One OCDMA PON System with 2D Multi-Length Two-Weight CHPCs

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***Abstract*-One OCDMA PON system is discussed in this paper. Multi-length Two-Weight Carrier Hopping Prime Codes is selected as encoder scheme, encoded information is transmitted through Optical fiber. Hard Limiter is utilized in receiver terminal to ensure lower bit error rate. Simulation shows that it can be used for large capacity optical networks.**

Keywords- large capacity optical networks; OCDMA-PON system; 2-D multi-length two-weight carrier hopping prime codes; hard limiter;

I. INTRODUCTION

Passive Optical Network (PON) [1] is a fiber-optic network that does not contain any active device. It is mainly made up of Optical Line Terminal (OLT) and Optical Network Unit (ONU) which are installed in the central control station and the Client. OLT and ONU are connected by Optical Distribution Node (ODN), which is made up by optical fiber or passive optical splitter or coupler. PON uses Tree Topology. It is simple to maintain, of high reliability and relatively low-cost, with less consumption of resource and can provide higher bandwidth to ensure the large capacity, and obtain better Quality of Service (QoS) service.

Time Division Multiplex Passive Optical Network (TDM PON) [2] and Ethernet Passive Optical Network (E-PON) [3] have been placed in developed countries. Because of the need of high speed transmission in PON, multiplexing and multiple access technologies have significant meanings to the issue. TDM PON can support 8-32 users with speed of 155Mb / s to 1 GB / s [4]. However, due to the time division multiplexing transmission, if there are large numbers of access users, each user can separately obtain more limited bandwidth. It is difficult to adapt to the high-capacity transmission in the case of more data users access, especially in the uplink data transmission, and more difficult to adapt to different bit-rate transmission between different users.

Wavelength Division Multiplexing Passive Optical Network (WDM PON) is passive optical network that uses wavelength division multiplexing technology. WDM PON has several schemes: first, to achieve data transmission through allocated wavelength proprietary with fixed virtual point-to-point connection between OLT and ONU; Second, ONU uses tunable laser to allocate wavelength dynamically. In this case, ONUs can share the wavelengths and in this case, the network has some reconfigurable characters; third, the scheme is independent between ONU and wavelength. Afterwards, the hybrid PON scheme whose downlink using WDM PON and uplink utilizing TDM PON. Transition from TDM PON to WDM PON is sure to become the future industry standards, and because of its relatively low-cost the ONU manufacturing costs, it can be used to provide a lot of passive optical networking products. Nowadays, 20nm spacing Coarse Wavelength Division Multiplexing of between 1270 and 1610nm wavelength has been recognized as PON architecture by International Telecommunication Union (ITU). However, because the number of wavelengths of the WDM PON is 18, it is insufficient for a medium number of multiple access system users [4].

In contrast, Optical Code Division Multiple Access (OCDMA) provides another possibility solution for passive optical network. However, because of the backward of codec manufacturing technology, Multiple Access Interference (MAI) between shared channels and Beat Noise which also limits its practical application to some extent. Therefore, it is excluded of the actual application after proposed in the 70s of last century and limited use only can be found in laboratory conditions around the 1980s.

Due to more mature manufacturing technology of optical code division multiple long sequence codec [6] and fiber threshold devices [7] recently, OCDMA has been the research hotspot nowadays. OCDMA technology relative to wavelength division multiple access (WDMA) and TDMA technology, the main features are: 1. The users are allocated with different code words to distinguish with each other. Thus it allows multiple users share the same channel with random access while the wavelength tunable is not required. In this case, the bandwidth resource is used much more sufficiently; 2. Time and frequency are asynchronous without signal consistent requirements between different users; 3. As for the asynchronous access, it needs no synchronization while almost no time delay, which is especially useful for gusty traffic, large capacity and high-speed network; 4. OCDMA utilizes launching and receiving point to encode and decode without any consideration of network structure, which can achieve a truly "transparent" all-optical network; 5.OCDMA uses spread spectrum coding technology that match exactly the user’s signals only in the sending and receiving ends. The others obtained will be treated as pseudo-random noise signals. Because of these advantages, optical code division multiple access technology has become a hot research area.

