# Performance of Optical Interleave Division Multiple Access Using Convolutional Codes

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*Abstract:* **In this paper, the performance of Optical Interleave Division Multiple Access (OIDMA) using convolution encoding technique is presented. Optimum multiple channel capacity is achievable only when entire bandwidth is devoted to coding. Convolution encoding technique is a low rate encoding technique. For maximizing the coding gain the combination of two operations coding and spreading using low rate codes are done. The graphs between bit error rate (BER) and no of simultaneous users in optical IDMA with convolution encoding technique are plotted by using MATLAB simulation. The implementation of convolution codes in an optical IDMA system provides significant improvement in system performance.**

*Keywords:* **optical IDMA, convolution codes, Viterbi decoding, iterative chip-by-chip (CBC) detection.**

## I. INTRODUCTION

Optical interleave division multiple access technique (optical IDMA) is a recently proposed multiple access technique in optical domain in which different interleaves are used to distinguish users. Optical IDMA uses a low-cost iterative chip-by-chip (CBC) multiuser detection algorithm with complexity independent of the no of users therefore higher number of users can be supported. Multiple access interference (MAI) is one of the major factors for performance degradation in an optical CDMA system [1-4]. Optical IDMA reduces the multiple access interference problems. Optical fiber is used in channel for long distance and high bandwidth. Coding is a technique which provides secure transmission of message through a communication channel. We show that the employments of the convolution codes in optical IDMA systems can remarkably improvement in system performance.

The paper is organized as follows: section II presents the system model of convolution coded Optical interleave Division Multiple Access (Optical IDMA). Section III presents computer based simulation result using MATLAB. Finally we conclude this work in section IV.

## II. SYSTEM MODEL OF CONVOLUTION CODED OPTICAL-IDMA

In this section the system model of convolution encoded with Viterbi decoded Optical IDMA is presented. Upper parts of the system model represent the transmitter structure and lower parts of the system model represent the receiver structure. The path between the transmitter and receiver is optical fiber through which the data are transmitted.

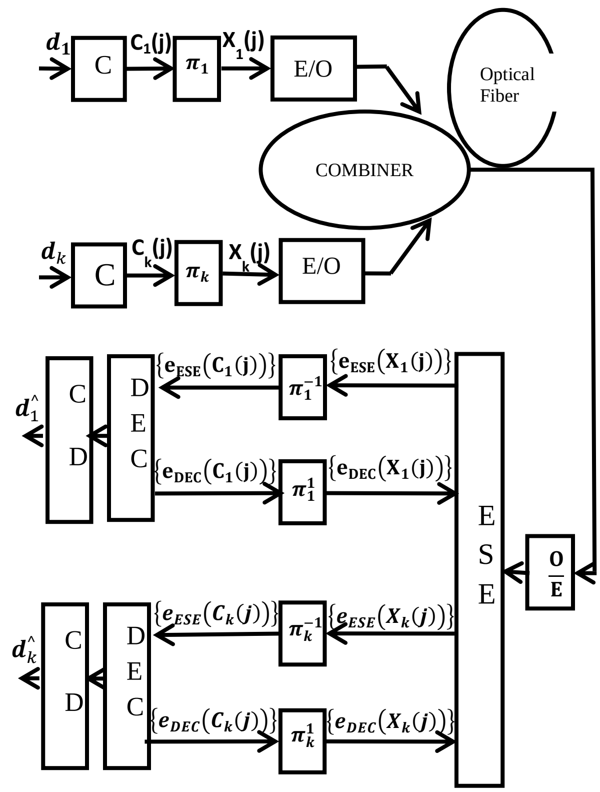


**Fig.1.Transmitter and Receiver structure of Optical IDMA**

### (a) TRANSMITTER MODEL

The upper part of Fig.1 shows the transmitter structure of the Optical IDMA scheme with K no of simultaneous users. The input data sequence $d_k$ of user-K is encoded using convolution encoder which is a low rate encoder C, generating a coded sequence $C_K \equiv [C_K(1), \ldots, C_K(j), \ldots, C_K(J)]^T$ , where J is the frame length. The elements in $C_K$ are referred to as coded bits.

