A Mathematical Interpretation and Simulations for the 2-D Prime/OOC coding in Long Reach OCDM Access Network

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Abstract:

In this article, the concept of long reach passive optical network (LR-PON) is discussed in the opening section. A number of access techniques are available but OCDMA technology is proposed for this network. There are many OCDMA coding schemes. Among these, a 2-D Prime/OOC code family is selected for encoding and decoding in the LR-PON on the grounds of its cardinality and good performance. This combination is simulated with two users to prove the feasibility of this scheme. The simulation is done for 100 km without any dispersion compensating arrangements. Results establish that this is a viable setup and can be deployed in the future access networks for cost efficiency and improved performance

Key Words: Optical Code Division Multiple Access Network (OCDMA), Long Reach Passive Optical Network (LR-PON), 2-D coding, Optical Orthogonal Codes (OOCs).

I. INTRODUCTION

Wide scale deployment of fiber to the home (FTTH) at the breakneck speed is the latest phenomenon in the access network and it is developing a new type of passive optical network (PON) that is beyond 20 km, called long-reach (LR) PON [1-2]. This is flourishing due to the large bandwidth demands in access network [3].

There are a number of optical access technologies used in LR-PON from TDM to WDM to hybrid of TDM with other technologies. Among these, OCDM is considered as a potential candidate for future access network because it has some advantages over other access solutions. It promises to fulfill the rising demands of higher bandwidth and to provide spectrally efficient access networks [4].

By combining OCDMA with long reach access network, a better and cost-effective solution can be developed for last mile section. When both of these are blended, it can produce a viable network solution that will have cost efficiency and enhanced performance.

There are various coding schemes used in OCDMA networks. Since 2-D codes have higher cardinality as compared to 1-D codes, these will be used in the networks having larger number of users. One of these 2-D codes is prime/OOC code. It uses OOC code in the time domain and prime coding is done for wavelength domain.

In this paper, LR-PON along with OCDMA is simulated. Section II gives a brief overview of LR-PON. After that, 2-D OCDMA code Prime/OOC OCDMA is discussed in section III. Simulation set up is described in section IV. In the last section of this article, results have been analyzed and performance of LR-PON OCDMA network is evaluated.

II. Long Reach PON (LR-PON)

A general LR-PON architecture consists of an enlarged shared optical fiber linking the central office (CO) and the local user exchange, and optical splitter connecting subscribers to the fiber. The basic idea of LR-PON is to enhance the reach of the network and reduce the switching nodes. This causes a much simpler architecture and produces a hierarchy of telecom networks. A consolidation of access and metro networks [5-6] is achieved in long reach networks as illustrated in fig. 1. LR-PON reduces both network capital expenditure (CapEx) and operating cost (OpEx) [7].

LR-PONs have usually larger split ratios. This results in the reduction of the cost of the equipment because optical components are shared by

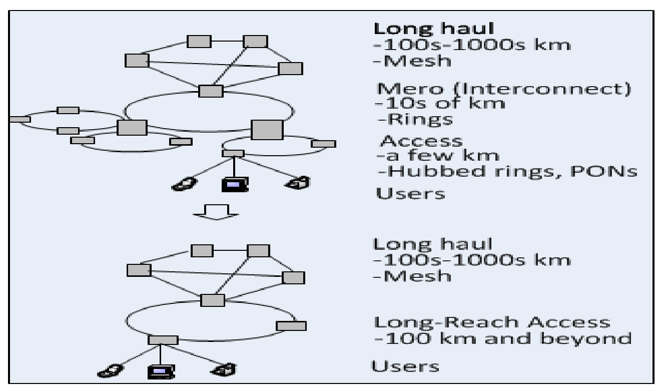

Fig. 1 Simplified Long-Reach PON

each subscriber among customers. Thus the cost of the equipment for each subscriber is reduced.

As per ITU-T standardization, Gigabit PON (GPON) is designed for 60 km distance between Optical Line Terminal (OLT) and farthest Optical Network Unit (ONU) with maximum 1:64 split ratio [8]. To further increase the link reach and coverage of OLT, optical amplifiers are to be used in GPON. Researchers in 1990s were also interested in the idea of extending the reach via intermediate optical amplifiers [9]. However, the maximum reach of Dense-Wavelength-Division-Multiplexed-Passive-Optical-Network (DWDM-PON) is limited due to chromatic dispersion [10-11]. It can be mitigated by using several dispersion compensating measures such as applying optical single sideband with carrier (OSSB+C) modulation, an optical carrier suppression modulation, Chirped Fiber Bragg Gratings (FBG) [12], and Dispersion Compensation Fiber (DCF) [13]. In recent years Fiber Bragg Gratings (FBGs) [14] and Dispersion Compensation Fiber (DCF) have been identified as effective remedies for minimizing the effects of chromatic dispersion and improving the bit error rates (BER) [15].

