

Performance of clustered OFDM with low density parity check codes over dispersive channels

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Abstract

We present a new LDPC coded clustered OFDM system with 16QAM modulation operating over a frequency selective fast fading channel. Various channel estimation methods are studied and pilot-symbol-aided channel estimation with uniquely designed spacing pattern is used to obtain channel side information in fast fading. A BER of 10^{-6} is achieved at 12.8dB with Doppler frequency $f_m = 200\text{Hz}$ and 14.8dB with $f_m = 100\text{Hz}$. The overall capacity of this system is about 1.56bit/s/Hz . Compared with other wideband systems, our design has much better performance in fading channels than the LDPC coded classical OFDM and is much simpler than TTCM-OFDM system.

1 Introduction

The main advantage of orthogonal frequency division multiplexing (OFDM) [5] is that it allows transmission over frequency selective channels with a low receiver implementation complexity. With cyclic prefix (CP) and IFFT/FFT processing, the frequency selective fading channel can be easily converted into parallel flat fading subchannels. Recently, clustered OFDM has been proposed to improve system performance. In clustered OFDM system, OFDM tones are divided into many tone clusters and each user accesses several clusters located at different frequency. An error correction code is used to obtain in-band frequency diversity gain of wideband dispersive fading channels.

Low density parity check (LDPC) codes were introduced by Gallager in the early 1960's, and were rediscovered by Mackay and Neal in the mid 1990's [1]. While LDPC codes with large block size were found to give similar performance to Turbo codes, one of the key distinction of LDPC codes is that they are much easier to decode and naturally adapted to parallel implementation. This property along with their excellent error correction capabilities makes them

worth considering for use in wideband systems.

For classical OFDM systems, either pilot-symbol-aided or decision-directed channel estimators [8] can be used to obtain channel information. Earlier work in [8] has shown that the optimum transforms for decision-directed channel estimation is the eigenmatrix of the channel frequency domain correlation matrix. Since there may be over a hundred contiguous tones for classical OFDM systems, the discrete Fourier transform can be used for fast and robust calculation with negligible edge effects. For clustered OFDM, [2] introduce a robust transform to reduce the edge effects, but the computation complexity is higher due to the lack of fast transform algorithm. Also considering that the decision-directed channel estimator experiences large performance degradation in fast fading, we chose pilot symbol aided channel estimator for our system.

We propose a LDPC coded clustered OFDM for a frequency selective fading environments. The paper is organized as follows. First we present the LDPC basics. Then we introduce clustered OFDM for high rate data access and channel estimation method is presented. Finally, performance of the proposed system is evaluated by computer simulation.

2 System Description

2.1 LDPC basics

LDPC codes are defined as codes using a sparse parity-check matrix with a small number of 1's per column (column weight) and per row (row weight). LDPC codes can be represented by a factor graph that contains two types of nodes: the bit nodes and the check nodes. Each bit node corresponds to a column of a parity-check matrix, which also corresponds to a bit in the codeword. Each check node corresponds to a row of a parity-check matrix, which represents a parity-check equation. An edge between a bit node and a check node exists if and only if the bit participates in

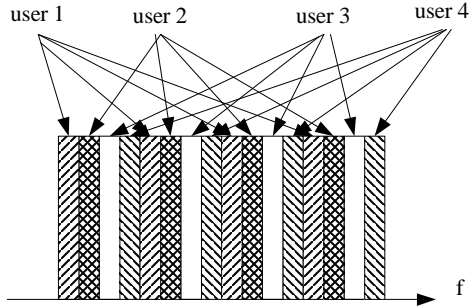


Figure 1. Concept of clustered OFDM

the parity-check equation represented by the check node. The graph representation completely describes all the relations of the code, and can be used for decoding using the message-passing algorithm. Starting with the input consisting of intrinsic probability for the bits, the message-passing algorithm uses the parity check relationships amongst the bits to iteratively pass messages between the bit nodes and check nodes to obtain extrinsic probabilities for the bits. The intrinsic and extrinsic probabilities can then be combined to give posterior probabilities for the codeword bits.

2.2 Clustered OFDM

The concept of clustered OFDM for wideband channels is shown in Fig.1. The wideband OFDM signal is divided into many groups of contiguous tones in frequency that are called clusters, and each user accesses several clusters. The clustered OFDM has some advantages over classical OFDM [3], such as:

- It provides a high degree of flexibility in supportable bit rates and quality-of-service (QoS) since clustered OFDM can allocate bandwidth by tone clusters.
- Error correction code can be used in each cluster to explore time diversity with relatively short block size.
- The clustering approach can result in an effective means for realization transmit diversity and combat multipath fading.
- The PAP ratio is reduced by $10 \log_{10}(L)$, where L is the number of clusters.