Convolution codes are represented by three parameters n, l, k. where k represents the number of shift registers used in the encoding part [20]. Where l represents the encoder's input. The coded sequence of n bits obtained after encoding not only depends on the k bit information message but also on the previous information bits that is transmitted [21]. In convolution codes decoding is done by using both hard decision method and soft decision method. For constraint length k<5, Viterbi algorithm is used and for k>5 MAP algorithm is used [22]. In this system, convolution encoder and decoder are implemented. Convolution encoder having shift registers (constraint length) k=2 and k=3 having code rate 1/2 and 1/3 is implemented.

Simple convolution encoders are shown in fig.2 and fig.3. in fig.2 constraint length is 2 and adders are 3. The coding rate of this encoder is 1/3 because three adders are used in it. In fig.3 constraint length is 2 and two adders are used in this encoder. Therefore coding rate is 1/2. A bit is shifted into the leftmost stage at each input and the bits previously existing in the shift registers are shifted one position to right. After applying the modulo-2 operation corresponding outputs are obtained. This process is continuing until the arrival of data at the input of encoder. The choice of connection between the shift registers and adders describes the characteristics of code. To describe an encoder, set of "m" connection vectors are required. These vectors have the same dimension as that of k (shift registers).

For encoder shown in Fig.2, we can write the connection vector $G_1$ and $G_2$ and $G_3$ as follows:

$G_1$= [1 0 0] $G_2$= [1 1 0] $G_3$=[1 1 1]

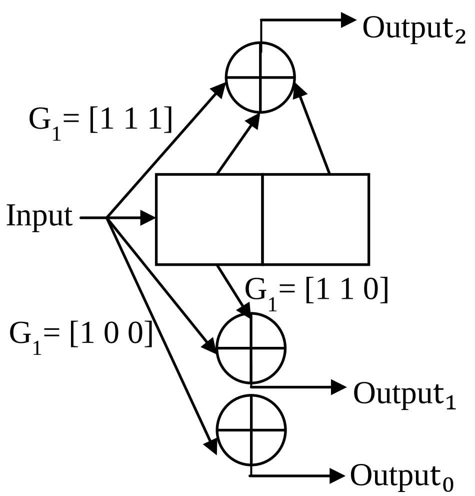


**Fig.2 Convolution Encoder with coding rate 1/3**

For encoder shown in Fig.3, we can write the connection vector $G_1$ and $G_2$ as follows:
$G_1$= [1 0 1] $G_2$= [1 1 1]

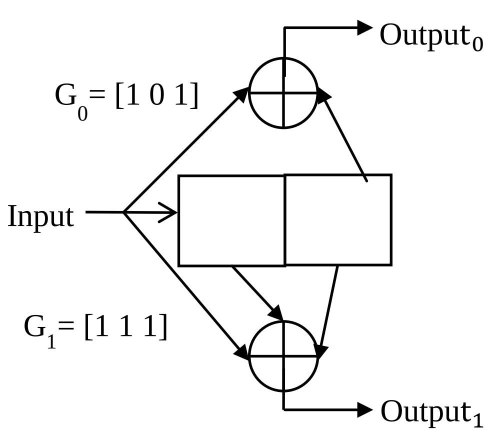


**Fig.3 Convolution Encoder with coding rate 1/2**

The coded sequence $C_K$ is permuted by an interleaver $\{\pi_K\}$ and producing $X_K \equiv [X_K(1),\ldots,X_K(j),\ldots..X_K(J)]^T$. The elements in $X_K$ are referred to as "chips". Here the users are distinguished by the interleavers, hence this multiple access technique is known as interleave-division multiple access (IDMA) technique. In IDMA system user specific interleavers are used means interleavers $\{\pi_K\}$ should be different for different users. We assume that the interleavers are generated independently and randomly. These interleavers disperse the coded sequences so that the adjacent chips are approximately uncorrelated, which facilitates the simple chip-by-chip detection scheme [5]-[8].

**(b) CHANNEL MODEL**

After interleaving, Electrical to Optical converter is used to get the Optical pulses. There are many types of E/O converters available but here we have used mod lock laser as the E/O converter. The electric field of mode locked laser can be written as [14].

$$E_{MLL} = e^{iw_0 t} \sum_{k=0}^{k-1} e^{ik(\Delta w)t} \quad (1)$$

Where k is the number of modes in the mode locked laser, and Δw is the channel spacing between two consecutive modes in the mode locked laser.

