Research on LDPC - CPM Coded Modulation Communication System

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Abstract. In order to improve the performance of communication system, using integrated coding and modulation process to balance the design, but after trying, we find it difficult to meet the expected requirements, so joint coding modulation came into being. Continuous phase modulation is a kind of constant-envelope modulation schemes with continuous phase which provides good spectral and power efficiency. In this paper, a continuous phase code modulation system based on soft information propagation is proposed. At first, it decodes the CPM by Soft-out Viterbi Algorithm (SOVA), and then uses the soft belief and the hard decision as the input of the LDPC decoder, and finally gets the simulation results. The simulation results show that the method can reach the performance close to the Shannon limit.

Keywords: CPM · LDPC · SOVA

1 Introduction

The development of multimedia service puts forward new requirements for the validity and reliability of satellite communication system. However, the power and bandwidth of satellite communication system are limited, and how to improve the effectiveness and reliability of satellite communication system under the limited power and bandwidth become an urgent problem to be solved. Since Shannon published the "mathematical theory of communication", coding and modulation technology is critical in any communication system. The role of the channel encoder/decoder is to improve the reliability of digital information transmission, however it will lead to the increased redundancy, then the information transmission rate will be reduced. By increasing the sign set of the modulation signal, it is possible to avoid the decrease in the information transmission rate due to the increased redundancy in the band limited channel. However, if the channel is not only limited frequency, power is limited, expanding the modulation signal symbol set will reduce the Euclidean distance of the signal and reduce the reliability of digital information transmission. This requires a higher gain coding method to compensate for the loss of performance, which will greatly increase the complexity of the code [1]. Therefore, purely increasing the modulation signal symbol set and the increased information redundancy is not an effective way to improve the performance of the communication system. Of course, the integrated coding and modulation process can be balanced design, but after trying to find the

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integrated design of the two system performance is still difficult to achieve the desired requirements. Of course, the design can be balanced through an integrated design coding and modulation process, but after trying, we find the integrated design of the system performance is still difficult to achieve the desired requirements. Because when the signal at the receiver is tested, the independent hard decision will be done, the next decoding can not get all the received information, resulting in channel coding gain can not be fully played [2]. Then the idea of joint coding modulation came into being, CPM decomposition method, making CPM as the inner code and the traditional coding cascade, the introduction of iterative detection to improve the system performance has became possible [3].

2 LDPC Codes Introduction

The low density parity (LDPC) code is a class of linear codes named by the sparse features of the parity check matrix, that is, almost all of the elements in H are zero, with only a very small number of nonzero elements. Gallager's first defined binary (N, dv, dc) LDPC code is a linear code with a codeword length of N and a design bit rate of R0 = 1−dv/dc. Each column of the check matrix H contains exactly dv "1" , each line contains just dc "1". Since the parity check matrix satisfying this structural condition is not unique, the LDPC codes with parameters (N, dv, dc) form a set of codes [4]. The following are some commonly used methods in LDPC codes. There are many representations of LDPC codes: (1) check matrix representation; (2) Tanner graph representation; (3) degree function representation. LDPC code construction methods: (1) PEG random configuration method; (2) QC structured construction method. LDPC code decoding method: (1) Sum-product algorithm; (2) BP decoding algorithm, etc. The advantages of LDPC codes are as follows: (1) LDPC decoding algorithm is a parallel iterative decoding algorithm based on sparse matrix. The computational complexity is lower than the Turbo decoding algorithm, and it is easier to implement in hardware because of the parallel structure. (2) LDPC code bit rate can be arbitrarily constructed, flexible; (3) LDPC code has a lower error leveling layer, can be used in wired communications, high-altitude communications and disk storage industry, where the bit error rate requirements are more demanding occasions; (4) its performance approximates the Shannon limit and it is described and implemented simply [5].

3 Continuous Phase Modulation

Continuous phase modulation has the characteristics of constant envelope and continuous phase, which has higher spectral efficiency and power utilization compared with other modulation methods. In addition, due to the memory characteristics, CPM signal has a certain coding gain [6].

