Design of zero cross correlation variable weight codes for multimedia services based on magic square in SAC-OCDMA systems*

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(Received 15 December 2020)

A variable weight address code based on spectrum amplitude coding (SAC) is proposed for optical code division multiple access (OCDMA) networks to support different quality of service (QoS) requirements of different services. The zero cross-correlation magic square variable weight optical orthogonal code (ZMS-VWOOC) proposed in this paper has great flexibility in terms of code weight and number of users. Zero cross-correlation can eliminate the influence of multiple access interference (MAI) and reduce the system complexity. Numerical results show that ZMS-VWOOC can provide better quality of service than similar codes. Numerical results for a ZMS-VWOOC OCDMA network designed for triple-play services operating at 0.622 Gbit/s, 2 Gbit/s, 2.5 Gbit/s and 3 Gbit/s are considered.

Document code: A **Article ID:** 1673-1905(2021)09-0539-7
DOI https://doi.org/10.1007/s11801-021-0198-z

The future Internet applications require higher data transmission capability and diversified acceptable quality of service (QoS). Optical code division multiple access (OCDMA) technology has become one of the alternative solutions for the next generation access network because it can provide asynchronous communication with high confidentiality and high QoS at the physical layer[1,2]. In addition, this technology has attracted great attention in optical sensor networks[3], free-space optical networks[4], cryptographic systems, orthogonal frequency division multiplexing (OFDM)[5] and lidar technologies[1,6,7].

Spectrum amplitude coding (SAC) technology has become one of the most successful methods in OCDMA networks because it reduces the multiple access interference (MAI) effect[8,9], simplicity[10] and the possibility of supporting diversified QoS transmission. The variable weight OCDMA system based on SAC technology is considered to be a reasonable solution for triple-play services. The codes of different code weights in this system can be used for different play services, such as video on demand, voice and data, among which users with high QoS requirements use a code with a higher code weight for transmission[11,12]. In order to improve the performance of the SAC-OCDMA system, several variable weight code schemes have been introduced. The traditional variable weight code is subject to certain restrictions on the choice of code weight (variable weight Khazani-Syed (KS)[13] can only choose even integers as the code weight), or the code length is longer (variable weight optical orthogonal code (VW-OOC)[14]). In order to support high transmission capacity in terms of data, reach and number of subscribers, and to provide different QoS for different multimedia applications, this paper proposes a ZMS-VWOOC. The code has the following advantages: 1) Any integer value can be selected as the code weight according to the QoS required by the user; 2) The code structure is simple; 3) Choosing the number of users is more flexible; 4) The cross-correlation value is 0. In the non-coherent SAC-OCDMA system, each user is assigned a different code. When the user sends a data bit 1, the code corresponding to the address code received by the target will be sent at the same time. At the receiver, all codes from different users are correlated. If the correct code is received, a higher peak auto-correlation function will be generated, otherwise a cross-correlation function will be generated and MAI will be generated. The main factors affecting the performance of the SAC-OCDMA system are MAI and photoelectric detection noise. This can reduce MAI and reduce the number of receiver filters by using a lower and same cross-correlation value code. Generally, the detection noise includes shot noise, phase induced intensity noise (PIIN) and thermal noise. The first two obey the negative binomial distribution[15], and the latter obey the Gaussian distribution. For the convenience of calculation, Gaussian approximation is usually used to analyze the bit error rate (*BER*) performance of the sys-

* This work has been supported by the Guangxi S&T Program (Nos.AB17292082 and AB18126025).
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tem[16]. Because the code has zero cross-correlation, the influence of PIIN can be ignored by using Direct Decoding (DD) technology[17]. Refer to *BER* and signal-to-noise ratio (*SNR*) to characterize the performance of the code. Analysis of the curve of *BER* and *SNR* shows that the SAC-OCDMA system based on the ZMS-VWOOC coding scheme can provide high transmission capacity and expected QoS.

Definition 1: The magic square of order Z can be represented by a matrix of order $Z\times Z$, which only needs to satisfy that the sum of elements in each row, column, and diagonal is equal. The elements in the magic square are not repeated, and the maximum number $K_{\max}\leq Z^2$.

