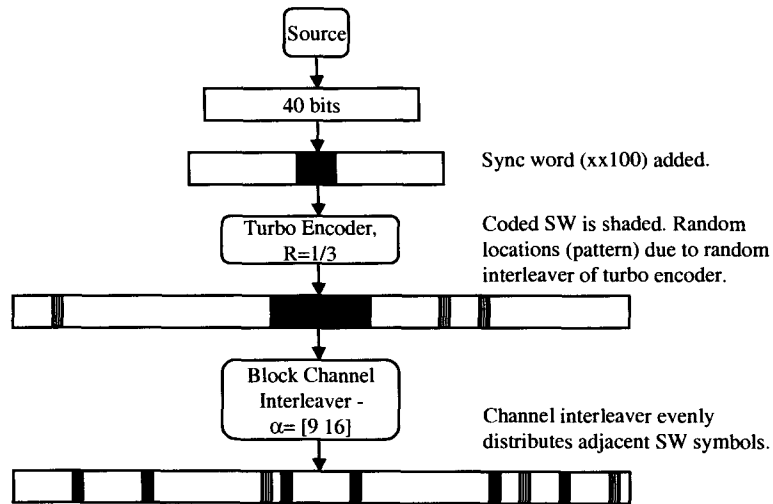


Figure 2. Flowchart of encoding process affecting coded SW distribution.

The design methodology for distributing the coded sync word symbols across the packet would follow these general steps:

- [1] Find worst case fade rate of the channel.
- [2] Derive ideal spacing for estimation symbols.

- [3] Determine packet size based on spacing requirements and given SW.
- [4] Design block interleaver according to spacing.
- [5] Find placement of sync word in data bits that in conjunction with block interleaver that would evenly and completely distribute coded symbols.

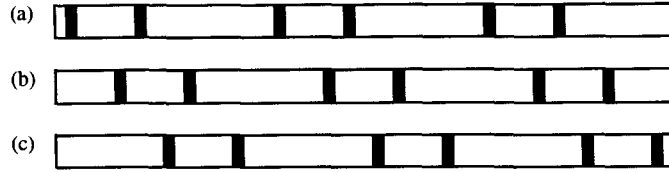


Figure 3. Effect of SW placement in turbo encoded 1/3 rate, 48-bit packet including xx100 SW, and a 8 by 18 block channel interleaver. (a) SW starts at bit position 22. (b) SW starts at bit position 23. (c) SW starts at bit position 24. Notice that the 2nd pseudo-random bits are not illustrated here for clarity purposes.

IV. Simulation Results

For a mobile traveling a vehicle at 70 mph, the fade rate, $f_d T_s$, is .005. The ideal spacing is approximately 16 [3]. For a turbo encoder with constraint length, $k_c=3$, the SW is xx100. The 'xx' in the SW refers to encoder state dependent bits that adaptively force the encoder state to zero. The SW bits are encoded at 1/3 rate leading to 9 coded symbols for estimation purposes. For a spacing of 16, the packet size can be 144 (9x16) with the appropriate block interleaver being 9x16. Placement of the SW in the original data stream is important for a balanced distribution. Figure 3 illustrates the effect of SW placement in the original data. The 'gaps' are due to the pseudo-random locations of the 2nd parity symbols that are not shown for distribution clarity. The 2nd parity bits are unknown due to the turbo encoder pseudo-random interleaver and random data stream. As a result, the effective number of coded symbols for estimation purposes in our example drops from 9 to 6. Two possible options are either to ignore the 2nd symbol bits, or puncture and replace with a known symbol. Figure 4 illustrates the performance difference in relation to use of the unknown parity symbols using the parameters specified above. Simulations indicated that the puncturing method results in a 0.5dB performance improvement.

