Design of a Hybrid WDMA-Optical-CDMA over Multi-Mode Fiber Transmission System based on LG Modes for Short Haul-Local Area Network

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Abstract. Various optical communication technologies use Optical-Code Division Multiple Access (Optical-CDMA) as a channel access technique, which allows transmission of different users simultaneously over the optical communication channel. Therefore, Optical-CDMA permits free undue interference transmission of several users. Whereas Wavelength-division multiple access (WDMA) is a technique that can be implemented on how the optical channel can be divided into subchannels. This paper proposes a Hybrid WDMA-Optical-CDMA over multi-mode fiber (MMF) transmission system for short haul-local area network. The WDMA system is carried out by using four Laguerre-Gaussian (LG) modes that operate over four main wavelengths (1551 nm, 1550 nm, 1549 nm and 1548 nm). Additionally, the Optical-CDMA system is carried out by using one dimension Zero Cross-Correlation (ZCC) code to overcome multiple access interference (MAI) between the four ZCC codes. The performance of our system is evaluated based on eye diagrams, Q-Factor and bit-error rates (BER) measurements. Keywords: WDMA, Optical-CDMA, multi-mode fiber, zero cross correlation, Laguerre-Gaussian.

1. Introduction

Over the last decades, different communication systems have been developed, where the primary objectives of the new forms of the systems are to increase the data rate, improve the transmission reliability by improving the transmission distance between the stations [1-3]. Furthermore, recent advancement in communication technology and the reliability of information exchange has supported and motivated better communication systems in society and economy [4]. These improvements further signaled remarkable development in wired, wireless, and optical fiber communication systems [5-7].

Mainly, an optical fiber is considered as one of the most integral constituents of current networking architectures [5, 8-12]. In the fiber-optic network, there are several types of fiber based on the core
diameter. Specifically, the one with a small core diameter known as single-mode fiber (SMF) and the other type with a bigger core diameter known as multi-mode fiber (MMF). MMF differs from the SMF by its core diameter, which makes MMF able to have more modes propagating through this core [13]. Furthermore, MMF is mainly used for short-range optical fiber networks [14]. The existing infrastructure for local area networks (LANs) widely uses MMF due to their easy handling and relatively good performance over short distance [1].

Contrary to the on-going misconception, optical fiber communication networks that accessing fiber links like bend-tapping are not secure and experiences the same security threats as wireless communication. Additionally, it poses challenges to network providers who due to similarities in sensitivities and vulnerabilities [15]. In order to increase information security (e.g., in military applications) code division multiple access (CDMA) was developed as a spread spectrum technique. CDMA has been used widely in wireless telecommunications in the late 1970s. The main use of this technique was in the fields of satellite communication, which has made an impressive contribution to the field of international communication. Additionally, it was used in wireless communication as well, such as mobile communication technologies [16].

Optical code division multiple access (Optical-CDMA) has a more powerful function and was built for optical access networks (LAN and WAN) [17-19]. The optical-CDMA scheme usually performs code multiplexing and transmissions for the large bandwidth of fiber optic [20]. Furthermore, in optical communication systems, Optical-CDMA encodes/decodes data using passive optical components that are simple and cost-effective to perform multiplexing and networking of optical signals. Moreover, Optical-CDMA has many advantages, such as providing multiple rates with good compatibility along with WDMA, flexible networking, and providing some privacy of transmission information [21, 22]. To fulfill the rapid increase in data traffic, optical fiber communication systems significantly require large transmission capacity. For this purpose, WDMA and optical-CDMA multiplexing transmissions have been widely recognized as one of the most demanded spatial multiplexing techniques in recent times. Therefore, in this paper, we propose a Hybrid WDMA and Optical-CDMA (WDMA-Optical-CDMA) for transferring high bandwidth over MMF and increasing the capacity in fiber optic [23-25].

The rest of this paper is structured as follows. Section 2 describes the design of Hybrid WDMA-Optical-CDMA over MMF. Section 3 evaluates our system and discusses the obtained results. Finally, Section 5 concludes the paper.

2. HYBRID WDMA-OPTICAL-CDMA SYSTEM

Fig 1 illustrates the structure of Hybrid WDMA-Optical-CDMA over the MMF transmission system. The system is simulated using opti-system [26] software. The system comprises of three parts: 1) optical transmitter; 2) fiber link; and 3) optical receiver. Specifically, the transmitter section consists of five components: laser, encoding, data generator, return-to-zero (NRZ) pulse generator, and Modulator. The first component is four spatial lasers (continuous-wave laser) with 0 dBm of input power is used for generating four Laguerre-Gaussian (LG) modes such as (LG 0 1, LG 0 2, LG 0 3, and LG 0 4) (see Fig 1).

