QUASI-CYCLIC LOW DENSITY PARITY CHECK (LDPC) CODES FOR DEDICATED SHORT RANGE COMMUNICATION (DSRC) SYSTEMS

Najmeh Khosroshahi and T. Aaron Gulliver

Dept. of Electrical and Computer Engineering
University of Victoria, P.O. Box 3055, STN CSC
Victoria, BC, V8W 3P6 Canada
Email: {nkhosros,agullive}@ece.uvic.ca

ABSTRACT

In this paper, we consider the performance of a dedicated short range communication (DSRC) system for inter-vehicle communications (IVC). The DSRC standard employs convolutional codes for forward error correction (FEC). The performance of the DSRC system is evaluated in three different channels with convolutional codes, regular low density parity check (LDPC) codes and quasi-cyclic (QC) LDPC codes. The effects of interleaving are considered. In addition, we compare the complexity of these codes. It is shown that LDPC and QC-LDPC codes provide a significant improvement in performance compared to convolutional codes.

1. INTRODUCTION

The main goal of intelligent transportation systems (ITS) is to improve traffic efficiency and mobile safety without new road construction. The dedicated short range communication system (DSRC) standard based inter-vehicle communications system plays a key role in ITS [1]. In October 1999, the Federal Communications Commission (FCC) allocated the frequency spectrum between 5.850 and 5.925 GHz for DSRC, which will enable vehicles to communicate with the road infrastructure, and allows for a large number of ITS applications. This provides an opportunity for automakers, government agencies, and related commercial entities to improve highway safety. However, inter-vehicle communications must operate effectively within transmit power limits and under received signal strength fluctuations and Doppler spread.

In [2], [3] and [4], the authors considered DSRC using orthogonal frequency devision multiplexing (OFDM) as a means of overcoming frequency selective fading. Convolutional coding was employed for forward error correction to achieve a bit error rate (BER) of less than 10^{-5}. The results in [3] show that antenna diversity can be used to improve performance. In [4], the BER performance of the DSRC standard was evaluated under the large Doppler frequencies and multi path delay spreads encountered in outdoor high-speed vehicle environments. The performance with LDPC codes was considered in [5], but interleaving was not examined.

In this paper, we consider DSRC performance using low density parity check (LDPC) codes and Quasi-Cyclic (QC)-LDPC codes. The effects of interleaving on performance is examined. Results are presented for several channel conditions and code rates which show the superiority of QC-LDPC and regular LDPC codes over convolutional code. The decoding complexity is also compared.

2. THE DSRC SYSTEM

Aside from the fact that the DSRC signal bandwidth is 10 MHz (half the IEEE 802.11a bandwidth), the DSRC physical layer has the same frame structure, modulation and training sequences as specified in the IEEE 802.11a standard [4]. The basic DSRC parameters are shown in Table 1.

The IEEE 802.11a standard was principally designed for indoor WLAN applications. Therefore, the physical layer parameters were optimized for the indoor low-mobility propagation environment. However, when vehicles are moving at speeds up to 120 miles/hour, and with communication ranges up to 1000 m, the channel is very different from the IEEE 802.11a environment [4]. As will be discussed later, the DSRC communication channel can be very hostile. One means of overcoming this problem is to use more powerful FEC. In this paper, we evaluate the performance of a DSRC system using

Table 1. DSRC Physical Layer Parameters [4]

Data Rate	3,4.5,6,9,12,18,27 Mbps
Modulation	BPSK,QPSK,16-QAM,64-QAM
Coding Rate	1/2, 2/3, 3/4
Number of Subcarriers	52
Subcarrier Spacing	156.25 KHz
Number of Pilot Tones	4
Guard Interval	1.6μ sec
OFDM Symbol Duration	8μ sec
Signal Bandwidth	10 MHz

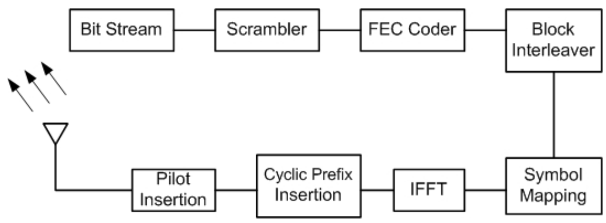

Fig. 1. The DSRC transmitter model.

QC-LDPC codes rather than convolutional codes. A DSRC channel model is used rather than the IEEE 802.11a model.