3.1 CPM Definition

The transmission signal of the CPM can be defined as

$$s(t,\alpha) = \sqrt{\frac{2E}{T}}\cos(2\pi f_0 t + \varphi(t,\alpha) + \varphi_0), (-\infty \leq t \leq +\infty) \tag{1}$$

Among them, E is the symbolic energy, T is the symbol interval, f_0 is the carrier frequency, φ_0 is the initial phase (usually use $\varphi_0 = 0$), $\alpha = (\alpha_0, \alpha_1, \alpha_2, \cdots)$ is sent to the finite length M of the information symbol sequence, $\alpha_i \in \{\pm 1, \pm 2, \cdots, \pm(M-1)\}$, $i = 0, 1, 2, \cdots$, with the same probability $1/M$ (M generally odd), the signal amplitude is constant. It can be seen from the definition of the CPM signal that the additional phase $\varphi(t,\alpha)$ is the result of the common effect of all the symbols before, not only by the single symbol.

Additional phase is

$$\varphi(t,\alpha) = 2\pi h \sum_{i=-\infty}^{\infty} \alpha_i q(t - iT), (-\infty < t < \infty) \tag{2}$$

$\alpha_i \in \{\pm 1, \pm 2, \cdots, \pm(M-1)\}, (i = 0, \pm 1, \pm 2, \cdots)$ value of the same probability, are $1/M$. h called the modulation coefficient, you can take any real number, but when h takes the number of irrational, CPM system will have numerous states, so h in practical applications should take a rational number, that is, $h = K/P$ (K, P for the quality of integer).

3.2 CPM Phase Status

The phase of the modulation obtained after the introduction of the tilt phase is:

$$\varphi(\tau + nT, \alpha) = R_{2\pi}\left(2\pi\frac{m}{p}R_p\left(\sum_{k=-\infty}^{n-L} u_k\right)\right) + R_{2\pi}\left(4\pi h\sum_{k=0}^{L-1} u_{n-k}q(\tau + kT)\right) + R_{2\pi}(\omega(\tau)) \tag{3}$$

set $v_n = R_p\left(\sum_{k=-\infty}^{n-L} u_k\right)$, $v_n \in \{0, 1, \cdots, p-1\}$, $S_n = \{v_n, u_{n-1}, u_{n-2}, \cdots, u_{n-L+1}\}$, the phase at this time corresponds to the phase state, and the number of phases of the tilted phase representation has nothing to do with the parity.

$$\begin{cases} \varphi(t,\alpha) = f(S_n, n) = g(\gamma(S_{n-1}, u_{n-1})) \\ N_s = pM^{L-1} \end{cases} \tag{4}$$

Where the function $g(x)$ is a time-invariant one-one mapping function, the state transition function $\gamma(x,y)$ is also a time-invariant function $\varphi(t,\alpha)$ can be launched for the Markov process [7].

3.3 CPM Model Decomposition

CPM can be decomposed into a Continuous Phase Encoder (CPE) and a Memoryless Modulator (MM) [8].

Memoryless Demodulator (MM). The physical tilted phase can be expressed in the following form:

$$\begin{aligned}\bar{\psi}(\tau+nT,u) &= R_{2\pi}[\varphi(\tau+nT,u)] \\ &= R_{2\pi}\left[2\pi h\sum_{i=0}^{n-L}u_i+4\pi h\sum_{i=P}^{L-1}u_{n-1}q(\tau+iT)+W(\tau)\right] \\ &= R_{2\pi}\left[2\pi hR_P\left[\sum_{i=0}^{n-L}u_i\right]+4\pi h\sum_{i=0}^{L-1}u_{n-i}q(\tau+iT)+W(\tau)\right],0\le\tau<T\end{aligned} \tag{5}$$

Is an item that is independent of the input data. According to Eq. (5), the physical phase of the CPM signal is determined by the input of the MM, so that the output signal is also determined by the input of the MM. The input of the MM can be defined as, $S_n=\{v_n,u_{n-1},u_{n-2},\cdots,u_{n-L+1}\}$, here the $v_n=R_p\left(\sum_{k=-\infty}^{n-L}u_k\right)$, the cumulative phase before the time n (besides the moment n). If you use $\bar{\psi}(\tau,\,S_n)$ to replace $\bar{\psi}(\tau+nT,\,u)(0\le\tau<T)$, $s(\tau,S_n)$ replace $s(\tau+nT,u)(0\le\tau<T)$, you can get:

$$\begin{aligned}s(\tau,S_n)=\sqrt{\frac{2E}{T}}\cos(2\pi(\tau+nT)f_1+ \\ \bar{\psi}(\tau+S_n)+\varphi_0),0\le\tau<T\end{aligned} \tag{6}$$

