2015년 2월 전자공학회 논문지 제 52권 제 2 호
Journal of The Institute of Electronics and Information Engineers Vol. 52, NO. 2, February 2015 http://dx.doi.org/10.5573/ieie.2015.52.2.119

논문 2015-52-2-15

광원 라인폭이 Spectral Amplitude Coding Optical CDMA시스템의 성능에 미치는 영향

(Effect of Line-Width of Optical Sources on Performance of Spectral Amplitude Coding Optical CDMA Systems)

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요 약

본 논문은 광원 라인폭이 spectral amplitude coding (SAC) OCDMA 시스템에 미치는 영향을 구하였다. q와 m값에 따라 다양한 코드를 구현할 수 있으므로 symmetric balance incomplete block design(BIBD) 코드를 분석에 사용하였다. 그 결과 입력파워가 큰 경우 ($P_{sr}=-10$ dBm) 이상적인 BIBD 코드가 비이상적인 BIBD 코드보다 더 좁은 광원 라인폭이 요구되었다. 그러나 입력파워가 작은 경우 ($P_{sr}=-25$ dBm)에는 그 반대로 비이상적인 BIBD 코드가 이상적인 BIBD 코드보다 더 좁은 광원 라인폭이 필요했다.

Abstract

In this paper, we analyze the effect of line-width of optical sources on the performance of spectral amplitude coding (SAC) optical code division multiple-access (OCDMA) systems. For a performance analysis we use a symmetric balanced incomplete block design (BIBD) code as the code sequence because we can construct a series of code families by choosing different values of q and m. The ideal BIBD code ($m=2$) requires narrower line-width than the nonideal BIBD codes when the effective power is large ($p_{sr}=-10$ dBm). But the nonideal BIBD codes ($m>2$) need narrower line-width than the ideal BIBD code when $p_{sr}=-25$ dBm.

Keywords : Balanced detection, multiple-access interference(MAI), balanced incomplete block design(BIBD), spectral amplitude coding optical code division multiple-access(SAC OCDMA)

Ⅰ. Introduction

Spectral amplitude coding (SAC) optical code division multiple-access (OCDMA) systems are attractive because we can eliminate multiple-access interference (MAI) when codes with fixed in-phase cross correlation (CC) are used as address sequences[1~9]. A symmetric balanced incomplete block design (BIBD) code[10] is an example of these codes. For the BIBD code, we can construct a series of code families by choosing different values of q and m, where q is a prime power given by $q=p^n$ with n being a positive integer, p being a prime number, and m denotes the finite vector's space dimension.

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접수일자: 2014년09월06일, 수정일자: 2015년01월14일
게재확정: 2015년01월27일

In SAC systems, the inherent phase-induced intensity noise (PIIN) severely affects the overall system performance. This noise is due to the spontaneous emission of the broad-band source. To suppress it, the value of in-phase CC λ should be as small as possible. When (N, w, λ) denotes a code with length N, weight w, and in-phase CC λ, a $(q^2+q+1, q+1, 1)$ code results with $m=2$, and it has ideal in-phase CC $\lambda=1$. When $\lambda=1$, we say the code has ideal in-phase CC, as this is the minimum value that can be achieved. Therefore, we call this code an ideal BIBD code. When $m>2$ we call theses codes nonideal codes.

In this paper, we investigate the effect of line-width of optical sources on the performance of SAC-OCDMA systems. Since OCDMA systems employing the SAC adopt low cost broadband incoherent sources, we need to specify the effect associated with a fixed bit-error rate (BER). Because of the limited bandwidth resource, the highest performance systems are generally those that achieve the largest number of simultaneous user at identical line-width. For a performance analysis we use the BIBD code as the code sequence because we can construct a series of code families by choosing different values of q and m.

Ⅱ. Performance Analysis

A $((q^{m+1}-1)/(q-1),\ (q^m-1)/(q-1),\ (q^{m-1}-1)/(q-1))$ code comes from a symmetric BIBD with element number $(q^{m+1}-1)/(q-1)$ and block size $(q^m-1)/(q-1)$, where every pair of blocks intersect in $(q^{m-1}-1)/(q-1)$ elements. This code is based on points and hyper-planes of the projective geometry $PG(m, q)$. For a performance analysis with the BIBD codes, we use the same assumptions in [11]~[13] that (1) the light sources are unpolarized and that their spectrum is flat over a determined bandwidth, (2) the power spectral components have identical width, (3) all users have equal power at the receiver, and (4) the bit patterns are synchronized.

