

Performance Evaluation of Spectral Amplitude Codes for OCDMA PON

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Abstract- In this paper, we present a performance evaluation of three codes; enhanced double weight (EDW), random diagonal (RD) and zero cross correlation (ZCC) for 10 Gb/s x 4 user, 20 km standard SMF transmission link for OCDMA PON. These SAC codes have ideal in-phase cross-correlation properties to reduce the MAI effects in OCDMA. The performance has been characterized through received optical power (ROP) sensitivity and dispersion tolerance assessments. The numerical results show that the ZCC code has a slightly better performance compared to the other two codes for the ROP and similar behavior against the dispersion tolerance. In the analysis we also consider the character of the code properties and the flexibility as criteria for OCDMA PON network instead of the performance.

Index Terms- optical code division multiple access (OCDMA), spectral amplitude coding (SAC), passive optical network (PON), multiple access interference (MAI)

I. INTRODUCTION

Spread spectrum communication in the form of code division multiple access (CDMA) offered large advantages to the wireless communication industry in the 1970s [1] in terms of cellular telephony network, global positioning system (GPS), etc. The success of this technique has also motivated interest for applications in optical communication networks. There are six main categories of the coding schemes: pulse amplitude coding (PAC) based on incoherent processing (i.e., summing of optical intensity) with fiber optical delay lines and incoherent optical sources, pulse phase coding (PPC) which utilize the optical fields by using phase modulator within fiber optic delay lines for introducing 0° or 180° phase shift to pulses in a code sequence, spectral amplitude coding (SAC) and spectral phase coding (SPC), relies on the wavelength domain and the spectral coding is performed by passing spectral components of the pulse through a phase or amplitude mask, and the coded spectral components are finally recombined by another grating to form a code sequence, spatial coding (SC) require the use of multiple fibers or multicore fibers with two-dimensional (2D) optical codes in the time and space domain simultaneously and wavelength time coding (WTC) require 2D coding in the time and wavelength domains [2-3]. These coding schemes for optical code division multiple access (OCDMA) can grouped into two broad categories, which are coherent and incoherent OCDMA systems [2]. In a coherent OCDMA system, a given user's code is generally generated via phase modulation of the pulses

in the encoding and decoding processes, whereas an incoherent OCDMA system typically relies on optical amplitude modulation and decoding is based on power summation rather than manipulation of field quantities. For coherent and incoherent OCDMA systems, bipolar and unipolar codes are respectively designed and applied in the network. Typically, incoherent OCDMA system architectures employ wideband incoherent sources, such as a broadband amplified spontaneous emission (ASE) source, while other incoherent architectures employ coherent laser sources as part of their implementation. Incoherent schemes use the simpler, more standard techniques of intensity modulation with direct detection (IM/DD) while coherent schemes are based on the modulation and detection of the optical phase [4]. Incoherent spectral amplitude coding SAC-OCDMA systems were chosen because it requires lower complexity (especially for synchronization) than the coherent system [5].

OCDMA is a promising approach for passive optical networks (PON) [6-7]. We consider the application of a SAC scheme in the PON environment; such systems offer an excellent ability to eliminate multiple access interference (MAI) [8]. Several codes for SAC have recently been proposed, including double weight (DW), modified double weight (MDW) [9] and enhanced double weight (EDW) [10]; mainly with the goal to overcome the limitations of non-orthogonality, reduced number of supported users and poor bit error rate (BER) performance [11]. The proposal of new SAC codes in [12-14] analyzed their performances in comparison with ordinary codes, for instance, to Hadamard [11] and modified frequency hopping (MFH) codes [15], which have high cross-correlation value and complexity in the code properties. However no comprehensive performance comparison has been made for the new arising codes in OCDMA PON.