Now the output of MLL is modulated with the interleaved data $X_k(j)$ which is usually a simple OOK modulation. Then the transmitted data can be expressed as

$$E_{MLL}X_k(j) = X_k(j)e^{iw_0 t} \sum_{k=0}^{k-1} e^{ik(\Delta w)t} \quad (2)$$

Where $X_k(j) \in (1,0)$

Pulse propagation in nonlinear Optical fiber has been studied widely using nonlinear Schrodinger equation (NLSE). A(z,t) is the slowly varying envelope of an Optical pulse propagating through nonlinear Optical fiber.
NLSE can be written as [11].

$$\frac{\partial A(z,t)}{\partial z} + \beta_1 \frac{\partial A(z,t)}{\partial t} + \beta_2 \frac{\partial A(z,t)}{\partial t^2} = j\gamma A(z,t)^2 A(z,t) - \frac{\alpha}{2} A(z,t) \quad (3)$$

Where $j=\sqrt{-1}$, t is time, $\beta_1$ and $\beta_2$ are the first and second derivatives of the propagation constant respectively, z is the distance along the fiber, $\alpha$ is the attenuation coefficient, and $\gamma$ is the nonlinear coefficient [10]-[12].
The nonlinear Schrodinger equation (NLSE) describing the pulse propagation $A(z,t)$ in an Optical fiber can be summarized as [10]:

$$A_z = (L + N)A \quad (4)$$

This is the nonlinear partial differential equation, where L and N are the linear and nonlinear operators, respectively. To obtain the next solution of the NLSE the Split-Step Fourier method (SSF) is used. The basic idea of Split-Step Fourier method is to split the original problem into sub problems which are simple than the original problem. The properties affecting the system performance are fiber attenuation and dispersion [9].By using split step method the pulse propagation $A(z,t)$ can also be written as [9].

$$A_z = -\frac{\alpha}{2}A - \frac{i\beta}{2}A_n + i\gamma|A|^2A \quad (5)$$

The nonlinear part [16],

$$A_z = e^{\frac{2\pi n_2 I}{A_{eff}}Xdz} \quad (6)$$

Where I=$|signal|^2$
$n_2$ is the nonlinear factor [16].
$A_{eff}$ is the effective cross-section area of the fiber's core.
The linear part can be written as [16].

$$\text{Attenuation}=e^{\frac{\alpha}{2}X\frac{dz}{2}} \quad (7)$$

Where $\alpha$ is the attenuation factor. dz is split-step distance.
The dispersion is expressed as [16].

$$\text{Dispersion}= e^{i\left(\beta_1\frac{w}{2}+\beta_2\frac{w^2}{2}+\beta_3\frac{w^3}{2}\right)X\frac{dz}{2}} \quad (8)$$

For single mode fiber, intermodal or modal dispersion equal to zero ($\beta_1$=0)

$$\beta_2 = \frac{\lambda^2 X D_1}{-2\pi c} \quad (9)$$

$$\beta_3 = \frac{1}{(2\pi c)^2}\left(D_3 + \frac{2D_2}{\lambda_{ref}}\right)\lambda_{ref}^4 \quad (10)$$

Where c is the velocity of light in free space
$D_2$ is the second order dispersion.
$D_3$ is the third order dispersion.

Here split step Fourier method for optical pulse propagation in optical fiber channel and chip-by-chip decoding algorithm for iterative decoding process are employed. Optical fiber operated with 155nm wavelength, bit rate is 1Gbps, transmitted power is 1mW, intensity dependent refractive index parameter is 2.35*$10^{-20}$, responsivity and efficiency are 0.65 and 0.80 has been taken respectively. The input to optical fiber is a Gaussian pulse.

