Analysis of LDPC Codes in DSRC System's Application

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***Abstract*—Nowadays, Dedicated Short Range Communication (DSRC) system's application is increasing fast, and has been applied to electronic toll collection, parking management, traffic control and other fields. Meanwhile, the complexity and quantity of data is also increasing, thus making the implementation and security requirements more strict. Compared with Turbo codes, Low Density Parity Check (LDPC) codes can achieve a better safety and performance, which have been widely studied. Based on this, we try to apply LDPC codes into DSRC system. In this paper, we first introduce the basic content of DRSC standard, and then analyze LDPC codes in DSRC system. At the end, by simulations, we do comparisons between LDPC codes and conventional Turbo codes in DSRC system when using different decoding algorithms and in different channels.**

***Index Terms*—DSRC system, LDPC codes, turbo codes, performance, complexity**

I. Introduction

DSRC is a short-range wireless communication system which was established at 5.9GHz band for intelligent transportation communications in 1999 [1]. It is a communication platform for on-road vehicles and roadside facilities [2]. By linking vehicles with roads through two-way transmission, drivers and pedestrians can enjoy traffic network resources freely, while providing information for traffic control centers with relevant data [3]. In recent years, with the development of DSRC, people put forward higher requirements for data safety and achievability. Finding some novel codes to replace traditional Turbo codes in the communication system is a good choice to solve this problem.

In 1963, LDPC codes were first proposed by Gallager [4], which are an important class of linear block codes. However, because of limited technical conditions and lack of feasible decoding algorithm, LDPC codes were ignored at that time. Not until the proposal of Tanner graph and the discovery of Turbo codes did people restart the research of LDPC. After several years of study and development, breakthroughs were made in many aspects [5]. It has been demonstrated that LDPC codes can provide decoding performance close to the Shannon capacity limit. For these reasons, LDPC codes have been adopted for several communication standards, including IEEE 802.3an (10GBASE-T), IEEE 802.16 (WiMAX), IEEE 802.11 (WiFi) and the digital video broadcasting (DVB-S2) standards.

In this paper, we provide a comprehensive analysis that applies LDPC codes into DSRC system, and do comparisons with Turbo codes in different kinds of situations. We hope that through this research, the development of DSRC system can be promoted.

The remaining sections of the paper are organized as follows: In Section II, we do a brief specification of DSRC system's principle, including its transmitter model and receiver model. Section III describes LDPC codes and some novel decoding algorithms which will be used in simulations. Section IV discusses how it works when applying LDPC codes into DSRC system and the complexity of this scheme. Then, simulation results are presented in Section V, which show the advantages of LDPC codes over Turbo codes. Finally, conclusions are drawn in Section VI.

II. The Principle of DSRC System

DSRC is one of the foundations of ITS that involves vehicle-to-vehicle, vehicle-to-roadside communications [6]. The DSRC standard was originally adopted from IEEE 802.11a standard, with an exception to the symbol duration (8.0μs with 1.6μs' guard interval) and signal bandwidth (~10MHz) [7].

A. Structure of DSRC System and Communication Process

DSRC system mainly consists of roadside equipment RSU, onboard unit OBU, the control center and some auxiliary equipment [8], [9]. The DSRC communication protocol is based on RSU and OBU wireless short-range communication to ensure safe and reliable transmission of core information technology [10]. Roadside equipment includes radio frequency part (such as antennas, transceivers, etc.), control unit and display equipment. Onboard unit and the control unit both have a radio frequency section depending on the specific application requirements, and vehicle-mounted device can be configured to display equipment. The roadside network is formed by roadside equipment, control center and other related auxiliary equipment. Vehicles and infrastructures can be connected to the network for information exchange, enabling automatic toll collection, geographic information downloads and information dissemination

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functions. Fig. 1 shows the DSRC system's structure and interface.

