A SYNCHRONIZATION SCHEME BASED ON DECODER 
SOFT OUTPUTS OF LDPC CODES OVER HF CHANNELS

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ABSTRACT

A frame synchronization scheme based on decoder soft outputs of low-density parity-check 
codes over high frequency channels is considered. In a coded orthogonal frequency division 
multiplexing based system, low-density parity-check code decoder soft outputs are exploited in order to 
perform frame synchronization. The decoder soft outputs are observed for several candidate frame start 
positions in order to determine the accurate frame boundaries and to provide an excellent system 
performance. The simulation results show that the system gives the best bit error rate performance at the 
frame synchronization point in which the decoder soft output values reach the maximum over high 
frequency channels.

KEYWORDS: Frame synchronization, low-density parity-check codes, decoder soft outputs, orthogonal 
frequency division multiplexing, high frequency channels.

1. INTRODUCTION

Channel coding is one of the most important tools in digital communication 
systems in order to perform reliable data transmission. Low-density parity-check 
(LDPC) codes [1], which were almost forgotten until the discovery of turbo codes 
[2], were invented in 1960’s by Gallager and re-discovered by MacKay and Neal, 
[3], [4] after the popularity of the turbo codes in many applications. Besides, 
orthogonal frequency division multiplexing (OFDM), in which information bits are 
transmitted to receiver in packets with different subcarriers, is one of the most 
effective ways of combating the degrading effects of multipath and fading to 
accomplish error-free communication. Furthermore, performing an accurate 
synchronization is essential for all receivers in digital communication systems.

In digital communication systems, finding out the boundaries of code 
words or packets, which is usually called as frame synchronization [5], is a vital
requirement when the information is organized in blocks. OFDM based receivers are very sensitive to synchronization mistakes, which can cause loss of orthogonality and unavoidable bit errors at the receiver. Moreover, channel decoder also needs to know start positions of each code word to decode received messages correctly.

Conventional frame synchronization is generally based on the known pilot symbols, which are inserted to the data packets to determine the correct start positions of a frame by using correlation between the inserted known pilot symbols and the received signal. For instance, a genetic algorithm is proposed to search for good pilot positions for frame synchronization in OFDM systems [6]. Frame synchronization with pilot symbols is a well-known field and an optimal maximum-likelihood correlation rule over an additive white Gaussian noise channel is described in [7]. In [8], Liu and Tan extend these results for M-ary signals. Conventional frame synchronization methods generally perform good results by increasing the length of the synchronization pilot symbols. However, the existence of pilot symbols among the data packet symbols results in reduced spectral efficiency and losses in the received power of the system. For instance, presence of 10% pilot symbols in a frame causes a power loss of nearly 0.5 dB [9]. In addition, especially at low SNR values, pilot symbols may also be corrupted and the synchronization performance degrades inevitably, which yields severe bit error rates.

On the other hand, it is possible to exploit channel decoder soft outputs for frame synchronization rather than adding more synchronization pilot symbols. In the literature, employing channel decoders for synchronization generally focuses on LDPC codes and turbo codes. In [10], soft outputs of the turbo decoder are used for synchronization. Howlader and Woerner describe inserting synchronization pilot symbols as part of the data symbols and using turbo decoder to assist synchronization [11]. In [12], joint synchronization for turbo codes in additive white Gaussian (AWGN) channels is investigated. Besides, Matsumoto and Imai [13] monitor the log-likelihood ratio (LLR) values of the variable nodes of the LDPC decoding algorithm in AWGN channels. Similarly, in [14], a pilotless frame synchronization method based on a maximum a posteriori (MAP) probability approach for LDPC codes is proposed. In addition, Lee et.al., show that the constraint nodes of the LDPC decoder can be used to assist the frame synchronization in a pilotless low-density parity-check coded transmission [15],[16].

Consequently, it is evident that detecting the start position of a frame can be easily accomplished by employing the decoder soft outputs. Besides, frame synchronization based on decoder outputs should improve the system throughput. In this paper, therefore, low-density parity-check decoder soft outputs are exploited in order to perform frame synchronization over high frequency (HF) channels. The method depends on monitoring the decoder soft outputs for several candidate frame start positions, which is described in [13]. The simulation results show that the
system gives the best bit error rate performance at the frame synchronization point in which the decoder soft output values reach the maximum value.