2.1. The DSRC Transmitter

A block diagram of the DSRC transmitter is shown in Fig. 1. The input bit stream is first scrambled and then encoded using a constraint length 7 rate $1/2$ convolutional code. Higher code rates are obtained by puncturing the convolutional encoder output. The interleaver redistributes the bits before transmission. This reduces the effects of burst errors caused by the fading channel on the performance of the convolutional decoder. When vehicles are moving slowly, i.e., in congested urban areas, the channel coherence time is typically much larger than the packet transmit period, so in this case the channel can be assumed to be time invariant over a packet interval. This slow or block fading introduces burst errors. Conversely in fast environments such as highways, the fading is faster and the errors can be considered independent.

According to the IEEE 802.11a standard, the encoded data is interleaved by a block interleaver with a block size corresponding to the number of bits in a single OFDM symbol, so in terms of bit length, the interleaving depth depends on the modulation employed. For example, with BPSK modulation the size is 48, while for QPSK it is 96. Next, the data is mapped into symbols based on the modulation employed, and these symbols are transmitted on a set of orthogonal subcarriers. An inverse Fast Fourier Transform (IFFT) is performed to obtain the time domain orthogonal frequency-division multiplexing (OFDM) symbol. A cyclic prefix is added at the beginning of each OFDM symbol, and 4 pilot symbols are inserted in each OFDM symbol for synchronization at the receiver.

2.2. The DSRC Channel

Although there have been numerous vehicle-to-vehicle communication studies, the channel model for vehicular environments is not well understood. However, the analysis in [6] shows that we can assume a Rician fading distribution when the distance between two vehicles is less than 100 m, and a Rayleigh fading distribution when this distance is greater than 100 m. These distributions are used in this paper. According to the investigation in [6], the relative speed observed between two vehicles is typically less than 10 miles per hour, so the corresponding maximum Doppler spread is approximately 100 Hz. In addition, it has been determined that the maximum Doppler frequency in urban environments is about 100 Hz [7], so here we consider $f_D = 100$ Hz.

With a Rician channel model, there is a line of sight (LOS) component, and the ratio of the LOS component power to the Rayleigh scattered power (NLOS), is called the Rician parameter K. In [6], the Rician fading parameter is said to lie in the range $K = [0, 2]$. Since $K = 0$ corresponds to Rayleigh fading, we consider $K = 2$ for Rician fading.

2.3. The DSRC Receiver

The DSRC receiver is shown in Fig. 2. We assume perfect timing and frequency synchronization. The received signal is transformed to the frequency domain using a fast Fourier transform (FFT). The resulting signal is then mapped to bits and de-interleaved. Finally, the soft information is input to channel decoder, and the output bits descrambled.

3. CONVOLUTIONAL CODING IN A DSRC SYSTEM

The output of the scrambler is encoded using code rates $R = 1/2$, $2/3$, or $3/4$, depending on the desired data rate. The convolutional encoder has rate $R = 1/2$ and constraint length 7 (memory length $m = 6$), as shown in Fig. 3. Higher rates are obtained by puncturing the output bit stream. Puncturing is a procedure for deleting some of the encoded bits, thus reducing the number of transmitted bits and increasing the code rate [8].

Using a longer constraint length can provide better error correction, but the complexity of the Viterbi decoding algorithm increases exponentially with m. In [9], the complexity of convolutional decoding, C, is measured as the number of branch metrics computed per decoded bit. Specifically, a binary encoder which takes in k bits per unit time has a trellis which has 2^k branches entering or leaving each state, and its decoder must output k information bits per unit time[9]. Thus, $C = S \times 2^k$ where $S = 2^m$. For the DSRC convolutional code, $k = 1$, and consequently the complexity of decoding n bits is $C_t = n \times S \times 2^k$

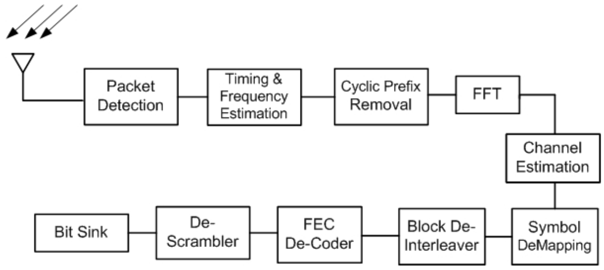

Fig. 2. The DSRC receiver model.

