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MWML-OOC Multimedia Optical CDMA Using SOC

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***Abstract*—In the MWML (Multiweight-Multilength) - OOC (Optical Orthogonal Code) Optical code division multiple acccess (CDMA), the differentiation of the transmission rate and QoS (Quality of Service) can be realized by changing the code-length and number of weights according to user requirement. However, mitigation of MAI (Multi Access Interference) is not done in the conventional MWML-OOC Optical CDMA. Therefore users who demand high QoS cannot achieve Bit Error Rate (BER) performance less than or equal to 10^{-12} due to the effect of the MAI. Moreover, general error correcting codes require the addition of the redundancy bits or an increase in number of weights, where the redundancy bits cause the decrease at the transmission rate, and the increase in the number of weights causes a decrease in the number of codes. In this paper, we apply SOC (Super-Orthogonal Code) which can correct errors without adding redundant bits as well as increasing in number of weight for MWML-OOC Optical CDMA to mitigate MAI. Since our scheme can reduce the number of optical pulses, the proposed scheme can mitigate the effect of MAI compared with the conventional scheme. We show that the proposed scheme can improve the BER performance in comparison with the conventional scheme.**

I. INTRODUCTION

In recent years, optical code division multiple access(OCDMA) systems have been widely investigated in the areas of high-speed optical local area network (LAN) and access network. In OCDMA systems, multiple users share an optical fiber by assigning a code sequence to each user. The major advantage of OCDMA systems is that each user can access the network asynchronously and simultaneously without strict wavelength control and timing control which are needed in the cases of wavelength division multiple access (WDMA) and time division multiple access (TDMA). In addition, OCDMA systems have benefits of inherent security, flexible access to networks and high tolerance to noise. Generally, the OCDMA systems suffer from the effect of multiple access interference (MAI) originating from other simultaneous users. Bit Error Rate (BER) performance deteriorates because of the effect of MAI. Therefore, the systems employ Optical orthogonal code (OOC), where the auto-correlation and cross-correlation values are at most ”1”, respectively. It is necessary to accommodate various traffics of the browsing web pages in addition to the high quality video data like high definition video in the same network. It is necessary to guarantee transmission rate more than or equal to 100Mbps for large capacity data and BER performance less than or equal to 10^{-12} on the optical fiber with which quality demand is severe. However, in conventional OCDMA systems, code-length and number of the weights are constant, so they can't change code-length and number of weights according to user requirement. OCDMA schemes which achieve multi-rate multi-quality(Multimedia) transmissions have been investigated [1]-[3]. In OFFH(Optical Fast Frequency Hopping)-CDMA scheme [1], in order to change transmission rate, code-length is changed. The frequency of optical pulse at the weighted position is changed for the sake of BER performance improvement. However, OFFH-CDMA scheme can change transmission rate according to user requirement but doesn't take into account the differentiation of BER performance. On the other hand, OPPM (Overlapping Pulse Position Modulation)-CDMA scheme is a method to extend PPM(Pulse Position Modulation) and optical pulses are excited corresponding to the information bits over some slots [2].The symbol length assigned to each user is changed according to user requirement. To differentiate BER performance, optical pulses that the user transmits may take high intensity and low intensity. As mentioned above, OPPM-CDMA system can realize multi-rate multi-quality, but the symbol length has the limitation. Only multiple of the basic symbol length can be taken in the scheme. Therefore, the scheme cannot flexibly change the transmission rate according to user requirement.

In [3], MWML(MultiWeight-MultiLength)-OOC in which both code-length and the number of weights ca be flexibly according to user requirement is proposed. There is no limitation to code-length like OPPM-CDMA scheme. However, when MWML-OOC is used, though the differentiation of QoS (Quality of Service) can be realized by changing number of weights, the high QoS users cannot achieve BER performance less than or equal to 10^{-12} for the effect of MAI. Moreover, general error correcting codes require the addition of the redundancy bits or an increase in number of weights, where the redundancy bits cause the decrease at the transmission rate, and the increase in the number of weights causes a decrease in the number of codes.

