Performance Analysis of ZCC-Optical-CDMA over SMF for Fiber-To-The-Home Access Network

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Abstract. To provide a sustainable fiber-to-the-home (FTTH), several multiplexing techniques have been developed for this purpose. The correlation features are the main obstacle behind the network performance limitation, which imposes a high level of multiple access interference. However, the development of multiplexing techniques helps to overcome these limitations, such as optical-code division multiple access (Optical-CDMA). Optical-CDMA is considered as one of the most powerful solutions for FTTH. This paper aims to enhance FTTH network performance by applying Zero cross-correlation code (ZCC) with Optical-CDMA with maximum link single-mode fiber. In the simulation, the system performance is demonstrated in terms of bit error rate, Q-Factor and eye diagram measurements.

1. Introduction

Every now and then new developments in fiber optic made the use for fiber optics usage possible to transmit media in modern communication systems [1, 2]. Communication over optical fiber has been preferred over the other transmission media because of its characteristics, such as low attenuation, high security and bandwidth, etc. [3]. With fiber-optic infrastructure, the world has been given endless digital opportunities, such as video games, automated houses, and vehicles, etc. However, all these opportunities started with a light, which was the driving force for building the infrastructure for electricity. Consequently, this led to creating a fundamental change for the coming generations. In this respect, there is a need for fiber optic to make all the devices to be connected and communicate with each other. Eventually, this connection is known as fiber-to-the-home (FTTH).
In the literature, a significant amount of effort has been devoted to developing the advanced techniques aimed to enable optical transmission with higher capacity. Various advanced modulation and multiplexing schemes have been studied by scholars to increase the channel capacity within a limited bandwidth, and to improve the spectrum efficiency of the optical systems [4-6]. The developments of the optical system have improved the transmission rates from 1 Gb/s to 10 Gb/s, and then to 100 Gb/s. The super-channel has also been demonstrated recently for Tb/s transport. With the popularity of the coherent technique, along with the high-order modulation, wavelength-division multiple access (WDMA) and time-division multiple access (TDMA) and other approaches, transmission rate over 100 Gb/s have become commercially available [5, 7-10].

However, the optical transmission systems are always faced with the challenges of achieving a higher channel capacity to cope with the fast expansion of traffic demand. Therefore, to improve the capacity for current and future demands, many techniques have been proposed as one of the most promising techniques is Optical-Code Division Multiple Access (Optical-CDMA). In this respect, there is a need for high bandwidth, capacity and data rate to cope with computer and Internet traffic expansion. In order to meet these demands, there are a number of requirements needed to be met, including high transmission rates, simple configurations, random traffic arrival accommodations, asynchronous, and high user number support. Additionally, meet other essential factors, such as secure, reliable, compatible, and enormous bandwidth [11].

These demands motivate researchers to come up with new approaches in advanced optical communication technology via Optical-CDMA [12]. Coding technique operates as the addresses represented by a unique code assigned by users [13]. The assigned code is unique so it can match the code in the receiver side if the sent code is matched at the receiver that’s mean the receiver can listen to the transmission when the code doesn’t match. Consequently, this means the transmission cannot be listened by the receiver. In Optical-CDMA technique, only the objective receiver has the ability to listen to the transmission [14]. The codes, which been used as addresses, are acquired from some code family. These codes have been designed to meet some requirements such as cross-correlation, off-peak, auto-correlation, code weight, and code length so as to achieve the desired data rate by the developed system[15].

Fiber optics have been deployed robustly by network providers in the access network to satisfy the bandwidth need. In order to provide fast connections, the subscribers need to be as close as they can to the optical fiber. To achieve this close relationship between the optical fiber and the subscriber, FTTH is considered as one of the most promising technologies (for a long-term objective). When the users are absolutely got the service they desire by optical fibers, the bandwidth can be increased in the future [16]. Furthermore, FTTH is considered as a promising future solution that can provide broadband services, such as TV and video on demand. Basically, there are two kinds of FTTH as follows:

1. The first type is responsible for comprising the comprise the electrically powered equipment, which also known as active optical networking (AON) including a router or a switch aggregator.
2. The other type uses passive splitters to distribute signals to the subscribers this type is known as passive optical networking (PON), which do not use a powered switch on the FTTH core network.

In optical access network links between optical network units (ONU) and/or optical network terminator (ONT) where the traditional PON consider as emerging for optical fiber networks.
While the connection between optical line terminal (OLT) and ONU or ONT has been performed by the passive optical splitter (POS). Whereas, the primary function of the optical distribution network (ODN) is to arrange the connection between the OLT and the users. The OLT broadcasts settings from services nodes to all ONU or ONT. This process can be done using ODN by wavelength multiplexing technique varied from with 1.55 um to 1.31 um in the downstream and upstream direction using SMF. Additionally, the main function of ONU is to receive the data from OLT such as video, audio, and other kinds of data and deliver it to the end-users.

The remainder of the paper is structured as follows. Section 2 introduces to the system model. The results of FTTH: Optical-CDMA is presented and discussed in Section 3. Finally, Section 4 concludes this paper.

2. System model

As shown in Figures 1 and 2, FTTH network architecture based on Optical-CDMA system has been simulated and designed using opti-system software [1, 2, 4, 17, 18]. The physical layer system (Optical-CDMA) is illustrated through three parts: 1) transmitter section, which is a central office; 2) fiber link; and 3) receiver section, which is the customer premises. In the transmitter section, an OLT for each user basically has five elements namely: Pseudo-random bit sequence (PRBS) (which is data generators), the function is to generate a PRBS base on different process modes features of random data, while the Non-return-to-zero (NRZ) is responsible for generating NRZ coded signal, Laser (LED), and finally the main function of the encoder regenerate the source based on a specific code which can be used based on Zero cross-correlation (ZCC).

