Low Density Parity Check Codes for Dedicated Short Range Communication (DSRC) Systems

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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 and regular LDPC codes. In addition, we compare the complexity of these codes. It is shown that LDPC codes provide a significant improvement in performance with similar complexity 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 (IVC) 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 auto-makers, 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. DSRC for inter-vehicle wireless communications can provide numerous safety applications, but these require reliable communications at a reasonable cost.

In [2],[3], and [4] the authors considered DSRC using orthogonal frequency dvision multiplexing (OFDM) as a means of overcoming frequency selective fading. Convolutional coding was employed for forward error correction to achieve a BER of less than 10^{-5}. The results in [3] suggest using antenna diversity to improve the received signal strength and improve performance. In [4], the bit error rate (BER) performance of the current DSRC standard was evaluated under the large Doppler frequencies and multipath delay spreads encountered in outdoor high-speed vehicle environments. Convolutional coding was used for forward error control (FEC) in all coses.

In this paper, we consider DSRC performance using low density parity check (LDPC) codes rather than convolutional codes. Results are presented for several channel conditions and code rates which show the superiority of LDPC codes. Decoding complexity is also compared.

2 The DSRC Wireless Transceiver Model

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. 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.

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

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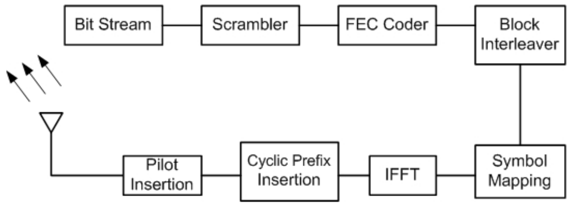

Figure 1. The DSRC transmitter model.

2.1 The DSRC Transmitter

A block diagram of the DSRC transmitter is shown in Fig. 1. The input bit stream is first scrambled using the generator polynomial, $S(x) = x^7 + x^4 + 1$ as defined in the IEEE 802.11a standard. Then the data bits encoded using a 64-state rate $1/2$ convolutional code. Higher code rates are obtained by puncturing the convolutional encoder output. The interleaver redistributes the bits in both the time and frequency domains 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 normally much larger than the packet transmit period, so in this case the channel can be assumed to be time invariant over a packet interval.

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 this amount is 48, while for QPSK it is 96. Next, the data is mapped into symbols based on the modulation scheme, 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 to combat the ISI introduced by the frequency selective fading channel. In addition, 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 mobile-to-mobile channel model for vehicular environments is not well understood. However, the analysis in [10] 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.

A measure of the expected time duration over which the channel response is essentially constant is the coherence time, T_c, which is inversely proportional to the Doppler spread of the channel, within a multiplicative constant. The channel is said to be slow fading if the symbol time, T_s, is much less than the coherence time, T_c, or equivalently the Doppler bandwidth, f_D, is much smaller than the signal bandwidth, $1/T_s$. Conversely, a channel is called fast fading if the symbol time is greater than the coherence time, or equivalently the Doppler bandwidth is greater than the signal bandwidth. According to the investigation in [10], 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. The resulting channel coherence time is 10 ms, so it can be assumed that the channel fades independently for time durations greater than 10 ms.

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 [10], 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 re-

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

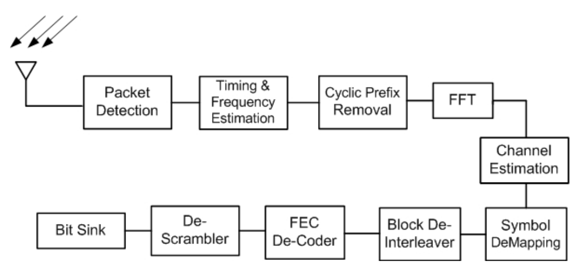

Figure 2. The DSRC receiver model.