In OCDMA-PON system, ONU is responsible to allocate each user a codec that contains a unique address code and a unique address code. After the allocation, the user’s data is modulated onto an optical carrier and is encoded via the optical encoder. The encoded data is transmitted through light distributing link to destination

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OLT and the decoder decodes the encoded optical signal in OLT. The decoded data streams are uploaded by the OLT transmitter to other core networks to achieve mutual communication between each ONU in different PONs. After the data stream of the core line, transmission is modulated by the OLT and encoded by the optical encoder. Then the coded data stream is transmitted to the optical distribution network through the fiber channel, and each ONU or ONT .After that, decoder in each ONU can decode them to recover the original data and achieve the receiving [8].

A basic OCDMA network is made up of OLT in the terminal and ONU in the client. They are connected via a star coupler. The sender and the recipient are located in ONU. Optical encoder of user's data sources is done in the sender terminal, and then superimposed together to form a signal vector and transmitted via the optical fiber. While receiving, the receiver decodes each signal vector and original signal is recovered via a specific threshold decision technology, and transmitted to the receiver to achieve the restoration of the original transmission data. A typical optical code division multiple access networks can be found in Fig 1 [4]:

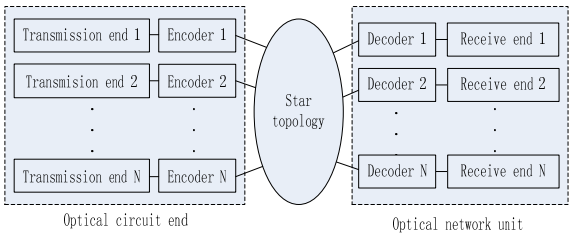

Fig 1 Basic optical code division multiple access passive optical network structure

Depending on the coding mode, the optical code division multiple access networks can be divided into coherent and non-coherent systems. Coherent systems utilize the phase of the light to transmit the signal. Non-coherent systems transmit the signal by the energy of the light field. Phase encoding can take advantage of strict sequence spread spectrum to reduce inter-symbol interference. However, its system structure is relatively complex, and it is strict to clock synchronization. In particular, in the case of lager transmission rate, it has very strict requirement of light source coherence. While the non-coherent systems use light intensity to represent the presence or absence of the information. In other words, it uses signals to represents '0' or '1'. The receiving end of each user can accept signal from a plurality encoder, and do correlation operation in the decoder to obtain the original signal by threshold decision. Device performance requirements of the system are more lenient, but multi-user interference is more serious and its error rate will rise when concurrent users focused.

II. THE CONSTRUCTION OF A TWO-DIMENSIONAL MULTI-CARRIER MULTI-HOP PRIME CODES.

A. *OCDMA Passive Optical Network Address Codes Selection*

Prime codes and optical orthogonal codes [9, 10] are used mostly in OCDMA systems nowadays. OOCs become a hot research area because of its good performance. Basic parameters of the optical address codes is $(n,\omega,\lambda_a,\lambda_c)$, where n is the length of code word, ω stands for the weight of code word which means the number of "1" in the (0,1) sequence, λ_a is autocorrelation coefficient which means the max value of autocorrelation peak, λ_c is cross-correlation coefficient which means the max value of cross-correlation peak[11]. One-dimensional optical orthogonal codes cycle should meet the autocorrelation and cross-correlation [12]:

$$\sum_{i=0}^{n-1} x_i x_{i\oplus\tau} \le \lambda_a, 0<\tau<n$$

$$\sum_{i=0}^{n-1} x_i y_{i\oplus\tau} \le \lambda_c,\ \ 0\le\tau\le n-1$$

Where $\oplus$ is modulo n plus.