In this paper, we apply SOC(Super-Orthogonal Code) which can correct the error without addition of redundancy bit and an increase in number of weight for MWML-OOC Optical CDMA to mitigate MAI. Since our scheme can reduce the number of optical pulses, the proposed scheme can mitigate the effect of MAI compared with the conventional scheme. To accommodate changing the number of weight in the proposed scheme, we consider the composition of the SOC encoder. In addition, we theoretically analyze BER performance when SOC is applied to MWML-OOC. We show that the proposed scheme can improve the BER performance in comparison with the conventional scheme.

II. CONVENTIONAL SCHEME

A. *MWML-OOC*

In MWML-OOC, to change the transmission rate and QoS, code-length and the number of weights are changed according to the transmission rate and the number of weight that users demand, and it classifies it into the Q classes. Because the code-length is changed according to transmission rate, the synchronization is not taken among users, and only the chip synchronization is taken. Moreover, to attempt the differentiation of QoS in each class, the number of weights is switched in MWML-OOC. In this case, the more number of weights is, the more the BER performance is improved, the number of weights is increased to the code of the class to which the user who demands the low BER performance belongs, and the number is reduced to the code of the class to which the user who doesn't demand low BER performance. Figure 1 shows the example of the transmission symbol of MWML-OOC. In Fig.1, user 1 is assigned the longest code and there are a lot of number of weights, transmission rate is low and QoS is high. And user 3 is assigned the shortest code and there are a few numbers of weights, transmission rate is high and QoS is low. As mentioned above, the differentiation of the transmission rate and QoS can be realized by changing code-length and the number of weight. The number of codes of MWML-OOC can be made as long as the following expressions are satisfied.

$$\frac{\sum_{q=1}^{Q} K_q W_q (W_q - 1)}{N_Q - 1} \leq 1 \tag{1}$$

where q is a class index, K_q is a number of codes of class q, W_q is a number of weights of class q, and N_Q is a code-length of maximum class and the longest code-length.

Figure 2 shows the BER performance versus the number of class2 users. In this case, Class 1 users demand high QoS and the transmission rate is 100Mbps. And code-length N_1 is 500, the number of weights W_1 is 8, the number of users K_1 is 4, respectively. We assume that Class 2 users don't demand high QoS and the transmission rate is 50Mbps, code-length N_2 is 1000, the number of weights W_2 is 4, the number of users K_2 is changed from 1 to 28, respectively. In Fig.2 the differentiation of the BER performance can be attempted in Class 1 and Class 2. However, when the number of users increases, Class 1 cannot achieve BER less then or equal to 10^{-12} for the effect of MAI in this scheme. Therefore, error correcting code need to be applied to MWML-OOC.

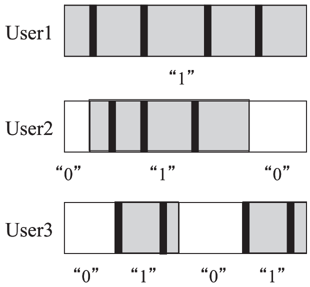

Fig. 1. The example of the transmission symbol of MWML-OOC.

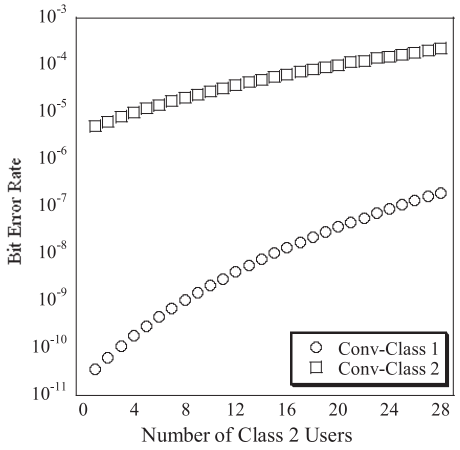

Fig. 2. The BER performance versus the number of class2 users.

B. *SOC[4]*

In general error correcting codes, the error correction is achieved by adding the redundancy bits or an increase of weights, where the redundancy bits cause the decrease at the transmission rate, and the increase in the number of weights causes a decrease in the number of codes. In this paper, we focus on SOC which can improve BER performance without adding the redundancy bit or an increase of the number of weights [4].

