Design and performance of a new 2D-OCDMA system using plastic optical fiber

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In this paper a study of a newly developed two- dimension optical code division multiple access (2D-OCDMA) code transmission named Time Hopping Odd Double Weight (THODW) using plastic optical fiber (POF) is proposed. The unique properties of POF have attracted attention for its potential to be used in transmitting signals within homes or buildings. The convenience of using POF with OCDMA systems is its compatibility with OCDMA codes used in constructing multi-user transmission systems, or control systems with different commands. POF can be used as a replacement for copper wires and conventional optical systems currently used for high-speed data transmission within the premises of a house or building. System implementation uses THODW, which emphasizes the unique properties of low bandwidth consumption, zero cross correlation, and simple encoder/decoder design as an advantage for using the OCDMA system in POF fibers. The system used BER as a validation factor, and two code weights are used in the study under different transmission rates. Results showed that using POF for indoor OCDMA transmission is valid, efficient and reaches up to 200 meters with a BER of 10^{-9}.

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1. Introduction

Optical communication systems development is progressing very fast. New devices, codes, and methods are continually being developed to fill the bandwidth demand which has grown over the last decade [1-3].

Wavelength Division Multiplexing (WDM) communication systems were proposed and implemented commercially decades ago. However, these historic systems have become updated with newer communications developments, and are unable to cope with the current bandwidth and transmission speed demands. Many methods and systems have been proposed and developed in order to overcome deficiencies in the infrastructure. One system of note is Optical CDMA [4-7]. OCDMA is a multiplexing technique developed to resolve many issues faced in WDM communication systems [8], such as security, band limitation, and asynchronous access [9, 10].

In a cost control development environment, the need for a reliable, flexible, and durable communication system is essential [11,12]. An optical fiber communication system provides this, however optical systems are yet to achieve all of the aforementioned conditions. On the other hand Plastic Optical Fiber (POF) development is promising with lighter, more reliable transmission medium, although it is yet to achieve the ultimate conditions for widespread usage [13-20]. Nevertheless, within some limited applications POF transmissions are currently possible [17, 18, 21-23].

THODW is a newly-developed, derived two-dimensional code proposed to overcome some of the OCDMA limitations such as large bandwidth consumption and multiple access interference [24]. This paper presents a THODW code design and performance study using plastic optical fiber based on an optical CDMA network. This paper is organized as follows: THODW construction is described in Section II; The simulation experiment setup parameters and the system design is in Section III; Performance study and comparisons (including all of the results and graphs related to this study) are presented in Section IV; Finally, Section V contains the conclusion of the Study.

2. THODW construction

THODW code is a combination of two domains: Spectral amplitude and time. Spectral amplitude represents the core of the code matrix construction, while the second dimension (time) is hopping for each user. The main advantages of THODW are the design and implementation simplicity and cost efficiency. In order to achieve design simplicity 1D-code Double weight (DW) [25, 26] with Odd numbers [8, 27, 28] is used as a core for THODW code generation. This is achieved by using odd numbers for basic code matrix generation and affecting each channel with temporal variance. The final result is 2D code [24].

A. Odd Base Matrix construction

The base matrix construction can be achieved by using equation (1) [29-31];

$$Bm_{n\ Final}=\sum_{j=1}^{Na} Bm[n,j] = Bm[j,j] \quad (1)$$

The final odd weight code matrix construction is carried out by using equation (2 and 3);

1- First shift

For first row

$$\text{a.} \quad \sum_{i=1}^{s} X(1,i) = y(W,i) \quad (2)$$

For the rest rows

$$\text{b.} \quad \sum_{i=1}^{s} \quad \sum_{j=1}^{W-1} X(j+1,i) = y(j,i) \quad (3)$$

2- Repeating step (1) (a) and (b) for second shift i.e[30].

X=Bm, Y=X

Next shift

X_{next}=the result from the previews shift operation, y= X_{next}

Fig. 1 shows the 1D-Odd DW construction matrix.

	A		B		D	
Users	C1	C2	C3	C4	C5	C6
1	**1**	0	**1**	**1**	0	0
2	**1**	**1**	0	0	**1**	0
3	0	0	**1**	0	**1**	**1**

Fig. 1. Odd DW code with W=3.

B. Temporal hopping for each user

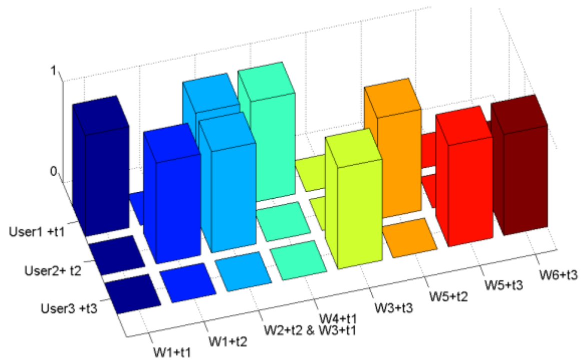

Fig. 2. THODW code constructions.