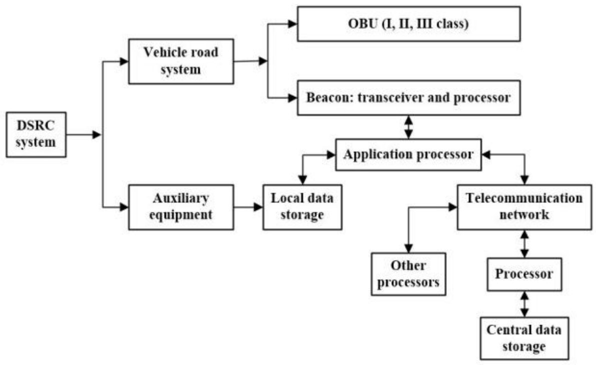

Figure 1. The structure and interface of DSRC system.

Fig. 2 and Fig. 3 show the transmitter and receiver model respectively.

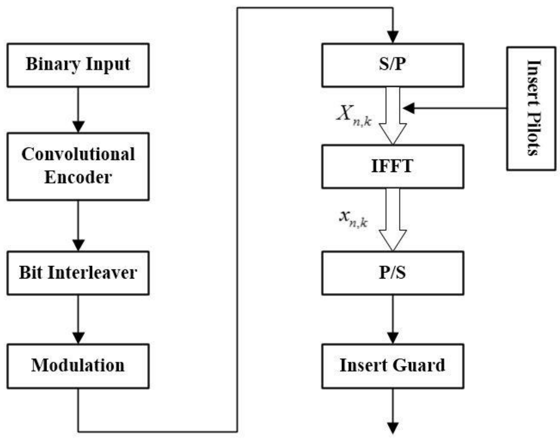

Figure 2. The DSRC transmitter model.

The thin line arrows represent the transmission of serial data, while the thick block arrows represent the transmission of parallel data. The baseband components of the system are individually discussed in the following subsections.

B. DSRC Channel Model

Empirical channel models [11] for a 5.9GHz DSRC system are not publicly available. This study utilizes the appropriate statistical models in representing and simulating the WAVE channel. The WAVE channel can be modeled using statistical models. Rayleigh fading channels may represent 2D isotropic scattering environments without a specular component. Under Rayleigh fading circumstance, the received complex envelope is treated as a wide-sense stationary Gaussian random process with zero mean. For DSRC applications, it would be appropriate to model the propagation as a scattering environment with a specular component. In that case, Rician Fading is considered, where the received complex envelope is treated as a wide sense stationary Gaussian random process with nonzero mean. The angle of arrival distribution of the received signal, which consists of a large number of plane waves, may have the form:

$$p(\theta) = \frac{1}{k+1}\hat{p}(\theta) + \frac{k}{k+1}\delta(\theta - \theta_0) \qquad (1)$$

where $\hat{p}(\theta)$ is continuous distribution, which represents the scatter components, and θ_0 is the angle of arrival of the specular component. The Rice Factor, K, is defined as the ratio between the specular power and scatter power. When $K = 0$ the channel exhibits Rayleigh Fading, when $K = 1$ there is no fading.

Although there have been numerous vehicle-to-vehicle communication studies, the mobile-to-mobile channel model for vehicular environments is not well understood [12]. However, we can assume a Rician fading distribution when the distance between two vehicles is less than 100m, and a Rayleigh fading distribution when this distance is greater than 100 m.

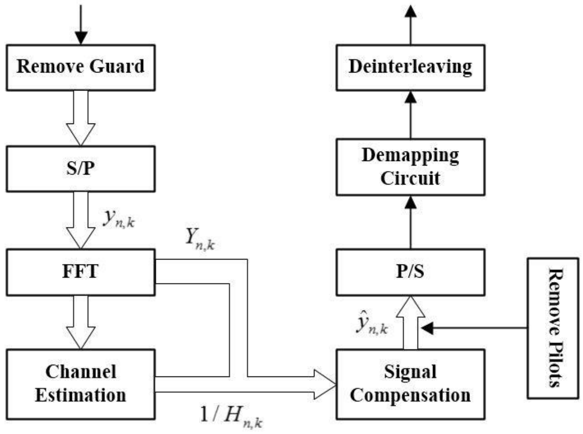

Figure 3. The DSRC receiver model.