The schematic of the LDPC coded clustered OFDM transmission system is shown in Fig.2 and 3. In a multipath fading channels, some sub-carriers of OFDM may be completely lost because of the deep fades. In this case, it is expected that many errors appear on continuous sub-carriers and occur in two dimension. We use LDPC codes to compensate for these two dimensional errors in both time and frequency domain.

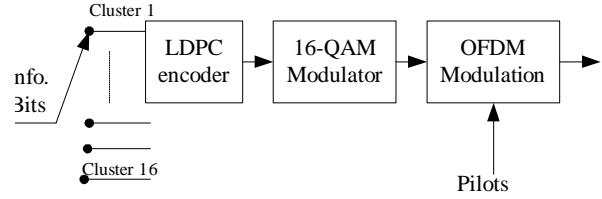


Figure 2. The transmitter structure of the LDPC coded clustered OFDM system

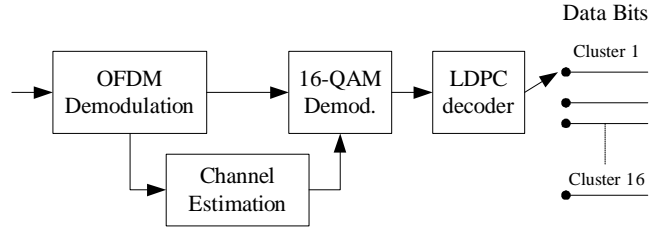


Figure 3. The receiver structure of the LDPC coded clustered OFDM system

At the transmitter, information bits are encoded by the LDPC encoder. The encoded bits are mapped to the modulation symbols directly without a interleaver since the LDPC code has a built-in interleaver. After the serial-to-parallel conversion, the modulated symbols are assigned to OFDM symbols for the purpose of compensating two dimensional errors in OFDM. At the receiver, demodulated bits from OFDM signals are decoded with each LDPC decoder and data bits are restored.

2.3 Pilot symbol aided channel estimation

Channel information is required by coherent detection and decoding. In this section, we describe the pilot symbol aided channel estimation method using two dimensional Wiener filter. Pilots can be scattered over several OFDM data symbols, or a whole OFDM symbol used as pilot tones. [4] shows that it is better to choose to transmit a few pilot tones in each symbol rather than clump them together in one symbol. This allows for better tracking of the channel variations. It is also shown that one should choose equally-spaced tones sets as pilot tones, to avoid the noise enhancement effect in interpolating the channel frequency response. Figure. 4 shows a block of 16 OFDM symbols with 16 sub-carriers used in our system. The gray sub-carrier values are known pilots. Comparing with pan-European terrestrial digital video broadcasting(DVB) system, our pilot spacing is more dense in frequency and sparse in time, because in clustered OFDM, one cluster contains fewer tones, which means more pilots are needed in frequency than in the DVB

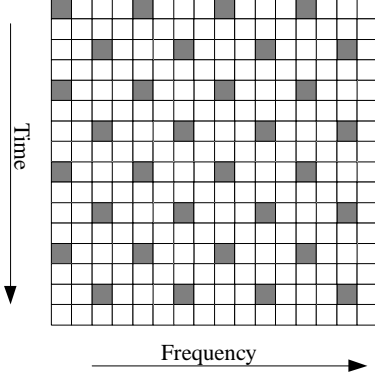


Figure 4. Pilots spacing in a block of 16 symbols in a cluster

system.

To be able to interpolate the channel estimates both in time and frequency from the available pilots, the pilot spacing has to fulfill the Nyquist sampling theorem. The bandwidths of the channel variation are equal to the Doppler spread f_{max} in the time domain and the maximum delay spread τ_{max} in the frequency domain. Hence the requirements of the pilot spacing in time and frequency s_t and s_f are $s_t < 1/B_d$ and $s_f < 1/\tau_{max}$. Assume the received pilots are arranged in a vector \mathbf{y} , the transmitted pilot symbols are \mathbf{x} , the channel values \mathbf{h} have to be estimated. The minimum mean square error estimate is given by

$$\hat{\mathbf{h}}_{\text{MMSE}} = \mathbf{R}_{\mathbf{h}\mathbf{y}} \mathbf{R}_{\mathbf{y}\mathbf{y}}^{-1} \mathbf{y} = \mathbf{G} \mathbf{y}$$

where

$$\mathbf{G} = \mathbf{R}_{\mathbf{h}\mathbf{h}} \mathbf{x}^H (\mathbf{x} \mathbf{R}_{\mathbf{h}\mathbf{h}} \mathbf{x}^H + \sigma_n^2 \mathbf{I})^{-1}$$

Assuming independent multipath fading, the autocorrelation matrix $\mathbf{R}_{\mathbf{h}\mathbf{h}}$ is

$$R_{hh}(l, k) = r_f(k) \cdot r_t(l)$$

r_f and r_t are the correlation functions in time and frequency, respectively. For an exponentially decaying multipath power delay profile, $r_f(k)$ is given by

$$r_f(k) = \frac{1}{1 + j2\pi\tau_{rms}k/T}$$

with $1/T$ is the sub-carrier spacing. For a time fading signal with maximum Doppler frequency f_{max} and a Jakes spectrum, the time correlation function $r_t(l)$ is given as

$$r_t(l) = J_0(2\pi f_{max} l T_s)$$

where $J_0(x)$ is the zeroth order Bessel function of the first kind and T_s is the OFDM symbol duration.