In Optical-CDMA systems, coding is one of the most important parts to be considered in the design. ZCC code is designed to meet the need to reduce MAI because of the overlapping between different users and consequently suppressed MAI [19, 20]. The ZCC code can be simply explained using a matrix K × L. Where K row represents the number of the users, while L element is the code length. The unipolar orders are used to amplitude code, while the source spectrum is known as the code-word. These orders correspond to the rows of K, and according to the transmitted signal, these orders are complemented.

![Figure 1. FTTH architecture based on ZCC-Optical-CDMA.](image-url)
In order to denote a group of ZCC based on the given values of $K$ and $w$, there is a set of minimum length zero matrices needed to be generated. For three users, when the weight is equal to two, the output unit code matrix for this code can be represented as follows:

$$P_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

While the code matrix for the above code is written as follows:

$$A^2_3 = [P_1 : P_1]$$

As a result, the mandatory three codes are the three rows of the $A^2_3$ matrix. Here, $w=2$, $K=3$, $L=6$,

$$A = P_k = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} K \times K$$

$$A = P_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} K \times K$$

$$A^2_3 = [P_k : P_k] = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 \end{bmatrix} K \times L$$

When the calculated weight equals to $w = 2$, based on that the Matrix $A$ will be $[P_k : P_k] k \times k$. Moreover, the modulators, which are used to control the amplitude, are Mach-Zehnder modulators. Here, the input modes are splits into two modes interferometer arms. Then, the signals that arrive from the transmitter will be merged by power combiner and travel straight into a single fiber. Furthermore, every single chip has a spectral width of 0.8 nm, and the system was performed at the rate of 622 Mbps for each user optical fiber link section. In the system, we used SMF transmission with 0.25 dB-Km attenuation at 1550 nm wavelength up to 60 km distance. In this system, the power splitter is used to representing the branches to the drop part on an ONU.

Furthermore, at the receiver side, it can be clearly seen that it displays the devices at the client sites. The received signal basically splits into three users, and each user composes into five essential components as follows:

1) SMF.
2) Decoder.
3) Photo-detector PIN used to perform the conversion from optical to electrical domain.
4) A filter which is Low Pass Bessel Filter (LPBF).
5) BER analyzer.
3. Results and Discussion

The discussion of the results begins with modeling three users of ZCC code in Optical-CDMA over SMF in Opt-system simulation. This study records the results are significant through improving the Eye Diagram, BER and Q-factor. The performance of the system is analyzed after 60 Km SMF distance using eye pattern as displayed on eye diagram visualizer for channels (users) one, two, and three. As shown in Figure 3, the outcomes of the users demonstrated an acceptable BER and Q-factor as (1.06E-9, 5.976), (1.04E-10, 6.343) and (6.89E-12, 6.764), respectively.

![Figure 2. Simulation setup of data transmission of ZCC-Optical-CDMA.](image)

**Figure 2.** Simulation setup of data transmission of ZCC-Optical-CDMA.

In the second experiments, we evaluated the BER over different distances of SMF for each user. As shown in Figure 4, at the distances 10, 20 and 30 km we achieved the results (7.91E-24, 4.06E-22, and 3.62E-26), (3.80E-23, 1.84E-21, and 1.05E-25) and (1.20E-21, 2.53E-20, and 2.33E-24), respectively. Whereas at the distances 40, 50 and 60 we got (6.55E-19, 4.30E-18, and 1.17E-21), (1.10E-14, 7.73E-15, and 2.39E-17) and (1.06E-09, 1.04E-10, and 6.19E-12),

![Figure 3. The eye diagram, Q-Factor and BER of the users.](image)

**Figure 3.** The eye diagram, Q-Factor and BER of the users.
respectively. Finally, the acceptable BER has achieved at a distance 70 km as (1.34E-05, 1.00E-06, and 6.44E-07).

Figure 4. BER result of three users over different distances.

Lastly, the performance of the system is evaluated based on Q-factors over different distances (10, 20, 30, 40, 50, 60 and 70 km) of SMF for the users. As depicted in Figure 5), the Q factor revealed an accepted value in the distances from 10 to 60 km. Very briefly, At the distances 10, 20 and 30 km, the results are (7.94156, 9.54153, and 10.4643), (9.79003, 9.38963, and 10.3682) and (9.4443, 9.0824, and 10.0758), respectively. Additionally, at the distances 40, 50 and 60, Q-factor changed to (8.77266, 8.55658, 9.45689), (7.620, 7.66058, and 8.37064) and (5.97602, 6.34346, and 6.76426). However, the result is not acceptable at 70 km where Q-factor dropped to (4.19375, 4.74932, and 4.83663).

Figure 5. Q-factors of three users over different distances.

4. Conclusion
In this study, we proposed an FTTH performance enhancement using the Optical-CDMA technique in terms of increasing system capacity and data rate. To improve the system, we conducted the design and analysis of ZCC code in Optical-CDMA over SMF as transmission media for FTTH networks. The ZCC- OCDMA over SMF is applied in Opti-system and has evaluated the performance based on the metrics measurement (eye diagrams, Q-Factor, and
BER). The outcomes demonstrated that the ZCC code in Optical-CDMA for FTTH can transmit data until 60 Km SMF.

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