In this proposed simulation, no any such dispersion compensation techniques have been applied. Only power boosting component EDFA is used.

Now the 2-D selected for this simulation is briefly described in the following section to give a theoretical understanding.

III. 2-D Codes in OCDMA

In OCDMA, coding is done on signal by using time domain, frequency domain or combination of both. Besides, space and polarization are also two another dimensions used for OCDMA coding. The later set of dimension is used when 3-D are required to be developed.

In 1-D code, only one aspect is used to encrypt the data. Like time spreading or frequency hopping. Their coding and construction is simple. But 1-D codes have many problems. Their cardinality is low and can sustain only limited number of simultaneous users equivalent to their cardinality. Secondly, if the codes use frequency spreading, then the no. of subscribers is in direct proportion to the length of code or in other words related to the frequency spreading. When the number of subscribers grows, multiuser interference also accumulates. Therefore the bit error rate also increases forcing the system to reduce the number of simultaneously communicating subscribers.

To overcome these shortcomings, many 2-D code families have been developed in the past for time spreading and wavelength hopping dimensions [16], [17]. Other dimensions space and polarization are also used to formulate 2-D and 3-D codes.

A 2-D code is represented by ($m\times n$, w, λ_a, λ_c). $m\times n$ is a two dimensional matrix consisting of rows and columns and m represents the number of wavelengths and n is number of time chips. It is also equal to the cod length. w is the weight of the code, λ_a is the autocorrelation and λ_c is the cross-correlation as defined below.

$$\sum_{i=0}^{m-1}\sum_{j=0}^{n-1} x_{i,j}x_{i,j\oplus\tau} = \leqslant \lambda_a \quad (1)$$

$$\sum_{i=0}^{m-1}\sum_{j=0}^{n-1} x_{i,j}y_{i,j\oplus\tau} = \leqslant \lambda_c \quad (2)$$

Where x ε {0,1}, τ is the chip duration ($0 \le \tau \le$ n-1) and ⊕ stands for modulo-n addition.

2-D codes also suffer from the same problem of low cardinality. Therefore there is always a need for new codes and new code families with good properties and having large cardinality in order to cater to a large number of simultaneous users. The desired codes should have the lowest cross-correlation in order to eliminate MAI.

Now let us discuss a new 2-D code family. This code family, based on wavelength-time was introduced in prime / OOC [18] with particular aim to increase the cardinality of the code. In order to increase the number of codes of a code family, cross-correlation was increased from 1 to 2. For this purpose, (n, w, λ_a, 2) was used. This increased cardinality can be useful in the applications where broadband services are offered with different data rates. Construction details of this code family can be found in the above reference. For time spreading, OOC is applied and in the wavelength domain, prime codes are used.

Cardinality of any OCDMA code can be defined by Φ(n, w, λ_a , λ_c). For 1-D OOC, cardinality can be optimized as given in equation 3.

$$\Phi_{(n,w,1,2)OOC} = \begin{cases} \dfrac{n-1}{w}, & for\ odd\ w \\ \dfrac{n-1}{w-1}, & for\ even\ w \end{cases} \quad (3)$$

For OOC (n, w, 2, 1), cardinality can be approximated by the relation (4):

$$\Phi_{(n,w,2,1)OOC} = \begin{cases} \dfrac{2(n-1)}{w^2-1}, & for\ odd\ w \\ \dfrac{2(n-1)}{w^2}, & for\ even\ w \end{cases} \quad (4)$$

To complete the comparison, cardinality of OOC (n, w, 1,1) is given in eq. 5

$$\Phi_{(n,w,1,1)OOC} = \frac{n-1}{w(w-1)} \quad (5)$$

From these three relations, it can be verified that the cardinality of OOC (n ,w, 1, 2) is the highest.

Now we will discuss prime codes that are widely used in OCDMA.

For prime codes, cardinality is p^2. The cardinality of the 2-D Prime/OOC code can be defined as $\phi_{(n,\, w,\, 1,\, 2)} \times p^2$.

The performance of prime code in terms probability of error at various values of prime number can be determined by the relation (6)

$$P_b = \frac{1}{2}\sum_{i=Th}^{N-1}\binom{N-1}{i}\left(\frac{p}{2p^2}\right)^i\left(1-\frac{p}{2p^2}\right)^{N-1-i} \quad (6)$$

Here p is the prime number and N is the number of simultaneous users. Th represents the threshold value. Performance curves for different values of p are given in figure 2.