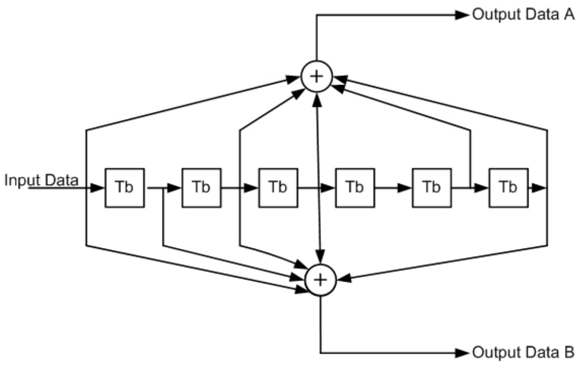

Fig. 3. The DSRC convolutional encoder based on the IEEE 802.11a standard.

4. LOW DENSITY PARITY CHECK CODES

Low density parity check (LDPC) codes were first introduced by Gallager [10]. The most important innovation was iterative or message passing decoding, which provides excellent performance compared with other decoding methods. LDPC codes are linear block codes which are specified by a very sparse parity check matrix H [11], hence the term “low-density”. For example, if H has dimension $n/2 \times n$ where n is an even block length, H may have three 1’s per column and six 1’s per row [12]. A code with these parameters is called a regular (3,6) LDPC code, and this code is employed in this paper. LDPC codes have significant advantages over other codes, such as superior performance and decoding implementations which can be parallelized. In addition, the encoding complexity of LDPC codes is quite manageable in most cases and provably linear in many cases [12]. A (t, u)-regular LDPC code is defined as a code represented by a parity-check matrix H in which each column has weight t and each row has weight u [15]. For a (3,6) regular code of length n, the encoding complexity has order n^2, however the actual number of operations required has been estimated as $0.017^2 \times n^2 + O(n)$, and because of the extremely small constant factor, even large block lengths can be practically encoded [12]. Based on the results in [14], the encoding complexity of QC-LDPC codes is on the order of the number of rows in the correspondence parity check matrix. Therefore they have lower complexity than regular LDPC codes, while providing similar performance, as will be shown in the next section.

Here we use rate 1/2 LDPC and QC-LDPC codes with parity check matrix sizes 504×1008 and 2000×4000. For QC-LDPC codes, we consider codes with girth six and eight[1], and compare the performance with that of LDPC and convolutional codes. Based on the discussion in [13], the complexity per iteration when using the log-SPA decoding algorithm to decode LDPC codes is $C = 2(3u-4)M(q-1)^2 + uM(t-1)(q-1)$ where t, u, are the column and row weights, respectively, N, M, is the size of the parity check matrix, and q is the field size, which in our case is 2. For N_{itr} iterations, the complexity is then $C_t = N_{itr} \times [2(3u-4)M(q-1)^2 + uM(t-1)(q-1)]$, and in this paper we use $N_{itr} = 15$.

[1]The smallest cycle length in the bipartite graph or parity check matrix

The parity-check matrix H of a (t, u)-regular QC LDPC code consists of $t \times u$ circulant (permutation) sub-matrices of size $m \times m$. As a result, The parity-check matrix H has size $m\ t \times m\ u$, and the associated code rate is $R \geq (1 - t/u)$ [15]. This is a regular code since every column and every row of H contains t ones and u ones, respectively.

The decoding of low-density parity-check (LDPC) codes allows a high degree of parallelism, which makes it very suitable for high data rate applications such as DSRC communications [15]. In addition quasi-cyclic (QC) LDPC codes have received significant attention due to their efficient hardware implementation and good performance [15]. This reduction in hardware complexity (and power consumption) is obtained by exploiting the regularity of the parity check matrix structure, and results in more efficient decoding that ordinary LDPC codes.

5. PERFORMANCE RESULTS

Fig. 4 shows the performance of the DSRC system in an AWGN channel with convolutional, LDPC and QC-LDPC codes. This shows that the LDPC codes are much better than the convolutional code, as expected, and there is little difference between the LDPC and QC-LDPC codes. However, the QC-LDPC code has lower complexity.

