Phase Induced Intensity Noise Evasion in SAC-OCDMA Systems Using Flexible Cross Correlation (FCC) Code Algorithm

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Abstract: In this paper, a new class of codes called the Flexible Cross Correlation (FCC) code is presented. The FCC code is significant in Spectral Amplitude Coding – Optical Code Division Multiple Access (SAC-OCDMA) systems since these codes effectively evade the effects of Phase Induced Intensity Noise (PIIN) and also has the Multiple Access Interference (MAI) cancellation property. The FCC code can be constructed using a simple tridiagonal matrix with shortest code length for any given number of users and Hamming-weights. The proposed coding systems utilizing FCC code has been analyzed with the presence of different noises such as shot noise, PIIN noise and thermal noise, respectively. The results revealed ours proposed FCC code indicated good performance since these codes offers 183%, 325%, 347% and 466% as a contrast to former SAC-OCDMA codes such as MDW \( (w=4, K=60) \), \( (w=6, K=40) \), MFH \( (w=8, K=38) \) and Hadamard \( (K=30) \), respectively. Furthermore, an extensive simulation results shown at 10km, taking the threshold cutoff BER 10\(^{-9}\), the FCC code could support 0.9Gbps for \( w=10 \) without requiring any amplifier.

Key words: FCC Code, PIIN, SAC-OCDMA, MAI, FTTH.

INTRODUCTION

In recent years, there has been a long time an extensive research in exploring Code Division Multiple Access (CDMA) techniques and applications in optical communication (Cottatellucci, L., 2010). Interest in OCDMA is always high due to tremendous demand for bandwidth due to internet services including electronic commerce, virtual-reality and tele-networking. Subscribers require higher bandwidth where the existing schemes such as Time Division Multiple Access (TDMA) and Wavelength Division Multiple Access (WDMA) transmission systems are unable to fulfill (H. M. R. Al-Khafaji, 2012). Recently, OCDMA was implemented in the local area, thus for applications in access network such as Fiber-To-The-Home (FTTH) (Othman, M., 2007). SAC encoding approaches were used in OCDMA where the spectrum of an incoherent broadband source is amplitude encoded. In SAC-OCDMA coding systems, improperly code designed and the highest number of simultaneous users can be seriously degraded the system performance due to the presence of MAI (M. S. Anuar, 2006). MAI is the interference resulting from other users transmitting at the same time which will limit the effective error probability with the presence of noise in the overall system. PIIN is deeply related to MAI due to overlapping spectra from different users (M.S. Anuar, et al, 2007). Therefore, the SAC-OCDMA coding system should have an efficient address code sequence with flexible cross-correlation. Inappropriate cross-correlation among the address sequences will cause PIIN between code sequences increased (Hilal, A. Fadhil, 2008).

Therefore, the design of the optical coding algorithm and flexible cross-correlation for used in the SAC-OCDMA coding system must be considered together to attain best quality of services (QoS) from the system proposed. Most codes have been proposed in SAC-OCDMA coding systems such as Hadamard code (E.D.J. Smith, et al, 1998), Modified Frequency Hopping (MFH) code (Z. Wei, H. Ghafouri-Shiraz, 2002) and Modified Double Weight (MDW) code (S.A. Aljunid, et al., 2005). However, these codes have several restrictions such as the code is either too long (e.g. Hadamard) and construction is complicated (e.g. MFH code). Finally, the code with fixed an even natural number (e.g. MDW) code. In this paper, the authors proposed a new algorithm for FCC code to improve system capacity and achieve highest performance possible through PIIN evasion and eliminating MAI. The proposed code also has an advantage of high cardinality and low received power with shorter code length. The code is optimum in the sense that, the code length is shorter for a given in-phase cross-correlation function and can be constructed for any given number of users and Hamming-weights. It will be proven with the theoretical calculations and intensive simulation results indicated that the systems with the proposed code is better than others SAC-OCDMA codes such as Hadamard, MFH and MDW codes, respectively. This paper is organized as follows; pursuing an essential of optical CDMA in Section 2. In Section 3 the theoretical and simulation results based on the derived SNR and BER formulas and finally the conclusions of this paper are shown in Section 4.

