Research on the system performance of SAC-FBGs codec scheme

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Abstract. The theory of codec based on non-coherent frequency domain codec (FBGs) and non-coherent spectral domain codec (SAC-FBGs) of light-brain grating is theoretically analyzed and its transmission performance is verified. The codec scheme with better performance is compared. An optical quadrature cyclic shift code with a code length N of 13, code weight ω of 4, and self-correlation λ of 1 is used to implement codec schemes using FBGs codec and SAC-FBGs codec, respectively. Based on multiple access interference, signal to interference ratio (SIR) and bit error rate (BER) are discussed separately. From experimental results, it can be concluded that under the condition that the optical orthogonal codes are identical and the number of concurrent users is the same, the signal to interference ratio of the OCDMA system obtained by using the SAC-FBGs coding and decoding scheme is higher than that of the OCDMA system obtained by using the FBGs coding and decoding scheme. The SIR has increased by nearly two orders of magnitude, and the multiple-site interference BER has decreased by 20 or even 100 orders of magnitude. The experiment verifies that the transmission performance of the same optical orthogonal code using the SAC-FBGs coding and decoding scheme is obviously higher than that of the system transmission performance using the FBGs coding and decoding scheme.

1. Introduction
After more than 40 years of development, optical communication technology has made obvious progress in many ways of multiplexing, optical devices and so on. It has now become one of the fastest developing technologies in the field of high technology [1]. Optical time division multiplexing (OTDM) has a high transmission rate, but its system capacity is smaller and the fiber broadband utilization is low; optical wavelength division multiplexing (OWDM) has a high bandwidth utilization rate and large system capacity, but it is difficult to realize the laser source, and the optical code division multiplexing (OCDMA) technology is confidential. It is a promising technology, especially in the aspect of increasing system capacity. The codecs frequently used in OCDMA systems are fiber delay line (FODL), array waveguide grating (AWG), fiber Bragg grating (FBG), etc. [2]. The coding and decoding efficiency of the optical fiber delay line codec is not ideal, and the AWG codec is more complex. Therefore, the FBG codec has attracted the attention of the public. The incoherent systems of OCDMA networks are more simple than coherent optical systems in both signal representation and signal processing, and SAC-FBGs codec is widely concerned with the presentation of non coherent optical OCDMA systems, but there are few
studies on the performance of the SAC-OCDMA system at present. In this experiment, the transmission performance of N, FBGs = (13,4,1) = (13,4,1) using FBGs codec and SAC-FBGs codec respectively is studied.

2. Optical orthogonal code ($q^2+q+1$, $q+1$, 1)
The core of the OCDMA technology is the optical address code. The application of the OCDMA system is closely related to the performance of the address code. Therefore, the codeword can be constructed by the transformation of the projective space and the corresponding relation between each other. The lines and the harnesses in the projective space correspond to the codeword and the code set of the optical orthogonal codes in the OCDMA system respectively [3], and all the points on the projective plane correspond to the code length L of the optical orthogonal codes. A codeword corresponds to a straight line, the number of points on the line corresponds to the code weight, and the cyclic shift of the codeword is represented by the same parallel class line. The intersection point represents the autocorrelation (lambda) 1. The cyclic shift of the different codewords is expressed as with different parallel lines [4], and the intersection points represent intercorrelation (lambda) of 1. The experiment uses the projection (plane) = (13,4,1) optical orthogonal code ($q=3$). The design of the codeword is optimized. If other factors that cause the error code are not considered, the orthogonal code can be transmitted without error, so the optical address code has excellent performance.