This paper is organized as follows. Transmitter and receiver models for the coded orthogonal frequency division multiplexing (COFDM) based system are briefly given in section 2. Frame synchronization scheme based on decoder soft outputs of low-density parity-check code is explained in section 3. Finally, simulation results are presented in section 4 and conclusions are given in section 5.

2. SYSTEM MODEL

Transmitter and receiver block diagrams of a COFDM based system [17] is given within this section.

Figure 1 gives the transmitter block diagram of the COFDM system. $K$ information bits are encoded using a rate $R_c$ code such as LDPC code or any linear block code. The $N=K/R_c$ encoded bits are interleaved over multiple blocks to mitigate the effects of fading. Interleaved coded bits are grouped in $m$ bits and then mapped to obtain the complex $2^m$ quadrature amplitude modulation (QAM) data symbols according to the constellation diagram. Finally, at the transmitter side, after inserting the pilot symbols to the data subcarriers for channel estimation, the inverse fast Fourier transform (IFFT) is performed to create the time waveform.

**Figure 1.** Transmitter block diagram of the COFDM system.

Receiver block diagram of the system is given in Figure 2. At the receiver side, after performing packet detection and frame synchronization, FFT of each symbol is calculated. Then, the FFT demodulator extracts distorted data and pilot symbols for channel equalization and estimation.
Channel is estimated at the known pilot symbol positions to be interpolated in order to obtain the channel frequency response at the data positions. Demodulated data symbols are equalized by simple channel inversion operations.

After channel equalization data symbols are de-interleaved, before a powerful forward error correction decoding algorithm is performed. The decoder is initialized with the soft inputs calculated in the form of log-likelihood ratios and the decoder delivers soft outputs. The decoding process is stopped either the maximum number of decoder iterations is met or the syndrome check is satisfied. The syndrome check is only satisfied when the decoding algorithm is accomplished with no errors. Finally, both hard and soft outputs are obtained at the decoder when the stopping criteria are met.

3. SYNCHRONIZATION BASED ON DECODER SOFT OUTPUTS OF LDPC CODES

In OFDM systems information bits are transmitted to the receiver in packets. Therefore, determining the correct frame boundaries, which is called as frame synchronization, is an essential requirement in order to provide good system performance. Besides, the decoder also needs to know the start position of the received code word to perform the decoding process in a correct manner.

A raw prior knowledge about the location of a frame can be simply obtained by carrier power detection. For instance, in [13], carrier power detection is used to provide information about the candidate frame start positions in order to perform frame synchronization via LDPC codes in AWGN channels. Since the receiver can easily calculate the frame start position coarsely, accurate information for the frame start position may be acquired by utilizing the LDPC decoder soft outputs.
In this paper, therefore, the correct start position of a frame is established by utilizing the LDPC decoder soft outputs over high frequency channels in order to improve the raw estimate of the carrier power detection.

We decided to utilize symbol reliabilities of the decoder outputs for frame synchronization. The reliability of a symbol is defined as the reliability of the least reliable bit composing \( m \) bits of a \( 2^m \)-QAM symbol where \( m \) bits of the \( 2^m \)-QAM symbol can be defined as \( q = [c_1, c_2, \ldots, c_m] \). A posterior probability of a bit \( c_i \) is given \( P(c_i | y) \) where \( y \) is the received codeword. The log-likelihood ratio of the decoder outputs is defined by equation (1).

\[
\lambda(c_i) = \log \left( \frac{P(c_i = 0 | y)}{P(c_i = 1 | y)} \right)
\]

As the LLR may take values in a wide margin, the reliabilities of each symbol, \( R(q) \), are calculated by mapping the corresponding bit LLR, \( \lambda(c_i) \), with the hyperbolic tangent function, to the narrower \([0, 1] \) interval, which is shown in equation (2).

\[
R(q) = \tanh(\lambda(c_i))
\]

The decoder is initialized with the de-interleaved soft outputs of the channel equalizer, as shown in Figure 2. The decoding algorithm is performed and the soft outputs are obtained from the decoder.