The design parameters of optical orthogonal codes Φ (L, ω, λ_a, λ_c), where L is the code length, ω is the code weight, λ_a is the auto-correlation, and λ_c is the cross-correlation. The optical orthogonal code in this paper uses the position number of "1" in the code to represent the "0,1" code sequence, and the corresponding relationship between the magic square and OOC is: $A_{\max}\rightarrow L$, $Z\rightarrow\omega$, where $A_{\max}=Z^2$, so the zero cross-correlation magic square constant weight optical orthogonal code (ZMS-CWOOC) is (Z^2, Z, λ_a, 0).

The ZMS-CWOOC is constructed according the following steps:

Step 1: Generate the required matrix by $\boldsymbol{A}$=magic(Z).

Step 2: Convert the elements generated by the magic square of order Z into the position of 1 in the "0, 1" code sequence to obtain a code sequence with a cross-correlation limit of 0.

For example, as shown in Fig.1, $\boldsymbol{A}$=magic (4).

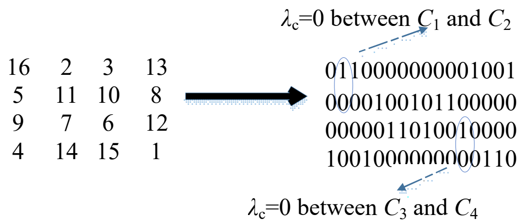

Fig.1 *A*=magic (4)

Therefore, the ZMS-CWOOC that a magic square of order 4 can generate is (16, 4, 1, 0).

The zero cross-correlation magic square variable weight optical orthogonal code (ZMS-VWOOC) constructed by the above theory is (L, W, Λ, λ_c, Q), W, Λ and Q represent the set $\{\omega_1, \omega_2, ..., \omega_i\}$, $\{\lambda_a^1, \lambda_a^2, ..., \lambda_a^i\}$ and $\{q_1, q_2, ..., q_i\}$, L is the code length, W is the code weight set, Λ is the auto-correlation, λ_c is the cross-correlation, and q_i is the ratio of the code capacity of different code weights to the total capacity.

The ZMS-VWOOC is constructed according the following steps:

Step 1: Select the code weight set required by the user and generate the corresponding matrix by $\boldsymbol{A}$=magic(Z), where Z is any positive integer greater than or equal to 3.

Step 2: Using mapping technology makes λ_c=0 between codes of different code weights[18], and at the same time expands the total number of users of the basic matrix.

$$\boldsymbol{B}(j)=\begin{bmatrix}\boldsymbol{A}_{\omega1} & 0 & 0\\ 0 & \ddots & 0\\ 0 & 0 & \boldsymbol{A}_{\omega i}\end{bmatrix}. \tag{1}$$

Step 3: $L=L_{\omega1}+L_{\omega2}+L_{\omega3}+...+L_{\omega i}$, i is any positive integer greater than or equal to 2, the total code capacity is $\Phi_i=Z_{\omega1}+Z_{\omega2}+...+Z_{\omega i}$, j is a positive integer greater than 0.

Step 4: The general structure of different code weight groups can also be constructed through mapping technology. The code weight group in the mapping matrix is different from each other, and a suitable code recombination matrix can be allocated according to the specific service quality required. Matrix $\boldsymbol{C}$ provides j groups of variable weight code sequences with different qualities of service. $\boldsymbol{C}_{\boldsymbol{B}(j)}$ shows the mapping basic matrix of different code weight groups. The maximum cross-correlation value between users in the same matrix is 0, and the maximum cross-correlation value between different mapped users is 0. Therefore, this technology ensures that the maximum cross-correlation value between all users in different code weight groups is 0.

$$\boldsymbol{C}_{\boldsymbol{B}(j)}=\begin{bmatrix}\boldsymbol{B}_1 & 0 & 0\\ 0 & \ddots & 0\\ 0 & 0 & \boldsymbol{B}_j\end{bmatrix}. \tag{2}$$

Step 5: The code length is $L(\boldsymbol{C}_{\boldsymbol{B}(j)})=\sum_{k=1}^{j}L_{\boldsymbol{B}_k}=L_{\boldsymbol{B}_1}+L_{\boldsymbol{B}_2}+\ldots+L_{\boldsymbol{B}_j}$, the total code capacity is $\Phi=\Phi_1+\Phi_2+...+\Phi_j$, where j is a positive integer greater than 0.