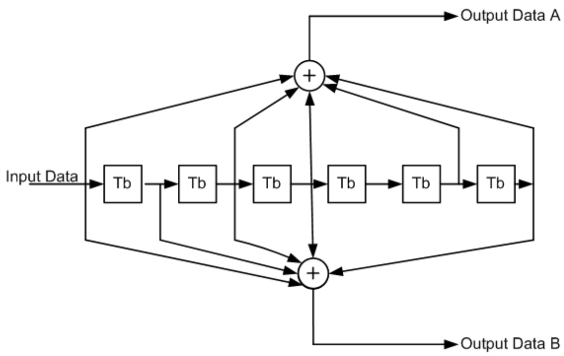

Figure 3. The convolutional encoder for a DSRC system based on the IEEE 802.11a standard.

ceived 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 a Viterbi 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 for rate $R = 1/2$ is shown in Fig. 3. Output bit A is transmitted before bit B. 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. A "zero" metric is used in the convolutional decoder at the receiver in place of the omitted bits [9]. An important parameter in convolutional coding is the constraint length, defined as $K = m + 1$ where m is the length of the shift register in the encoder. The constraint length in Fig. 3 is 7. A longer constraint length provides more powerful codes, but the complexity of the Viterbi algorithm increases exponentially with the constraint length.

In [14], 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[14]. Thus, $C = S \times 2^k$ where $S = 2^m$ and k is the number data bits per unit time. For the DSRC convolutional codes, $k = 1$, and consequently the complexity of decoding n bits is $C_t = n \times S \times 2^k$

4 Low Density Parity Check Codes

Low density parity check (LDPC) codes were first introduced by Gallager [11]. The most important innovation was iterative or message passing decoding, which provides excellent performance compared with other decoding methods. An LDPC code is a linear block code which is specified by a very sparse parity check matrix H [16], hence the term "low-density" is used. 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 such a code is used in this paper. LDPC codes have significant advantages over other codes, such as a simple description of their code structure 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]. 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]. Here we use a rate 1/2 LDPC code with two parity check matrix sizes, 504×1008 and 2000×4000. Based on the discussion in [15], the complexity per iteration when using the log-SPA decoding algorithm 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 $N_{itr} = 15$.

5 Performance Results

As mentioned previously, the DSRC system employs an interleaver, thus the fading can be characterized as independent. Doppler is an important factor as there is typically a speed difference between vehicles. According to [17], the Doppler frequency in urban enviroments is about 100 Hz, so we consider $f_D = 100$ Hz for fading channels.

Figs. 4, and 5, show the performance of convolutional and LDPC (504,1008,3,6) codes for different code rates. These figures show that the LDPC code performance for rate $2/3$ is about 1dB better. As expected, the LDPC codes are much better in all cases. Figs. 6, 7, and 8 show that for an AWGN channel, the LDPC code provides an improvement of approximately 1.6 dB for LDPC (504,1008,3,6) and approximately 1.9 dB for LDPC (2000,4000,3,6), over convolutional coding in a DSRC system. The corresponding values are 1.1 dB and 1.5 dB, respectively, for a Rician fading channel, and 1 dB and 1.5 dB for a Rayleigh fading channel. Thus we can conclude that LDPC coding, even

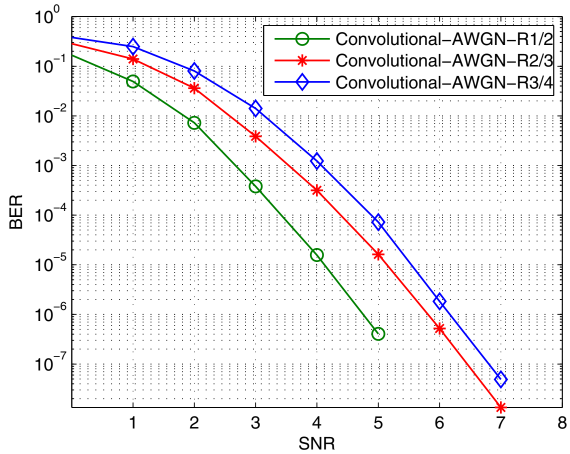

Figure 4. BER for a $K = 7$ convolutional code with different code rates in an AWGN channel.

with a small blocklength of 1008, provides a significant performance advantage over convolutional coding.