The code words capacity of one-dimensional optical orthogonal codes $(n,\omega,\lambda_a,\lambda_c)$ is the number of code words, denoted as $|C|$. For OOCs, there is generally $\lambda_a=\lambda_c+a$ (a is a non-negative integer). It means that orthogonal code is asymmetric code. The upper limit of its maximum possible capacity $\Phi(n,\omega,\lambda_a,\lambda_c)$ is:

$$\Phi(n,\omega,\lambda_a,\lambda_c)\le\frac{(n-1)(n-2)\ldots(n-\lambda_c)\lambda_a}{\omega(\omega-1)(\omega-2)\ldots(\omega-\lambda_c)}$$

For $(n,\omega,\lambda_a,\lambda_c)$, greater capacity can be obtained by relaxing cross-correlation constraints, but inter-symbol interference can be increased, in proportion, the bit error rate is also increased. Increase the capacity in the case of smaller inter-symbol interference and bit error rate is the key of this study. Currently the research mainly focused on constructing multiple optical orthogonal codes. Hard Limiter [12] is the threshold value judgment and it is used in the sending and receiving end also possessing significantly meaning to improve the system performance.

One-dimensional optical orthogonal codes and prime codes are inadequate to the transmission of large amounts of data. Therefore, it is particularly important to effectively increase the capacity as much as possible with sufficient fault tolerance. Currently, the mainly methods are spreading spectrum coding technologies with multidimensional codes that extend the data to time domain, frequency domain and airspace to increase the capacity.

B. *Construction of 2-Dimensional Multi-Carrier Hopping Prime Codes.*

Multi-Dimensional coding techniques have been studied by many scholars. Current research focuses on 2 Dimensional Optical Orthogonal Codes (2D OOC), which mainly include: Prime Codes/Prime Codes (PC/PC) [13],

Prime Codes/ Optical Orthogonal Codes (PC/OOC) [14], Extended Quadratic Congruence Codes/Prime Codes (EQC/PC) [15] and so on. The sequence of prime numbers utilized by 2D OOC and EQC/PC are wavelength hopping sequence. PC/OOC utilizes hopping sequence of OOCs.

2-Dimensional Multi-length Carrier Hopping Prime Codes (2DMCHPCs) [16] can achieve the transmission in different rates and different bit-error-rates. The construction of multi-carrier hopping prime codes is as follows:

Given two positive integers ω and t_1, if $t_1 \le p_1$, $p_2 \ge p_1 \ge \omega$. For Galois field $GF(P_1)$ and $GF(P_2)$, the shorter matrix X_{i_1} can be obtained as:

$$\{(0,0),(1,i_1),(2,2_{\Theta p_1} i_1),\ldots,(\omega-1,(\omega-1)_{\Theta p_1} i_1)\},\quad i_1 \in [1,t_1-1]$$

A longer matrix can be obtained as:

$$\{(0,0),(1,i_1+i_2p_1),(2,2_{\Theta p_1} i_1+(2_{\Theta p_2} i_2)p_1),\ldots,(\omega-1,(\omega-1)_{\Theta p_1} i_1+((\omega-1)_{\Theta p_2} i_2))\},$$

Where $i_1 \in [t_{1,p_1-1}]$, $i_2 \in [0, p_2-1]$, Θp_j donates modulo-p multiplication. Double-long CHPC codes [6] structure is completed in this way. Its code weight is ω, length of matrix t_1-1 is p_1 and length of matrix $p_2(p_1-t_1)$ is $p_1 p_2$.Take $\omega = p_1 = p_2 = 3$, $t_1 = 2$ for instance. The length of matrix $t_1 - 1 = 1$ of this double-long CHPC codes is 3. It is the $X_1 = [(0,0),(1,1),(2,2)]$. The length of matrix $p_2(p_1-t_1) = 3$ is 8. They are:

$X_{2,0} = [(0,0),(1,3),(2,2)]$, $X_{2,1} = [(0,0),(1,5),(2,7)]$, $X_{2,2} = [(0,0),(1,8),(2,4)]$. If use the horizontal and vertical axes of the matrix to represent the positions and transmission carriers of the data segments. Its schematic diagram can be shown as Fig 2: Thus, it can be expressed as some forms of sequence: $S_1=W_0W_1W_2$, $S_{2,0}=W_{00}W_2W_1$, $S_{2,1}=W_0000W_10W_2$, $S_{2,2}=W_0000W_2000W_1$.