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2. Essential of Optical CDMA:

Optical codes are family of $K$ (for $K$ users) binary [0, 1] sequences of length $N$, Hamming-weight $w$ (the number of “1” in each codeword) and the maximum cross-correlation, $\lambda_{\text{max}}$. The optimum code set is one having flexible cross-correlation properties to support the maximum number of users with minimum code length. This ensures guaranteed quality of services with least error probabilities for giving number of users $K$ at least for the short haul optical networking (M. S. Anuar, et al., 2006). Now, let $A= \{a_i\}$ and $B= \{b_i\}$ be the sequences of length $N$ such that:

$$\{a_i\} = \text{‘0’ or ‘1’, } i = 0, \ldots, N-1$$

$$\{b_i\} = \text{‘0’ or ‘1’, } i = 0, \ldots, N-1$$

(1)

The auto and cross-correlation functions of these sequences are defined, respectively by (Z. Wei, H. Ghafouri-Shiraz 2002);

$$\lambda_a(\tau) = \sum_{i=1}^{N} a_i a_{i+\tau} = W \text{ for } \tau=0$$

(2)

$$\lambda_{ab}(\tau) = \sum_{i=1}^{N} a_i b_{i+\tau} \leq 1 \text{ for } \tau=0$$

(3)

Since $a_n$ is a {0, 1} binary sequence, the maximum value of $\lambda_a(\tau)$ in equation (2) is for $\tau=0$ and is equal to $w$, the Hamming-weight of the sequence can be expressed as;

$$\lambda_a(0) = w$$

(4)

If $\lambda_{\text{a, min}}$ & $\lambda_{\text{b, min}}$ denote the maximum out of phase auto–correlation and cross-correlation values respectively, then an optical code of length $N$ and Hamming-weight $w$ can be written as $(N, w, \lambda_{\text{a, min}}, \lambda_{\text{b, min}})$. A $(N, w, \lambda_{\text{a, max}}, \lambda_{\text{b, max}})$- for FCC code is called the constant- weight symmetric FCC when $\lambda_a = \lambda_{\text{a, max}}$ and we used the shorthand notation of an $(N, w, \lambda_{\text{max}})$ for the largest possible cardinality (number of users). It may also be noted that for an optical code $a_n$ with Hamming-weight ‘$w$’ for auto-correlation can be written as follows;

$$\lambda_a(0) = W$$

(5)

In practice for $K$ users, it is required to have a $K$ number of codes in a set for given values of $(N, w, \lambda_{\text{max}})$. The codes described by equation (1) can also be represented in vector form as;

$$A = \{a_i\} \text{ for } i = 0, 1, \ldots, N-1$$

$$B = \{b_i\} \text{ for } i = 0, 1, \ldots, N-1$$

(6)

Where, $A$ and $B$ are vectors of length $N$ with elements as defined by equation (6). In terms of the vectors $A$ and $B$, equations (2) and (3) can be written as;

$$\lambda_A(0) = AA^T = W$$

(7)

$$\lambda_{AB}(0) = AB^T$$

Where $A^T$ and $B^T$ denote the transpose of vectors $A$ and $B$, respectively.

2.1 Algorithm of FCC Code Development:

Optical non-zero cross-correlation codes are sets of optical sequences that require;

$$\lambda_{AB}(0) = AB^T \leq 1$$

(8)
That is,

\[ AB^T = \leq 1 \quad (9) \]

In OCDMA systems to allow receivers to distinguish each of the possible users, to reduce channel interference and to accommodate a large number of users, optical cross-correlation codes should have large values of \( w \) and size \( K \). However, it is difficult to design such an optical tridiagonal code which satisfied all the requirements, for example the condition expressed in equation (8) is only achieved at the expense of larger values of \( w \) or larger values of code length \( N \) or smaller values of code size \( K \).