For example, as shown in Fig.2, select any code weight set W={5, 4, 3} to generate the corresponding matrix $\boldsymbol{A}_{\omega i}$.

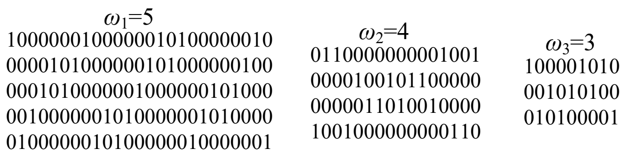

Fig.2 Matrix $A_{\omega i}$ generated by code weight set W={5,4,3}

The corresponding code matrix is generated according to the mapping method. Each "0" in the mapping matrix is a series of zeros, as shown in Fig.3.

The generated ZMS-VWOOC is (50, {5, 4, 3}, 1, 0, {5/12, 4/12, 3/12}).

Based on the above steps, the magic square sorting order reduction method is used to expand the code capacity of different code weights, the code length is appropriately shortened, and the magic square matrix before the reduction is odd-order, there can be two construction methods.

Method 1: the steps are as follows:

Step 1: Generate odd-order magic square matrix with order greater than the required code weight by magic algorithm.

$$B(1)=\begin{bmatrix} \begin{bmatrix} 10000001000000010100000010 \\ 00001010000000101000000100 \\ 00010100000001000000101000 \\ 00100000001010000001010000 \\ 01000000101000000010000001 \end{bmatrix} & 0 & 0 \\ 0 & \begin{bmatrix} 0110000000001001 \\ 0000100101100000 \\ 0000011010010000 \\ 1001000000000110 \end{bmatrix} & 0 \\ 0 & 0 & \begin{bmatrix} 100001010 \\ 001010100 \\ 010100001 \end{bmatrix} \end{bmatrix}$$

Fig.3 A new codeword matrix is generated according to the mapping method

Step 2: The magic square matrix generated in step (1) is sorted in ascending order from left to right by sorting algorithm, and the magic square matrix corresponding to the required code weight is selected.

Step 3: Use the largest element in the magic square matrix generated in step (2) as the code length to construct the code sequence matrix.

For example: Let ***A***=magic(5) generate a magic square matrix to construct a code sequence matrix with a required code weight of 4, as shown in Fig.4.

17	24	1	8	15	Sort ascending →	1	8	15	17	24
23	5	7	14	16		5	7	14	16	23
4	6	13	20	22		4	6	13	20	22
10	12	19	21	3		3	10	12	19	21
11	18	25	2	9		2	9	11	18	25

Fig.4 A new code sequence matrix with code weight of 4

Then, the corresponding code sequence matrix is generated according to the magic square matrix.

ω=4
10000001000000101000
00001010000001010000
00010100000010000001
00100000010100000010
01000000101000000100

Fig.5 Code sequence matrix generated by magic square matrix of order 5

Step 4: When the order of the magic square matrix is odd, the code length (L) of the generated new code sequence is equal to the product of the code weight (W) and the number of users required (N).

$$L=W\times N. \tag{3}$$

Method 2, the corresponding odd-order magic square matrix can be directly generated according to the following steps:

Step 1: Make sure the order of the required magic square matrix is an odd number N, so $i_K\times j_K$ magic square matrix can be generated, $i=1, 2, 3, ..., N$, $j=1, 2, 3, ..., N$, $K=1, 2, 3, ..., N$.