Fig. 2 shows the final shape of the THODW code matrix. The construction is carried out by applying temporal hops for each channel. Therefore, t1 is applied on channel 1, t2 and t3 are applied on channel 2 and 3 respectively. Consequently, each channel will keep the same wavelength shifted in time. From Fig. 2, the Y-axis represents the time delay applied for each channel, and the X-axis represents each of the channel chips. In the case of User 1 at W2 and User 2 at W3 there seems to be overlapping, but actually there is none since the wavelengths are different and under different time slots. As a result of the code matrix each channel will have all of the chips free with no overlapping, hence the conclusion that THODW code has zero cross correlation.

3. Simulation experiment Setup

The simulation experiment designed to study the performance of the THODW code for different bit rate transmissions is shown in Fig. 3. Each chip has a spectral width of 0.2nm. The tests are carried out at the rate of 622 Mbps and 1.25 Gbps for the two weights, W=3, and W=5. The input transmitting power is fixed at 10 dBm.

According to Koike [15], the attenuation of Low-Loss Grade Indexed Polymer Optical Fiber (GI-POF) is between 100-120 dBm/km for 1.5 µm wavelength. In our experiment we set the attenuation to 120 dBm/km [32, 33].

The performance of the system is characterized by referring to the bit error rate and the eye patterns.

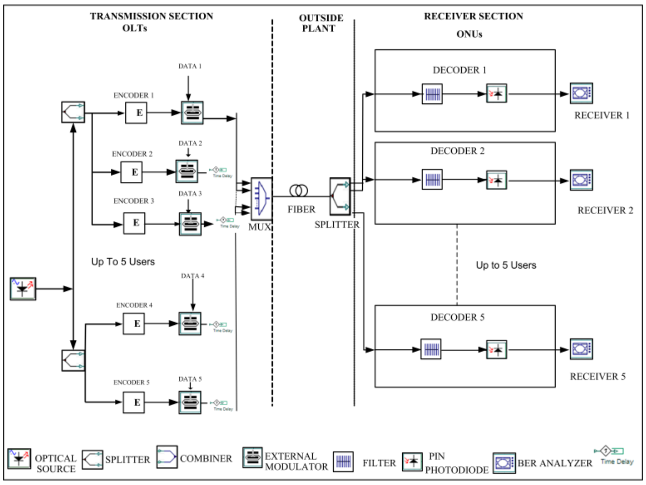

Fig. 3. THODW W=5 System Network.

Fig. 3 shows the system network configuration for the basic code matrix W=5. In this setup, each channel is encoded with the code matrix wavelength (i.e. user wavelengths). The time delay component is attached to each user subsequent to all encoded wavelengths to ensure all wavelengths have the same delay. Of note, User 1 did not require any delay component since the delay there is zero. The delay is added for each of the encoded user wavelengths to ensure the 2nd dimension is imposed on the code matrix. The delay amount and period, however, are variable and depend on the code weight, design, and properties of the system. In our case the delay was 0.2 nano second. At the receiver side, a direct detection technique is used to detect each user wavelength, and subsequently extract data [29, 34].

4. Results and discussion

THODW code allows the signal to transmit for a longer distance due to zero cross correlation as well as signal spread by the 2nd dimension time delay. The high attenuation and dispersion in POF is associated with a disrupted signal and serious deformation to the signal shape. However the zero cross correlation property of the system minimizes the effect of multiple access interference MAI and crosstalk. As a result, the system was able to receive acceptable signal power at distances up to 200 meters from the transmitter.

The eye pattern diagrams for User 1 at (1.25 Gbps), (2.5 Gbps), and at (622 Mbps) for 2D code W=3 and 5 are shown in Fig. 4. System configurations were fixed at a distance of 120m, transmission power of 10dBm, and attenuation of 120 dBm/km.