In SOC, to collect error without adding the redundancy bit or an increase the number of weights, the number of optical pulses transmitted every one bit is decreased. The SOC encoder is used to decide the weighted position where optical pulse is not transmitted. Figure 3 shows the example of the SOC encoder. The SOC encoder consists of L shift register and block encoder as shown in Fig.3. Each user decides the weighted position where optical pulse is excited according to the output of the SOC encoder. The Hadamard-Walsh encoder is used as block encoder in the SOC encoder. This is because the number of "1" and "0" is the same in Walsh code, and optical pulse is excited only "1" position in SOC, so the number of optical pulse is half of the weighted positions. In addition, the orthogonality is kept between each code. Figure 4 shows the example of transmitted optical pulse of SOC. In Fig.4 we assume the code whose code-length is 32, the number of weights is 4, and the weighted position is 1, 10, 13, 28. The output of the SOC encoder is assumed to be "1010",

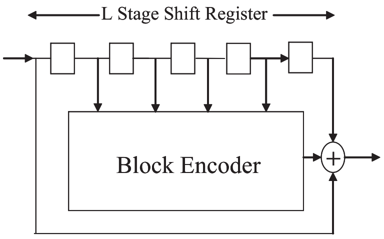

Fig. 3. The example of the SOC encoder.

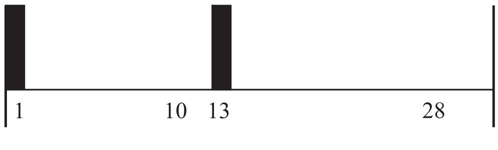

Fig. 4. The example of transmitted optical pulse of SOC.

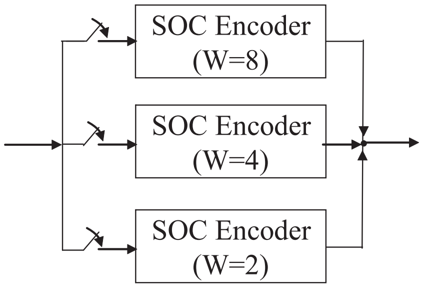

Fig. 5. The block diagram of SOC encoder in proposed scheme.

optical pulses are excited only at the 1st and 3rd weighted positions where the output of the SOC encoder is “1”, and optical pulses are not excited at the 2nd and 4th weighted positions where the output is “0” on the transmitter side. Moreover, when SOC is used, OOC can be used as a signature code, the auto-correlation and cross-correlation property can keep “1” as well as OOC when SOC is not used.

III. Proposed Scheme

Here we propose to apply SOC to MWML-OOC optical CDMA in order to realize the differentiation of the transmission rate and QoS and achieve BER performance of high QoS users less than or equal to 10^{-12} regardless of the number of activeusers. In the proposed scheme, to achieve switching the code-length and the number of weight in MWML-OOC and consider the limitation to the number of weight of SOC at the same time, encoder and decoder are switched at the transmitter and receiver.

SOC scheme uses Hadamard-Walsh encoder as block encoder and output is restricted to 2^n(n is integer), but the output of MWML-OOC is not restricted. Therefore, the number of weights of the code is restricted to SOC. In the proposed scheme because the output of the SOC encoder is 2^{L-2}(L is a number of shift register), the number of weights of code is 2^{L-2}, and the number of weights is decided according to QoS that a user demands. The number of weight is increased to the users who demand low BER performance, and the number of weight is reduced to the users who do not demand low BER performance as well as the conventional scheme. The users with different code-length exist together in the proposed scheme. Therefore, frame synchronization is only taken among same class users, and not taken among users with different code-length. Moreover, if transmission rate which users demand changes and spreading code of different class is used, a user who change transmission rate take frame synchronization for users that have already communicated.

Figure 5 shows the block diagram of SOC encoder in proposed scheme. In Fig.5, we assume the number of weight takes 2, 4 and 8, and the number of weight is switched according to the received quality. It is necessary for proposed scheme to be done before the transmission for the switching the number of weight. To accommodate changing the number of weight, the switch function is added to SOC encoder to change the number of weights according to the received quality in the proposed scheme. In addition, each user decides the weighted positions where the optical pulses are excited according to the output of the SOC encoder.