Another primary goal that has to be considered in OCDMA systems is the data extraction by a user in the presence of other users in other words, the presence of multiple access interference (MAI). At the receiver, all the codewords from different users are correlated. If a correct codeword arrives, an autocorrelation function with a high peak results is archived. MAI was generated when the incorrect codewords arrives at the receiver. MAI can be reduced by using subtraction technique. The most common subtraction technique is the complementary subtraction or balanced detection technique [2,15]. The AND subtraction technique [16] were purpose to reduce the receiver complexity and at the same time to

improve the system performance. Currently, spectral direct detection (SDD) technique [12-14] were applied and shown successfully to eliminate MAI as only the desired spectral chips in the optical domain will be filtered. Subsequently, phase-induced intensity noise (PIIN) is suppressed at the receiver, and the system performance is improved.

In the following we describe the SAC-OCDMA passive optical networks (PON) architecture and the codes construction complexity in section II. In section III, we give an overview of the simulation setup. Section IV presents the performance comparison numerical results of EDW, RD and ZCC codes. Finally, section V gives some brief concluding remarks.

II. SPECTRAL AMPLITUDE CODING OCDMA PON

A. Principles of SAC-OCDMA PON

Spectral amplitude coding (SAC) is one of the coding schemes that has been introduced in the early 1990's [2]. In the SAC scheme, an incoherent broadband optical signal source (BOSS), such as light emitting diode (LED) or amplified spontaneous emission (ASE) source is preferable, due to their cost effectiveness [2,12]. A typical application of OCDMA PON is presented in Fig. 1. The figure shows that in OCDMA systems, each user is assigned with a unique code that serves as its address. The encoder and decoder consists of fiber Bragg gratings (FBGs) that act as optical filters to define the spectral chips for a given code. In the OCDMA-PON network, data is encoded into optical codes by the encoder at the transmitter, and multiple users share the same medium by using the power combiner and splitter. At the receiver side, only the user with the correct matched filter will recognize the signals. The data is recovered by electrical thresholding.

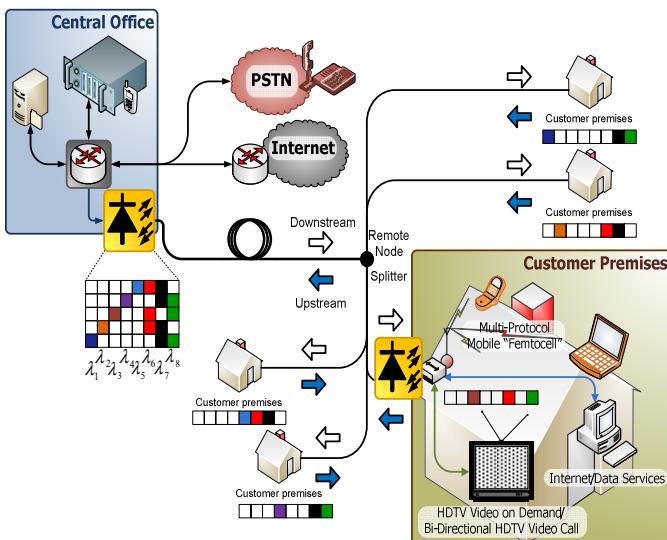


Fig. 1. Overview of OCDMA-PON system architecture

In general, OCDMA-PONs have several advantages such as easy scalability, fair division of bandwidths among users,

differentiated service provision at the physical layer, the asynchronous access capability, etc [17-18] that have attracted attention of the researcher community. Asynchronous downstream OCDMA transmission does not require timing coordination because the signal and interference are received with random overlapping. The effect of random overlapping is taking care by most codes designs that keep the cross-correlation (λ_c) as minimum as possible. In contrast to synchronous transmission, proper timing coordination, to carefully avoid overlaps between signal and interference [19] is required, with the trade-off that it increases the transmission efficiency [20]. Due to possible different distances of the optical network units (ONUs) to the remote node, near-far attenuation difference issue arises [21-22]. To overcome the near-far problem, measures such as optical power leveling [21] and power control [23] was introduced in OCDMA.