Step 2: For example, i=1, K=1, 1_1=1:

$$1_2=1_1+N+1,\ldots, 1_{\frac{N+1}{2}}=1_{\frac{N-1}{2}}+N+2, 1_{\frac{N+3}{2}}=1_{\frac{N+1}{2}}+N+2, 1_{\frac{N+5}{2}}=1_{\frac{N+3}{2}}+N+2,\ldots,1_N=1_{N-1}+N+2. \tag{4}$$

Step 3: After determining the first row according to step (2), j=1, K=1, 1_1=1:

$$1_2=j\times N,\ 1_3=1_2-1,\ \ldots,\ 1_N=1_{N-1}-1. \tag{5}$$

When j=2,

$$2_2=2_1-1,\ 2_3=2_2-1,\ 2_4=j\times N,\ 2_5=2_4-1,\ldots,\ 2_N=2_{N-1}-1. \tag{6}$$

When j=3,

$$3_2=3_1-1,\ 3_3=3_2-1,\ \ldots,\ 3_6=j\times N,\ 3_7=3_6-1,\ \ldots,\ 3_N=3_{N-1}-1. \tag{7}$$

When $j=N$,

$$N_2=N_1-1,\ N_3=N_2-1,\ \ldots,\ N_N=j\times N. \tag{8}$$

The number of users that constitute the basic matrix is determined by the maximum number of users required in different code weights, and the codes of the remaining code weights are selected according to the mapping technology to select the magic square matrix corresponding to the required code weight.

In Tab.1, ZMS-VWOOC is compared with the other three codes in terms of code attributes, including code length, maximum cross-correlation value, code weight, and total number of users. These three codes are VW-OOC, VW-KS and VW-MS[18].

Tab.1 Comparison of different variable weight codes properties

Codes	Code length	λ_{cmax}	Code weights	Total users
VW-OOC	427	1	4{5, 4, 3, 2}	50
VW-KS	170	1	4{8, 6, 4, 2}	50
VW-MS	108	1	4{5, 4, 3, 2}	50
ZMS-VWOOC	168	0	4{5, 4, 3, 2}	48

In Tab.1, the code weight sets of the codes are all 4, and both support about 50 users. The results show that in the synchronous SAC-OCDMA system, the maximum cross-correlation of ZMS-VWOOC is smaller than other codes. When the number of users and the code weight are close, the code length of ZMS-VWOOC is significantly smaller than that of VW-OOC, and the supported code weight is more flexible than VW-KS.

Fig.6 depicts the correlation between the same code weight and different code weights in the same code, where $\lambda_{\omega i\omega i}$ represents the correlation between codes of the same code weight, and $\lambda_{\omega i\omega j}$ represents the correlation between codes of different code weights[14].

We have established a mathematical model of ZMS-VWOOC, which takes into account the main performance degradation factors in the SAC-OCDMA system, including MAI and photo detection noises. Because ZMS-VWOOC has a fixed and same cross-correlation value, the influence of MAI can be ignored. And the code has zero cross-correlation value, so this article considers the impact of shot noise and thermal noise. In addition, the performance of ZMS-VWOOC is analyzed based on the

DD technology. Studies have proven that the direct decoding detection technology only obtains non-overlapping wavelengths, so only one photodetector is needed, which reduces the cost and complexity of the receiver, and the number of systems that can be supported is higher than complementary subtraction (CS) and AND subtraction detection technology[19].

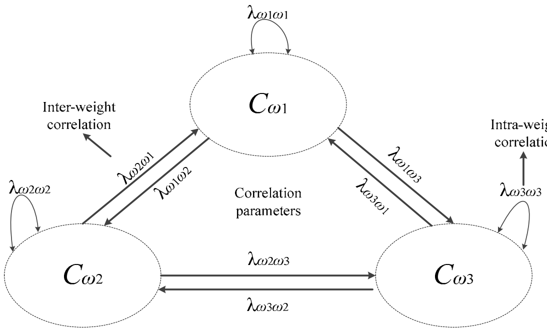

Fig.6 Code correlation analysis

The block diagram of the constructed ZMS- VWOOC system is shown in Fig.7. It is composed of transmitter and receiver respectively. The transmitter consists of a broadband light source (BBS), encoder, user data and modulator. At the encoder, the code can be generated by selecting the wavelength from the broadband light source through a filter, and the selected wavelength corresponds to the unique code of each user, and then the wavelength of each user is data modulated by the Mach-Zehnder modulator (MZM), and finally combine and transmit the output data to the optical fiber. The receiver uses DD technology, which uses non-overlapping wavelengths to detect each user's signal. The decoder consists of a filter, a photodetector and a low pass filter (LPF). Non-overlapping wavelengths are selected and sent to the photodetector and then passed through a LPF to restore the original data. Since only the required signal spectrum in the optical domain is filtered out, the MAI effect is successfully eliminated completely.