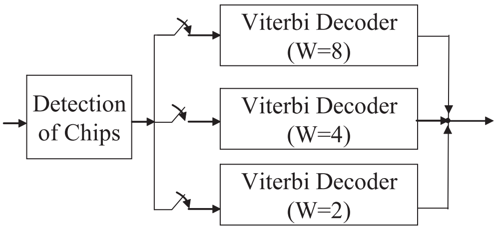

Fig. 6. The block diagram of the receiver in the proposed scheme.

Figure 6 shows the block diagram of the receiver in the proposed scheme. In the receiver, transmitted symbol is detected whether the optical pulses exist in each weighted position of the spreading code or not. Viterbi decoding is performed based on detection results. To perform maximum likelihood decoding using Viterbi decoding, the bit errors caused by the effect of MAI can be reduced. The number of weights is switched according to the received quality that user demands, the symbol length of SOC is different in the proposed scheme. In this thesis, the switch function is added to the receiver side, and the Viterbi decoder corresponding to the symbol length decided by the number of weight is used. Moreover, it is necessary to switch the Viterbi decoder before the transmission.

IV. Theoretical analysis

A. Error rate of the weighted position

Desired user’s interference probability I from same code-length and the number of weights is $I = W/2N$, where code-length is N, the number of weight is W and occurrence probabilities of ‘0’ and ‘1’ are $1/2$, respectively. If code-length and the number of weight of interference users are the same as those of a desired user and OOK modulation is used for SOC as a modulation scheme, the probability $P(0|0)$ of correctly detecting “0” with the condition of transmitting “0” and the probability $P(0|1)$ of wrongly detecting “1” with the condition of transmitting “0” are obtained, respectively, as follows.

$$P(0|0) = \left(1 - \frac{W}{2N}(1-e^{-\lambda})\right)^{K-1} \cdot e^{-\lambda_d}, \tag{2}$$

$$P(0|1) = \left(1 - \frac{W}{2N}(1-e^{-\lambda})\right)^{K-1} \cdot e^{-\lambda_d-\lambda}, \tag{3}$$

where, λ is an average photon count at each weighted position, λ_d is an average dark current at each chip, and K is the number of total users, respectively. The probability $P(1|0)$ of wrongly detecting “1” with the condition of transmitting “0” and the probability $P(1|1)$ of correctly detecting “1” with the condition of transmitting “1” are obtained, respectively, as follows.

$$P(1|0) = 1 - P(0|0), \tag{4}$$

$$P(1|1) = 1 - P(0|1). \tag{5}$$

To apply SOC to MWML-OOC, a desired user experiences interference not only from users whose code-length and the number of weight is same but also from users whose code-length and the number of weights are different in the proposed scheme. In different classes, code-length and the number of weight are different from those of a desired user. Therefore, if desired user's class is $\overline{q}$ and interference user's class is q, interference probability $I_{q\overline{q}}$ from different class user to desired user is obtained as follows.

$$I_{q\overline{q}} = \frac{W_q}{2N_{\overline{q}}} \cdot \frac{N_{\overline{q}}}{N_q} = \frac{W_q}{2N_q}. \quad (6)$$

In addition, because code-length and the number of weight of interference user are different in each class and the number of user of each class is different, interference from each class to a desired user is different. Therefore, the following value is used as weight value for the effect of interference according to the number of active users of each class.

$$\frac{K_q}{K_1 + K_2 + \cdots + K_Q - 1} = \frac{K_q}{K-1} \quad (7)$$

where, $K_q = K_{\overline{q}-1}$ if interference users and a desired user are in the same class. Therefore, the probability $P_{\overline{q}(0|0)}$ that the desired user who belongs to class $\overline{q}$ correctly detects "0" with the condition of transmitting "0" is obtained as follows.

$$P_{\overline{q}}(0|0) = \left(1 - \frac{1}{K-1}\sum_{i=1}^{Q} K_i I_{i\overline{q}}(1 - e^{-\lambda_{\overline{q}}})\right)^{K-1} e^{-\lambda_d}. \quad (8)$$

Similarly the probability $P_{\overline{q}(0|1)}$ that the desired user who belongs to class $\overline{q}$ wrongly detects "0" with the condition of transmitting "1" is obtained as follows.