III. LDPC Codes and Decoding Algorithms

At the channel receiving end, LDPC decoder generally uses the principle of belief propagation to get the received values. Here are some novel decoding algorithms which have been studied widely [13].

Assume the sending codewords $\mathbf{c} = (c_1, c_2, \cdots, c_n)$ is modulated by BPSK and transmitted in AWGN channel, then received information is $\mathbf{y} = (y_1, y_2, \cdots, y_n)$. The set $N(m)$ is connected to the variable node v_m, the set $M(\mathrm{n})$ is connected to the check node c_l.

A. SPA Decoding

Suppose that c_m is the m-th symbol of $\mathbf{c}$, y_m is the m-th symbol of $\mathbf{y}$. In the i-th iteration, the probability information from variable node v_m to check node c_l is $P_{ml}^{(i)}$, the probability information from check node c_l to variable node v_m is $Q_{lm}^{(i)}$. The maximum number of iterations is i_m.

Then the steps of SPA algorithm are shown as follows:

1) Initialization: for the m-th variable node, initialize $P_{ml}^{(0)}$ to $P_{CH}^{(\mathrm{m})}$, wherein $l \in N(m)$, $1 \le \mathrm{m} \le \mathrm{n}$.

$$P_{CH}^{(m)} = \Pr(c_m = 1 / y_m) = \frac{\exp(L_{CH}^m)}{\exp(L_{CH}^m) + 1} \quad (2)$$

where L_{CH}^m is the log-likelihood ratio of channel receive value y_m, which abides by:

$$L_{CH}^m = \log\left(\frac{\Pr(c_m = 1) / y_m}{\Pr(c_m = 0) / y_m}\right) = \frac{4y_m}{N_0} \quad (3)$$

2) Check node update: for each check node and $m \in M(l)$, $1 \le l \le \text{n} - \text{k}$,

$$Q_{lm}^{(i)} = \frac{1}{2} - \left(\frac{1}{2} \prod_{m' \in M(l)/m} (1 - 2P_{m'}^{(i-1)})\right) \quad (4)$$

3) Variable node update: for each variable node and $l \in N(m)$, $1 \le m \le \text{n}$,

$$P_{ml}^{(i)} = \frac{P_{CH}^m \prod_{l' \in N(m)/l} Q_{l'm}^{(i)}}{P_{CH}^m \prod_{l' \in N(m)/l} Q_{l'm}^{(i)} + (1 - P_{CH}^m) \prod_{l' \in N(m)/l} (1 - Q_{l'm}^{(i)})} \quad (5)$$

4) Decision: for $l \in N(m)$, $1 \le m \le \text{n}$,

$$P_m^{(i)} = \frac{P_{CH}^m \prod_{l' \in N(m)} Q_{l'm}^{(i)}}{P_{CH}^m \prod_{l' \in N(m)} Q_{l'm}^{(i)} + (1 - P_{CH}^m) \prod_{l' \in N(m)} (1 - Q_{l'm}^{(i)})} \quad (6)$$

If $P_{\text{ext}}^m > 0.5$, we can decide that $\hat{c}$ is 1; if not, then $\hat{c}$ is 0.

