Research On LDPC-DFH Code Modulation And Demodulation System Based On Hard Decision Decoding

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Abstract. In order to reduce the bit error rate of differential hopping transmission, differential frequency hopping (DFH) is combined with low density parity check code (LDPC). On the basis of not adding more system complexity, the hard decision bit inversion algorithm (BF) and weighted error check based bit inversion algorithm (WVBF) are proposed to decode LDPC-DFH system. The check matrixes of different generation methods are used respectively. The BF decoding method and WVBF decoding method are used to simulate the Gaussian channel and Rician channel. The influence of different decoding methods on the bit error rate is discussed. The simulation results show that the BER of the DFH system with LDPC code is lower than that of DFH without LDPC, and the WVBF algorithm is better than the BF algorithm.

1. Introduction

Differential frequency hopping is one kind of communication technology which combines the functions of Frequency Hopping pattern, information modulation and demodulation. The ordinary frequency hopping communication system sends the modulated signal with variable frequency according to the prepared frequency hopping pattern, and the information to be transmitted does not participate in determining the frequency point. However, the next hop frequency of the signal of the differential frequency hopping communication system is determined by the hop frequency of the current signal and the current information to be sent. The information is mainly transmitted by using the correlation between adjacent hop frequencies, which is determined by the designed frequency transfer function G [5].

Low density parity check (LDPC) is a linear block code given by a check matrix H containing a small number of ones. It is a hot spot in the field of coding in recent years, and the latest fifth-generation mobile communication system (5G) also adopts LDPC coding technology. When the LDPC code length reaches a certain length, the error performance can be very small compared with the Shannon limit.

In the literature [1], the multi-domain LDPC code is combined with the differential frequency hopping technology, and the multi-domain LDPC code itself is used to replace the common frequency transfer function to generate the hopping point sequence, which forms a new kind. The LDPC-DFH code modulation technique is simulated under gaussian channel and short wave channel. In the literature [3], the irregular binary LDPC code is used as the error correcting code of the differential frequency hopping system, and it is optimized under the partial frequency band interference channel. The improved LDPC code is used to improve the anti-interference performance of the system. The method of the
literature [1] changes the frequency transfer function of differential frequency hopping. The method of the literature [3] adds a soft input soft output (siso) decoder and information information extraction part to the system. The decoding methods in the above documents all use BP decoding, and the hardware implementation is complicated. The BF algorithm is a very effective algorithm that can compromise between error correction performance and decoding algorithm complexity.

The research in this paper is applicable to the LDPC-DFH system with low error performance requirements. It uses the Bit Flipping Algorithm (BF) and its improved algorithm based on weighted error check (WVBF)[2] performs decoding to reduce system complexity, and selects the check matrix generated by different methods and the code length of different check codes to compare and analyze the decoding performance and bit error rate under gaussian channel and rician channel.

2. LDPC-DFH code modulation and demodulation system model based on hard decision decoding

![Fig. 1 Model diagram of LDPC-DFH code modulation and demodulation system](image)

The LDPC-DFH coding and demodulation system based on hard-decision decoding simulates the transmission and reception of LDPC-DFH signals under rician channel and gaussian channel respectively, and the LDPC decoder adopts BF algorithm and WVBF algorithm respectively. The model of this system is shown in Fig 1.

It can be seen from the model diagram in figure 1 that compared with the basic DFH system, the LDPC-DFH system with hard decision only needs to encode the transmitted information and decode the output of DFH. There is no need to adjust or modify the DFH system.

2.1. LDPC-DFH system coding module

The coding algorithm adopts a partial iterative coding algorithm to perform row-column permutation on the check matrix H, so the lower triangular form appears in the upper right corner of the check matrix, and then the matrix is divided, so that the lower triangular matrix in the upper right corner is separated into a sub-matrix. And iterative coding is performed by the special structure of the sub-matrix, the approximate lower triangular LDPC code check matrix is shown in Fig 2.
N is the code length, m is the check bit number, and g is the distance between the matrix and the next triangular matrix. Figure 2 can be denoted as:

\[
H = \begin{bmatrix} A & B & T \\ C & D & E \end{bmatrix}
\]

(1)