$$P_{\overline{q}}(0|1) = \left(1 - \frac{1}{K-1}\sum_{i=1}^{Q} K_i I_{i\overline{q}}(1 - e^{-\lambda_{\overline{q}}})\right)^{K-1} e^{-\lambda_d - \lambda_{\overline{q}}} \quad (9)$$

B. Performance of SOC

The upper bound on the bit-error probability of a convolutional code can be obtained using the path generating function of the code. The generating function of the SOC is computed in [5] as

$$T(Z,b) = \frac{bG^{L+2}(1-G)}{1 - G(1 + b(1 + G^{L-3} - 2G^{L-2}))}, \quad (10)$$

where, $G = Z_{\overline{q}}^{2^{L-3}}$ and L is a number of shift resisters. The parameter in a binary input channel is given by

$$Z = \underset{R|1}{E}\left\{\sqrt{\frac{P(R|0)}{P(R|1)}}\right\}, \quad (11)$$

where variable R denotes the output of the coding channel. Using Eq.(11), the parameter Z in an asymmetric binary input binary output channel can be found from the transition probabilities, namely $P(i|j)\, i,j \in \{0,1\}$, is as follows.

$$Z_{\overline{q}} = \sqrt{P_{\overline{q}}(1|0)P_{\overline{q}}(1|1)} + \sqrt{P_{\overline{q}}(0|1)P_{\overline{q}}(0|0)}. \quad (12)$$

Using the generating function, an upper bound on the bit error probability is obtained as follows.

$$P_b < \frac{\partial T(Z,b)}{\partial(b)}\Big|_{b=1} = \frac{G^{L+2}}{(1-2G)^2}\left(\frac{1-G}{1-G^{L-2}}\right)^2. \quad (13)$$

V. NUMERICAL RESULT

In numerical results, we assume that some users demand low BER performance and others do not demand low BER performance. Figure 7 shows BER performance versus the number of Class 2 users in the conventional scheme and the proposed scheme. In Fig. 7, BER performance of Class 1 and Class2 of the conventional scheme are shown by Conv-Class 1 and Conv-Class 2, and BER performance of Class 1 and Class 2 of the proposed scheme are Prop-Class 1 and Prop-Class 2. Class 1 users demand high QoS and the transmission rate is 100Mbps, and code-length N_1 is 500, the number of weights W_1 is 8, the number of users K_1 is 4, respectively. We assume that Class 2 users don't demand high QoS and the transmission rate is 50Mbps, code-length N_2 is 1000, the number of weights W_2 is 4 and the number of users K_2 is changed from 1 to 28, respectively. In the conventional scheme, BER performance of Class 1 cannot achieve less than or equal to 10^{-12} even if the number of active users is small. However, if the number of active users becomes 32, BER performance of Class 1 can achieve less than or equal to 10^{-12} in the proposed scheme. This is because, by using SOC, optical pulse can be reduced and interference probability is decreased in comparison with the case without using SOC. In addition, when BER performance of Class 1 is compared with that of Class 2, Class 1 is more improved than Class 2 in proposed scheme. This is because the number of weights of Class 1 is larger than that of Class 2 and the symbol length of Class 1 is longer than that of Class 2. Therefore, the improvement effect of Viterbi decoding of Class 1 is large in comparison with Class 2.

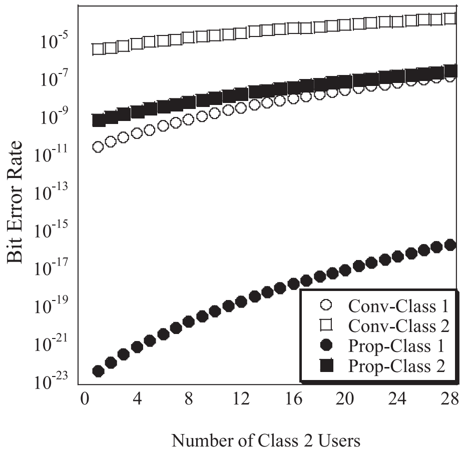

Fig. 7. The BER performance versus the number of class2 users (Class 1:$N_1 = 500, W_1 = 8, K_1 = 4$, Class 2:$N_2 = 1000, W_2 = 4$).