In simulation, we assume the channel statistical information is known. Robust channel estimators have been proposed in [2] and can be easily implemented.

3 Performance evaluation

3.1 Simulation Environment

The operating environment directly dictates the system parameters. In our simulation, we target at the channel which models mobile receiver in urban environment at a carrier frequency of 2GHz transmitting in a bandwidth of approximately 4 MHz, and hence is representative of UMTS channel. The typical urban delay profile of the channel is reported in Table. 1 [6].

The choice of OFDM parameters is a tradeoff between various requirements. Given the bandwidth of 4 MHz and the demand for an integer number of samples both within the FFT/IFFT interval and in the symbol interval, we divide the bandwidth to 256 sub-carriers with sub-carriers spacing 16K Hz. The guard time interval should be about two to four times the root-mean-squared delay spread and the symbol duration 6 times the guard time, which implies a 1dB SNR loss because of the guard time. The system parameters are shown in Table. 2. Combining with rate 1/2 coding and 16QAM modulation scheme, the bit rate is 6.68Mbps.

Table 1. Impulse response and amplitude delay profile of COST207 typical terrain channels

Tap#	Delay μs	Power(DB)
1	0	-3
2	0.2	0
3	0.6	-2
4	1.6	-6
5	2.4	-8
6	5.0	-10

Table 2. System Parameter

Number of sub-carriers	256
Number of cyclic prefix	50
Sub-carriers spacing	16KHz
OFDM symbol period	$(256 + 50)/4M = 76.5\mu s$
Cyclic prefix period	$50/4M = 12.5\mu s$
Bandwidth	4MHz

As described above, LDPC encoding is done across both sub-carriers and OFDM symbols. The whole 256 sub-carriers are divided into 16 clusters, each with 16 sub-carriers. We assume no frequency offset, therefore no guard tones between clusters. Each LDPC coding block consists

16 sub-carriers in frequency and 60 OFDM symbols in time. With this scheme, multiple access can be achieved by providing each user with different clusters. Table. 3 shows the parameter of LDPC encoder.

Table 3. Encoder and modulation parameter

Modulation scheme	16QAM
Constellation Mapping	Gray
LDPC block size	$60 * 16 * 4 = 3840$
LDPC code rate	1/2
LDPC code type	column regular
Column weight of parity check matrix	4

3.2 Simulation results

Fig. 6 and Fig. 7 report our result over the UMTS channel simulated by Jakes extended model for Doppler frequency f_m at 100Hz, 200Hz and ∞ , corresponding to vehicle speed at 54Km/hour and 108Km/hour, while $f_m = \infty$ is uncorrelated fading. The maximum LDPC decoding iteration is set to 5, which is a reasonable number considering the tradeoff between complexity and performance [9]. Better performance can be achieved by larger number of iterations.

In Fig.8 we compare the mean square error of channel estimator using three different scattered pilot pattern (a),(b) and (c) shown in Fig.4 and 5. The pilot density of pattern (a) is 1/16, corresponding to a 0.5dB loss in E_b/N_0 . Pattern (b) has the same pilot density as (a), but the resulting MSE is much worse. Pattern (c) reduce the pilot density to 1/32, corresponding a 0.25dB E_b/N_0 save in pilots compared to (a). However the MSE of pattern (c) get worse and the SNR saves in pilot is offset by the error in channel estimation, resulting the degraded overall performance especially when f_m becomes larger.

It is noteworthy that compared with $f_m = 100$ Hz case, although the MSE of channel estimation is larger when $f_m = 200$ Hz, the overall BER performance is still better. This is because the larger the f_m is ,the shorter the deep fade interval becomes, and hence there is higher time diversity for LDPC code to explore in one coding block.

Comparing with the LDPC coded classical OFDM system [10], which suffers severe performance degradation in fading environment, our system achieves huge performance improvement. While Turbo TCM OFDM system [7], which use a 5000-symbol interleaver, has similar performance over UMTS channel, our system has much lower complexity.