B. OCDMA codes complexity

Recently, a number of conventional codes have been modified or developed for enhancing the performance of OCDMA [6-12]. An OCDMA code is represented in the form of (N, W, λ_c) , where N is the code length, W is the weight of the code (the number of "1" inside the code sequence), and λ_c denotes the maximum cross-correlation value between any two code sequences (number of spectral overlapping in the sequence). Codes with ideal in-phase cross-correlation ($\lambda_c \leq 1$) are desirable in OCDMA systems [8] since these codes can reduce MAI. Another key factor is that increasing the weight necessarily increases the signal power of the users. This gives a better signal to noise ratio (SNR). But if the code length is too long, it is considered disadvantageous in implementation since either very wide band sources or very narrow filter bandwidths are required.

TABLE I
COMPARISON OF SEVERAL OCDMA CODES FOR 30 USERS

No	Codes	Number of user (K)	Weight (W)	Code Length (N)	Cross-correlation (λ_c)
1	OOC	30	4	364	≤ 1
2	Prime Code	30	31	961	≤ 2
3	MFH Code	30	7	42	$= 1$
4	Hadamard	30	16	32	≥ 1
5	MDW Code	30	4	90	$= 1$
6	EDW Code	30	3	60	$= 1$
7	RD Code	30	4 / 3	35 / 33	≥ 1
8	ZCC Code	30	4 / 3	120 / 90	$= 0$

Table I summarizes the three important elements in code properties for 30 users. From the table, the first four are the ordinary codes that already be mentioned before. There are

significant limitations associated with these ordinary codes, including high complexity because it's dependant on code weight (eg. Optical orthogonal code (OOC) and MFH code) [2,15]. The larger the code weight can increase the complexity and also lead to high power losses at encoder/decoder. For Hadamard and Prime codes [2, 11], the large cross-correlation value results in intensify the MAI effects, too long code lengths (eg. OOC and MFH) needs a broader spectrum, and fixed weight (eg. MDW and EDW) doesn't give a flexibility to the customers. Although these new SAC codes are not perfect but they do overcome some problems RD code for example, have shorter code length. RD and ZCC codes also have an advantage in flexibility to increase the weight. Therefore, for comparison purposes we will examine three codes: enhancement double weight (EDW) [10], zero cross-correlation (ZCC) [13], and a random diagonal (RD) code [14] because these new SAC codes never being compared before. The code structures for four users used in our simulations are shown in Table II – IV. The table also shows the code length for the three codes. The code length for EDW is 10, RD is 7 and ZCC is 12 respectively.

TABLE II
EDW CODE STRUCTURE FOR 4 USERS

Wave-length	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_9	λ_{10}
User 1	0	0	0	0	0	0	1	1	0	1
User 2	0	0	0	0	0	1	0	0	1	1
User 3	0	0	0	0	1	1	0	1	0	0
User 4	1	1	0	1	0	0	0	0	0	0

TABLE III
RD CODE STRUCTURE FOR 4 USERS

Wave-length	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7
User 1	0	0	0	1	1	1	0
User 2	0	0	1	0	0	1	1
User 3	0	1	0	0	1	0	1
User 4	1	0	0	0	1	1	0

TABLE IV
ZCC CODE STRUCTURE FOR 4 USERS

Wave-length	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_9	λ_{10}	λ_{11}	λ_{12}
User 1	0	0	0	0	0	0	0	1	0	1	0	1
User 2	0	0	0	1	0	1	0	0	0	0	1	0
User 3	0	1	0	0	1	0	0	0	1	0	0	0
User 4	1	0	1	0	0	0	1	0	0	0	0	0

III. SIMULATION SETUP

The simulation was performed using the VPI 8.3 software tool. In our computer simulations we considered only four users to observe the code behavior in the network and reduce the required simulation time. As the number of users increase so does the effect of MAI, this factor is under current investigation. The code weights are fixed to three for all codes at 10 Gb/s bit rates. A simple schematic diagram of the simulation setup is illustrated in Fig. 2. The model is represented by three sections: transmitter section, link section and receiver section.

