Performance Analysis and Simulation of a New Coded Pulse Position Modulation

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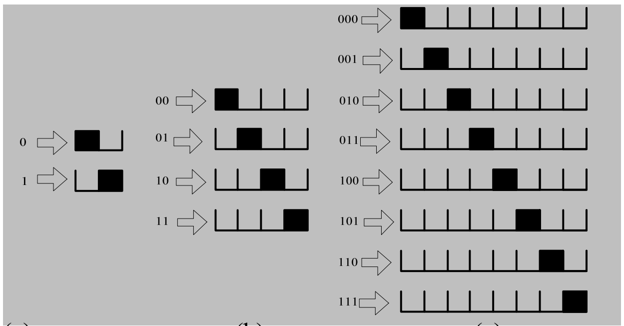
***Abstract* —To solve the problem which the effective combination of pulse position modulation (PPM) and channel error correction code for wireless optical communication, an atmospheric wireless optical communication product encoding PPM new scheme is proposed. The bit interleaving and iterative encoding technology into grouping product PPM, using bit interleaved signal fading becomes independent. According to the maximum likelihood criterion is derived from the weak turbulence Gaussian cascade channel under PPM soft demodulation method, and block codes of soft input soft output (SISO) decoding algorithm is combined. In weak atmospheric turbulence under the condition of simulation and analysis show that the scheme with independent demodulation and decoding of bit product interleaving coded PPM compared to there is about 1dB gain at BER 10-5. Excellent error performance can be obtained at high bit rate. It is conducive to reducing the system transmission bandwidth requirements and provides high reliability of information transmission.**

Keywords-Modulation coding, Pulse modulation, Performance analysis, Iterative decoding, Optical pulses, Bit error rate

I. INTRODUCTION

With the rapid development of wireless communication technology and rapid growth for spectrum demand, spectrum resources become increasingly scarce, and also has been one of the bottlenecks restricting the development of wireless communications. Scarce spectrum resources resulting main reasons: the one hand, the spectrum management scheme now used uses a fixed spectrum allocation system. The other hand, the utilization of licensed spectrum resources is very low. In recent years, the survey found that fixed wireless spectrum allocation led to partial spectrum efficiency is only 15% to 85% [1], highlighting the fixed wireless spectrum allocation unreasonable. In order to solve the problem of the spectrum resource scarcity and low licensed spectrum utilization, in 1999, Motorola [2] first proposed the concept of cognitive radio (CR).

PPM is a modulation format that maps message bits to pulse positions. In the modern use of the term, a PPM symbol comprises M slots, exactly one of which contains a pulse. Input message bits determine which of the M positions is used. For the simplest mapping, M is typically taken to be a power of 2, in which case $\log 2^M$ message bits specify one of the M possible positions of the pulse, as shown in Figure 1.If the slots are numbered0, 1, …, M－1, then in the mapping shown in Figure 1,the decimal representation of the bits is the number of the slot containing the pulse. As shorthand, M-ary PPM is often referred to as M-PPM. Mathematically, M-ary PPM may be described as the encoding of a k-bit source U=(U1 , …, Uk)∈{0,1} k to yield a signal X = (0,…,0,1, 1, 0, …, 0)∈{0,1}M, M =2k ,which contains a single one in the position indicated by the decimal representation of U.



(a) (b) (c)

Figure 1. M-ary PPM maps log2M bits to a pulse in one ofM positions−(a) binary PPM, (b) 4-ary PPM, (c) 8-ary PPM

As the technology is mature, the realization is simple, Intensity modulation(IM) and direct detection (DD)are general used to control the on-off keying(OOK) in the wireless optical communication system. To provide a sufficient power to overcome the random fading of light signals caused by atmospheric turbulence, the high power output of the laser is not only difficult, and it must be economical, and the output of the optical power should also ensure the safety of the human eye. For this purpose, people study the new modulation method in wireless optical communication [1].Which PPM is a kind of "average power efficient modulation", aroused people's interest [2]. Compared to OOK, PPM not only has high power utilization, but also can obtain the optimal detection without setting the dynamic threshold in hard decision, and the error performance is also significantly better than OOK and digital pulse interval modulation(DPIM) [3]. The disadvantage of PPM is that a certain bandwidth is sacrificed, but the bandwidth of optical communication is rich.It limits the maximum switching speed and signal broadening, which can be improved gradually with the development of high performance devices. Based on the above reasons, PPM is