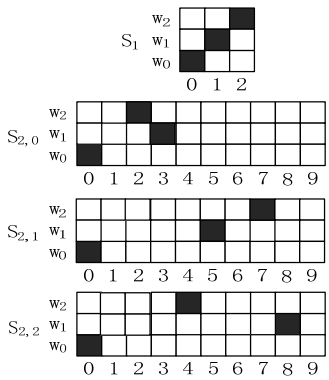

Fig 2 Schematic diagram of MCHPC code with $\omega = p_1 = p_2 = 3$, $t_1 = 2$

III. System Constitute and Performance Analysis

All of the codes of 2DMCHPC consumption the same sequence of energy (chip power), support different QOS and service priorities. 2D Multi-Length Multi-Weight CHPCs employ the same two sequences of 2DMCHPCs with different code weights. In other words, they combine the low code weight codes and high code weight codes. A double 2-D MCHPCs OCDMA PON system is made up by the encoder, optical fiber transmission and decoder parts, which can provide large-capacity data transmission, improve the spectral efficiency. The wavelength number must not greater than the number of slots in this system. Hard limiter is utilized in the decoder section to reduce the bit noise and inter-symbol interference. Suppose that there are N users transmitting data with shared multiple access fiber channels. Each user uses its unique optical coding sequence for data transmit, the basic structure of the system can be showed as in Fig 3.

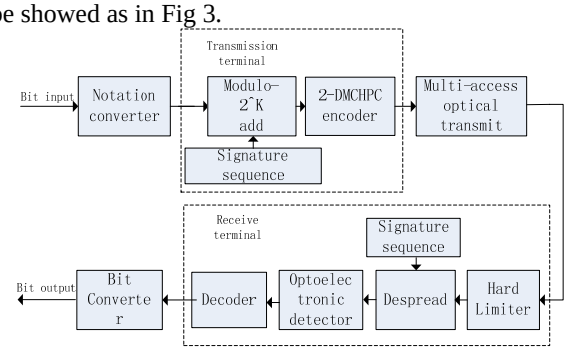

Fig 3 Basic structure of OCDMA PON system with double 2DMCHPCs

For users that use low-weight code of a double 2DMCHPC. The high-weight codes will always result in a complete hit. After hard limiter, the BER of receive end can be found as [9]:

$$P_{e,l} = \frac{1}{2}\sum_{i=0}^{\omega_l}(-1)^i\binom{\omega_l}{i}\left(1-\frac{iq_{l,1}}{\omega_l}\right)^{M_l-1}\times\left(1-\frac{iq'_{l,1}}{\omega_h}\right)^{M_h}$$

Where ω_l is the code weigh of low weight code, ω_h is the code weight of high weight code, M_l donates the number of low weight codes, M_h stands for the number of high weight codes, $q_{l,1}$ is the number of one complete hit by low weight codes, $q'_{l,1}$ is the number of one complete hit by high weight codes. Because of the equal probability of 0 and 1 transmitted in OOK, for a given code word, the possibility of hit by other codes are: $q_{l,1} = \frac{\omega_l^2}{2mn}$, $q'_{l,1} = \frac{\omega_l\omega_h}{2mn}$.