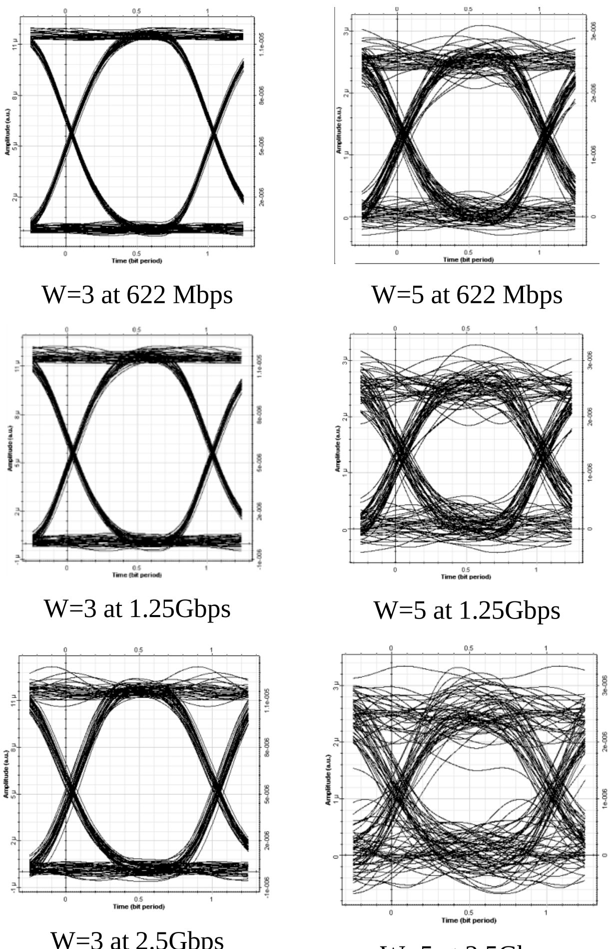

Fig. 4. Eye diagram for W=3 and 5 for a distance of 120m.

Fig. 4 clearly shows that the performance drops when the code weight becomes higher, and the transmission speed is higher. POF properties and Koike experiments suggested that 200 meters is the maximum acceptable range to transmit data safely for the system parameters listed above.

For single mode fiber, the number of wavelengths transmitted in POF or any optical fiber cable will affect the signal performance. This is clear in Fig. 4, where the transmitted data with code weight W=3 shows better eye opening, and less deformed signals compared to the W=5 signal data.

The performance comparison between THODW W=3 and W=5 under three transmission bit rate is shown in Fig. 5.

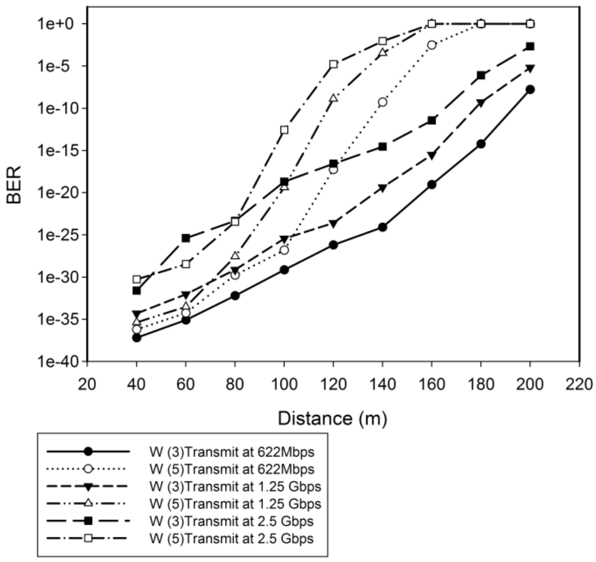

Fig. 5. THODW W=3 and W=5 at 622Mbps, 1.25Gbps, and 2.5 Gbps.

Fig. 5 shows the performance comparison of THODW under three transmission bit rates for W=3 and W=5. The simulation experiment showed that the maximum lengths to achieve with BER = $\sim 10^{-9}$ for W=3 under 622 Mbps is 198m, 185m at 1.25 Gbps, and 165m at 2.5 Gbps. The maximum length to achieve BER = $\sim 10^{-9}$ for W=5 under 622 Mbps is 135m, 120m for 1.25 Gbps, and 105 m at 2.5Gbps.

The rapid drop in performance is due to the high dispersion of POF, and is even faster when there are more users involved. Eventually, as in any OCDMA system, there is no escape from MAI, crosstalk, and other types of noise. Therefore, more crosstalk and insertion loss is produced when the code weight is higher. Additionally the thermal noise effect cannot be ignored in POF and it will affect the overall performance of the system.

The performance of the code under three transmission bit rates indicates the superiority of W=3 over W=5. It should be noted that W(5) performed well enough to transmit across distances of over 100m of POF. It is clear that this code is suitable for use in a POF-based system. Under these criteria, it is likely that various applications can use POF technology as an effective alternative medium, particularly in situations where harsh environmental challenges compromise communications equipment integrity.

Incorporation of the POF-based system with the usage of an OCDMA as a control system is possible. The OCDMA control system can be achieved by setting one user as data bus and the other user as control bus. Alternatively, since this code is considered to be a zero cross correlation code, and therefore does not suffer from overlapped data effect, the data bus and control bus can be distributed within one user code array, and the separation will be at the detection section using direct or other detection techniques.

5. Conclusion

A discussion for THODW construction is shown in this paper. The performance of the newly proposed code, system design, setup, and comparison of multiple weights at different transmission bit rates are discussed thoroughly. The supporting graphs and diagrams disclose the tremendous performance of THODW code using POF as its medium. Due to the properties of optical communications systems and materials, this system can be considered as an option for building inexpensive, efficient communication or control systems that are resistant to harsh environmental conditions.

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