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considered to be one of the modulation methods which is suitable for future wireless optical communication and has an important application prospect. At the same time, in order to improve the anti-jamming capability of the wireless optical communication system, it is important to use the channel encoding technology and how to realize the effective combination of PPM and channel encoding is an important problem. Some channel codes such as convolution code, Turbo convolution code (TC) and Solomon Reed (RS) codes have been applied in PPM [4-6].Since the binary encoding does not apply to the higher order mapping, when the demodulation error occurs, the error cannot be effectively corrected. Non binary in higher order modulation has better applicability, such as, for (n,K)RS codes and M-PPM, when n=2M-1, that is, to achieve the two matching. So RS code is widely used in PPM. Reference [7] also discussed the cascade of RS codes and convolution codes should be used in atmospheric wireless optical communication. RS code based on binary code, has a strong ability to correct for errors in a symbol of the hard decision, when multiple symbol error occurs, its effectiveness is not high. The RS code with soft decision has been used for the high speed atmospheric wireless optical communication system. In addition, the trellis coded modulation(TCM) technology has been applied to PPM modulation [8]. This scheme can effectively increase the minimum Euclidean distance of the modulated signal set because of the combination of encoding and modulation. Therefore, in the fading channel, the effective of the scheme is not satisfactory, so the additional modulation gain is obtained under Gauss condition. Because of the higher order error demodulation is not suitable for the binary code, to improve the receiver performance, some of the literature use the soft output of the decoder to modify the demodulation method. Reference [9-11] presented a serial concatenated convolution encoding PPM modulation scheme, convolution codes with accumulator PPM are cascaded, signal at the receiving end of the demodulator and decoder iteration of this scheme is applied to the deep space optical communication. On the basis of the above, a parity check unit is added to the encoder, and the variable rate is obtained, which is called SCPPM. But this scheme increases the complexity of decoding, and can only be realized under low bit rate adjustment. Reference directly have convolution codes and PPM cascade, given a method to reduce the complexity of decoding of the SCPPM program, and further study the iterative demodulation in multi pulse position modulation (MPPM) application. However, because the soft input and output of the convolution code (SISO) algorithm can be used to increase the number of registers and parallel input and output, the scheme can only be applied to low bit rate.

In this paper the scheme is proposed which use iterative demodulation and decoding of bit interleaving product code pulse position modulation. It has the combination of bit interleaved, packet product encoding PPM and iterative demodulation decoding technology. Based on the application of bit interleaved signal time diversity, the soft demodulation method of weak turbulence and the PPM and analysis of SISO Chase decoding algorithm are derived. The external information joint iteration of the demodulation and decoding is realized.

II. SYSTEM MODEL

To facilitate the analysis in this paper, we now formalize a description of the system model. The transmission channel for each slot, the slot channel, is a binary-input un constrained-output channel. This is illustrated in Figure 2.

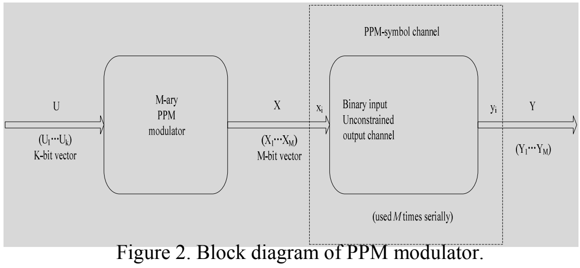

Figure 2. Block diagram of PPM modulator.

Input bits are first fed into a linear block product encoder for encoding, which has been mapped into the PPM symbol by the encoding information and converted to light pulses emitted out. The product of encoding and symbol mapping constitute a serially concatenated system. Among them, the bit interleaved burst error in the time domain is broken up, forming time diversity, , which makes the packet of the input decoder is not related to the approximation of the packet, and improves the decoding accuracy, and the decoding will achieve the best results in the full interleaving/decoding. The product code and symbol mapping are equivalent to cascade system of outer and inner codes respectively. Therefore, the receiving end of the demodulator and channel decoding can be adopted the joint iterative method to improve the error performance. In order to focus on the performance of the scheme, the intensity of the light intensity is constant and there is no inter symbol interference in each PPM transmission time slot, and the path attenuation coefficient is 1. For a PPM open slot, use I indicates that the received optical power is received at the corresponding time slot.