Figs. 9 to 11 present the performance in AWGN, Rician fading and Rayleigh fading channels with convolutional and two different types of LDPC codes, respectively. For BER $= 10^{-3}$, convolutional coding requires 2.7 dB, 5 dB, and 7 dB, respectively, and this decreases to 2.2 dB, 4.3 dB, and 6.3 dB with LDPC (504,1008,3,6) coding. Increasing the blocklength to an LDPC (2000,4000,3,6) code further decreases these values to 1.7 dB, 3.6 dB and 5.5 dB.

6 Conclusions

In this paper, we investigated the performance of the DSRC inter-vehicle communication standard with regular LDPC codes for forward error correction (FEC). Results were presented which show that 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. Thus LDPC codes provide an attractive tradeoff between performance and complexity, and should be considered as an alternative for DSRC systems.

References

[1] X. C. Qing, H. S. Gui, L. Z. Ping, W. T. Wu, T. K. Ren, and M. Tomisawa, “A digital intermediate frequency

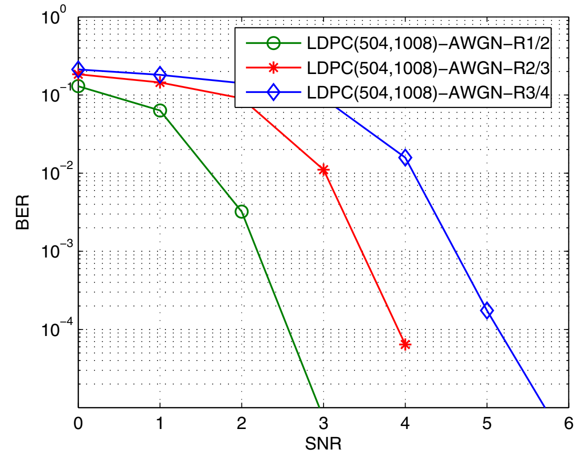

Figure 5. BER for an LDPC (504,1008,3,6) code with different code rates in an AWGN channel.

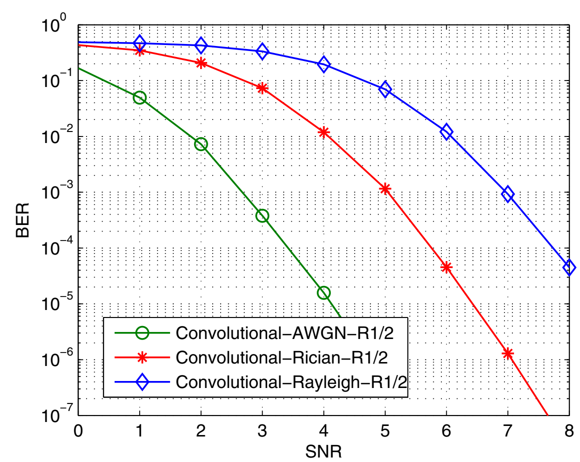

Figure 6. BER for a rate 1/2 convolutional code in three different channels.

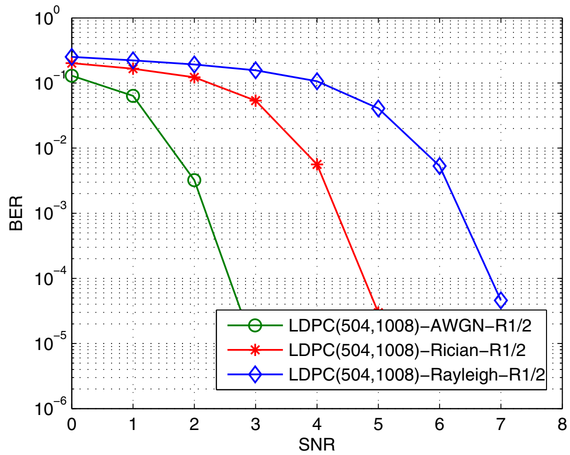

Figure 7. BER for an LDPC (504,1008,3,6) code in three different channels.