In Figs. 5 and 6 the performance is given for Rayleigh and Rician channels, respectively, with independent fading for each symbol. The difference between the QC-LDPC codes with girth 6 and 8 is not significant. For a Rayleigh fading channel at a BER of 10^{-5}, the improvement over the convolutional code is approximately 1 dB for LDPC (504,1008,3,6) and approximately 1.5 dB for LDPC (2000,4000,3,6). The corresponding values are approximately the same for a Rician fading channel. The improvement with the QC-LDPC code over the LDPC code increases as the number of decoding iterations increases. With two iterations, the performance is almost the same, but the difference is significant at 15 iterations. In a Rayleigh fading channel, the QC-LDPC codes provide an improvement of approximately 1.5 dB for QC-LDPC (504,1008,3,6) and approximately 4 dB for QC-LDPC (2000,4000,3,6), over convolutional coding in a DSRC system. The corresponding values are 1.5 dB and 3 dB, respectively, for a Rician fading channel. While the performance difference between the LDPC and QC-LDPC codes in fading channels is significant with these particular codes, the choice of QC-LDPC codes is based on the lower encoding and decoding complexity.

Fig. 7 shows the AWGN performance in comparison with rate 2/3 QC-LDPC codes obtained by changing the number of ones per column and row to 2 and 3, respectively. The rate 2/3 LDPC and convolutional codes were obtained by puncturing the corresponding rate 1/2 codes. The QC-LDPCs codes have 1 dB better performance than the convolutional code, and are about 0.5 dB better than the LDPC codes.

Figs. 8 and 9 show the performance with and without an interleaver in a block fading channel. These results were obtained using a slow fading channel where the fading changes only every 120 bits. This corresponds to a very congested urban environment with heavy traffic. This shows that there are error floors with no interleaving due to the burst errors (the QC-LDPC code error floors occur at higher BERs). With interleaving, the error floors are eliminated. The performance of the LDPC code is now approximately the same as that with the QC-LDPC codes. Thus the interleaving improves the LDPC code more in comparison with the QC-LDPC codes.

6. CONCLUSIONS

In this paper, we investigated the performance of the DSRC inter-vehicle communication standard with regular LDPC and QC-LDPC codes for forward error correction (FEC). Results were presented which show that LDPC and QC-LDPC codes provide a significant performance improvement in AWGN and fading channels. The complexity of the LDPC (2000,4000,3,6) and (504,1008,3,6) codes is, respectively, 4.9 and 1.2 times that of the convolutional code in the DSRC standard. Since the complexity of a QC-LDPC code is less than that of a comparable LDPC code, the complexity of the QC-LDPC codes employed here is comparable to that of the convolutional code. Thus a QC-LDPC code provide an attractive trade off between performance and complexity, and should be considered as an alternative for DSRC systems. Note that although QC-LDPC codes have lower complexity, they have performance similar to that of regular LDPC codes.

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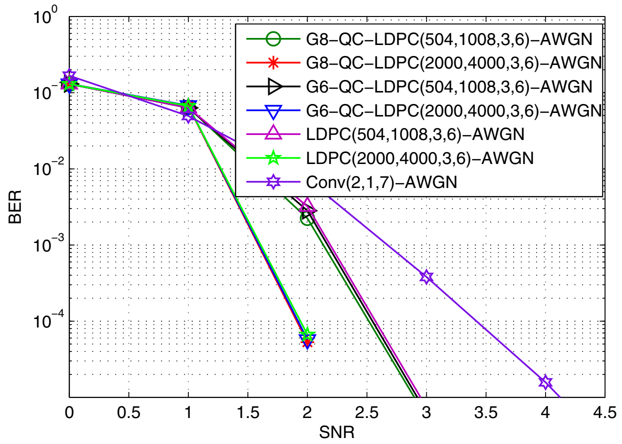

Fig. 4. Performance with three different codes in an AWGN channel.

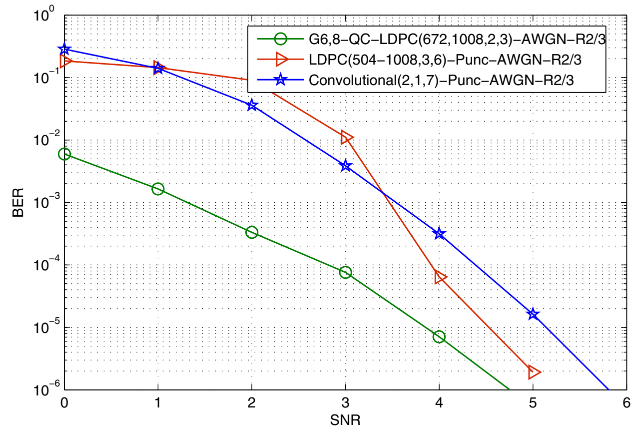

Fig. 7. Performance with three different rate 2/3 codes in an AWGN channel.