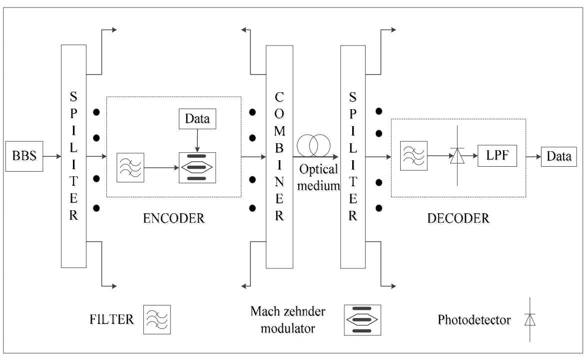

Fig.7 Block diagram of system setup for proposed ZMS-VWOOC

This code is mainly affected by shot noise, PIIN and thermal noise in the SAC-OCDMA system. For the convenience of calculation, Gaussian approximation is usually used to analyze the BER performance of the system. Because the ZMS-VWOOC code has zero cross-correlation characteristics, the influence of PIIN can be ignored. Assuming that there is an incoherent broadband heat source, the photocurrent noise generated by the detection of the naturally occurring ideal unpolarized thermal light can be expressed as

$$I_{\text{noise}}^2 = I_{\text{shot}}^2 + I_{\text{thermal}}^2 = 2eBI + \frac{4K_{\text{b}}T_{\text{n}}B}{R_{\text{L}}}, \tag{9}$$

where I_{shot} represents shot noise, I_{thermal} represents thermal noise, I is average photocurrent, B is the equivalent current bandwidth of the receiver noise, e is electronic charge, K_{b} is Boltzmann's constant, and T_{n} is the absolute noise temperature of the receiver, and R_{L} is the load resistance of the receiver.

In order to simplify the analysis of the ZMS-VWOOC system, the following assumptions are made[20-23]:

1. Each light source is ideally unpolarized and its spectrum is flat for given bandwidth $[v_0-\Delta v/2,\ v_0+\Delta v/2]$, where v_0 is the central optical frequency and Δv is optical source bandwidth.

2. Each spectral power component has the same spectral width.

3. The received power is the same for each user.

4. Each bit stream is synchronized from each user.

The power spectral density (PSD) of the received optical signals can be written as[24,25]

$$G(v) = \frac{P_{\text{sr}}}{\Delta v}\sum_{n=1}^{N_{B_j}} d_n \sum_{l=1}^{L} C_n(l)\Pi(l)\cdot \tag{10}$$

In the above formula, P_{sr} represents the effective power of broadband source at receiver, d_n represents the data sent by the nth user is "1" or "0", and $C_n(l)$ is the lth element of the nth code sequence.

$\Pi(l)$ can be defined as[26,27]

$$\Pi(l) = u\left[v - v_0 - \frac{\Delta v}{2L}(-L+2l-2)\right] - u\left[v - v_0 - \frac{\Delta v}{2L}(-L+2l)\right] = u\frac{\Delta v}{L}\cdot \tag{11}$$

And $u(v)$ is the unit step function expressed as

$$u(v) = \begin{cases} 1, & v \geq 0 \\ 0, & v < 0 \end{cases}. \tag{12}$$

According to the nature of the code of ZMS-VWOOC, using DD technology, the relevant attributes of the lth user whose code weight is W can be expressed as

$$\sum_{l=1}^{L} C_n(l)C_m(l) = \begin{cases} W_j,\ n = m & \text{The same mapping matrix} \\ 0,\ n \neq m & \text{The same mapping matrix} \\ 0,\ n \neq m & \text{Different mapping matrix} \end{cases}. \tag{13}$$

The power spectral density $G(v)$ received by the photo detector at the lth receiver is

$$G(v) = \frac{P_{\text{sr}}}{\Delta v}\sum_{n=1}^{N_{B_j}} d_n \sum_{l=1}^{L} C_n(l)C_m(l)\left\{u\frac{\Delta v}{L}\right\}. \tag{14}$$