Then, the matrix is transformed linearly, and the sub matrix e is transformed into an all-zero matrix by the gaussian elimination method multiplied by a matrix. The matrix deformation process of formula (1) is as follows.

\[
H = \begin{bmatrix} I & 0 & 0 & 0 & 0 \\ -ET^{-1} & I & -ET^{-1} & 0 & 0 \end{bmatrix}
\]

(2)

At this point, the code word vector is divided into three parts according to the column. The three parts are \( c=[u \ p_1 \ p_2] \), where \( u=[u(1),u(2)\cdots u(k)] \) is the k-bit information code, \( p_2=[p_2(1),p_2(2)\cdots p_2(g)] \) is the g bit check code, and \( p_2=[p_2(1),p_2(2),\cdots p_2(m-g)] \) is the remaining m-g bit check code, According \( Hc^T = 0 \) to the expansion.

\[
Au^T + Bp_1^T + Tp_2^T = 0
\]

(3)

\[
(-ET^{-1}A + C)u^T + (-ET^{-1}B + D)p_1^T = 0
\]

(4)

The encoding can be completed by finding \( p_1 \) and \( p_2 \) by the above equation (3) and (4).

2.2. LDPC-DFH system decoding module
LDPC-DFH system decoding module adopts hard decision decoding, and decoding methods adopt the following two hard decision decoding methods:

2.2.1. BF algorithm. BF algorithm is a hard decision algorithm. The advantage of this algorithm is that it does not need to know the information of channel environment and receive soft information in advance. Simply put, the BF algorithm first computes all the unsatisfied check equations in the check matrix H, and then "flips" the received code word to fail to check more than a certain number of bits. This step is repeated for the corrected code word until all check equations meet or reach the maximum number of iterations. The equation which fails to check can be indicated by \( s = rH^T \), where \( r \) is the received code word after the decision. For each code word bit, the number of equations whose checksum fails is contained in an n-dimensional vector \( f = sH \) (integer operation).
2.2.2. WVBF algorithm. The downside of Gallager's BF algorithm is that the weight of each error-checking equation is the same for the bit nodes. However, in fact, these weights should be affected by the number of bit nodes in the equation and the number of equations in which these bit nodes are involved in the check error [2]. In reference [2], an improved LDPC bit inversion decoding algorithm WVBF is proposed. In this method, the weight of elements involved in each check equation is calculated, and then the sum of the weight of elements at the corresponding position is added. Finally, the bit is flipped according to the total weight of each element, instead of flipping the bit according to the number of elements that do not meet the check equation, and the element with the largest weight is flipped.

That combines channel soft information with checksum. In literature [9], a BF flip in the improved method of BF algorithm, there is another improved algorithm is proposed to weight bits by channel soft information. It is pointed out that for Gaussian channel, the amplitude of received signal is larger. The more reliable the corresponding bit of information is 1. Therefore, WBF algorithm first calculates the signal amplitude value of all bits contained in each check equation. And then you flip the bits by combining the checksum. In WBF algorithm, channel information still needs to be collected, so we do not do too much research.

3. LDPC-DFH system operation process and algorithm complexity analysis

3.1. System operation process.

The operation process of LDPC-DFH system is as follows:

① The information to be transmitted is LDPC coded by the coding module. The coding method adopts a partial iterative algorithm, and the coded code word is selected by the G function.

② The selected frequency points are modulated and transmitted through 4FSK, and gaussian channel and rician channel are selected as analog channels respectively. At the receiving end, fft processing is carried out for the received signal, and the frequency point exceeding the threshold is selected.

③ The selected frequency sequence is used to calculate the code word sequence to be decoded through the function, and the information code word sequence is decoded through the decoding module.

Through the above system flow analysis, the LDPC-DFH system operation flow can be shown in Fig3.