**Step 1:** We have considered a set of code matrix \((N, w, \lambda_{\text{max}})\) for \( K \) users. This set of notation is then represented by a \( K \times N \) code matrix \( A^w_K \) where, the matrix \( A^w_K \) is here called the **Tridiagonal Code Matrix** and it is given by equation (10) and the rows \( A_1, A_2, A_K \) represent the \( K \) code words.

\[
A^w_K = \begin{bmatrix}
a_{11} & a_{12} & a_{13} & 0 & 0 & \cdots & 0 \\
a_{21} & a_{22} & a_{23} & a_{24} & 0 & \cdots & \vdots \\
0 & a_{32} & a_{33} & a_{34} & a_{35} & 0 & \vdots \\
0 & 0 & a_{43} & a_{44} & a_{45} & a_{46} & \vdots \\
\vdots & \ddots & \ddots & \ddots & \ddots & \ddots & \vdots \\
0 & 0 & \cdots & \cdots & \cdots & a_{KN} & \vdots \\
\end{bmatrix} = \begin{bmatrix}
A_1 \\
A_2 \\
A_3 \\
\vdots \\
A_K \\
\end{bmatrix}
\]

where,

\[ A_1 = a_{11}, a_{12}, a_{13} \ldots a_{1N} \]
\[ A_2 = a_{21}, a_{22}, a_{23}, a_{24} \ldots a_{2N} \]
\[ A_3 = a_{31}, a_{32}, a_{33}, a_{34} \ldots a_{3N} \]
\[ \vdots \]
\[ A_K = a_{K1}, a_{K2}, a_{K3} \ldots a_{KN} \]

**Step 2:** Based on the \( K \times N \) matrix \( A^w_K \) as defined in equation (10), the Hamming-weight of each of the \( K \) codes is assumed to be \( w \). The elements \( a_{ij} \) of \( A^w_K \) is binary \([0, 1]\) can be expressed as follows;

\[
A^w_K = \left\{ a_{ij} = '0' \text{ or } '1', i=1,2,..K, j=1,2,..N \right\} 
\]

Since the \( K \) codes represented by the \( K \) rows of the code matrix are unique and independent of each other, \( A^w_K \) should have rank \( K \). Moreover, for \( A^w_K \) to have rank \( K \), the code length must be greater or equal to \( K \), and can be denoted as \( N \geq K \).

**Step 3:** The \( K \) codes represented by the \( K \) rows of the \( K \times N \) matrix \( A^w_K \) in equation (10) are to represent a valid set of \( K \) codeword with in-phase cross-correlations \( \lambda_{\text{max}} \) and Hamming-weight \( w \), it must satisfy the following conditions;

1. The elements \( a_{ij} \) of \( A^w_K \) must have values “0” or “1” which is;

\[
a_{ij} = "0" \text{ or } "1" \text{ for } i=1,2,..K, j=1,2,..N
\]

2. The Hamming-weight \( w \) of each codeword should be equal to \( w \) where;

\[
\sum_{j=1}^{N} a_{ij} = w, \ i=1,2..K
\]

3. The in-phase cross-correlation, \( \lambda_{\text{max}} \) between any of the \( K \) code words \((K \text{ rows of the matrix } A^w_K)\) should not exceed Hamming-weight \( w \). That is;
From equation (14), it is seen that the \( w = A_i A_i^T \) is the in-phase auto-correlation function of codes. \( A_i A_j^T \) is the out-of-phase correlation between the \( i \)th and the \( j \)th codes. It follows that \( A_i A_i^T \) should be greater than \( A_i A_j^T \). In other words, weight must be greater or equal to \( \lambda_{\text{max}} \), and can be denoted as \( w \geq \lambda_{\text{max}} \).

