USER SPREAD OPTICAL INTERLEAVE DIVISION MULTIPLE ACCESS SCHEME (US-OIDMA) FOR HIGH SPEED TRANSMISSION WITH ZERO DISPERSION FIBER

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ABSTRACT

User spread is recent technique which is applied in optical IDMA (O-IDMA) to achieve the high rate transmission with zero dispersion fiber. User spread optical interleave division multiple access is a multiple access scheme which has less inter symbol interference (ISI) and multiple access interference (MAI) as compared to conventional CDMA. US-OIDMA is the combination of CDMA and IDMA. The efficient bandwidth utilization is one of the key aspects for improving the performance of optical fiber based communication system. Therefore US-OIDMA is used in optical fiber mode for high speed transmission with zero dispersion fiber. The performance of US-OIDMA has been evaluated and compared with OIDMA using MATLAB software. It is concluded that US-OIDMA is far better than OIDMA and support more number of users and less bit error rate.

Keywords: user spread OIDMA (US-OIDMA), convolutional code, prime inter-leaver, probability of error (Pₑ).

1. INTRODUCTION

CDMA system is used frequently in wireless communication and it has limitations of multiple access interference (MAI) and inter symbol interference (ISI). Though it has some attractive features like variable channel sharing, better network planning management and avoidance against multiple transmission.

The optical fiber system possesses very attractive bandwidth and low attenuation. It can simplify challenging service such as high quality video transmission. By extending optical fiber to the access network, it is capably stroked to share fibers between different users and there is no need of adding active components in networks.

CDMA is a multiplexed form of DSSS (Direct sequence spread spectrum communication) and having benefits of using enormous bandwidth of DSSS system which is wasted in simple DSSS systems. It can serve large number of users at the same bandwidth with minimum cost and greater security and low probability of interception.

A very motivating methods has been developed by L. Ping [1-3] to combine coding and spreading, and it uses dissimilar inter-leavers to separate users known as Interleave division multiple access (IDMA). The major challenge with CDMA multiple access system is to reduce the ISI and MAI because as number of user increases ISI and MAI also increases and BER increases.

IDMA is the multiple access technique which has low ISI and MAI and support more number of user in wireless communication. The advantage of IDMA can be utilized in optical fiber communication known as OIDMA [4-6]. It deals large band width for larger number of users at minimum cost. Higher capacity optical networks are required to achieve the growth of internet services and new digitized schemes. In order to enhance the performance of OIDMA the user spread OIDMA may be the alternative technique which is known as US-OIDMA.

In conventional IDMA, single spreader is used for spreading different users and different inter-leavers are used for user separation. In IDMA, Each user is encoded by the same spreading code due to this there is so much redundancy is introduced which degrades the speed of transmission. To improve this limitation we use separate spreading codes for each users and then apply the phenomenon of contemporary IDMA for transmission. This new techniques is known as User-Spread IDMA. It helps to mitigate ISI and MAI and also reduces the Probability of bit error (Pₑ).

In this article, the performance of user spread Optical Interleave Division Multiple Access (US-OIDMA) is simulated with MATLAB. In US-OIDMA, low rate convolutional code is used for encoding, PSK modulation technique is used. Avalanche photo diode (APD) is used at the receiver to detect the optical signal and zero dispersion wavelength fiber is used to avoid attenuation. Prime interleaving mechanism is used to separate the use this interleaver mechanism plays better performance as compare to other interleaver mechanism [7-8].

Using the concept and ethics discussed above this paper subdivided in various sections. In the introduction part the ethics and concept of OIDMA is discussed in section 2, US-OIDMA is introduced in section 3. In section 3, block diagram of whole proposed system is shown in Figure. 4 and Figure-5. In the next section 4, simulation results are discussed using Probability of error (Pₑ) and larger number of users. In the last section 5, the whole research work has been concluded and show the further scope.
2. OPTICAL IDMA SYSTEM

In the block diagram of IDMA system is shown in figure 1, having q different users, offering single path of optical window 1550 nm [9-13]. In consequence of q users having shown as \( d_q \). It all q users having converted in code length \( n \), which is assumed to be low rate. Where length of chip is indicated by \( W \).