B. MSA Decoding

By simplifying the equation during check node update, we can get MSA algorithm with lower complexity. The steps are as follows:

1) Initialization: Initialize variable node

$$LP_n = L(c_n / y_n) = \log\left(\frac{\Pr(c_n = 1) / y_n}{\Pr(c_n = 0) / y_n}\right) = \frac{4y_n}{N_0} \quad (7)$$

2) Check node update: for each check node and $n \in N(m)$,

$$Lr_{mn} = \left(\sum_{n' \in N(m)/n} sign(Lq_{n'm})\right) \times \min_{n' \in N(m)/n} |Lq_{n'm}| \quad (8)$$

3) Variable node update: for each variable node and $m \in M(n)$,

$$Lq_{nm} = LP_n + \sum_{m' \in M(n)/m} Lr_{m'n} \quad (9)$$

$$LQ_n = LP_n + \sum_{m' \in M(n)} Lr_{mn} \quad (10)$$

4) Decision: If $LQ_n \ge 0$, we can decide that $\hat{c} = 0$; if not, then $\hat{c} = 1$.

C. Stochastic Decoding

Stochastic computation is a novel approach for decoding LDPC codes. In this approach, probabilities received from the channel are converted to Bernoulli sequences. The frequency of ‘1’s in a stream of bits represents a probability of belief message. For example, a probability of 0.2 can be converted to a stream of bits whose 20% of bits are ‘1’s. The transformation of a probability to a stochastic sequence is non-unique, which means that the order of ‘1’s in a stochastic stream is not important.

In stochastic decoding algorithm, each variable node contains a random bit generator and a counter, which are used to generate random bit streams and make decisions.

Assume that: $R_m^{(t)}$ represents a random number generated at variable node v_m in the t-th decoding cycle. $Bit_{CH,m}^{(t)}$ represents the random bits generated at variable node v_m in the t-th decoding cycle. $Bit_{m\to l}^{(t)}$ represents the bits sent from variable node v_m to check node c_l in the t-th decoding cycle. $Bit_{l\to m}^{(t)}$ represents the bits returned from check node c_l to variable node v_m in the t-th decoding cycle. $Counter_m^{(t)}$ is the value of the counter when variable node v_m contents in the t-th decoding cycle.

The steps of stochastic decoding algorithm are shown as follows:

1) t=0;

2) Initialize variable node: for the m-th variable node, initialize $Bit_{m\to l}^{(0)}$ to $Bit_{l\to m}^{(0)}$, wherein $l \in N(m)$, $1 \le \text{m} \le \text{n}$.

$$Bit_{CH,m}^{(0)} = \begin{cases} 1, P_{CH}^m > R_m^{(t)} \\ 0, P_{CH}^m \le R_m^{(t)} \end{cases} \quad (11)$$

$$Bit_{m\to l}^{(0)} = Bit_{CH,m}^{(0)} \quad (12)$$

3) Check node update: for each check node and $m \in M(l)$, $1 \le l \le \text{n} - \text{k}$,

$$Bit_{l\to m}^{(t)} = \left(\sum_{m' \in M(l)/m} Bit_{m'\to l}^{(t)}\right) \%2 \quad (13)$$

4) Variable node update: for $l \in N(m)$, $1 \le \text{m} \le \text{n}$, each variable node generates a new random bit at the same time.

$$Bit_{m\to l}^{(t)} = \begin{cases} Bit_{CH,m}^{(t)}, Bit_{l'\to m}^{(t-1)} = Bit_{CH,m}^{(t)}, l' \in N(m)/m \\ Bit_{m\to l}^{(t-1)} \end{cases} \quad (14)$$

5) Decision: for $1 \le m \le \text{n}$,

$$Bit_m^{(t)} = \begin{cases} Bit_{CH,m}^{(t)}, Bit_{l'\to m}^{(t-1)} = Bit_{CH,m}^{(t)}, l \in N(m) \\ Bit_{CH,m}^{(t-1)} \end{cases} \quad (15)$$

$$Counter_m^{(t)} = \begin{cases} Counter_m^{(t-1)} + 1, Bit_m^{(t)} = 1 \\ Counter_m^{(t-1)} - 1, Bit_m^{(t)} \ne 1 \end{cases} \quad (16)$$

If $Counter_m^{(t)} > 0$, we can decide that $\hat{c}$ is 1; if not, then $\hat{c}$ is 0.