5. All \( K \) rows of \( A_K^w \) should be linearly independent because each codeword must be uniquely different from other words. That is to say the rank of the matrix \( A_K^w \) should be \( K \). One of the matrices that satisfy the above four conditions is the \( K \times N \) Matrix \( A_K^w \) whose \( i \)th row is given by;

\[
A_i = \begin{bmatrix} r(i-1) w & \ldots & r(K-i) w \\ 0 \ldots 0 & 11 \ldots 1 & 0 \ldots 0 \end{bmatrix}
\]

where,

\[
r = (w - \lambda_{\text{max}})
\]

The length \( N \) of the codes which is the length of the rows of the matrix \( A_K^w \) is given by;

\[
N = wK - \lambda_{\text{max}}(K - 1)
\]

It can be seen that the length \( N \) is minimum under the assumed conditions.

**Step 4:** On the basis of the above discussions, the construction of an optical code having a value of \( K \), Hamming-weight \( w \), and \( \lambda_{\text{max}} \) consists of the following steps:

- For a given number of users \( K \), and Hamming-weight \( w \), forms a set of flexible in-phase cross-correlation code with a minimum length as given by Equation (15).
- The length \( N \) of code matrix has defined by the Equation (16)

This procedure will now be explained with the help of an example:-

Assume that in Table 1, it is desired to generate a set of codes with minimum length and flexible in-phase cross-correlation for \( K=4, w=3, \lambda_{\text{max}} \leq 1 \).

**Table 1:** The FCC codeword with \( w=3, K=4, \lambda_{\text{max}} \leq 1 \) and \( N=9 \).

<table>
<thead>
<tr>
<th>Number of Users</th>
<th>Codeword</th>
<th>( \lambda_{\text{max}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_1 )</td>
<td>( {1,1,0,0,0,0,0,0,0} )</td>
<td>1</td>
</tr>
<tr>
<td>( K_2 )</td>
<td>( {0,0,1,1,0,0,0} )</td>
<td>0</td>
</tr>
<tr>
<td>( K_3 )</td>
<td>( {0,0,0,0,1,1,0,0,0} )</td>
<td>1</td>
</tr>
<tr>
<td>( K_4 )</td>
<td>( {0,0,0,0,0,0,1,1,1} )</td>
<td>0</td>
</tr>
</tbody>
</table>

**2.2 System Performance Analysis with Presence of Different Noises:**

Here we are considering the FCC codeword as shown in Table 1 with flexible cross-correlation optical code families. The auto-correlation of each codeword \( A_i = (a_1,a_2,a_3,...,a_N) \) and the cross-correlation between any two distinct codeword \( A_i = (a_1,a_2,a_3,...,a_N) \) and \( B_j = (b_1,b_2,b_3,...,b_N) \) are satisfy as mentioned in equations (2) and (3).

Hence, according to the properties of the FCC codeword in Table 1, the \( A_i \) and \( B_j \) denoted the \( i \)th element of the \( K \) row and \( j \)th element of \( N \) column for FCC codeword sequences which can be written as;

\[
\sum_{j=1}^{N} \sum_{i=1}^{K} A_i B_j = \begin{cases} 
  w_i, & \text{For } i = j, \\
  1, & \text{For } i \neq j 
\end{cases}
\]
Thus, MAI can be fully suppressed when the subtraction is valid for \( A_{ij} \cdot B_{ij} \) with \( A_{ij}B_{ij} \) when \( i \neq j \). In our analyses, we only considered shot noise \( \langle i_{\text{shot}} \rangle \), incoherent intensity noise \( \langle i_{\text{PN}} \rangle \) and thermal noise \( \langle i_{\text{thermal}} \rangle \) to evaluate the system performance. The SNR is defined as the average of the signal-to-noise ratio, \( \text{SNR} = \frac{[I^2]}{\sigma^2} \) where \( \sigma^2 \) is the average power of noise which is given by (E.D.J. Smith, et al., 1998);

\[
\sigma^2 = \langle i_{\text{shot}}^2 \rangle + \langle i_{\text{PN}}^2 \rangle + \langle i_{\text{thermal}}^2 \rangle
\]