The chip \( c_q \) is interleaved by a chip level interleaver \( \pi_q \), producing a transmitting chip sequence \( x_q = [x_q(1), x_q(j), ... , x_q(J)] \). After transmitting through the channel, the bits are seen at the receiver side as \( u_q = [u_q(1), u_q(j), ... , u_q(J)] \). The channel opted is additive white Gaussian noise (AWGN) channel, for simulation purpose.

In receiver section, after chip matched filtering, the received signal from the k user can be written as

\[
u(j) = \sum_{q=1}^{q} h_q x_q(j) + n(j), \quad j = 1, 2, ..., J.
\]

Where \( h_q \) the channel coefficient for user-q and \( \{n(j)\} \) are samples of an AWGN process with zero mean and variance \( \sigma^2_n = \sigma_n^2/2 \). we assume that the channel coefficient \( \{h_q\} \) are known a priori at the receiver.

In the receiver side, elementary signal estimator is used for multiple detection. APP and SDEC have variable iterative mechanisms.

The obtained outputs of various components for receiver are based on LLRs. Which is expressed as

\[
e(x_q(j)) = \log \left( \frac{p(x_q(j) = +1)}{p(x_q(j) = -1)} \right)
\]

for all \( q \), and \( j \).

The produced LLR are further classified in two ways, one which is produced by PSE and another which is generated by DEC.

For special case of random interleave mechanism which is based on chip by chip type \( u(j) \)

\[
u(j) = h_q x_q(j) + \rho_q(j)
\]

Where \( \rho_q(j) \) is the distortion (including interference-plus-noise) in \( u(j) \) with respect to user-k.

The concept and ethics involved in CBC has shown in equation 2, the function of ESEB and APP decoders are based on users. The obtained values of LLRS for both SDEC and ESEB are shown in the expression.

\[
e_{SDEC}(x_q(j)) = 2h_q r(j) - E(u(j)) + h q E(x_q(j)) Var(u_j) - \frac{h_q Var(x_q(j))}{2}
\]

2.1 Prime inter-leaver

Though the random inter-leaver is simplest type of interleave but has acquire large memory. So reduce memory space in random inter-leavers a Special type of inter-leaver is invented which is totally based on prime numbers. The proposed prime inter-leaver has capabilities of acquiring lesser bandwidth and consumes least power during data sending [14-15]. It gives better performance as compare to random inter-leaver. The generation number based on seeds, where seeds are only prime number that why it is called prime inter-leaver. The principle involved in generation of user-specific prime inter-leaver is as follows first we decide the seed indicated as P. If we want N bits interleaving using prime seed P. Define N bits on a Galio field \( G[N] \). Seed shows the separation between interleaved bits on \( G[N] \).

For example to understand the phenomena of prime inter-leavers. Let us assume that seed is considered as 5.

Let us assume \( G[N] = \{1, 2, 3, 4, 8, ..., N\} \) For sake to simplicity let \( N = 8 \).

Our aim is to interleave N bits with seed 5 then the generated interleaved bits are as follows.

\[
1 \Rightarrow 1 \\
2 \Rightarrow (1+1x5) \text{mod} 8 \Rightarrow 6 \\
3 \Rightarrow (1+2x5) \text{mod} 8 \Rightarrow 3 \\
4 \Rightarrow (1+3x5) \text{mod} 8 \Rightarrow 8 \\
5 \Rightarrow (1+4x5) \text{mod} 8 \Rightarrow 5 \\
6 \Rightarrow (1+5x5) \text{mod} 8 \Rightarrow 2 \\
7 \Rightarrow (1+6x5) \text{mod} 8 \Rightarrow 7 \\
8 \Rightarrow (1+7x5) \text{mod} 8 \Rightarrow 4
\]

So the generated interleaved sequence for \( G[8] \)

\[
[1, 2, 3, 4, 5, 6, 7, 8] \quad \text{original sequence} \\
[1, 6, 3, 8, 5, 2, 7, 4] \quad \text{interleaved sequence}
\]

The generated interleaved sequence differ each bit by prime length 5.
Applying this logic in hardware, we can seed only the seed value. This curtails a lot of memory space. By using prime inter-leaver the complex structure of random inter-leavers is simplified and which reduce the size, cost as well as power consumption.