Phase Encoder (CPE). As noted earlier, according to the next input data u_{n+1} the CPE can update the input of the MM from S_n to S_{n+1}. In $v_n=R_p\left(\sum_{k=-\infty}^{n-L}u_k\right)$ using n + 1 to replace n, you can get:

$$\begin{aligned}V_{n+1}=R_P\left[\sum_{i=0}^{n-L+1}u_i\right] &= R_P\left[\sum_{i=0}^{n-L}u_i+u_{n-L+1}\right] \\ &= R_P\left[R_P\left[\sum_{i=0}^{n-L}u_i\right]+u_{n-L+1}\right] \\ &= R_P[V_n+u_{n-L+1}]\end{aligned} \tag{7}$$

Obviously, it is possible to obtain the update of the first L components of S_n by the nearest L data shift. In this way, the CPE can calculate the current MM input from formula (7) based on the current data and the input of the previous MM, and MM can calculate the output information according to formula (6).

4 LDPC - CPM System Model

4.1 SOVA Decoding Algorithm

Combined with the literature [9], it is easy to know the 2^s states of a time unit t, taking the i th one as an example. The memory stores the current state S_{ti}, the maximum partial measure $SM([r|v]_{t,i})$ and the partial likelihood code word sequence $V^*_{t,i}$, when entering the current state of the current state. In the iterative process, the grid table is used in the reverse direction, such as the state of m entering $S_{t,i}$ at time $t-1$, it is respectively $S_{t-1,j=1:m}$.

$$SM\left([r|v]_{t,i}\right) = \max_{j=1:m}\left\{SM\left([r|v]_{t-1,j}\right) + \log P\left(S_{t,i}|S_{t-1,j}\right)\right\} \tag{8}$$

$$V^*_{t,i} = \left[V^*_{t-1,j} V^*_{j \xrightarrow{\max} i}\right] \tag{9}$$

SOVA basic operation and Viterbi algorithm are the same, the only difference is that each information bit attaches to a reliability instruction to the hard decision output, that is, soft output. This soft output is $ms = abs(ms_0 - ms_1)$ for binary and multiplied by the ± 1 value representing v.This is similar to SISO, but SISO has both forward and backward. It is envisioned that the method of subtracting the minimum value from the maximum value of SISO is used in Multi-system (Fig 1).