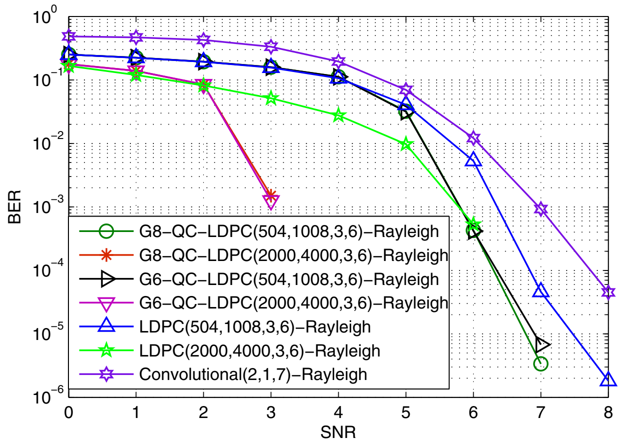

Fig. 5. Performance with three different codes in a Rayleigh fading channel.

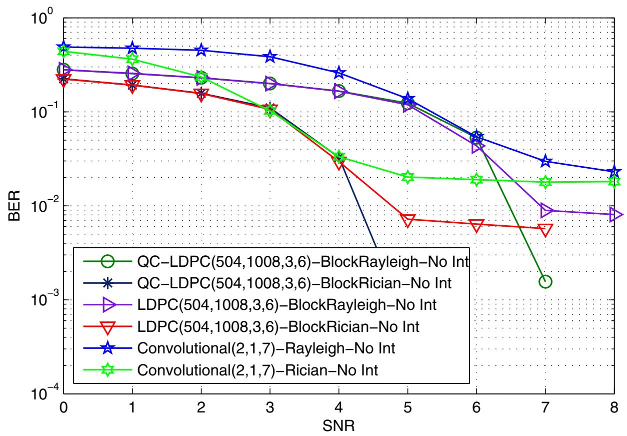

Fig. 8. The effect of block fading on three different small parity check matrix codes.

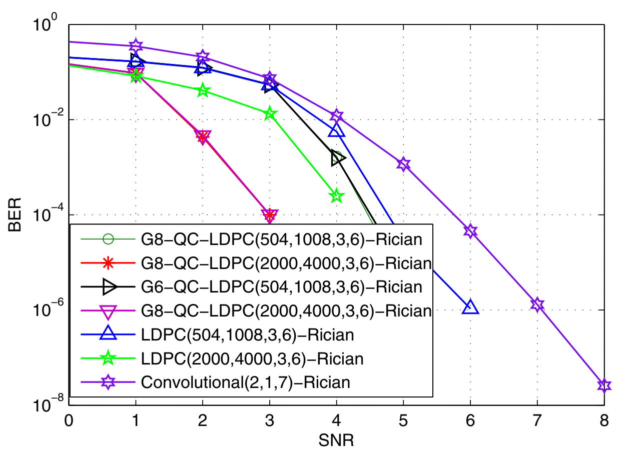

Fig. 6. Performance with three different codes in a Rician fading channel.

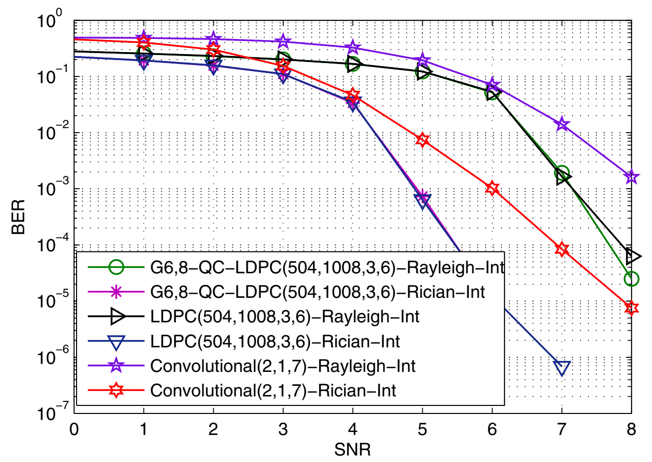

Fig. 9. The effect of block fading with interleaving on three different small parity check matrix codes.