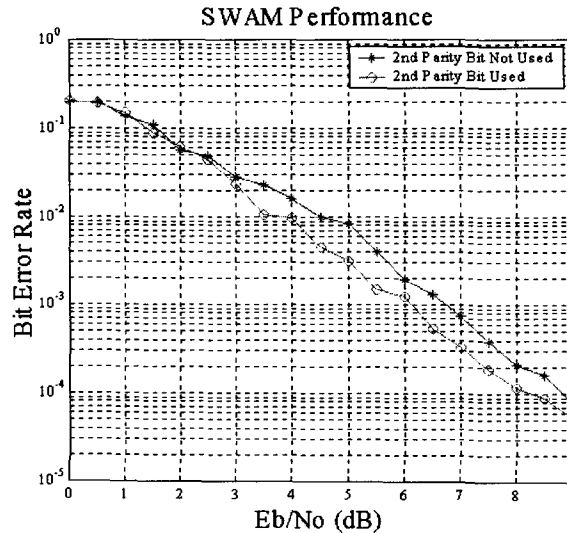


Figure 4. SWAM performance using and not using the 2nd parity bit. The encoder was of constraint length $k_c = 3$, fade rate $f_d T_s = .005$, packet length $L = 48$ including SW xx100, SW placement 22, a [8 18] block interleaver, and a resultant coded sync word spacing of 18. The decoder employed 8 iterations.

For comparison purposes, an equivalent PSAM simulation is performed. The only difference in setup is that 9 pilot symbols are inserted in the encoded data stream. The constraint length, length of data,

block interleaver, code rate, and number of iterations remain the same. As seen in Figure 5, the performance of the PSAM is identical to SWAM (puncturing and replacing unknown parity symbols) within experimental error.

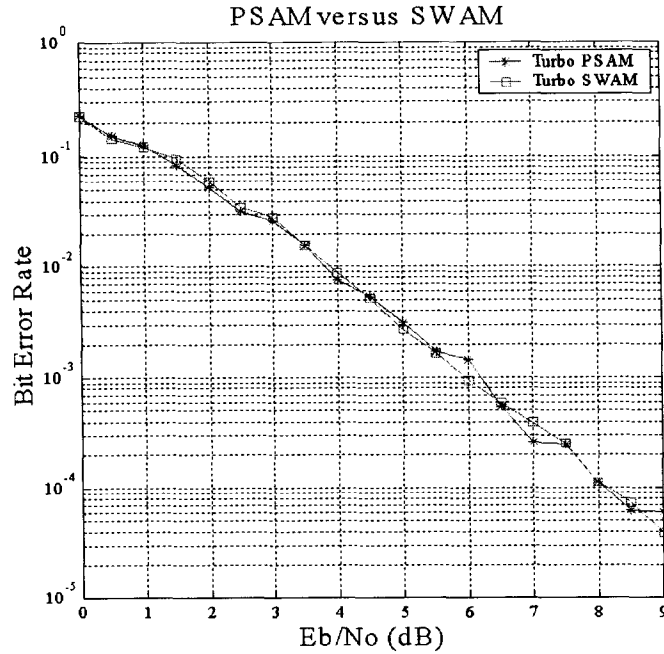


Figure 4. PSAM versus SWAM (puncturing and replacing unknown parity symbols). For SWAM, the encoder is of constraint length $k_c = 3$, fade rate $f_d T_s = .005$, packet length $L = 48$ including SW $\times 100$, SW placement 22, a [9 16] block interleaver, and a resultant coded sync word spacing of 16. The decoder employed 8 iterations. The PSAM encoder and decoder is exactly the same with the exception of inserting 9 pilot symbols spaced every 16 symbols in the encoded data stream.

V. Conclusion

In conclusion, the proposed SWAM method for decoder assisted channel estimation can achieve the same results as PSAM without the additional increase in bandwidth. The only drawback to SWAM is that it is not as scalable as PSAM. For SWAM, the number of estimation symbols is tied into the size of the SW. If the packet size increases but the SW remains the same, then the spacing is increased leading to degradation in performance depending on the channel. Future testing is needed to address the effect puncturing of the unknown SW coded parity symbols has on frame synchronization. Also, the performance link between block channel interleaver and SWAM needs to be further investigated. To properly distribute the coded SW, the block interleaver is modified and may not be ideal.

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