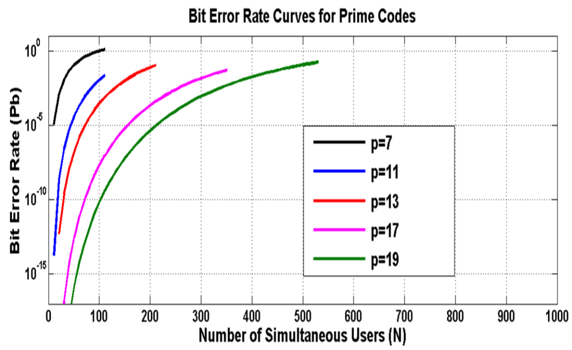

Fig. 2 Performance curves of Prime code

Figure 2 displays the behavior of prime codes. When you increase the prime number, the performance increases and the code can support increased number of simultaneously active users.

If the value of prime number is increased, thereby increasing the length of code, bit error rates falls. It means that with lengthy codes, OCDMA network will provide a better performance. Besides long codes will have lower cross-correlation and therefore are suitable for application where MAI is high and needs to be reduced. However, lengthy codes result in increased complexity for the network.

IV. Simulation Setup

In this simulation, 2-D OCDMA encoding and decoding is done. For the encoding in time spreading (13, 4, 1, 2) OOC code is used and for wavelength hopping, prime code having *p* equal to 7 is used. It means that no. of wavelengths is seven but code weight is four. Therefore four wavelengths will be used for encoding.

Two codes have been used in this simulation for two users: Code for user one is λ_1 λ_2 0 λ_3 0 0 0 0 0 λ_4 0 0 0 and for second user is λ_3 λ_5 0 λ_0 0 0 0 0 0 λ_2 0 0 0. As it can be seen, there are two common wavelengths between the two codes. Therefore cross-correlation of this coding scheme is 2. The reason for high value of cross-correlation is to enlarge the coding set. Optical orthogonal coding is done in time

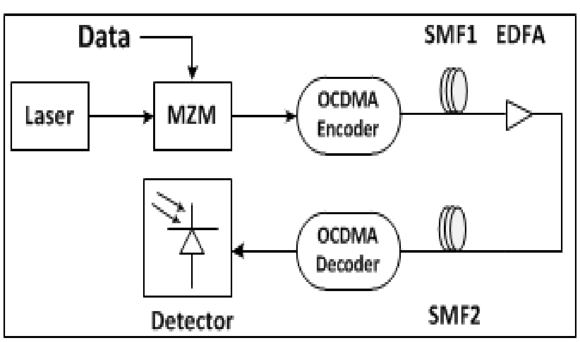

Fig. 3 Simulation setup for OCDMA LR-PON

domain. For the encoding in time domain, optical fiber delay line (FODL) is used. Since FODL can only support high data rates of 1 Gb/s at maximum, therefore data rate is limited to 1 Gb/s. For wavelength hopping and encoding, FBG filters are utilized with spectral width of 0.8 nm. A series combination of FBG is used to get the desired reflected spectral components constituting the 2-D code. Since there are 4 marks in the code set, 4 FBGs are added serially in the simulation to encode the signal.

Table 1 Parameters used in OCDMA LR-PON simulation

Parameter	Value
SMF Length	100 km
Dispersion of SMF	16.75 ps/nm/km
Attenuation Coefficient of SMF	0.2 dB/km
Non Linear index-coefficient of SMF	2.6×10^{-20} m^2/W
Responsivity of Photo detector	1 A/W
Dark current of photo detector	10 nA
Spectral width	0.8 nm
Data Rate	1 Gb/s
Noise Figure (NF) of EDFA	4 dB

To extend the reach of the OCDMA network from conventional 20 km to very high distance of 100 km, an optical amplifier is used to boost the sagging power in between two sections of the fibers as shown in figure 3.

For the transmitter and receiver side, simple OOK modulation format is employed to keep simulated environment less complicated. The broadband sources for both users have zero powers. At the receiver side, direct detection is done.

Parameters used in this simulation are summarized in table-1.