Equation (19) can be expressed as;

\[
\sigma^2 = 2eBI + I^2B\tau_c + \frac{4K_bT_nB}{R_L}
\]

where, \( e \) is the electron charge, \( I \) is the average photocurrent, \( I^2 \) is the power spectral density for \( I \), \( B \) is the noise equivalent of electrical bandwidth, \( K_b \) is the Boltzmann constant, \( T_n \) is the absolute receiver noise temperature and \( R_L \) is the receiver load resistor. From equation (20) it has been assumed that the optical bandwidth is much larger than the maximum electrical bandwidth. The coherence source time \( \tau_c \) is given as (E.D.J. Smith, et al., 1998);

\[
\tau_c = \frac{\int G(v)dv}{\int [G(v)]^2dv}.
\]

where, \( G(v) \) denotes as the single sideband source power of spectral density (PSD). Noticed, the effect of receiver’s dark current has been neglected in this proposed system analysis. The broadband pulse coming thru to the fiber Bragg grating (FBG) as an incoherent light field is mixed and incident upon a photo-detector while the phase noise of the fields causes an intensity noise in term of the photo-detector output. The proposed system was analyzed with transmitter and receiver, we used the same assumption that used in (E.D.J. Smith, et al., 1998) and those are important for mathematical preliminaries simplicity. Since, to analyze the proposed system we use the following assumptions;

- Each unpolarized source PSD and its spectrum is flat over the system bandwidth of \([v_o, \Delta v/2]\) with amplitude \( \text{Psr}/\Delta v \), \( v_o \) is the central optical frequency and \( \Delta v \) is the optical source bandwidth expressed in Hertz.
- Each user has equal power at receiver.
- Each bit stream from each user is synchronized.
- Each power spectral component has an identical spectral width.

Based on the above assumptions, the proposed systems can easily analyze using the Gaussian approximation. The power spectral density of the received optical signals can be written as (S.A. Aljunid, et al., 2005);

\[
G(v) = \frac{P_{sr}}{\Delta v} \sum_{i,j,\neq j} dK \sum_{j=1}^{N} \sum_{i=1}^{K} X_{ij}Y_{ij} [\Pi(i)],
\]

where, \( P_{sr} \) is the received power from a single source, \( \Delta v \) can be assumed as a perfect rectangular unit step function and can be illustrated in Fig. 1.
Fig. 1: Bandwidth of $\Delta V$. 

The unit step elements are \{0, 1\} and it is given as follows;

$$
\prod_{(i)} = \begin{cases} 
1, & \text{for } v > 0 \\
0, & \text{for } v < 0
\end{cases}
$$

(23)

From equation (22) the total incident powers at the receiver of PIN 1 and PIN 2 is given as follows;

$$
\int_{0}^{\infty} G_1(v) \, dv = \frac{P_{w}}{\Delta V} \sum_{i, j, k, l} dK \sum_{i=1}^{j} \sum_{k=1}^{i} X_{y_i} Y_{y_j} \left\{ W \left[ \frac{\Delta V}{N} \right] \right\} \, dv
$$

$$
= \frac{P_{w} W}{N} + \frac{P_{w}}{N} \sum_{i, j, k, l} dK
$$

(24)

$$
\int_{0}^{\infty} G_2(v) \, dv = \frac{P_{w}}{\Delta V} \sum_{i, j, k, l} dK \sum_{j=1}^{i} \sum_{k=1}^{j} X_{y_j} \bullet Y_{y_j} \left\{ W \left[ \frac{\Delta V}{N} \right] \right\} \, dv
$$

$$
= \frac{P_{w} W}{N} + \frac{P_{w}}{N} \sum_{i, j, k, l} dK
$$

(25)

Only one PSD spectrum will be calculated and the photodiode current $I$ and can be written as follows;

$$
I = \Re \int_{0}^{\infty} G(v) \, dv
$$

(26)

$\Re$ represents as the responsivity of the photo-detectors. Consequently, the photo current $I$ can be expressed as;

$$
I = \Re \left[ \frac{P_{w} W}{N} \right]
$$

(27)

From the simplified equations (24) and (25), the power of shot noise can be written as;

$$
\langle i_{\text{shot}}^2 \rangle = 2eB\Re \left[ \frac{P_{w}}{N} \right] [W + 3]
$$