Let $c_k(i)$ denote the ith element of the kth BIBD code sequence. The code properties can be written:

$$\sum_{i=0}^{N-1} c_k(i)c_\ell(i) = \begin{cases} w, & k=\ell \\ \lambda, & k\neq\ell \end{cases} \quad k,\ell \in 0,\cdots,K-1. \tag{1}$$

and

$$\sum_{i=0}^{N-1} c_k(i)\overline{c_\ell}(i) = \begin{cases} 0, & k=\ell \\ w-\lambda, & k\neq\ell \end{cases} \quad k,\ell \in 0,\cdots,K-1. \tag{2}$$

where $c_\ell(i)$ is the ith element of the ℓth receiver.

The power spectral densities (PSDs) at PDs 0-1 of the receiver using the codeword c_k during one bit period can be written:

$$G_0(v) = \frac{P_{sr}}{\Delta\nu}\sum_{k=0}^{K-1} d_k \sum_{i=0}^{N-1} c_k(i)c_\ell(i) \bullet \begin{Bmatrix} u\left[\nu-\nu_0-\dfrac{\Delta\nu}{2N}(-N+2i)\right] \\ -u\left[\nu-\nu_0-\dfrac{\Delta\nu}{2N}(-N+2i+2)\right] \end{Bmatrix} \tag{3}$$

$$G_1(v) = \frac{\alpha P_{sr}}{\Delta\nu}\sum_{k=0}^{K-1} d_k \sum_{i=0}^{N-1} c_k(i)\overline{c_\ell}(i) \bullet \begin{Bmatrix} u\left[\nu-\nu_0-\dfrac{\Delta\nu}{2N}(-N+2i)\right] \\ -u\left[\nu-\nu_0-\dfrac{\Delta\nu}{2N}(-N+2i+2)\right] \end{Bmatrix} \tag{4}$$

where P_{sr} is the effective source power at the receiver, Δv is the line-width of the source, ν_0 is the central optical frequency, K is the number of active users, d_k is the data bit of the kth user that is “1” or “0”, N is the code length of the spectral code sequence, $\alpha=\lambda/(w-\lambda)$, and $u(\nu)$ is the unit step function.

When all the users are transmitting bit “1”, the average output currents of PDs 0-1 of the desired receiver can be expressed[14~15]:

$$I_0 = R\int_0^{\infty} G_0(\nu)d\nu = \frac{RP_{sr}}{N}\{w+\lambda(K-1)\} \tag{5}$$

$$I_1 = R\int_0^{\infty} G_1(\nu)d\nu = \frac{RP_{sr}\alpha}{N}\{(w-\lambda)(K-1)\} \tag{6}$$

where R is the responsivity of the photodiode.

The total current produced by the conventional balanced detector is:

$$I = (I_0 - I_1) = \; = \frac{RP_{sr}w}{N}. \tag{7}$$

The shot noise for both photodiode is given by:

$$\langle I_{shot}^2 \rangle = 2eB(I_0 + I_1) = \frac{2eBRP_{sr}}{N}\{w+2\lambda(K-1)\}. \tag{8}$$

where B is the noise-equivalent electrical bandwidth of the receiver.

The thermal noise for the receiver is given by:

$$\langle I_{th}^2 \rangle = \frac{4K_b T_n B}{R_L}. \tag{9}$$

where K_b is Boltzmann's constant.

The mean square optical powers can be written as:

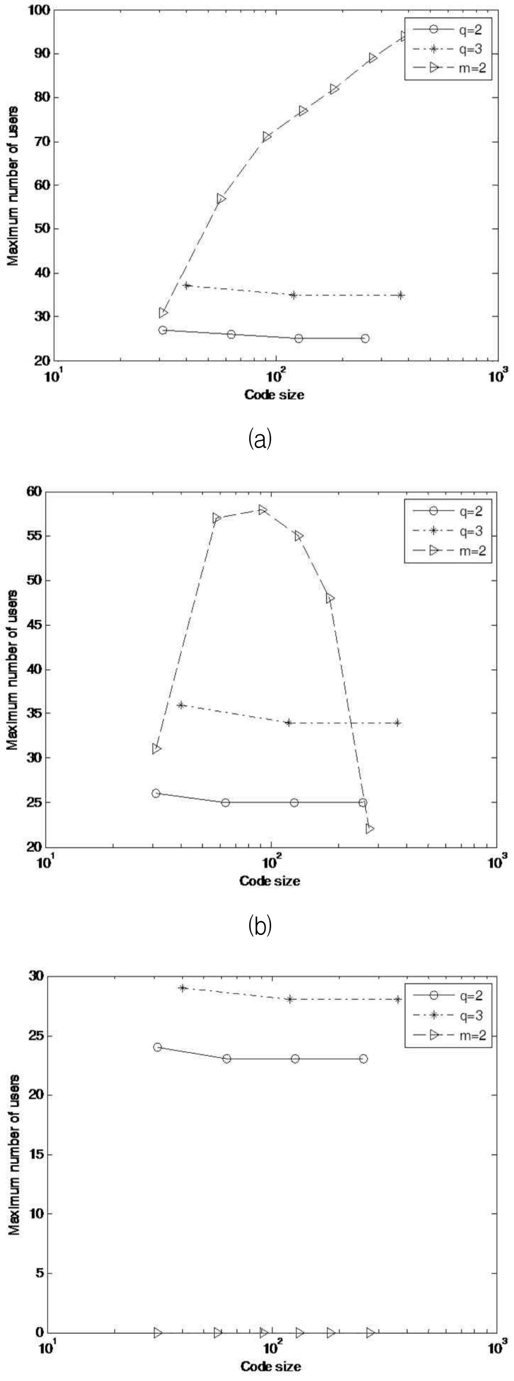
$$\begin{aligned}\int_0^{\infty} G_0^2(\nu)d\nu &= \frac{P_{sr}^2}{N\Delta\nu}\sum_{i=0}^{N-1}\left[\sum_{k=0}^{K-1} c_k(i)c_\ell(i)\right]^2 \\ &= \frac{P_{sr}^2}{N\Delta\nu w}[w+\lambda(K-1)]^2\end{aligned} \tag{10}$$

$$\begin{aligned}\int_0^{\infty} G_1^2(\nu)d\nu &= \frac{\alpha^2 P_{sr}^2}{N\Delta\nu}\sum_{i=0}^{N-1}\left[\sum_{k=0}^{K-1} c_k(i)\overline{c_\ell}(i)\right]^2 \\ &= \frac{P_{sr}^2}{N\Delta\nu(N-w)}[\lambda(K-1)]^2.\end{aligned} \tag{11}$$

The PIIN is given by:

$$\begin{aligned}\langle I_{IN}^2 \rangle &= BR^2\left[\int_0^{\infty} G_0^2(\nu)d\nu + \int_0^{\infty} G_1^2(\nu)d\nu\right] \\ &= \frac{BR^2P_{sr}^2}{N\Delta\nu}\left\{\frac{1}{w}[w+\lambda(K-1)]^2 + \frac{1}{(N-w)}[\lambda(K-1)]^2\right\}.\end{aligned} \tag{12}$$

Since "1" and "0" are sent with equal probability for every user, the signal to noise ratio (SNR) can be



(a)

(b)

(c)

그림 1. $\Delta\nu = 3.75$ THz일 경우 BER=10^{-9}을 만족하기 위한 코드크기와 최대 동시 사용자 수의 관계 (a) $P_{sr} = -10$ dBm (b) $P_{sr} = -20$ dBm (c) $P_{sr} = -25$ dBm

Fig. 1. Maximum number of simultaneous users versus code size for a BER=10^{-9} with $\Delta\nu = 3.75$ THz (a) $P_{sr} = -10$ dBm (b) $P_{sr} = -20$ dBm (c) $P_{sr} = -25$ dBm.

expressed by:

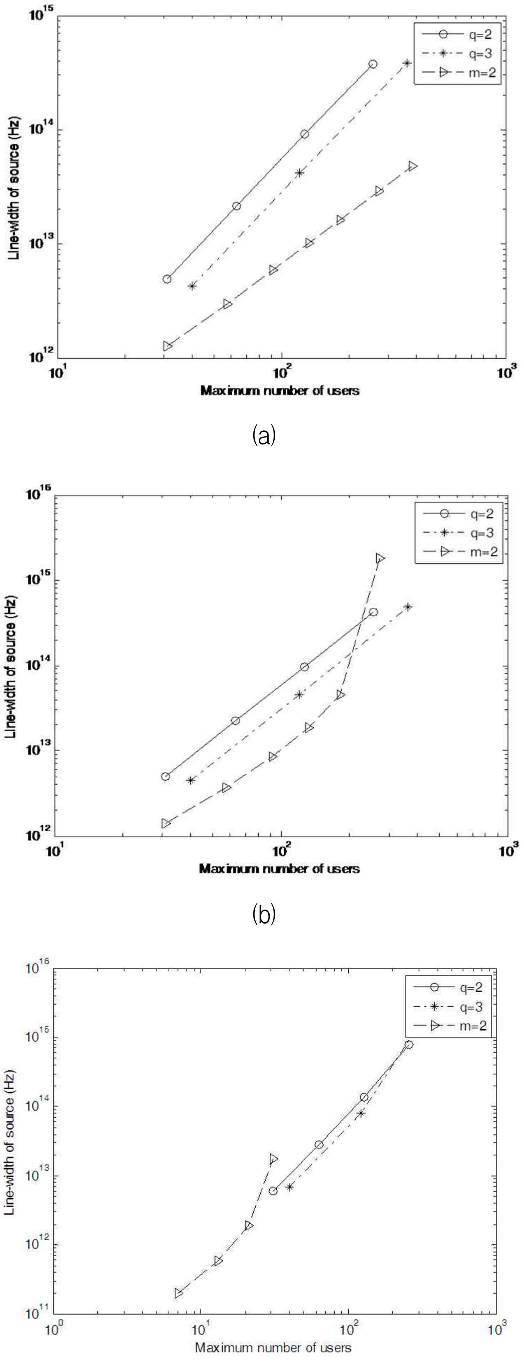
$$SNR = \frac{I^2}{\langle I^2 \rangle} = \frac{I^2}{\left[\frac{\langle I_{IN}^2 \rangle}{2} + \frac{\langle I_{shot}^2 \rangle}{2} + \langle I_{Th}^2 \rangle \right]}. \tag{13}$$