3. Codec technology of SAC-FBGs

3.1. The principle of SAC-FBGs encoder
The encoding and decoding scheme of SAC-FBGs is similar to that of FBGs encoding and decoding scheme. The incoherent light of "1" or "0" enters the FBGs encoder and regulates the central reflection wavelength of FBGs by voltage, thus selectively reflecting the incident spectrum and decomposing it into a series of spectral [5]. For the optical orthogonal code with a code length of L, the FBGs is cut into a spectral slice with a central reflection wavelength ($\lambda_1, \lambda_2, \lambda_3, ..., \lambda_{L-1}$) [6], in which the user address code greatly affects the selected reflection spectrum and forms a spectrum sequence corresponding to the user address sequence code $X_j = (\chi_0, \chi_1, \chi_2, ..., \chi_{L-1})$.

![Figure 1. Schematic diagram of SAC-FBGs encoder](image)

In order to represent the transmission information ($m_j = 0$ or $1$) of the first user, the encoded signal of the second user is the address code vector of the first user. In this way, the coupling superposition signal vector of a user is:
3.2. The principle of SAC-FBGs decoder

The SAC-FBGs decoder is different from the FBGs decoder. For the SAC-FBGs decoder, it contains two FBGs decoders. After FBGs1, the spectrum passes through the 1 / Q attenuator into the phototube PD_1. The reflected light signal is delayed by FBGs2 to compensate for the time delay of each light pulse and then into a new light signal and then into the phototube PD_2. Finally, the balance detector is used to detect and output the signal. The structure diagram of the SAC-FBGs decoder and decoder is as follows:

![Figure 2. Schematic diagram of FBGs decoder](image)

![Figure 3. Schematic diagram of SAC-FBGs decoder](image)

4. Signal detection and recovery of SAC-OCDMA system

Figure 4 is a schematic diagram of the SAC-OCDMA system structure. From the diagram, it can be seen that after the user data of the SAC-OCDMA system receiver is divided into two paths after the coupler, a signal corresponding to the user address code is entered into the forward phototube via the decoder A, and a signal corresponding to the complement code of the address code is entered into the reverse optoelectronic via the decoder A. After the balance detector is detected, the original data is recovered after judgment [7]. If the user's data is to be recovered, the user address code,
which reflects the power, can get its positive current, and the complement of the user address code can get its reverse current, and the final received signal power is "0" when the result is "0", and the final received signal power is "1" when the result is "1". In terms of energy transfer, the decoding based on FBGs and the encoded energy transfer function are linearly conjugate, which makes its linear recovery and reconstruction possible. In order to improve the signal interference ratio (SIR) of the FBG codec, the FBGs should have the center wavelength of the equal number sequence, and the tolerance of the decoder is much greater than that of the codec's reflection spectrum [8], and the corresponding reflectivity should be kept as consistent as possible to ensure that the reflected signal power of the FBG is as much as possible at the same level.

5. Transmission performance of system

5.1. Performance analysis of OCDMA system

The system using the FBGs codec is a OCDMA system. At the same time, if a total of K users send the signal simultaneously, one of the users receives multiple access interference from other K-1 users, in which the sigma is the variance, the number of concurrent users, the code weight, and the code length. Therefore, the information interference ratio and the bit error rate can be obtained.

\[
SIR = \frac{\omega^2/2}{(K-1)\sigma^2} = \frac{\omega^2/2}{(K-1)(2L-\omega^2)\omega^2/4L^2} = \frac{2L^2}{(K-1)(2L-\omega^2)}
\]

\[
BER = \Phi(-\sqrt{SIR/2}) = 0.5 + 0.5\text{erf}(-\sqrt{SIR/2})
\]

Among them, the lower side probability under the Gauss distribution and the error function:

\[
\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x \exp(-t^2)dt
\]