(28)

We assume that, the intensity noise will dominate the broadband sources. Hence, with power spectral density from each user is the same; therefore we calculate the receiver intensity noise directly from the total power spectral density of each photodiode. Using equation (19) the intensity noise at the receiver output is given by (E.D.J. Smith, et al., 1998);

$$
\langle i_{\text{PN}}^2 \rangle = B(T_1^2 \tau_{c1} + T_2^2 \tau_{c2}) = T^2 \ast \tau_e \ast B
$$

(29)
where, \( I_1 \) and \( I_2 \) are the average photodiode currents, \( \tau_{c1} \) and \( \tau_{c2} \) are the coherence times of the light incident on each photodiode. By using equations (21), (24), (25) and (29), the variance of the receiver photo-current can be simplified as;

\[
\langle i_{FN}^2 \rangle = \frac{BN^2P_{sr}^2KW}{N^2\Delta v}[W+3] \tag{30}
\]

Since, from equations (12-16), shown the properties of FCC code are unique and independent of each other, equation (30) is also independent of the active users' data, consequently proposed coding systems does not depend on the timing of transitions in the user data and it applied to the asynchronous systems. Thermal noise is given as (Bartolo, 2012);

\[
\langle i_{thermal}^2 \rangle = \frac{4K_BT_nB}{R_L} \tag{31}
\]

From equations (27), (28), (30) and (31) the SNR for the proposed FCC code is defined by;

\[
SNR = \frac{[9P_{sr}W]^2}{N} \left[ 2eBRP_{sr} \frac{1}{N} [W+3] + BR^2 \frac{P_{sr}^2KW}{N^2\Delta v} [W+3] + \frac{4K_BT_nB}{R_L} \right] \tag{32}
\]

Since, there is no data sent for the ‘0’bit and assuming that the noise distribution is Gaussian thus, the corresponding bit error rate (BER) can be obtained as follows (Nasim Ahmed, et al., 2012);

\[
P_e = \frac{1}{2} \text{erfc} \left( \frac{\text{SNR}}{8} \right) \tag{33}
\]

Finally, the equations (32) and (33) will be used for the theoretical calculation for an evaluation of the proposed coding system utilizing FCC code.

**RESULTS AND DISCUSSIONS**

In OCDMA systems using SAC encoding approaches, the length of the codes is an important parameter. It is desirable to have smaller code length as this will require smaller bandwidth. Moreover, codes with smaller length will require less number of filters at the encoder as well decoder (M. S. Anuar, et al., 2007). This will reduce the complexity and cost of the systems. Table 2 shows the comparison of code length \( N \), for 30 numbers of users for various SAC-OCDMA codes. It is clearly shown that, the FCC code had a shorter code length which is \( N=31 \) as compared with MFH \( (N=42) \), RD \( (N=35) \), MQC \( (N=56) \) and MDW \( (N=90) \), respectively. Furthermore, the FCC code can be designed with smaller code weight is equal to two \( (w=2) \) as compared with other SAC-OCDMA codes such as MFH, RD, MQC and MDW, respectively.

<table>
<thead>
<tr>
<th>NUMBER</th>
<th>CODES</th>
<th>NUMBER OF USERS (K)</th>
<th>WEIGHT (#)</th>
<th>CODE LENGTH (N)</th>
<th>CROSS CORRELATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MFH</td>
<td>30</td>
<td>7</td>
<td>42</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>RD</td>
<td>30</td>
<td>4</td>
<td>35</td>
<td>Variable 2c</td>
</tr>
<tr>
<td>3</td>
<td>MQC</td>
<td>30</td>
<td>8</td>
<td>56</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>MDW</td>
<td>30</td>
<td>4</td>
<td>90</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>FCC</td>
<td>30</td>
<td>2</td>
<td>31</td>
<td>( \lambda_{max} \leq 1 )</td>
</tr>
</tbody>
</table>