Integrate the above formula to get the power of the photodetector:

$$\int_0^\infty G(v)\mathrm{d}v=\int_0^\infty\left[\frac{P_{sr}}{\Delta v}\sum_{n=1}^{N_{B_j}} d_n\sum_{l=1}^{L} C_n(l)C_m(l)\left(u\frac{\Delta v}{L}\right)\right]\mathrm{d}v=$$
$$\frac{P_{sr}}{\Delta v}\frac{\Delta v}{L}\sum_{n=1}^{N_{B_j}} d_n\sum_{l=1}^{L} C_n(l)C_m(l)=$$
$$\frac{P_{sr}W_j}{L}d_l+\frac{P_{sr}}{L}\sum_{n=1,n\neq m}^{N_{B_j}} d_n=\frac{P_{sr}W_j}{L}. \quad (15)$$

When all users send data as 1, the photo current of the photodetector is

$$I=R\int_0^\infty G(v)\mathrm{d}v=R\frac{P_{sr}}{\Delta v}\frac{\Delta v}{L}\sum_{n=1}^{N_{B_j}} d_n\sum_{l=1}^{L} C_n(l)C_m(l)=$$
$$\frac{RP_{sr}W_j}{L}. \quad (16)$$

In the above formula, R is the responsivity of the photodetector, which is determined by

$$R=\frac{\eta e}{hv}, \quad (17)$$

where η is the quantum efficiency, h is the Planck's constant, v is the center frequency of the original broadband optical pulse, and e is the electron charge.

The shot noise can be expressed as

$$I_{\mathrm{shot}}^2=2eBI=\frac{2eBRP_{sr}W_j}{L}. \quad (18)$$

The thermal noise can be expressed as

$$I_{\mathrm{thermal}}^2=\frac{4K_bT_nB}{R_L}. \quad (19)$$

As bit '1' and '0' have the same sending probability, the photocurrent noise can be written as

$$I_{\mathrm{noise}}^2=\frac{eBRP_{sr}W_j}{L}+\frac{4K_bT_nB}{R_L}. \quad (20)$$

The *SNR* can be written as[28]

$$SNR=\frac{I^2}{I_{\mathrm{noise}}^2}=\frac{\left(\frac{RP_{sr}W_j}{L}\right)^2}{\left(\frac{eBRP_{sr}W_j}{L}+\frac{4K_bT_nB}{R_L}\right)}. \quad (21)$$

Using Gaussian approximation, the *BER* can be written as

$$BER=P_e=\frac{1}{2}erfc\left(\sqrt{\frac{SNR}{8}}\right). \quad (22)$$

The quality of the received signal is evaluated by a factor of *SNR*, which represents the ratio of average signal power to total noise power. As shown above, the *SNR* is closely related to the *BER*, and a better *SNR* can achieve more efficient performance and better QoS. In order to analyze the proposed system in depth, refer to the system performance parameters shown in Tab.2, and analyze the mathematical formula proposed in the previous section from the aspects of *SNR*, *BER*, and received power.

Fig.8 shows the relationship between the number of users and the *SNR* of ZMS-VWOOC under the same effective power of −10 dBm.

Fig.8 shows that under the same effective power, the *SNR* of ZMS-VWOOC decreases with the increase of the number of users, and under the same number of users, the larger the code weight, the higher the *SNR* of the code.

Tab.2 The parameters used to find out the numerical results for VW code

Symbol	Parameter	Value
η	Photodetector quantum efficiency	0.6
R_b	Bit rate	622 Mbit/s
B	Electrical bandwidth	311 MHz
R_L	Receiver load resistor	1 030 Ω
λ	Operating wavelength	1 550 nm
P_{sr}	Received optical power	−10 dBm
T_n	Receiver noise temperature	300 K
e	Electron charge	1.6×10^{-19} C
h	Planck's constant	6.63×10^{-34} Js
K_b	Boltzmann's constant	1.38×10^{-23} J/K