IV. LDPC CODES IN DSRC SYSTEM

The output of the scrambler [14] is encoded using code rates R = 1/2, 2/3, or 3/4, depending on the desired data rate. The LDPC encoder for rate R = 1/2 is shown in Fig. 4.

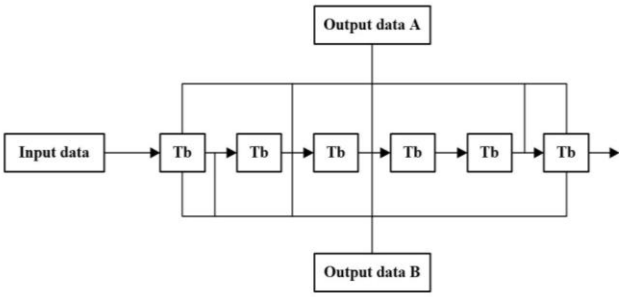

Figure 4. LDPC encoder for rate R=1/2.

Output bit A is transmitted before output bit B. Higher rates are obtained by puncturing the output bit stream [15]. Puncturing is a procedure to delete some of the encoded bits, thus reducing the number of transmitted bits and increasing the code rate. A "zero" metric is used in the LDPC decoder at the receiver in place of the omitted bits. An important parameter in LDPC coding is the constraint length, defined as $K = m+1$, where m is the length of the shift register in the encoder. A longer constraint length provides more powerful codes, but the complexity of Viterbi algorithm increases exponentially with the constraint length. In addition, the encoding complexity of LDPC codes is quite manageable in most cases and provably linear in many cases. For a (3, 6) regular code of length n, the encoding complexity is n^2.

However, the actual number of operations required has been estimated as $0.172^2 \times n^2 + O(n)$, and because of the extremely small constant factor, even large block lengths can be practically encoded. So, for LDPC code (2048, 1723), the complexity per iteration when using the LDPC decoding algorithm is:

$$C = M[(2u-3)+u(t-1)](q-1) \tag{17}$$

where *t*, *u* are the column and row weights, respectively, *M*, is the size of the parity check matrix, and *q* is the field size. For N_{itr} iterations, the complexity is then:

$$C_t = N_{itr} \times [M(2u-3)(q-1)+uM(t-1)(q-1)] \tag{18}$$

V. SIMULATION

In order to evaluate the scheme presented in the previous sections, simulations were done under three different channels: AWGN channel, Rician channel and Rayleigh channel [16]. For fading channels, we considered that Doppler frequency is 100Hz. The block length was equal at 2048 coded bits while the code rate was 0.84. It is assumed that 250km/h would be the legal maximum of relative vehicular velocity, so we chose a mean value at 120km/h. All simulations were carried out with Matlab. In 802.11p, there are three different modulation schemes: QPSK, 16-QAM and 64-QAM. For 16-QAM, the forgetting factor was selected to $\gamma = 0.4$ based on many simulated trial runs.

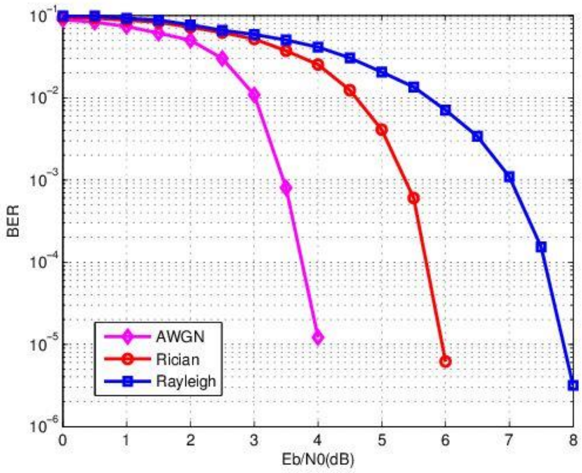

Figure 5. Performance of LDPC (2048, 1723) code in different channels.