For user that uses high weight code, high weight code always contributes a complete hit. But low weight code can only built $P_{c,l}/P_{c,h}$ hits. In other words, there should have $f = \lceil P_{c,h}/P_{c,l} \rceil$ low weight codes to complete a complete hit. Where $\lceil\ \rceil$ stands for the ceiling function. After the hard limiter, high weight code error rate in the receiver ends can be expressed as:

$$P_{e,h} = \frac{1}{2}\sum_{\omega=0}^{\omega_h}\binom{\omega_h}{\omega}\left\{\sum_{i=0}^{\omega}(-1)^i\binom{\omega}{i}\left(1-\frac{iq_{h,1}}{\omega}\right)^{M_h-1}\times\sum_{r=0}^{f(\omega_l-\omega)}(-1)^r\binom{f(\omega_l-\omega)}{r}\times\left[1-\frac{rq'_{h,1}}{f(\omega_l-\omega)}\right]^{M_l}\right\}$$

Where M_l is the transmission number of low weight codes, M_h is the transmission number of high weight codes, $q_{h,1}$ stands for the probability of one complete hit by the high weight codes once, $q'_{h,1}$ donates the probability of one complete hit by the low weight codes. Because of the equal probability of transmitting 0 and 1 in OOK, for a given code word, the probability that interrupted by the hit in each condition can be expressed as:

$q_{h,1} = \frac{\omega_h \omega}{2mn}$, $q'_{h,1} = \frac{\omega_l(\omega_h - \omega)}{2mn}$ .Suppose that the system adopts $\{11\times121,\{7,5\},0,1\}$ double 2-D MCHPCs, the system performance with selection of low weight and high weight codes can be shown in Fig 4:

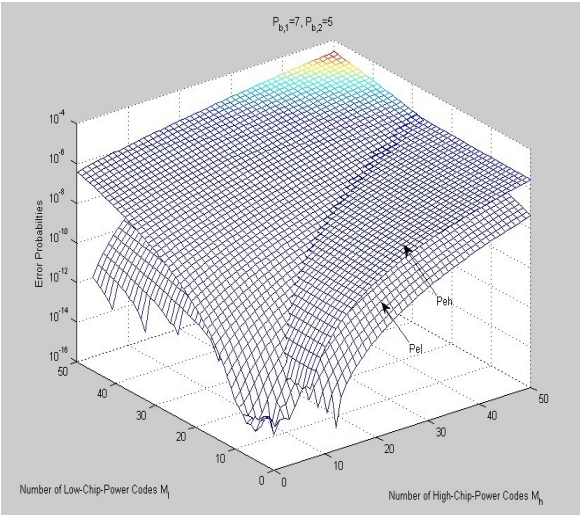

Fig 4 System performance with selection of low weight and high weight codes

As can be seen from the figure, for the system, the initial selection of low-weight code will bring small error rate. But as the number of users increasing, the bit error rate of low-weight code increases more quickly. Suppose only low-weight codes or high-weight codes are used in the systems respectively, they can be showed as the Y, X axis curves in the figure above. From the figure, for system utilizes low-weight codes only, the initial error rate is low. With the increasing number of users, bit error rate is on the rise. The error rate increase becomes much placid with the increasing number of access users. System that utilizes high weight code has the same performance. Error rate increases more rapidly for the system with low-weight codes.

In order to maintain good system performance, the system can alternately select the program of high weight codes and low-weight codes. In the case of small number of users, the article mainly uses low-weight code as transmission coding schemes. As the number of users increases, the system will use high weight code as the encoding scheme to get better performance.

IV. CONCLUSION

For one-dimensional OCDMA PON system, it can get better performance by using multiple 2-D MCHPCs OCDMA PON system, which can accommodate more concurrent users. The use of spectrum is also increased to some degree in this way. Hard limiter used in the receiving end reduces some bits of noises and inter-symbol interferences. Simulation results show that the OCDMA PON system that uses multiple 2-D MCHPCs, as the number of users increases, the bit error rate of low and high weight codes possess diversity between each other.

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