$$\gamma = \eta I + n \qquad (1)$$

In the formula $\eta = \gamma_e Teg\lambda / (hc)$ express conversion efficiency, $\gamma_e, T, g, \lambda, e, h, c$ express detector quantum efficiency, time of slot, doubling gain, wavelength, quantum charge, Planck constant and the speed of light. The noises of the receiver circuit mainly come from thermal noise, shot noise and dark current detector. This assumes that the receiver which is one of the heated noise and represented by n.It has nothing to do with the received optical signal and available with zero mean and variance σ^2 white Gaussian noise expressed. The off time slot on the PPM has no light pulse, and the receiving signal is r=n.

The optical pulse is affected by turbulence. It will arise the amplitude and phase distortion. The influence of turbulence on the received signal is mainly reflected in the DD/IM system, which makes the I become random. For the atmospheric wireless optical communication system, this is within a distance of several thousand meters. Through aperture smoothing, the number obeys the lognormal distribution [2].

$$f(I)=\frac{1}{2\sqrt{2\pi}\sigma_x I}\exp\left[\frac{-(\ln\frac{I}{I_0}+2\sigma_\chi^2)^2}{8\sigma_\chi^2}\right] \quad (2)$$

In the formula I_0 express statistical average of I, σ_χ express scintillation index.

III. SOFT DEMODULATION ALGORITHM OF PPM

In the maximum likelihood criterion, the soft information of the demodulator and decoder is measured by the log likelihood ratio (LLR).On the M-PPM modulation of the receiver symbol of R, after the demodulation of the receiver dj(j∈{0,1,…,M-1}). The LLR is:

$$\Lambda_{post}(d_j)=\ln\frac{P(d_j=1/R)}{P(d_j=0/R)} \quad (3)$$

The use of Bayesian formula can be

$$\Lambda_{post}(d_j)=\ln\frac{P(R/d_j=1)}{P(R/d_j=0)}+\ln\frac{P(d_j=1)}{P(d_j=0)}=\Lambda_c(d_j)+\Lambda_{priori}(d_j) \quad (4)$$

In the formula (3), The posterior estimation of d_j is made up of two parts. The first part of the d_j is recognized to 1 or 0 of the probability of receiving R. It's likelihood ratio is expressed by $\Lambda_c(d_j)$. The second part is the prior probability of d_j, which is expressed by $\Lambda_{priori}(d_j)$.

First $\Lambda_c(d_j)$ is analyzed, time slot position i of the receiving R symbol on PPM which is corresponding to a group of M bits (d0,d1,d2,…,dM-1). So when the received bit dj is estimated to be 0 or 1, the pulse in the R must have a corresponding time slot position is judged to be 1. According to this, the PPM symbol can be divided into two sets of all time slots. We define the C_j^1 as the 1 corresponding to the slot location set for the bit packet within the first j bit and the C_j^0 as the 0 corresponding to the slot location set for the bit packet within the first j bit. We can derive the formula.

$$\Lambda_c(d_j)=\ln\frac{\sum_{i\in C_j^1}P(d_j=1/R)}{\sum_{i'\in c_j^0}P(d_j=0/R)}=\ln\frac{\sum_{i\in C_j^1}P(R/m_i=1)}{\sum_{i'\in c_j^0}P(R/m_{i'}=1)} \quad (5)$$

mi is the binary representation of i slots.

Because a PPM symbol is provided with only one "1" time slot, each receiving time slot is independent of each other.

$$\Lambda_c(d_j)=\ln\frac{\sum_{i\in C_j^1}\left[P(r_i/m_i=1)\prod_{s\neq i,s=0}^{2^M-1}P(r_s/m_s=0)\right]}{\sum_{i'\in c_j^0}\left[P(r_{i'}/m_{i'}=1)\prod_{S\neq i',s=0}^{2^M-1}P(r_s/m_s=0)\right]} \quad (6)$$