The bit error rate (BER) can be expressed as:

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{SNR}{8}} \right). \tag{14}$$

We can construct the ideal BIBD code by choosing different values of q for $m=2$. If choosing different values of $m>2$ for $q \geq 2$, we can construct the nonideal BIBD codes. The maximum number of simultaneous users for a BER=10^{-9} is calculated from (13). In particular, SNR=143.9 is required to attain a BER=10^{-9}. Fig. 1(a) shows the relation between the code size and the maximum number of simultaneous users for a BER=10^{-9} when $\Delta\nu = 3.75$ THz and $P_{sr} = -10$ dBm. The system parameters are: for $B = 80$ MHz; bit-rate 155 Mb/s; central wavelength 1550 nm; $T_n = 300^o$ K; $R_L = 1030\,\Omega$ and photodiode quantum efficiency 0.6. The ideal BIBD code $(m=2)$ results in a much better performance due to the effective suppression of the PIIN when the effective power is large ($P_{sr} = -10$ dBm). For medium signal power ($P_{sr} = -20$ dBm) the performance degradation of the ideal BIBD code can be seen with the increment of the code size, as shown in Fig. 1(b). Fig. 1(c) shows variations of the maximum number of simultaneous users with the code size for BER=10^{-9} when $P_{sr} = -25$ dBm. Only nonideal BIBD codes ($q=2$ and $q=3$) can attain the BER of 10^{-9} because the thermal noise becomes the main factor that limits the system performance.

The line-width of optical source required to attain a BER=10^{-9} is also calculated from (13) using $K=N$. As seen in Fig. 2(a), the line-width of the source with any code family increases with increasing the maximum number of simultaneous users when $P_{sr} = -10$ dBm. As expected, the ideal BIBD system leads to the best line-width performance. The



(a)

(b)

(c)

그림 2. $K=N$일 때 BER=10^{-9}을 만족하기 위한 최대 동시 사용자 수와 광원 라인폭의 관계 (a) $P_{sr}=-10$ dBm (b) $P_{sr}=-20$ dBm (c) $P_{sr}=-25$ dBm

Fig. 2. Line-width of optical source required to attain a BER=10^{-9} versus maximum number of simultaneous users using $K=N$ (a) $P_{sr}=-10$ dBm (b) $P_{sr}=-20$ dBm (c) $P_{sr}=-25$ dBm.

line-width of source required for a BER=10^{-9} versus the maximum number of simultaneous users when $P_{sr}=-20$ dBm is also shown in Fig. 2(b). The numerical results show that the line-width performances of the system using the ideal BIBD code are worse than those of the system with nonideal BIBD codes under the maximum number of simultaneous users of $N=273$. Fig. 2(c) shows that the nonideal BIBD codes outperform the ideal BIBD code when $P_{sr}=-25$ dBm.

Ⅲ. Conclusion

In this paper, we investigate the effect of line-width of optical sources on the performance of SAC-OCDMA systems. For a performance analysis we use the BIBD code because we can construct a series of code families by choosing different values of q and m. The ideal BIBD code $(m=2)$ requires narrower line-width than the nonideal BIBD codes when the effective power is large ($p_{sr}=-10$ dBm). But the nonideal BIBD codes $(m>2)$ need narrower line-width than the ideal BIBD code when $p_{sr}=-25$ dBm.

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