**(c) RECEIVER MODEL**

Lower portion of Fig.1 shows optical IDMA receiver. At the receiver front we used photo detectors (P-I-N or APD avalanche photo detector (APD) device. A photo detector is used to detect the intensity of the received signal [14]. Square law Detection has been considered here for APD[14].

$$\boldsymbol{r}(X_k(j)) = \left|X_k(j)e^{-iw_0t}\sum_{K=0}^{K-1}e^{ik(\Delta w)t}\right|^2 \quad (11)$$

$$\boldsymbol{r}(X_k(j)) = X_k(j)\left|\sum_{K=0}^{K-1}e^{ik(\Delta w)t}\right|^2 \quad (12)$$

If we sample this signal at time $t$ = 0 then the received signal will be $dK^2$ and we can retrieve the transmitted data $X_k(j)$ using a threshold detector. and $\boldsymbol{r}(X_k(j)) \in$ (1,-1).
The output of APD is assumed to be a Gaussian distribution. The probability that a specified number of photons are absorbed from an incident optical field by an APD detector over a chip interval with $T_c$ is given by a Poisson distribution [13]. The average number of absorbed photons over $T_c$ is

$$\lambda_s = \frac{\eta P_w}{hf} \quad (13)$$

Which is the photon absorption rate, $P_w$ is the received laser power, $\eta$ is the APD efficiency, h is the Plank's constant and f is the Optical frequency. After APD, receiver consists of an elementary signal estimator (ESE) and posteriori probability (APP) decoders (DECs) of K users which are independent. [6]-[9].
The output of the ESE and DECs are extrinsic log –likelihood ratios (LLRs) about $\{X_k(j)\}$ and defined as

$$e_{ESE}(X_k(j)) \equiv \log\left(\frac{\Pr(X_k(j))=+1}{\Pr(X_k(j))=-1}\right)\forall k,j \quad (14)$$

$e_{ESE}(X_k(j))$ be the extrinsic a posteriori log-likelihood ratios (LLRs) generated by the DECs of user-K. for K users , we can rewrite equation (11) as

$$r(j) = h_k X_k(j) + \xi_k(j) \quad (15)$$

Where
$\xi_k(j) \equiv r(j) - h_k X_k(j) = \sum_{k'=k} h_{k'} X_{k'}(j) + n(j)$ We list the CBC detection algorithm as follows (with initialization $e_{DEC}(X_k(j)) = 0 \forall k,j)$ [1].

**The CBC algorithm**

$$E(X_k(j)) = \tanh(e_{DEC}(\frac{X_k(j)}{2})) \ \forall k,j \quad (15a)$$

$$Var(X_k(j)) = 1-(E(X_k(j)))^2 \forall k,j \quad (15b)$$

$$E(\xi_k(j))=\sum_{k'=k} h_{k'}E(X_{k'}(j)) \quad \forall k,j \quad (15c)$$

$$Var(\xi_k(j))=\sum_{k'\neq k}|h_{k'}|^2 Var(X_k(j)) + \sigma^2 \ \forall k,j \quad (15d)$$

$$e_{ESE}(X_k(j)) = \frac{2h_k}{Var(\xi_k(j))}(r(j)-E(\xi_k(j)))\forall k,j \quad (15e)$$

After the APP decoding in the DECs is performed to generate the LLRs $\{e_{DEC}(X_k(j)), \forall k,j\}$. Then go back to (15a) for the next iteration [6][9].

After the APP decoding the Viterbi decoding is performed. In this algorithm resemblance between the received symbol and transmitted symbol is measured by hamming distance. Paths which are not suitable for maximum likelihood are rejected by this algorithm. Suppose there is more than one path that emerges from the one particular state, then the state having the lowest path metric is selected and this path is called the surviving path [23]. This process of selecting the surviving path is done for every state. The decoder proceeds in this way deeper into the trellis, assembling results by rejecting the paths having high metric.

## III. SIMULATION RESULT

The Figure 4 and 5 shows BER performance of coded optical IDMA in optical channel with different numbers of simultaneous users. During the simulation, the spreading length is chosen as 16, and the iterative number is set to be 10. The variation is user count has been opted as parameter of performance has been displayed in the figure during performance comparison to OIDMA system. For simulation purpose, the input data for each user is assumed to be same i.e. 512 bits. Optical fiber has been operated with 155nm wavelength with maximum bit rate of 1Gbps capability. The transmitted power is chosen to be 1mW, while intensity dependent refractive index parameter is $2.35*10^{-20}$. The responsively and efficiency is 0.65, 0.80 has been taken respectively. The input to optical fiber is a Gaussian pulse and ON-OFF keying (OOK) is used for pulse transmission. The simulations have been performed using random interleavers.