From formula (6) we can see that the likelihood ratio depends on the probability density distribution of the "1", "0" pulse. In order to facilitate the numerical calculation and analysis, the distribution of the time slot of the transmission "1" pulse can be approximated as Gauss model. The mean and variance is $r_i=\eta P_0$ and $\sigma_1^2=(\eta P_0)^2\left[\exp(4\sigma_\chi^2)-1\right]+\sigma^2$. As the "0" pulse is only affected by the noise of the n, so "1", "0" pulse at the receiving end of the current probability density can be expressed as;

$$p_1(r_i)=\frac{1}{\sqrt{2\pi}\sigma_1}\exp\left[-\frac{(r_i-\eta I_0)^2}{2\sigma_1^2}\right] \quad (7)$$

$$p_0(r_i)=\frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\frac{r_i^2}{2\sigma^2}\right] \quad (8)$$

$$Q(a)=\int_a^\infty\frac{1}{\sqrt{2\pi}}\exp(-\frac{y^2}{2})dy \quad (9)$$

Using the formula (7-9) we can derive formula:

$$\Lambda_c(d_j)=\ln\frac{\sum_{i\in C_j^1}\left\{\left[1-Q(\frac{r_i-\eta I_0}{\sigma_1})\right]\prod_{s\neq i,s=0}^{2^M-1}\left[1-Q(\frac{r_s}{\sigma})\right]\right\}}{\sum_{i'\in c_j^0}\left\{\left[1-Q(\frac{r_{i'}-\eta I_0}{\sigma_1})\right]\prod_{s\neq i',s=0}^{2^M-1}\left[1-Q(\frac{r_s}{\sigma})\right]\right\}} \quad (10)$$

The C_j^1 and C_j^0 is determined by the PPM mapping method. Therefore, according to the PPM specific mapping method and the receiving instantaneous signal,the estimated likelihood ratio of the received bit dj can be calculated by formula (10).

IV. SIMULATION AND ANALYSIS

When we have the simulation of the PPM performance of this paper, PPM is used the Gray mapping method and the product codes have two component codes to select the same BCH code. Bit interleaving is used as a method of random interleaving. The interleaving length is a product code block. The source rate is 1Gb/s. Other simulation parameters are shown in Table 1. The simulation results and analysis are carried out under equal average power which sends the same information bits to consume the same optical power. Therefore, the relationship between the average optical power and the transmitted light power is:

$$I_{trans}=I_{aver}R_c 2^M \quad (11)$$

Rc is the encoding rate, M is the modulation order.

Table 1 Simulation parameter

Parameter	Value
λ	1.55um
γ_e	0.5
g	100
α^2	2╳10-30

In $\sigma_\chi=0.1$ weak Gaussian turbulence cascade channel and 3 order PPM, for further comparison and validation scheme performance,in this paper we are comparison the product interleaved coded PPM(PICPPM) with independent demodulation and decoding. Where the product codes are selected (63, 51)2 code and (31,21)2 code, using the PICPPM-1 and PICPPM-2 respectively in this iterative scheme and taking the 3 iteration. G(7,5) codes with convolution codes in SCPPM and RS codes are 7 / 2 bit rate (3,2,7) codes with three order modulation matching (3,5) codes. The simulation results are shown in figure 3.

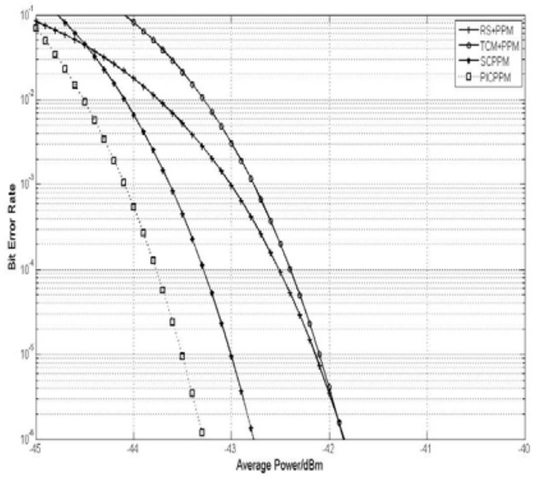

Figure 3. Comparison of different coded modulation schemes under weak turbulence and Gaussian cascaded channel

From the figure can be seen, the hard decision of TCM and RS coding scheme have similar performance, but inferior to using bit interleaving convolution coded modulation and turbo product coded modulation scheme. That in atmospheric optical wireless communication employing bit interleaved coded modulation performance is superior to the matching design method of coded modulation schemes. Since PPM with amplifies the input rate, so under the same input rate and modulation order number, high rate code modulation of a transceiver device rate requirements lower. PICPPM provides not only excellent error performance, but also reduce the bandwidth of the system demand. It can be realized under the given device which has the highest switching rate limiting.