The transmitter section, which represents the central office consists of five components: pulse pattern generator (PPG), non-return-zero (NRZ) pulse generators, single broadband optical source: ASE, FBGs and external modulators. The pulse pattern generator (PPG) transmits a pseudo-random bit sequence of length 2^7-1 bits by using on-off keying (OOK) modulation. The time window is set to 256 μ s and the sampling rate is 5120 GHz. The function of the FBG is to encode the source according to the specific code or wavelength that is intended to the user. One unique encoded spectrum represents one channel. The modulators are Mach-Zehnder modulators. The signals that coming from the transmitter will be combined and launched into a single fibre. At the fibre link section, we assessed a PON of length 20 km, implementing ITU-T G.652 standard single mode fibre (SMF). Fibre attenuation was set to 0.2 dB/km, a chromatic dispersion parameter 16 ps/nm-km was used, and nonlinear effects were activated in our simulation model. The polarization mode dispersion (PMD) coefficient is set to 0.1 ps/ $\sqrt{\text{km}}$. In this network, the splitter splits the branches of PON to the receiver.

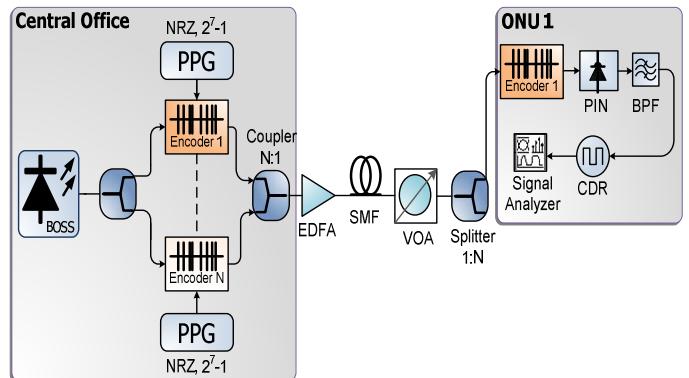


Fig. 2. Simulation setup for OCDMA-PON system architecture

At the receiver, Fig. 2 shows the equipment of the optical network unit (ONU) at the customer premises. The incoming signal is decoded by the FBG. The decoder has its own matched filtering frequency to recover the signal. The dark current value is set at 5nA and the thermal noise coefficient is 1.8×10^{-23} W/Hz for each of the photo-detectors. The clock data recovery (CDR) is used to recovered the intended signal. The

performance of the system was characterized by assessing the sensitivity of bit error rate (BER) at 10^{-9} against received optical power (ROP) and dispersion tolerance assessment with spectral direct detection (SDD) technique.

IV. RESULTS

The BER back to back (B2B) and after 20 km transmission of EDW, RD and ZCC codes is plotted in Fig. 3. The sensitivity at BER of 10^{-9} for EDW, RD and ZCC for B2B are -23.2 dBm, -23.25 dBm and -24 dBm respectively. A 0.75 dB difference in B2B receiver sensitivity is observed between RD and ZCC. This improvement is attributed to the ZCC code structure, which the design properties does not have overlapping chips between the users which directly reduces MAI effects. In OCDMA system, PIIN is strongly related to MAI due to the overlapping spectra of different users. In this aspect ZCC code has an advantage because of the suppression of PIIN in non-overlapping code structures. After 20 km transmission using single mode fiber (SMF), a 0.2 dB transmission penalty was measured for ZCC code compared to 0.15 dB for RD and 0.1 dB for EDW codes. The result shows that the codes still give a good performance after 20 km transmission compared with B2B by using a single ASE source.