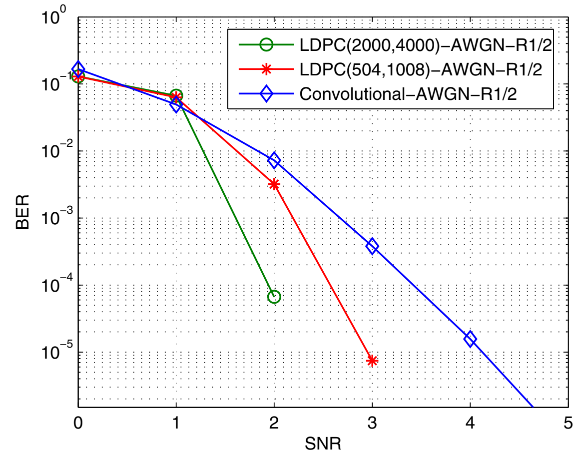

Figure 9. BER for convolutional and LDPC codes in an AWGN channel.

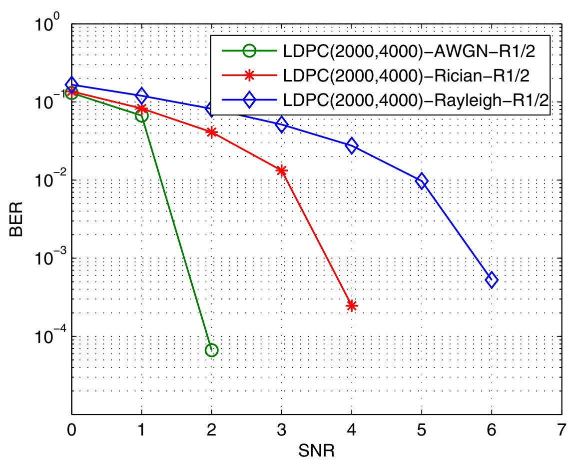

Figure 8. BER for an LDPC (2000,4000,3,6) code in three different channels.

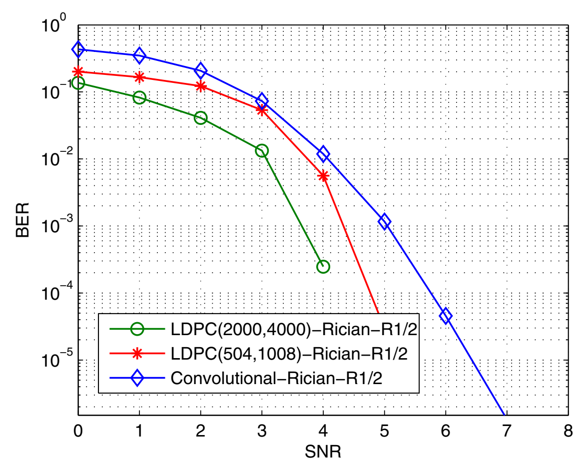

Figure 10. BER for convolutional and LDPC codes in a Rician fading channel with $k = 2$.

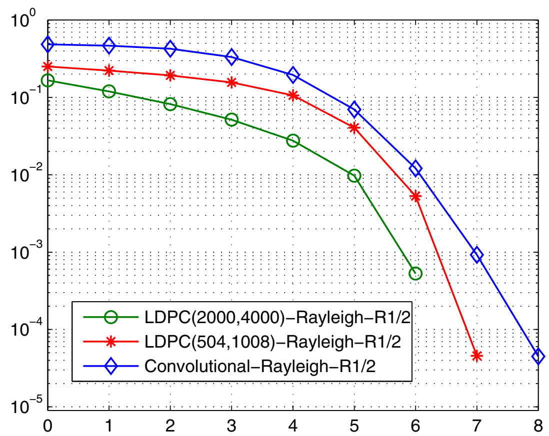

Figure 11. BER for convolutional and LDPC codes in a Rayleigh fading channel.

receiver for inter-vehicle communication," *Proc. IEEE Intelligent Vehicle Symp.*, pp. 840–845, June 2007.