5.2. Performance analysis of SAC-OCDMA system

The system using SAC-FBGs codec is SAC-OCDMA system. In an ideal case, the optical pulse can be considered to have a strictly flat power spectrum, so each chip cut through the FBGs has equal power, and the Intercode interference at this time can completely overcome the [9]. However, the power spectrum of light source can not be completely flat, and the power spectrum of different chips can not be exactly equal. When the number of users is transmitted at the same time, the code power will be generated after repeated stacking. For long optical orthogonal codes \( X = (x_0, x_1, x_2, \ldots, x_{L-1}) \), the power of each piece of chip is:

\[
P_i = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(\frac{(\hat{\lambda}_i - \lambda_0)^2}{2\sigma^2}\right)
\]
Among them, the center wavelength of the light source is \( \lambda_0 \), the wavelength of each chip is \( \lambda_i \) and the variance of the Gauss distribution is \( \sigma \). The signal power of a detector receiving a user is: 

\[
S = \sum_{i=0}^{L-1} x_i^2 p_i
\]

If there is a number of K concurrent users, the multiple access interference of the other K-1 users to the forward biased photodiode of the detector is \( \sum_{j=1}^{K-1} \sum_{i=0}^{L-1} x_i x_{i\oplus j} p_i \), the multiple access interference of the other K-1 users to the detector reverse bias photoelectric tube is \( \alpha \sum_{j=1}^{K-1} \sum_{i=0}^{L-1} x_i x_{i\oplus j} p_i \oplus \) which is the mode sum \( (i \oplus j = \text{mod}(i + j, L)) \). Therefore, the total multiple access interference is:

\[
I = \sum_{j=1}^{K-1} \left( \sum_{i=0}^{L-1} x_i x_{i\oplus j} p_i - \alpha \sum_{i=0}^{L-1} x_i x_{i\oplus j} p_i \right)
\]

\[
\text{SIR} = \frac{S}{I} = \frac{\sum_{i=0}^{L-1} x_i^2 p_i}{\sum_{j=1}^{K-1} \sum_{i=0}^{L-1} (\sum_{i=0}^{L-1} x_i x_{i\oplus j} p_i - \alpha \sum_{i=0}^{L-1} x_i x_{i\oplus j} p_i)}
\]

\[
\text{BER} = \frac{1}{2} \text{erfc}\left(\frac{\text{SIR}}{2}\right)
\]

5.3. The experimental result

Figure 5 and Figure 6 are 14 users, respectively, to send a code length of 13, a code weight of 4, a correlation of 1, for the signal \((N, \omega, \lambda) = (q^2 + q + 1, q + 1, 1) = (13,4,1)\), a interference ratio (SIR) and a bit error rate (BER) relative to the concurrent user number K, respectively.
Figure 6. Comparison of BER

It can be seen from the diagram that when the code length, the code weight and the correlation of the optical orthogonal codes are exactly the same, the signal interference ratio of the same number of users, whether through the OCDMA system or the SAC-OCDMA system, decreases with the increase of the number of concurrent users, and their bit error rates are all increasing with the increase of the number of concurrent users. The difference is that, when the optical address code is the same and the number of users is the same, the signal interference of the signal through the SAC-OCDMA system is nearly two orders of magnitude higher than the signal interference ratio through the OCDMA system, and the error rate of multiple access interference is reduced by 20 or even 100 orders of magnitude. It can be seen that the transmission performance of the SAC-OCDMA system is obviously higher than that of the OCDMA system.

6. Summary
At present, the SAC-OCDMA system has significant advantages in system transmission. The incoherent codec is simpler to be realized than the coherent codec, although it requires that the user capacity is consistent with the time domain codec synchronization OCDMA system, but does not require time to synchronize strictly. Optical orthogonal code \((N, \omega, \lambda) = (13,4,1)\) is chosen as the user address code, because its correlation is 1, it can guarantee better transmission performance. With the continuous improvement of the FBG technology level, the width of the reflection spectrum of FBGs seriously affects the number of pulse slices of the user signal. The narrower the width of the reflection spectrum of FBGs is, the more the number of pulse slices of the user signal, which makes the SAC codec can be carried out in a more complex address code, thus improving the channel capacity. Therefore, the SAC-FBGs encoding and decoding scheme provides a more effective way to decode and decode OCDMA systems.

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