Fig. 5 is the BER for an LDPC (2048, 1723) code in three different channels. We can see that compared with AWGN channel, there is about 1.9dB loss in Racian fading channel and 3.8dB loss in Rayleigh fading channel. And we chose Rayleigh channel to simulate DSRC environment.

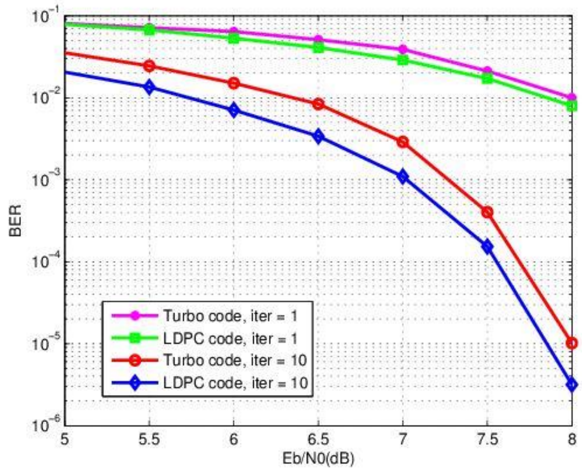

Figure 6. Performance comparison between LDPC (2048, 1723) code and Turbo code in DSRC system.

Fig. 6 shows that with LDPC scheme the performance is slightly better than the Turbo coding chain. At BER of 10^{-5}, the gain is about 0.2dB. In addition, with the increase of iterations, the difference is getting bigger.

In Fig. 7, three decoding algorithms have been used to see the influence. The iteration number of SPA and MSA is 10. In stochastic decoding, the maximum number of decoding cycles is 10K and the length of edge memories is set to 32. As shown, at BER of 10^{-4}, the stochastic decoding algorithm loses about 0.35dB than SPA algorithm, however, as explained above, the hardware complexity of it is much lower.

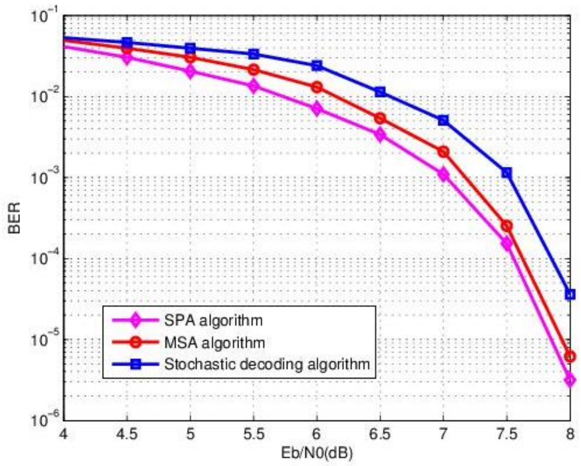

Figure 7. Performance of LDPC (2048, 1723) code in Rayleigh channel with different algorithms.

VI. Conclusion

In this paper, we have mainly done the following research:

Firstly, discuss the principle of DSRC system. This part is described from two aspects, which are the structure of DSRC system and DSRC channel model.

Secondly, introduce LDPC codes and decoding algorithms. We mainly focused on three novel decoding algorithms: SPA, MSA and stochastic decoding. Through formula derivations, we can know that the three algorithms have similar steps, but the main ideas are very different.

Thirdly, apply LDPC codes into DSRC system and do simulations in different channels using the three algorithms. From comparisons, we can conclude that LDPC codes perform better than Turbo codes in DSRC system.

Although LDPC codes have the advantages of better performance, the complexity is very high due to its loop iterations. And stochastic decoding is a good means to solve this problem with little performance loss. Therefore, LDPC codes should be an alternative for DSRC system and vehicular communications. Future work will be done to realize a better compromise between performance and complexity.

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