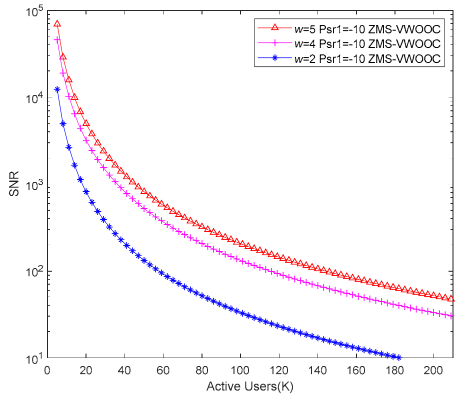

Fig.8 The relationship between active users and *SNR* in ZMS-VWOOC under the same effective power P_{sr}=−10 dBm

In Fig.9, the data transmission rate is set to 622 Mbit/s (ITU-T STM-4 standard). Under the same code weight set and effective power, the relationship between the number of users and *BER* of VW-MS and ZMS-VWOOC is shown in Fig.9.

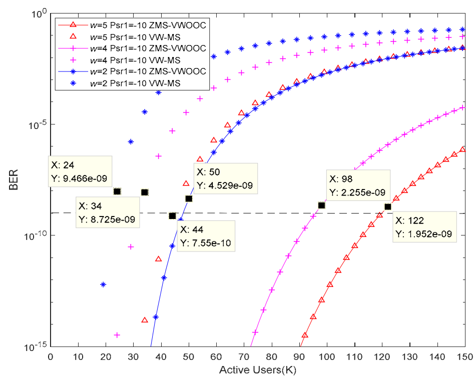

Fig.9 The relationship between the number of users

and *BER* of ZMS-VWOOC and VW-MS under the same effective power P_{sr}=−10 dBm

Fig.9 shows that under the same effective power of −10 dBm, the *BER* of ZMS-VWOOC increases with the number of users. Under the same number of users, the larger the code weights of ZMS-VWOOC, the better the bit error performance. Under the same conditions, when the acceptable *BER* of the reference data is 10^{-9}, the code weights in ZMS-VWOOC are 5, 4, and 2 can accommodate 122, 98, and 50 users respectively. The code weight of VW-MS is 5, 4, and 2 can accommodate about 44, 34, and 24 users, respectively. Therefore, the maximum number of users that ZMS-VWOOC can support is greater than the maximum number of users that VW-MS can support. In addition, since there are non-overlapping wavelengths in the ZMS-VWOOC system, the use of DD technology reduces the number of photodetectors, and the cost is lower than that of the VW-MS system.

Fig.10 shows the relationship between data rate and *BER* of ZMS-VWOOC and VW-MS codes under the same number of users 95 and the same code weight set.

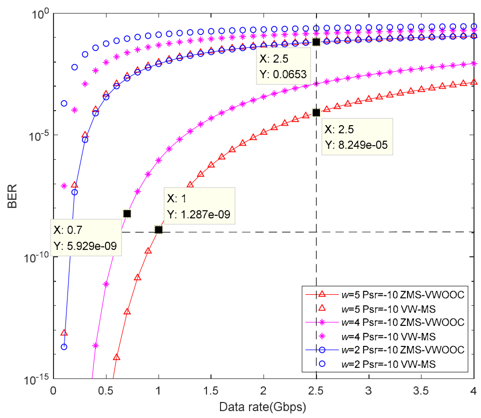

Fig.10 The relationship between the data rate and *BER* of ZMS-VWOOC and VW-MS under the same effective power P_{sr}=−10 dBm

Fig.10 shows the relationship between the data rate and *BER* of ZMS-VWOOC and VW-MS under the same effective power. Under the same conditions, when the acceptable *BER* of the reference data is 10^{-9}, the larger the code weight in the ZMS-VWOOC code, the greater the allowable transmission data rate (the allowable transmission data rate for a code weight of 5 is 1 Gbit/s, and the allowable transmission data rate for a weight of 4 is 0.7 Gbit/s). At the same transmission data rate, ZMS-VWOOC has better error performance than VW-MS. (When the transmission data rate is 2.5 Gbit/s, the *BER* of the ZMS-VWOOC with a code weight of 5 is three orders of magnitude lower than that of the VW-MS with a code weight of 5).