Fig. 2 shows the variation plots of the system BER versus the number of active users of FCC code \( (w=4) \) with various SAC-OCDMA codes such as MDW \( (w=4, \ K=60) \), MFH \( (w=8, \ K=38) \) and Hadamard \( (K=30) \). The percentage number of active users' improvements is 183%, 325%, 347% and 466% as a contrast to MDW \( (w=4, \ K=60) \),...
(w=6, K=40), MFH (w=8, K=38) and Hadamard (K=30), respectively. Hence, SAC-OCDMA coding systems with FCC code can support a higher number of users compared to the systems with MDW (w=4, K=60), (w=6, K=40), MFH (w=8, K=38) and Hadamard (K=30), respectively. This is true even when the FCC code uses the small Hamming-weight equal to w=4 as opposed to w=8 for MFH code.

Fig. 3 shows the plots between the Psr versus BER when the number of active users is 170. The values of Psr varied from -35dBm to -5dBm. Here, we have considered the effects of the shot, PIIN and thermal noises, respectively. From the graph shown that, the FCC code gives better performance with other SAC-OCDMA codes such as MDW (w=4, K=60), (w=6, K=40), MFH (w=8, K=38) and Hadamard (K=30) codes respectively when the effective receive power Psr is large (when Psr > -25dbm). When the Psr for all SAC-OCDMA codes at the lower values (when Psr < -25dbm), the performance of all SAC-OCDMA codes had shown nearly the same. Systems with proposed FCC code can have better received power without any amplifier required.

The performance of the system is simulated using Optisystem simulator software. The systems were tested at the rate of 155Mbps and 622Mbps for 10-70km distance with the ITU-T G.652 standard single mode optical fiber using FCC code (w=2). Attenuation of 0.2 dB/km, dispersion of 18ps/nm-km and nonlinear effects such as four wave mixing and self phase modulation were activated to simulate as closely as industrial specifications. The dark current value is 10nA and the thermal noise coefficient is 1.0 x 10^{-22} W/Hz for each of the photodetectors. Each chip has a spectral width of 0.8nm. Fig. 4 clearly shows that the BER decrease as the fiber length increasing. This can be explained as longer fiber will affect the signal thus provide a large attenuation. Attenuation is basically a transmission loss in optical fibers and it largely determines the maximum transmission distance prior to signal restoration. This is proved, SAC-OCDMA coding system are suitable for LAN and FTTH access network.
Fig. 4: BER versus fiber length of FCC code.

Fig. 5 shows the variation of BER against bit rate utilizing FCC code. The bit rate varied from 155Mbps to 2.5Gbps with different Hamming-weight \( w \). It had shown that as the bit rate increase, BER will decrease. We can ascertain this as when increasing the bit rate the pulse width also will decrease, thus producing sensitive bits signal to dispersion effect. At a fixed distance of 10 km, SAC-OCDMA system running on the FCC code could support bit rates up to 700Mbps (0.7Gbps) very well at BER = 10^{-12} for \( w = 10 \). At 1Gbps though, the bit rate became too fast for the system and was not supported well for all the Hamming-weight values. Taking BER 10^{-9} as the threshold cutoff BER value, the highest bit rate supported was 0.9Gbps for \( w = 10 \).

Fig. 5: BER versus different bit rate for FCC code.

4. Conclusions:

A new class of optical codes for the SAC-OCDMA coding system was proposed. It has been shown that the proposed code performs better than other optical code such as MDW (\( w = 4 \), \( w = 6 \)), MFH (\( w = 8 \)) and Hadamard, respectively. The advantages of the proposed code are: easily in code construction, flexible number of users \( K \), Hamming-weights, \( w \) and can be designed with flexible cross-correlation to have shorter code length. A system with shortest code length, therefore, will increase the transmission efficiency thus produce better performance in the presence of noise. Moreover, in simulated results shown advantages of the proposed code could supports bit rate 0.9Gbps for 10km with Hamming-weight equal to ten (\( w = 10 \)) without required any amplifier at the receiver side to achieve better quality of transmission at BER = 10^{-9}.

REFERENCES