The modes operate over four wavelengths (1551 nm, 1550 nm, 1549 nm and 1548 nm). Whereas, the second component is one dimension Zero cross-correlation (ZCC) code used for four users (see Fig 2). One of the most considerations in developing and implementing optical-CDMA systems is coding. It is worth mentioning that the ZCC code has been designed to reduce (multiple access interference) MAI.
Fig. 1: The architecture of the Hybrid WDM-OCDMA system.

In the Optical-CDMA system, phase induced intensity noise (PIIN) is strongly related to MAI because of overlapping spectra from different users [27, 28]. In the literature, Matrix $K \times L$ is used to present the 1D-ZCC code, where $K$ represents the number of users, and $L$ represents the elements that are written as the code lengths. To amplitude code the source spectrum, the unipolar sequences are used and expressed as the code-word. These sequences are complemented according to the transmitted signal and corresponded to the rows of $K$. The following equations represent the methods of generating a family of ZCC, $K$ (the number of active users) and generate a set of minimum length:

$$K = w + 1$$  \hfill (1)

$$L = w(w + 1)$$  \hfill (2)

where the matrix is generated as follow with the basic ZCC code:

$$ZCC(w + 1) = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$  \hfill (3)

According to the following map, the increase in the number of users has occurred:

$$ZCC(w = 2) = \begin{bmatrix} Z_1 & 0 \\ 0 & Z_2 \end{bmatrix}$$  \hfill (4)

Finally, the following represents the unit code matrix for this code in ZCC codes for 4 users.

$$ZCC(w = 2) = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \end{bmatrix}$$  \hfill (5)

Turning back to the transmitter components, in the third component, the input signal is generated using four pseudo-random binary sequence (PRBS) from the data generator at 2.488 Gbps. Whereas, the fourth component is an NRZ generating signal sequence. The last component in the transmitter parts is Mach-Zehnder Modulator and the multiplexing (which multiplexes four WDMA signal
channels). As mentioned earlier, the second part of the transmitter is fiber optic link (i.e., MMF), where the maximum distance link is 6 km with a 50 nm core radius and 0.25 dB-Km attenuation. Finally, the third section is the receivers where the incoming signal from MMF go through the following: 1) De-multiplexing signal into four channels and four decoders; 2) Photo-detector PIN used to perform conversion from optical to electrical domain; 3) a filter which is Low Pass Bessel Filter (LPBF); and 4) analyzer.

3. RESULT AND DISCUSSION

In this section, we explain the outcomes of simulating hybrid WDMA-Optical-CDMA over MMF carried out by using four LG modes operate over four wavelengths (1551 nm, 1550 nm, 1549 nm and 1548 nm) and four 1D-ZCC code. The performance of the system is evaluated based on improving eye diagrams, Q-Factor and BER. The performance of the hybrid system has analyzed after distance 6 Km MMF using eye pattern as displayed on eye diagram visualizer for (LG 01, LG 02, LG 03 and LG 04) for (User 1, User 2, User 3 and User 4), respectively. As shown in Fig 3, the acceptable range of Q-factor and BER are (7.05161 and 8.83016e-13), (6.70978 and 9.70609e-13), (8.96813 and 1.50772e-19), and (7.72984 and 5.36038e-19) for the four modes, respectively.

As illustrated in Fig 4, the second performance measurement, our system was based on BER and obtained over different distances starting from 1 Km to 8 Km. In the distance 6 Km, the system achieved acceptable BER results for all users. In contrast, the outcomes of BER in other distances (except 6 Km) are not acceptable for transmission. Similar to BER outcomes
The last evaluation was carried to calculate the Q-Factor of our system over different distances starting from 1 Km to 8 Km (see Fig 5). Similar to BER outcomes, in the distances 6 Km, the system obtained acceptable Q-Factor results. By contrast, unacceptable measurements are obtained on rest distances.

**Fig. 4: BER results of four users over different distances.**

**Fig. 5: Q-factor results of four users over different distances.**

**4. CONCLUSION**

Hybrid Optical-CDMA over WDMA based on MMF link is an intriguing technique due to various characteristics, such as asynchronous access, flexible bandwidth, the flexibility of installation and implementation, low-cost, ability to support multimedia mode services. In this paper, a hybrid system has successfully transmitted ZCC codes based on different LG modes operated through four wavelengths (1551 nm, 1550 nm, 1549 nm and 1548 nm). The performance evaluation demonstrated a successful transmission data over 6 Km MMF link with acceptable eye diagrams, Q-Factor and BER

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