2.2. Convolutional coding

Coding is done in communication for reducing errors in the channel and amount of redundancy introduced in data specifies the error detection and correction capabilities of a code. Block codes and convolutional codes are major classification [16-17]. In convolutional each n-bit encoded block not depend only on the k information bit input but it depends on the previous (m-1)q bit information bits. The main difference between convolutional code and block code is that of memory existence in convolutional codes.

A general convolutional encoder is represented like (n, k, m) having m shift register and each register can store k bit information and also v-Ex OR gates are used to generate the encoded output sequence.

![Figure-2. (n, k, m) convolution encoder.](image)

For an example having n=2, n=3, and information bit = 1.

![Figure-3. (2, 1, 3) convolution coder.](image)

2.3. Connection diagram

Let the output of three stage be \( Y_0, Y_1 \) and \( Y_2 \), so the encoded bits are:

\[
\begin{align*}
Z_1 &= Y_0 + Y_2 \\
Z_2 &= Y_0 + Y_1 + Y_2 \\
\end{align*}
\]

This coding is working regularly on every data bit as shift register.

For example let data bit = [1 0 1]

Then the output results will be shown in Table-1.

<table>
<thead>
<tr>
<th>Time</th>
<th>Input</th>
<th>( Y_0 )</th>
<th>( Y_1 )</th>
<th>( Y_2 )</th>
<th>( Z_1 )</th>
<th>( Z_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Output = 11 01 00 11 11 00
Total output = \( z (m + L) \)
= 2 (3+3)
= 12 bits

Polynomial way of presentation, for the same example we can write generator polynomial as

\[
g_1(x) = 1 + y^2 \\
g_2(x) = 1 + y + y^2
\]

The output is also in polynomial form

\[
c(x) = d(x) g_1(x), \text{ joined with } d(x) g_2(x)
\]

so far \( d = (1 0 1) \) data polynomial = \( 1 + y^2 \)

\[
d(x) = (1 + y^2) (1 + y^2) = 1 + y^4
\]

\[
d(x) = (1 + y^2) (1 + y + y^2)
\]

*where “+” denotes the Ex-OR operation.

and writing code by using code polynomial

\[
c(x) = (1.1) + (0.1)x + (0.0)x^2 + (0.1)x^3 + (1.1)x^4
\]

c = [11 01 00 01 11]

Another way of representing convolutional code is state representation and state diagram. We also represent it by making code tree for decoding purpose we are using code tree. From code tree either exhaustive search method or sequential decoding is used. Sometime trellis diagram is an alternative representation of code tree and it makes decoding much simply. We are using distance properties of convolutional codes. A convolutional codes with free distance \( d_{\text{free}} \) can correct l errors if

\[
d_{\text{free}} \geq 2l+1
\]

Since we know that minimum hamming weight of code words represents \( d_{\text{free}} \). This \( d_{\text{free}} \) can be found from
2.4. Maximum likelihood decoding

The convolutional decoder selects ĉ for all equally data sequence.

If \( P(r/ĉ) = \text{Max}_{all\, c_i} P(r/c_i) \)

Where \( r \) and \( c_i \) represents received sequence and all possible transmitted sequence respectively is called maximum likelihood decoding. We define \( P(r/c) \) as likelihood function, which is basically a conditionally probability.

2.5. Viterbi decoding method

Limitation of maximum likelihood decoder is its computational problem. By using Viterbi algorithm we choose short constraint length codes [18-19]. In this decoding, path selected by trellis structure is in such a way that selected path contains minimum distance between received and transmitted sequence. It basically based on minimum hamming distance decoding overlooking the computational complexity by taking special structure in trellis diagram. In the f each four state can be travelled by two states only. By Viterbi algorithm only these path which match the received sequence \( r \) (minimum hamming distance path) must be retained. The retained selected path is name as survivor at that stop. Each branch of every surviving path assigned and its hamming distance from the concerning branch of \( r \). By adding all branch metric produce path metric and received is finally decoded with surviving path having lower metric.