Fig.11 shows the relationship between the number of users and *BER* of ZMS-VWOOC with different code weights when P_{sr} is −10 dBm and the transmission rate are 2 Gbit/s and 3 Gbit/s. In order to represent voice, data and video, different code weights of 2, 4 and 5 are assigned respectively. The acceptable *BER* of reference voice, data and video are 10^{-3}, 10^{-9} and 10^{-12} respectively. When the transmission rate is 2Gbit/s, the maximum number of users that ZMS-VWOOC can support in VW-OCDMA system is 291, 149 and 129, respectively. When the transmission rate is 3Gbit/s, the maximum number of users supported by the code is 249, 123 and 103, respectively. If the number of users required for each service is not equal, code weight optimization can be performed to obtain acceptable quality for all services.

Fig.12 shows the relationship between effective power and *BER* of different code weights of ZMS-VWOOC and VW-MS when the number of users is 95, and each user accesses the medium at a data rate of 622 Mbit/s at the same time.

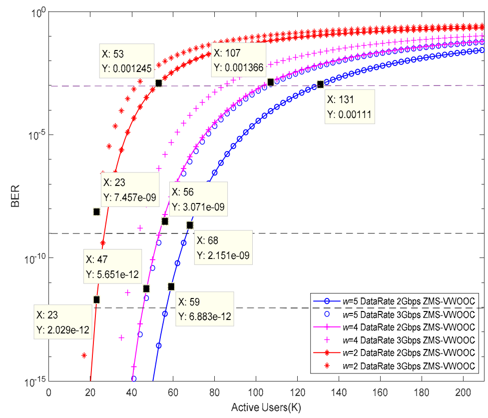

Fig.11 The relationship between the number of users and *BER* of ZMS-VWOOC with the transmission data rates of 2 Gbit/s and 3 Gbit/s

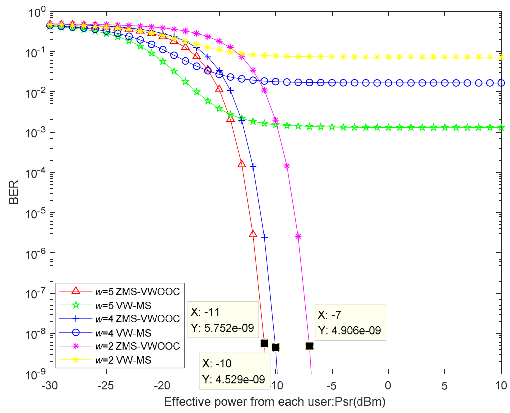

Fig.12 The relationship between effective power and *BER* of ZMS-VWOOC and VW-MS under the same number of users 95

It can be seen from Fig.12 that when the code weight is 5 and P_{sr} is greater than −14 dBm, the *BER* of ZMS-VWOOC decreases more significantly than that of VW-MS. This can be explained by the zero cross-correlation characteristic of ZMS-VWOOC. The research results show that with the increase of effective power, ZMS-VWOOC reduces the *BER* faster than VW-MS under the influence of photocurrent noise. The acceptable *BER* for the reference data is 10^{-9}, and the effective source powers with code weights of 5, 4 and 2 in ZMS-VWOOC are −11 dBm, −10 dBm and −7 dBm respectively. Obviously, the larger the code weight, the lower the required power value.

This paper proposes a new code ZMS-VWOOC that uses SAC-OCDMA technology to support multiple QoS. The design, structure and characteristics of the code are described, and performance comparisons are made with similar codes VW-OOC, VW-KS and VW-MS. The ZMS-VWOOC code has good performance. The results show that the algorithm design of the code has great flexibility in the choice of code weight and the number of users, and can effectively suppress PIIN. With reference to the allowable *BER* for voice, data and video services, when the data rates are 0.622 Gbit/s, 2 Gbit/s, 2.5 Gbit/s and 3 Gbit/s, it is proved that the number of users supported by ZMS-VWOOC in the SAC-OCDMA system is 270, 149, 137 and 123, so that it has good adaptability and flexibility.

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