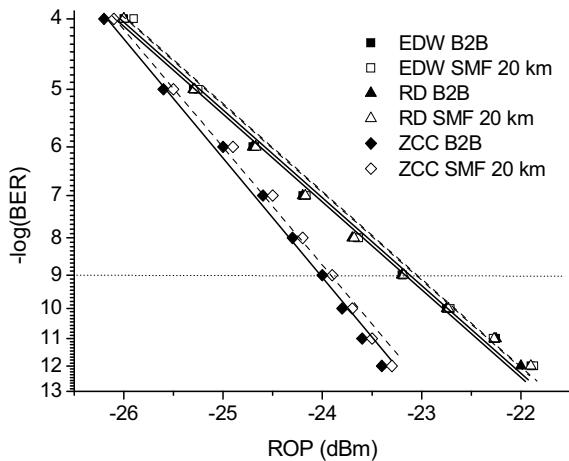


Fig. 3. BER plot for EDW, RD and ZCC codes against ROP

Receiver input power penalty at BER of 10^{-9} as a function of dispersion is depicted in Fig. 4. The 2 dB penalty dispersion limit was chosen for the three codes. The dispersion was applied in positive and negative form and nonlinear effects and attenuation was disregarded. All codes show similar behavior of positive and negative chromatic dispersions. For EDW code the dispersion limit is ± 1750 ps/nm and ± 1780 ps/nm for RD code. For ZCC code the dispersion limit is ± 1690 ps/nm, i.e. slightly lower than the other two codes. From the reading in Fig. 4, the difference to each other is

really small, meaning that the robustness of these codes to dispersion tolerance is quite similar.

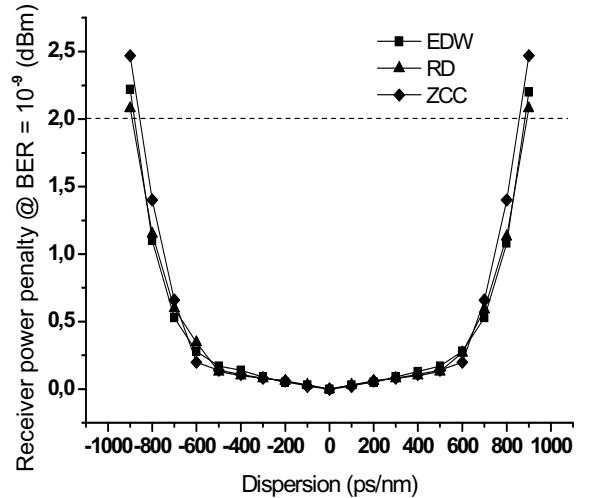


Fig. 4. Dispersion tolerance of 10 Gb/s EDW, RD and ZCC codes

V. CONCLUSION

The performance of EDW, RD and ZCC codes against the received optical power and the dispersion limits was evaluated in SAC-OCDMA PON. Codes with ideal in-phase cross-correlation ($\lambda_c \leq 1$) are desirable in OCDMA systems since these codes can reduce MAI and also suppressed the effect of PIIN. The numerical results show that ZCC have a slightly better performance compared to the other two codes for ROP but have a similar behavior for the dispersion tolerance. This is because only thermal noise and short noise has been considered, PIIN is neglected due to zero cross-correlation between users. ZCC code also has a flexibility to increase the weight. However in other aspects, when the number of users increases the code length will also become longer, thus demanding larger bandwidth. In order to avoid this problem we can narrow down the spacing between the chips but still maintaining the same spectral bandwidth. By the way, RD code gives a good performance in the results. The difference due to power penalty is not that big when compared with ZCC. RD code have an advantages because is just requires a shorter code length and variable weight systems. EDW also have the same performance with RD in ROP performance. However, the EDW code weight is always fixed to 3. So in order to find the suitable code we have to consider the flexibility for instance; freedom in adding new channel in the network, reduce the crosstalk inside the traffic, increase the security and other limitations factor rather than performance itself. From here what we can summarize that EDW, RD and ZCC codes has a potential to be applied in OCDMA PON.

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