From the above analysis, we can see that the choice of product code will have an important impact on the final performance of the scheme. The product code is a block encoding; the size of the encoding block depends on the length of the code word after encoding. As a result, the longer the code word length, the longer the interleaving length, the better the time diversity characteristic is obtained by interleaving. In addition, for long code word, optional component code type more, configuration is also more flexible. But the long code word can lead to the increase of the interleaving delay and algorithm complexity. In the application, we should first determine the appropriate code word length according to the practical system cost. In the code word length, the influence of code selection on the scheme is analyzed. With BCH (63,57) code, (63,51) code and (63,45) code as the product code, the performance of PICPPM scheme is simulated and compared. The PPM modulation order is 3 and the atmospheric scintillation index is 0.1. The simulation results shown in Figure 4, the solid line is for the performance curve of PICPPM. Control of different component codes PICPPM curve can be seen, the BCH(63,57) code of the curve into the waterfall declines earlier. Secondly, (63, 51) code, and (63,45) flat area code is longer, this is because of (63, 45) code of product code rate is low. The average power will therefore need to be more caused by error rate falls down, it also shows that the low bit rate system will consume more power. Comparing the waterfall area curve downward trend can be seen, in the waterfall area and the curve in opposite order, (63,45) decrease code curve in the waterfall area most steep. Thirdly for (63, 51) and (63, 57) code, because the low bit rate code word has more redundant bits, so the error correction ability is stronger and more steep decline curve. It can be seen from the chart, although (63, 45) code error correction ability is stronger, but because of its flat area is too long resulting in low bit rate. Therefore, in the 63 code length BCH code, (63,51) code is a good choice of component codes.

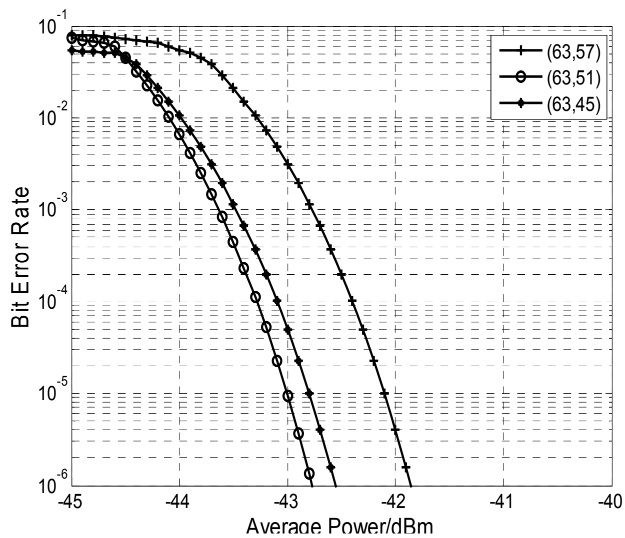

Figure 4. Performance of PICPPM under different subsides

Based on the above analysis we can see that the proposed scheme is based on bit interleaved product encoding PPM, using iterative demodulation and decoding to restore independent decoding losses. Comprehensive cost and improve the effect of iterative algorithm in this paper, using the iteration number should be 3-5 times. Product code selection will affect the final performance of the scheme, taking into account the optical wireless communication speed and performance requirements, BCH component codes should be in code word longer and higher bit rate selection.

V. CONCLUSIONS

The PICPPM will be bit interleaving and joint iterative technique is introduced into the product code in PPM, using bit interleaving the fading in the code word to become independent, and further based on the maximum likelihood criterion is derived PPM symbol soft demodulation method. Simulation results show that the proposed scheme with respect to the independent demodulation and decoding PICPPM and obtain 1dB gain improvement in bit error rate of 10-5. In conditions of high bit rate can provide excellent error performance, to provide high transmission efficiency in optical transceiver system devices limit the highest rate, lower bandwidth requirement and high reliability of information transmission. A new effective method is provided for the combination of PPM and channel encoding in wireless optical communication.

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