3. US-IDMA SYSTEM

Figure-4 and Figure-5 represents the optical US-IDMA system model. In the transmitter section, the block size of \( N \)-length information bits from each user-\( q \) is coded using a convolutional code. These coded data breast-fed into spreading sequence generator to spread the data. We have developed a general method to generate spreading sequences in its place of repeater in the transmitter of the IDMA system. This spreader structure is not only spreads the information bits but also separates data from the specific users [7-8]. Note that the user’s spreading sequences are random and change energetically from symbol to symbol. We uses shift registers for the spreading sequence. Initially, all shift registers are adjusted with 1. The all 1’s sequence is multiplied by the first coded data. After out-putting the first sequence from the generator, the shift registers shift one bit right direction. This process continues for all data bits. Thus, the spreading sequences are changing energetically according to the user data. This spread data is fed into the user definite inter-leavers (\( π_1, \, π_2, \ldots, \, π_q \)). The resultant signal is then transmitted over the multiple access channel.

The US-IDMA receiver works a chip by chip detection process same as the conventional IDMA system. The received signal is first expected by Elementary Signal Estimators (ESE) and fed into the de-inter-leavers. The de-interleaved data is de-spread and de-coded using a Posteriori Probability (APP) decoder. The process is path iteratively for a given number of iterations. For the de-spreadming, initially we assign the similar spreading sequence (all “1”) for spreading and de-spreadming in the receiver. In the detection process, the spreading and de-spreadming sequences are then providing by the decoded data for each user. The simple multiple access interference and error propagation in the receiver may cause the disspreading sequences to be unequal with spreading sequences. We consider the recovery of the spreading sequence at the receiver lacking a priori knowledge. The received signal strength would conclude the reliability of the recovered spreading sequence and would thus affect bit decisions subsequently. For the error trying of the disspreading sequences, we use genetic search algorithm and Markov chain analysis. These algorithms help to define de-spreadming sequences and update in an optimal manner.

4. RESULT AND DISCUSSIONS

In Figure-6, a graph is plotted between different number of users which is varied between 60 and 200, vs probability of error for two cases that is uncoded OIDMA and uncoded US-OIDMA. The channel parameters are optical fiber having 1513nm wavelength, optical detector APD has the gain 1000 and efficiency 0.85. The whole result is plotted for spread length 16 a data length \( m=512 \).
In Figure-6 the upper graph for OIDMA indicates that probability of bit error ($P_e$) varies from $10^{-7}$ up to $10^{-5}$ as number of users increasing from 60 to 200 While in the same Figure-6, the lower graph is shows the improved performance reducing $P_e$ up to $10^{-8}$ for 60 users. In Figure-7, graph is plotted between number of users vs $P_e$ for convolutional coded OIDMA and US-OIDMA. In this figure same trend is obtained for coded OIDMA but $P_e$ reduced up to $10^{-8}$ for 60 users indicates better performance compare to uncoded OIDMA. In Figure-7 the lower graph implies the same nature of variation of $P_e$ with number of users as observed in uncoded US-OIDMA. By using convolution coding for the same case $P_e$ is much reduces up to approximate $10^{-9}$ as compare to uncoded US-OIDMA case.

5. CONCLUSIONS

The performance of OIDMA and US-OIDMA have been evaluated and shown that BER of US-OIDMA and is superior to OIDMA because ISI and MAI is reduced. It is also concluded that convolutional coding play important role to upgrade the OIDMA and US-OIDMA. As the number of user increases the BER also increases but in case of US-OIDMA, BER is better and can support more number of users. Finally it concluded that US-OIDMA may be used in place of OIDMA and convolutional code may be used for coding.

REFERENCES