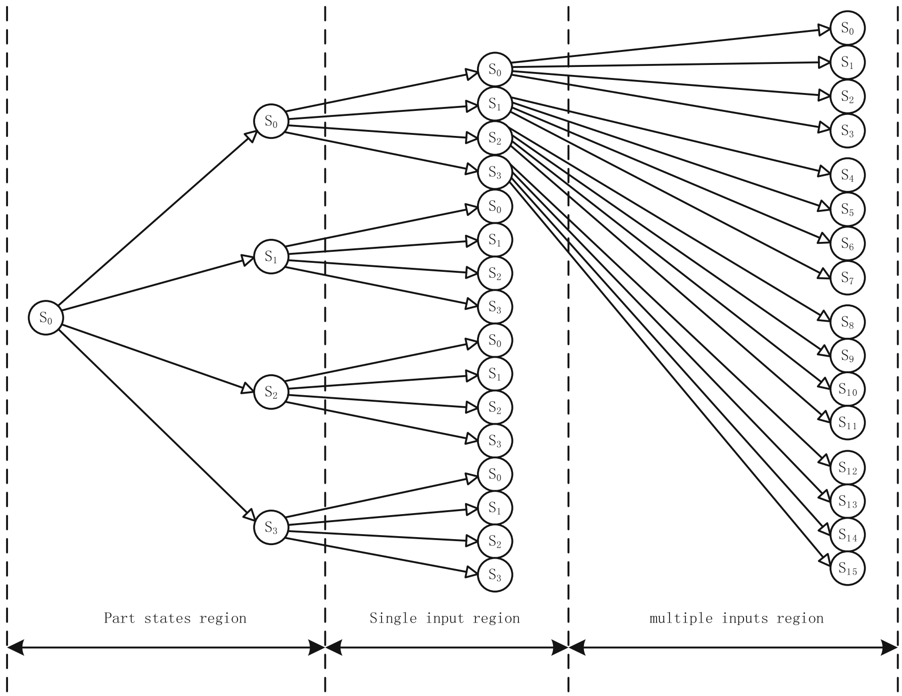

Fig. 1. SOVA messaging

4.2 System Model

CPM modulation is a constant envelope modulation system, which is not sensitive to the non-linear characteristics of the amplifier, allowing the use of non-linear power amplifier, so that the power amplifier can work in a saturated state, for airborne and deep space communications stations and other limited power applications having important significance [10]. The CPM is used as a component code of the concatenated code and the soft message obtained by the soft decoding algorithm is transmitted to the LDPC decoder to make the system have the dual characteristics of the LDPC code and the concatenated code. The system has the following two advantages: 1. The error level is lower, the bit error rate increases with SNR has acute drop characteristics, compared with the SCCPM, the performance is improved significantly. 2. The interleaver does not exist in the system and does not need multiple iterations, the decoding time can be reduced compared with the SCCPM [11].

The decoding process firstly makes demodulation and decoding of the CPM as MM and CPE, respectively. The MM modulator is usually demodulated in a manner of matching the template, and the CPE decoder decodes the relevant values as priori information. The system decoder stores all the CPM waveform template, and demodulation can use these templates in parallel. MM demodulated soft messages are passed directly to the CPE decoder and decoded by the SISO algorithm to pass the posterior probabilities to the LDPC decoder in the form of soft messages. In the LDPC decoder, the soft message provided by the CPE decoder is used as a priori information, and the second-order decoding is performed by the confidence propagation algorithm. Because of the entire process from the MM demodulation to the CPE decoding and then to the LDPC decoding, it is all the soft messages, you can guarantee as little as possible the amount of loss of information, so the transmission of soft messages cascade decoder can achieves better bit error performance than the decoder performs the hard decision [12]. The LDPC-CPM system model is shown below (Fig 2).

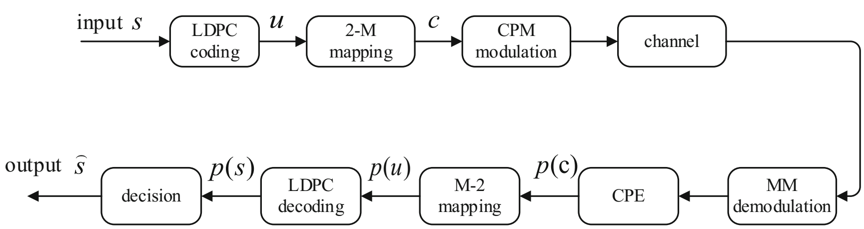

Fig. 2. LDPC cascade CPM system model

5 Results and Summary

The simulation results are as follows:

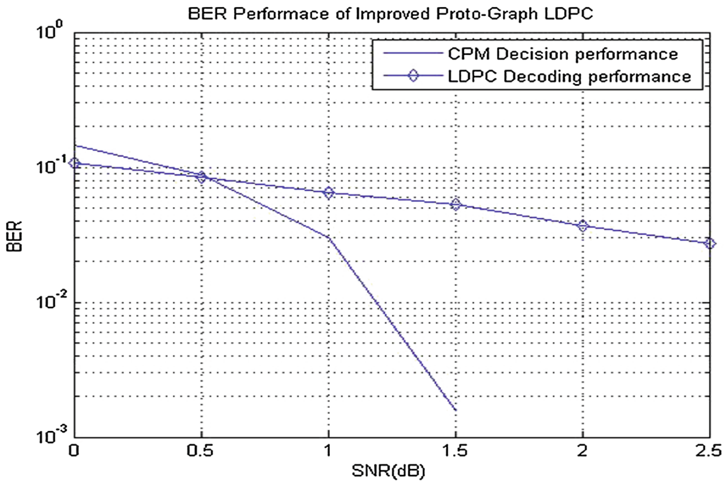

Fig. 3. Simulation results

From the Fig. 3 it can be seen that the LDPC can obtain almost no error decoding when the CPM decision performance reaches 0.03, that is, when $E_b/N_0 = 2\text{dB}$, LDPC reaches the waterfall area, which proves that the system designed has excellent performance.

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