Nonbinary LDPC Coding for Multicarrier Underwater Acoustic Communications

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Abstract

Recently, multicarrier modulation in the form of orthogonal frequency division multiplexing (OFDM) has been shown feasible for underwater acoustic communications via effective algorithms to handle the channel time-variability. In this report [1], [2], we propose to use nonbinary low density parity check (LDPC) codes to address two other main issues in OFDM: (i) plain (or uncoded) OFDM has poor performance in fading channels, and (ii) OFDM transmission has high peak to average power ratio (PAPR). We develop new methods to construct nonbinary regular and irregular LDPC codes that achieve excellent performance, match well with the underlying modulation, and can be encoded in linear time and in a parallel fashion. Based on the fact that the generator matrix of LDPC codes has high density, we further show how to reduce the PAPR considerably with minimal overhead. Experimental results confirm the excellent performance of the proposed nonbinary LDPC codes in multicarrier underwater acoustic communications.

I. Extended Abstract

Multicarrier underwater acoustic communication, in the form of orthogonal frequency division multiplexing (OFDM), has been actively investigated recently (see e.g. [3], [4] and references therein). It has been shown through experimental tests that OFDM system with good channel coding can handle high-rate transmissions over long dispersive underwater channels. This report is dedicated to a thorough investigation on using the advanced non-binary LDPC codes in underwater OFDM systems.

We adopt nonbinary LDPC codes as our channel coding scheme [5], [6]. We will consider both regular and irregular LDPC codes over GF(q). For regular LDPC codes, we will use cycle codes that have column weight 2 and fixed row weight d, based on the work in [7]. We also develop a novel method to construct irregular LDPC codes that have mixed column weights of 2 and t, where $t \geq 3$. All the codes constructed can be encoded in linear time and in a parallel fashion. In addition, we present another benefit of using LDPC codes that it can help to reduce the peak-to-average power ratio (PAPR) of OFDM through selected mapping (SLM) transmission.

We have simulated the performance of many different combinations of modulations such as BPSK, QPSK, 8-QAM, 16-QAM and 64-QAM, and LDPC codes of rate 1/2, 2/3, 3/4, 5/6 and 7/8 using both an AWGN channel and an underwater Rayleigh fading channel with the OFDM parameters as in [3] and [4]. Specifically, the bandwidth is 12kHz, and the delay spread is 10ms, resulting in 120 channel taps in discrete-time. Each OFDM block is of duration around 100 ms, and has 1024 subcarriers, out of which 672 subcarriers are used for data transmission. Each OFDM block contains one codeword. For the bandwidth efficiency ranging from 0.5 to 5 bits/symbol, we only keep the combination that has good performance in the Rayleigh fading channel and record the LDPC code parameters. We collect the seven modulation-coding pairs in Table I, and propose to use these seven modes for future OFDM modem development. Fig. 1 shows the block-error-rate (BLER) performance of different modes under the Rayleigh fading channel.

We have applied the modes 2 to 5 in Table I in a multicarrier system and collected data from the Rescheduled Acoustic Communications Experiment (RACE) which took place in Narragansett Bay, Rhode Island, from March 1st through March 17th, 2008. The spectral efficiencies for the RACE08 experiment are 0.5864, 0.8795, 1.1727, and 1.7591 bits/sec/Hz, for transmission modes with QPSK, 8-QAM, 16-QAM, and 64-QAM constellations, respectively. The achieved data rates are 2.86, 4.29, 5.72, and 8.59 kbps, respectively. Fig. 2 shows the corresponding BLER performance for modes 2 to 5 in Table I. Results from this experiment demonstrate that the proposed transmission modes are fairly robust to the varying channel conditions within those 13 days.

TABLE I

NONBINARY LDPC CODES DESIGNED FOR UNDERWATER SYSTEM [1], [2]. EACH CODEWORD HAS $672b$ BITS WITH A SIZE-2^b CONSTELLATION.

Mode	Bits/symbol	Code rate	η	t	Galois field	Constellation
1	0.5	$1/2$	2.8	4	GF(4)	BPSK
2	1	$1/2$	2.8	4	GF(4)	QPSK
3	1.5	$1/2$	2.8	4	GF(8)	8-QAM
4	2	$1/2$	2.3	3	GF(16)	16-QAM
5	3	$1/2$	2.0	-	GF(64)	64-QAM
6	4	$2/3$	2.0	-	GF(64)	64-QAM
7	5	$5/6$	2.0	-	GF(64)	64-QAM

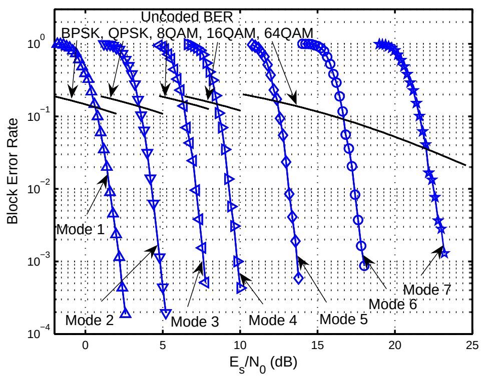

Fig. 1. BLER performance of different modes over the Rayleigh fading channel [1], [2].

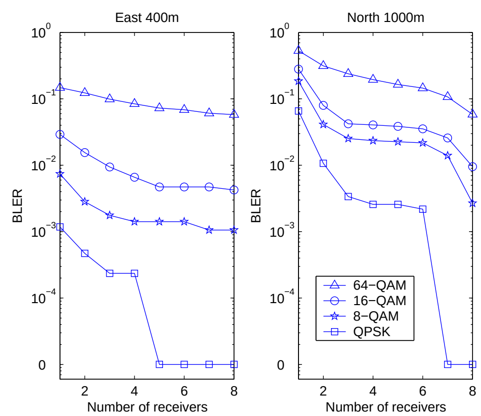

Fig. 2. The block error rate as a function of the number of receive-elements; the results are averaged over the data collected from 13 days in the RACE08 experiment [2].

Building upon our current progress, we next will pursue:

- implementation of parallel linear-time encoding and efficient decoding algorithms for the proposed nonbinary irregular LDPC code using FPGA/DSP.
- application of the proposed nonbinary irregular LDPC codes into the OFDM modem prototypes currently under development at UConn.

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