![Flow chart of system LDPC-DFH](image)

3.2. Analysis of algorithm complexity

In order to compare the complexity of different decoding algorithms, the addition times, multiplication times and division times of BF algorithm, WVBF algorithm and BP algorithm are compared. The calculation amount of different decoding algorithms is shown in table 1.
Table 1. decoding algorithm calculation scale

| Decoding algorithm | Number of operation | Number of addition | Number of Multiply | Number of divide |
|--------------------|---------------------|--------------------|-------------------|-----------------|
| BF algorithm       | n-1+p*2p            | 0                  | 0                 |                 |
| WVBF algorithm     | n-1+p*2p            | 0                  | 0                 |                 |
| BP algorithm       | n(3p+1)             | 11np-9n            | n(p+1)            |                 |

Where n is the code length and p is the column weight. As can be seen from the table, BF algorithm and WVBF algorithm only have addition operation, while BP algorithm contains addition, multiplication and division. The operation complexity is far greater than that of BF algorithm and WVBF algorithm.

4. Simulation results and analysis

In order to test the proposed hard decision decoding method for LDPC-DFH code modulation and demodulation system, the LDPC-DFH system with BF decoding algorithm and WVBF decoding algorithm and the DFH system without LDPC code were simulated. The simulation environment is set as gaussian white noise channel environment and rician channel environment.

Simulation parameters are set as follows:

(1) DFH: the frequency hopping is 5000Hz, the modulation is 4FSK, the sampling frequency is 100MHz, the fan-out coefficient is 4, and the frequency points are 128.

(2) LDPC-DFH: frequency hopping rate of 5000Hz, modulation of 4FSK, sampling frequency of 100MHz, fan-out coefficient of 4, frequency points of 128, code length of 576 and 1440, maximum number of decoding iterations of 50, check matrix using IEEE 802.16e standard generation and mackay random construction generation [10].

Let the channel be the Rician channel, the code length is 576, the check matrix is 802.16e standard structure, the LDPC-DFH system with BF decoding algorithm and WVBF decoding algorithm and the DFH system without LDPC code. The bit error rate curves of the three simulation methods are shown in Fig 4.

Fig. 4 in the case of Rician channel, the code length is 576. The check matrix uses 806.16e standard structure to construct the bit error rate comparison chart. It can be seen from Fig 4 that, in the case of Rician channel, DFH with LDPC code added is lower than the normal DFH code error rate after SNR -16dB, WVBF algorithm has no error code after -16dB, BF algorithm has no error code after -15.5dB, and the uncoded system has no error code after -15.5dB.
Fig. 4 Rician, code length 576, 806.16e standard check matrix

Fig. 5 Gaussian, code length 576, 806.16e standard check matrix

Fig. 5 is a LDPC-DFH system with a code length of 576 and a parity check matrix of 802.16e under the Gaussian channel, a decoding method of the BF algorithm and the WVBF algorithm, and a BER test result of the DFH system. Compared with Figure 4, the error rate of the whole system under Gaussian channel is reduced, and the decoding performance is better. After more than -16dB, the WVBF algorithm performs best.

Fig. 6 Rician, code length 576, Mackay random structure check matrix

Fig. 6 is a LDPC-DFH system with a code length of 576 under the Rician channel, a check matrix of Mackay, a decoding method of the BF algorithm and the WVBF algorithm, and a BER test result of the DFH system. As can be seen from the comparison of Fig. 7 and Fig. 5, the error rate of the check matrix of Mackay randomly constructed is lower than the check matrix of the 802.16e standard structure when it is larger than -16dB.

Fig. 7 Rician, code length 1440, 806.16e standard check matrix

Fig. 7 is a LDPC-DFH system with a code length of 1440, a check matrix using the 802.16e standard, a decoding method of the BF algorithm and the WVBF algorithm, and a bit error rate test result of the DFH system. As can be seen from the comparison of Fig. 7 and Fig. 5, the performance of the bit error rate of 1440 is not significantly improved compared with the 576 code length. The reason for the analysis is that the BF decision and its derivative improvement algorithm are used, and the channel soft information is not utilized, so that the advantages that the LDPC code should have in the long code are not exerted. Secondly, the performance of the WVBF algorithm depends on the construction of the check
matrix. The check matrix of the 802.16e standard is detected. It is found that there are a large number of four rings, which will affect the performance of the WVBF algorithm.

5. Conclusion
In this paper, LDPC code is combined with DFH system, and BF algorithm and its modified algorithm WVBF algorithm are proposed for decoding, which solves the problem of adding complex channel information extraction part in LDPC-DFH communication system using soft decision algorithm, and effectively reduces the complexity of LDPC-DFH system.

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