For frame synchronization, number of decoding iterations is set to only one in order to reduce both the complexity and latency. After mapping the decoder soft outputs to the symbol reliabilities as shown in equation (2), the mean value of the symbol reliabilities of the decoded code word is calculated. Finally, the procedure is repeated for other candidate frame start positions in order to observe the behavior of decoder soft outputs for the related frame start position. The results are given in section 4.

4. SIMULATION RESULTS

In this section, we demonstrate the low-density parity-check decoder soft output behavior for several candidate frame start positions over high frequency channels.

Nowadays, HF communication is once again popular due to the renewed interest and the new approaches in military and commercial use of the spectrum between 3 MHz and 30 MHz. HF channel is being used frequently in long haul communication, especially by naval and air forces, where other ways of communication are not sufficient or not feasible. In addition, HF channel is also
frequently used in long distance radio broadcasting and civil defense communication, especially during major force events such as earthquakes.

HF channel is characterized as a multipath time varying environment that produces both time and frequency dispersion. Spectral efficiency is an essential issue due to very narrow bandwidth of HF channels. Therefore, performing frame synchronization accurately via the decoder outputs will help to improve the system throughput in HF channels. Furthermore, coded OFDM system, which is used to combat the degrading effects of HF channels, is very sensitive to synchronization errors.

International Telecommunication Union Radio Communication sector defines the standard poor HF channel as a disturbed channel in mid latitudes which has several spectral notches in the signal’s spectrum. Poor HF channel [18], used in our simulations, is characterized by two independently fading paths with equal mean attenuation, equal frequency spreads of 1 Hz and 2 ms differential time delay between two paths.

As described in section 2, at the transmitter information bits are encoded using a rate 3/4 both column and row regular LDPC code whose parity check matrix is generated randomly. Coded bits are interleaved and 64-QAM symbols are generated using a gray coded square QAM constellation. At the receiver side, a normalized LDPC code decoding algorithm [19] is used. Only one decoder iteration is performed and the outputs of the LDPC decoder are observed. The decoder soft outputs are mapped to the symbol reliabilities and the mean of the symbol reliabilities of a code word is calculated. This process is repeated for different code words and the results are given in Figure 3 for different frame start positions.

In Figure 3, the sample points refer to the candidate frame start positions and the symbol reliability is the mean symbol reliability value of code words for the corresponding frame start location.
According to the simulation results maximum reliability is obtained at the sample point 0. Candidate frame start positions that are different from the sample point 0, which is the frame start position that has the maximum mean symbol reliability, are defined as the synchronization offsets. Besides, as shown in Figure 3, in both negative and positive synchronization offsets, mean symbol reliabilities decrease.

In order to test the effect of the frame start position on the receiver, bit error rate (BER) performance of the system with different frame start locations is analyzed. The number of maximum decoder iterations is set to five and the system performance is calculated for two different signal-to-noise ratios. The results are given in Figure 4.

As shown in Figure 4, the receiver system has the best bit error rate performance at the synchronization point in which the maximum reliability is obtained, as shown before in Figure 3. Any synchronization offsets, both in negative and positive directions, degrade the system BER performance; however negative synchronization offsets cause more degradation in BER performance than the
positive synchronization offsets do. Figure 4 also shows that the increasing SNR improves the system BER performance.

![Figure 4. Bit error rate versus candidate frame start positions](image)

5. CONCLUSIONS

In this paper, we monitor the decoder soft outputs of low-density parity-check codes for frame synchronization in a coded orthogonal frequency division multiplexing system over high frequency channels. Simulation results show that the best bit error rate performance is obtained at the frame synchronization point in which the decoder soft outputs of the low-density parity-check codes have the maximum reliability. Furthermore, both negative and positive synchronization offsets yield to degradation in system performance and reduction in the mean symbol reliabilities of the decoder outputs.

REFERENCES