[2] T. Maehata, M. Imai, K. Tanaka, H. Takahashi, N. Hirakata, A. Kamemura, and N. Yumoto, "DSRC using OFDM for roadside-vehicle communication system," *Proc. IEEE Vehic. Tech. Conf.*, pp. 148–152, May 2000.

[3] Y. Yoshida, T. Maehata, H. Takahashi, N. Hirakata, and A. Kamemura, "Novel BER improvement method for OFDM simulcast road vehicle communication system," *Proc. IEEE Vehic. Tech. Conf.*, pp. 2101–2105, Sept. 2002.

[4] J. Yin, T. ElBatt, G. Yeung, B. Ryu, S. Habermas, H. Krishnan, and T. Talty, "Performance evaluation of safety applications over DSRC vehicular ad hoc networks," *Proc. ACM Int. Workshop on Vehic. Ad hoc Networks*, pp. 1–9, Oct. 2004.

[5] T. Schwengler and M. Gilbert, "Propagation models at 5.8 GHz - path loss and building penetration," *Proc. IEEE Radio and Wireless Conference (RAWCON)*, pp. 119–124, Sept. 2000.

[6] G. Durgin, T. Rappaport, and H. Xu, "Measurements and models for radio path loss and penetration loss in and around homes and trees at 5.85 GHz," *IEEE Trans. Commun.*, vol. 46, no. 11, pp. 1484–1496, Nov. 1998.

[7] T. S. Rappaport, *Wireless Communications: Principle and Practice*, Prentice-Hall, New Jersey, 1996.

[8] S. Sibecas, C. Corral, S. Emami and, G. Stratis, "On the suitability of 802.11a/RA for high-mobility DSRC," *Proc. IEEE Vehic. Tech. Conf.*, pp. 229–234, May 2002.

[9] *IEEE Standard for Information Technology, Telecommunications and Information Exchange Between System, and Local and Metropolitan Area Network*

[10] J. Yin, G. Holland, T. ElBatt, F. Bai, and H. Krishnan, "DSRC channel fading analysis from empirical measurement," *Proc. IEEE Int. Conf. on Commun. and Networking in China*, pp. 1–5, Oct. 2006.

[11] R. G. Gallager, Low-Density Parity-Check Codes, Cambridge, MA: MIT Press, 1963.

[12] T. J. Richardson and R. L. Urbanke "Efficient encoding of low-density parity-check codes," *IEEE Trans. Inform. Theory*, vol. 47, no. 2, pp. 638–656, Feb. 2001.

[13] J. Hou, P. H. Siegel, and L. B. Milstein, "Performance analysis and code optimization of low density parity-check codes on Rayleigh fading channels," *IEEE J. Select. Areas Commun.*, vol. 15, no. 5, pp. 924–934, May 2001.

[14] D. W. Matolak, and S. G. Wilson, "Variable-complexity trellis decoding of binary convolutional codes," *IEEE Trans. Commun.*, vol. 44, no. 2, pp. 121–126, Feb. 1996.

[15] H. Wymeersch, H. Steendam, and M. Moeneclaey, "Log-domain decoding of LDPC codes over GF(q)," *IEEE Int. Conf. Commun.*, pp. 772–776, June 2004.

[16] N. F. Kiany and J. H. Weber, "Analysis of random regular LDPC codes on Rayleigh fading channels," *Proc. Symp. on Inform. Theory in the Benelux*, pp. 69–76, June 2006.

[17] X. Zhao, J. Kivinen, and P. Vainikainen, "Characterization of Doppler spectra for mobile communication at 5.3 GHz," *IEEE Trans. Vehic. Tech.*, vol. 52, no. 1, pp. 14–23, Jan. 2003.