V. Results and Analysis

Results of the simulation are presented here in the form of BER curve against the received power detected by the photodiodes. Both users have same

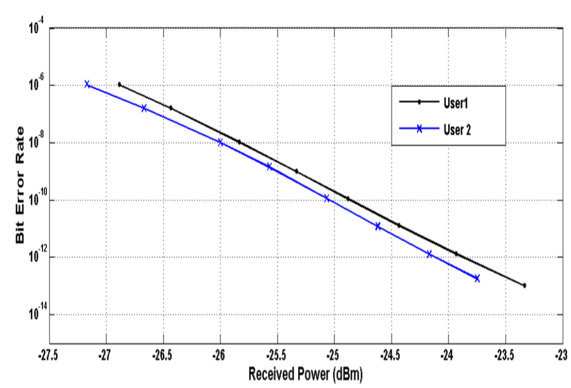

Fig. 4 BER diagram for two users

BER characteristics. At BER 10^{-9}, received optical power is around -25 dBm. Second user

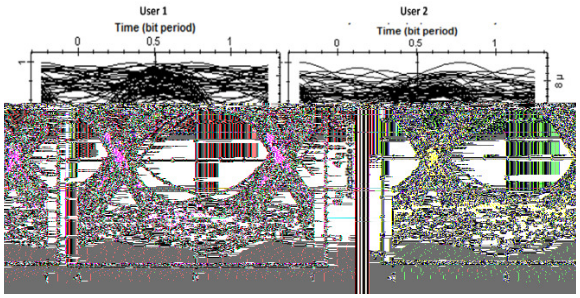

Fig. 5 Eye diagram of two users

exhibits better power sensitivity as compared to first one. In fig. 5 eye diagrams of the two users are given. Eyes are clear and wide open reflecting a fault free transmission. Figure 6 displays the eye diagram of both users when codes mapped on these are reversed. It proves that the codes can interchangeably be applied without degrading the system performance.

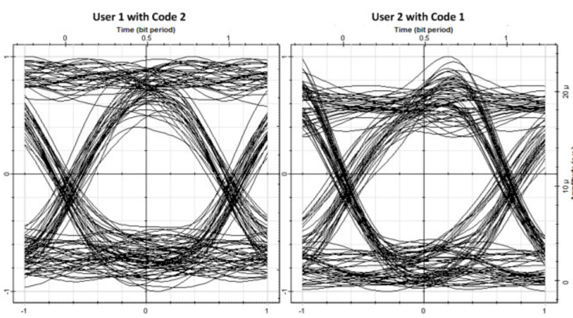

Fig. 6 Eye diagram of users with Codes reversed

These diagrams establish that upto 100 km OCDMA network can be extended without deteriorating transmission.

It is therefore concluded here that an OCDMA network can be applied in the last mile section for longer distances to extend the telecom services in the far flung areas in the cost efficient and spectrally efficient schemes. This simulation affirms the viability of this combination of OCDMA with LR-PON.

VI. Conclusion

In this paper, the concept of long reach passive optical network (LR-PON) is discussed in the opening section. A number of access techniques is available but OCDMA technology is proposed for this network. There are many OCDMA coding schemes. Among these, a 2-D Prime/OOC code family is selected for encoding and decoding in the LR-PON on the grounds of its cardinality and good performance. This combination was simulated with two users to prove the feasibility of this scheme. The simulation was done for 100 km without any dispersion compensating arrangements. Results assert that this is a viable setup and can be deployed in the future access networks for cost efficiency and improved performance.

VII. References

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Quotations

- Memory is the mother of all wisdom
  Aeschylus

- Memory is a net; one finds it full of fish when he takes it from the brook, but a dozen miles of water have run through it without sticking.
  Oliver Wendell Holmes, Sr.

- Better by far that you should forget and smile than that you should remember and be sad.
  Christina Rossetti

- Obstinacy is the result of the will forcing itself into the place of the intellect.
  Arthur Schopenhauer

- Smallness of mind is the cause of stubbornness, and we do not credit readily what is beyond our view.
  Francois de La Rochefoucauld

- Opinion is ultimately determined by the feelings, and not by the intellect.
  Herbert Spencer

- Prejudice is an opinion without judgment.
  Voltaire

- Give every man thine ear, but few thy voice.
  William Shakespeare

- Prejudice is the chains forged by ignorance to keep men apart.
  Marguerite, Countess of Blesington

- The ignorant are always prejudiced and the prejudiced are always ignorant.
  Charles Victor Roman

- Minds are like, parachutes: they only function when open.
  Thomas R. Dewar

- Prejudice is the child of ignorance.
  William Hazlitt

- Knowing your own darkness is the best method for dealing with the darkness of other people.
  CarlJung

- Work and love – these are the basics. Without them, there is neurosis.
  Theodore Reik