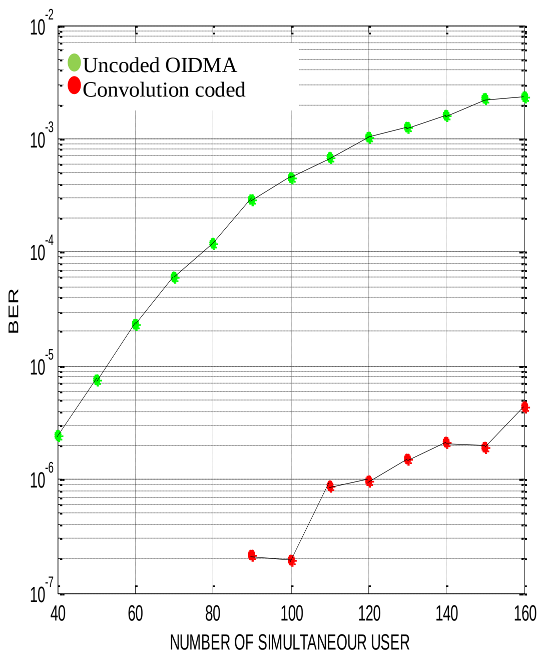


**Fig.4 Performance of Coded OIDMA with data length = 512 & coding rate 1/3**

The BER performance of Coded Optical IDMA system for various users using convolution coding rate is 1/3 are shown in fig.4. and fig.5 shows the BER performance of coded Optical IDMA system for various users using convolution coding rate is 1/2. Fig. 4 shows that in case of uncoded OIDMA the error starts from 40 users where in case of convolution coded Optical IDMA with coding rate 1/3, the error is zero up to 90 users and error stars above 90 users. Moreover in Fig. 5 for convolution coded Optical IDMA with coding rate 1/2, the error is zero up to 100 users and error stars above 100 users. Therefore Fig.4 and fig.5 shows that the convolution coded OIDMA gives the better BER as compared to the uncoded Optical IDMA and the coding rate is also important. Hence Convolution coded Optical IDMA support the more number of simultaneous users as compared to the uncoded Optical IDMA.

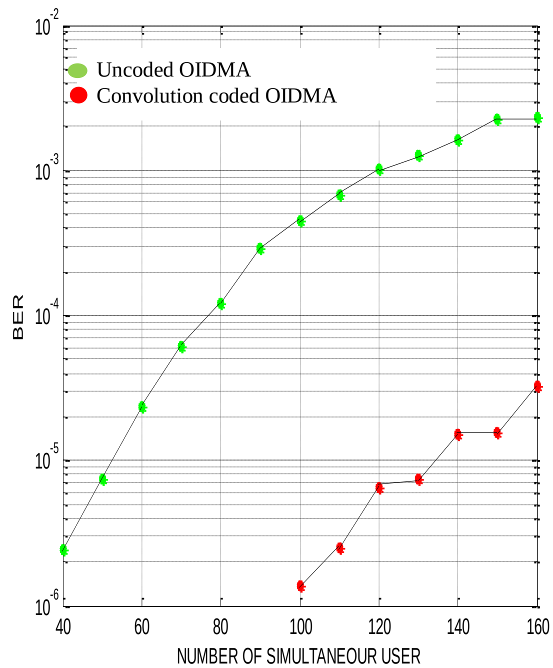


**Fig.5 Performance of Coded OIDMA with data length=512 & coding rate 1/2**

## IV. CONCLUSION

In this paper first we discuss the importance of the OIDMA system and explain the role of interleavers and then we have proposed the model of convolution coded Optical IDMA and analyzed its BER performance using MATLAB. The proposed system has better BER and can support the more no of user as compared to the uncoded optical IDMA. By using convolutional encoder the performance of OIDMA system is improved. In Convolutional encoder the coding rate is an important parameter and using suitable coding rate for a particular OIDMA system the performance can be improved.

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