Figure 8 shows BER performance versus code-length N_2. In Fig.8, Class 1 is code-length $N_1 = 500$, the number of weights $W_1 = 8$ and the number of users $K_1 = 4$, respectively. Class 2 is the number of weights $W_2 = 4$ and the number of users $K_2 = 16$, and code-length N_2 is changed from 750 to 3000. Table 1 shows code-length versus transmission rate. From Fig.8, BER performance of the proposed scheme is more improved than that of the conventional scheme. When BER performance of Class 1 is compared with that of Class 2, Class 1 is more

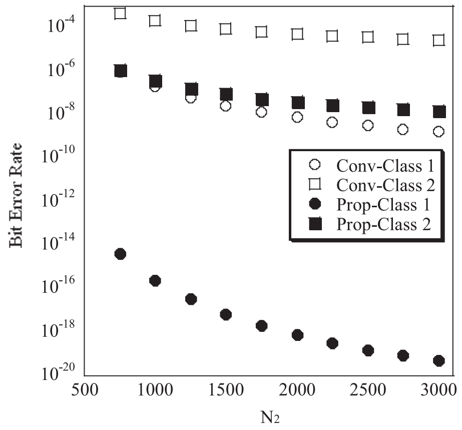

Fig. 8. BER performance versus code-length N_2 (Class 1:$N_1 = 500, W_1 = 8, K_1 = 4$, Class 2:$W_2 = 4, K_2 = 16$).

TABLE I
CODE-LENGTH N VERSUS TRANSMISSION RATE(MBPS)

Code-length	500	1000	1500	2000	2500	3000
Transmission rate (Mbps)	100	50	33.3	25	20	16.7

improved than Class 2 in the proposed scheme. This is because the longer code-length N_2 becomes, the smaller optical pulse which users transmit is within a fixed time. However, the code-length of Class 1 is not changed and the number of weights in a fixed time is not changed, so interference from interfering users decreases.

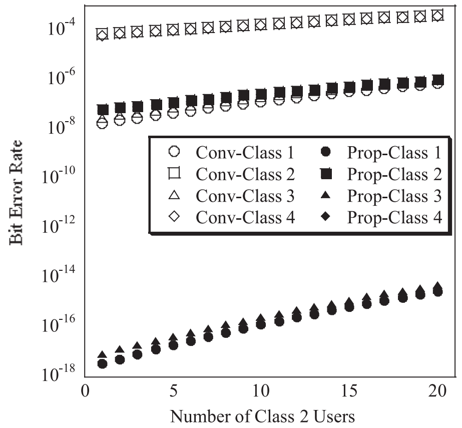

Fig. 9. BER performance verses the number of Class 2 users (Class 1:$N_1 = 500, W_1 = 8, K_1 = 4$, Class 2:$N_2 = 1000, W_2 = 4$, Class3:$N_3 = 1000, W_3 = 8, K_3 = 4$, Class4:$N_4 = 500, W_4 = 8, K_4 = 4$).

Figure 9 shows BER performance verses the number of Class 2 users. In Fig.9, we assume 4 classes. In addition, Class 1 is 100Mbps and demands low BER and Class 2 is 50Mbps and does not demand low BER, and the number of Class 2 users K_2 is changed from 1 to 20. In addition, Class 3 is 50Mbps and demands low BER and Class 4 is 100Mbps and does not demand low BER. BER performance of the proposed scheme is more improved than that of the conventional scheme in each class. And low BER users of Class 1 and Class 3 can achieve BER performance less than or equal to 10^{-12}. This is because, by using SOC, optical pulse that each user transmits every one bit decreases, and hence, interference probability decreases. In addition, since the number of weights of Class 1 and Class 3 become large, the symbol length of Class 1 and Class 3 become long. Therefore, BER performance improves.

VI. CONCLUSION

We have applied SOC which can correct the error without addition of redundancy bit and an increase in number of weight for MWML-OOC Optical CDMA to mitigate MAI. Since our scheme can reduce the number of optical pulses, the proposed scheme can mitigate the effect of MAI compared with the conventional scheme. Numerical results show that the proposed scheme can improve the BER performance in comparison with the conventional scheme. And users who demand low BER performance can achieve BER performance less than or equal to 10^{-12} without relying on the number of active users.

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