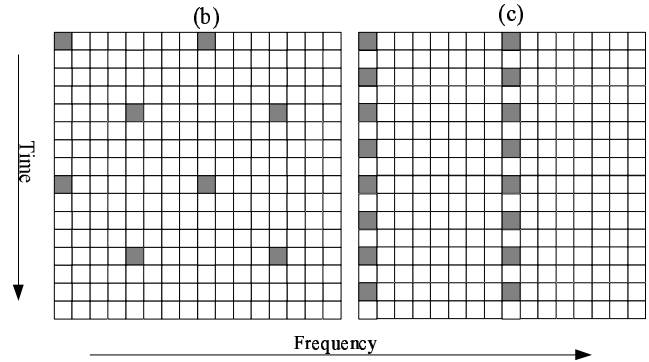


Figure 5. Other pilot spacing in a block of 16 symbols in a cluster

4 Conclusions

In conclusion, the LDPC coded clustered OFDM scheme constitutes a more attractive solution than the TTCM or LDPC coded classical OFDM system. With pilot symbol aided channel estimation, very accurate channel side information can be get even in fast fading channel. A BER of 10^{-6} is achieved at 12.8dB when $f_m = 200$ Hz and 14.8dB when $f_m = 100$ Hz with estimated channel.

5 Acknowledgment

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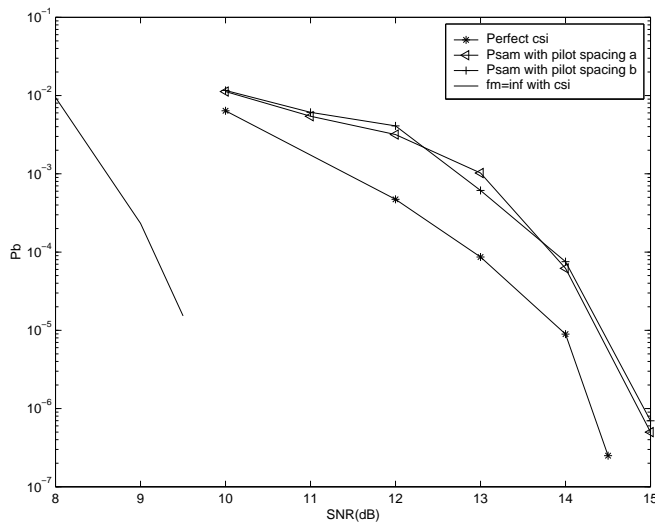


Figure 6. Performance of the 16QAM LDPC-OFDM system over UMTS channel simulated by Jakes model at $f_m = 100Hz$

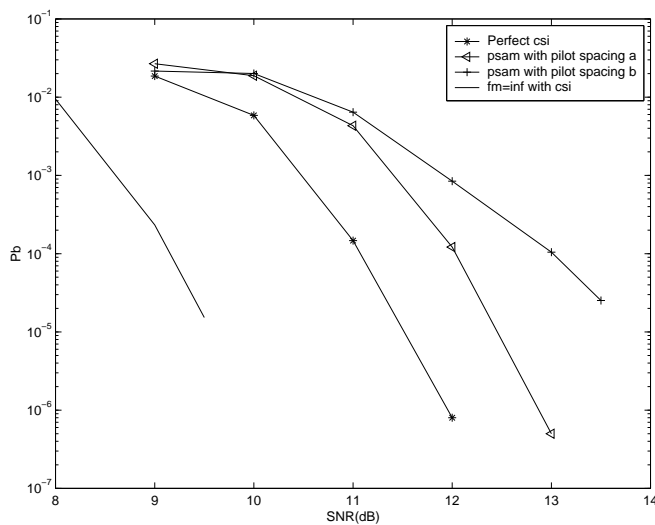


Figure 7. Performance of the 16QAM LDPC-OFDM system over UMTS channel simulated by Jakes model at $f_m = 200Hz$

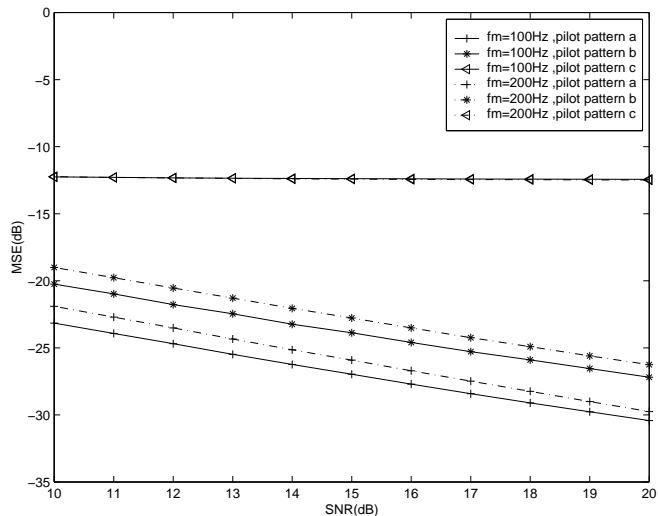


Figure 8. MSE of of the 16QAM LDPC-OFDM system over UMTS channel

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